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A Comparison of Teleneuropsychological and Traditional Neuropsychological Battery Factor Structures

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A COMPARISON OF TELENEUROPSYCHOLOGICAL AND TRADITIONAL NEUROPSYCHOLOGICAL BATTERY FACTOR STRUCTURES

by

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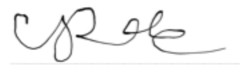

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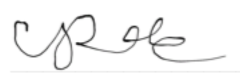

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A COMPARISON OF TELENEUROPSYCHOLOGICAL AND TRADITIONAL NEUROPSYCHOLOGICAL BATTERY FACTOR STRUCTURES

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ABSTRACT

This study compared the factor structures of a traditional neuropsychological battery, administered in-person, and a teleneuropsychological battery, administered remotely. Participants were divided into two groups dependent on test condition (i.e., in-person or remote). Individuals in the in-person test condition group (*n* = 100) were selected from a sample of individuals who were assessed in-person in a previous archival study, and individuals in the remote testing condition group (*n* = 100) were assessed via teleneuropsychology in their home environment.

Two Exploratory Factor Analyses (EFA) using Principal Component Analysis (PCA) method were conducted on the T-scores and scaled scores of each subtest to compare the internal factor structures of the two neuropsychological batteries. For hypothesis one, it was hypothesized an EFA using PCA method of the subtests from the in-person neuropsychological battery would reveal three primary factors: general intelligence, auditory memory, and verbal comprehension. The Parallel Analysis recommended a three-factor solution for the in-person neuropsychological battery, and the factors extracted were labeled as general intelligence, general memory, and processing speed. For hypothesis two, it was hypothesized an EFA using PCA method of the subtests from the teleneuropsychological battery would reveal three primary factors:

general intelligence, attention/ working memory, and verbal comprehension. The Parallel Analysis also recommended a three-factor solution for the teleneuropsychological battery, and the factors extracted were labeled as general memory, attention, and verbal comprehension.

Results of the two EFAs using PCA method revealed both similarities and differences between the two factor structures. Both batteries extracted a memory factor. However, although the teleneuropsychological battery was designed to measure the same cognitive constructs as a traditional neuropsychological battery, there were more differences than there were similarities. The in-person battery extracted general intelligence and processing speed factors, which were not captured in the teleneuropsychological battery. The teleneuropsychological battery extracted attention and verbal comprehension factors, which were not found to be primary factors in the in-person battery. Altogether, results of the two factor analyses do not indicate the batteries measured the same underlying cognitive skills. This suggests different cognitive skills are utilized when some measures, traditionally administered in person, are administered virtually.

These findings have several implications on the use of teleneuropsychology. The interpretation of results obtained from testing using virtual platforms must be altered as it cannot be assumed that virtual assessments measure the same cognitive domains as tests administered in-person. It is essential for clinicians to be cognizant of the differences between virtual and in-person batteries and incorporate this knowledge while conceptualizing an individual's performance. Clinicians should openly acknowledge this limitation and be cautious in their ability to form definitive conclusions from virtual testing.

Results of the present study also illuminate the potential benefits of teleneuropsychological testing and extending neuropsychological services to patients in their home environment. Though the interpretation of results of remote testing must be altered and require further understanding, this study showed valuable information can still be acquired regarding an individual's cognitive abilities through virtual testing. Implementing teleneuropsychological testing can help reduce numerous barriers for patients who would not otherwise have access to healthcare, particularly during a global pandemic which has limited the use of in-person neuropsychological testing.

Statement of Original Work

I declare the following:

I have read the Code of Student Conduct and Academic Responsibility as described in the Student Handbook of Nova Southeastern University. This dissertation represents my original work, except where I have acknowledged the ideas, words, or material of other authors.

Where another author's ideas have been presented in this dissertation, I have acknowledged the author's ideas by citing them in the required style.

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Chapter I: Statement of the Problem

Telemedicine, referring to the utilization of telecommunication technology to provide medical services to patients in remote locations, dates back to the invention of the telephone. These services have grown exponentially with the increased availability of advanced technology, and have allowed for the extension of services to populations who may not otherwise be reached without remote services. A newer subdomain of telemedicine that has gained increased attention in recent years is teleneuropsychology, defined as the remote neuropsychological assessment of an individual through virtual methods. Despite the wide-ranging benefits of remote assessment, few clinicians employed, and fewer researchers studied, remote neuropsychological assessment prior to the COVID-19 pandemic. As a result of a global viral pandemic that requires social isolation, the traditional use of face-to-face neuropsychological assessment decreased substantially due to the risk of contagion. Thus, the option to remotely assess patients during this time through technological platforms became increasingly popular for both patients and clinicians.

The need for remote testing was high prior to the current, pressing need for teleneuropsychological assessment such as the need for distributed healthcare and remote assessment of underserved populations in rural areas. Moreover, remote assessment can help alleviate the burdens of those whose lives and work must be disrupted to attend appointments that require travel, which particularly affects those in lower socioeconomic classes who cannot afford the loss of work hours. Not only can remote assessment reduce costs associated with travel for individuals with distant appointments, but it has been shown to reduce costs relating to test administration and scoring as well. Despite the need for teleneuropsychological services for these populations, there has been little effort to transition from traditional face-to-face assessment to virtual assessment until the current pandemic, in which neuropsychologists have been enlightened to the benefits and accessibility for remote testing.

While the benefits of remote assessment are plentiful, many questions exist regarding the psychometric properties of teleneuropsychological measures. Researchers have begun to explore the correlations between assessments that are traditionally administered face-to-face and the adapted versions of these measures that can be administered virtually. It is important for clinicians and researchers to understand that computerized versions assessments that are traditionally administered face-to-face are new, different tests. This has implications on the interpretation of results as examiners must consider the role of the differences between the nature of virtual and non-virtual assessments, such as the interface. Failure to account for these differences can significantly threaten the validity of the interpretation of test scores. It is therefore critical for examiners to have a clear understanding of how these assessments compare and differ, dependent on the platform in which they are administered.

Ultimately, while there has been an increase in literature and practice of telemedicine in recent years, less is known about teleneuropsychology. A comprehensive understanding of the administration and interpretation of teleneuropsychological measures is necessary, especially regarding measures that are traditionally administered face-to-face. Though there may be many similarities between virtual and non-virtual administration of the same measure, it is clear many differences exist that have implications on the interpretation of results. This requires a fundamental shift in the way neuropsychologists conceptualize scores from teleneuropsychological assessments, which is currently in its early stages of study.

Chapter II: Review of the literature

Telemedicine

While subtle variations in the definition of telemedicine exist in the literature, telemedicine refers to the use of technology to provide medical services at a distance. Telemedicine has been used for decades, beginning with providing services via telephone. Advances in technology have allowed telemedicine to grow in recent years, incorporating various devices to communicate with patients beyond communicating over the telephone. Technological platforms including videoconferencing, email, and text messaging, as well as improvements in the quality and speed of internet connectivity have allowed healthcare practitioners to connect with patients in countless ways.

The increased practice of telemedicine has identified various benefits that are appealing to both the clinician and the patient. Perhaps the most commonly referenced advantage of telemedicine highlighted by clinicians and researchers pertains to the accessibility that services via technology provides. Telemedicine allows the extension of services to individuals in rural areas who may not otherwise have access to quality healthcare, let alone specialized services. Moreover, the provision of remote services helps to reduce the burden of difficulties and costs associated with transportation, especially for those who are required to travel far distances to receive the health care they need. The convenience of receiving services from one's home environment is simply appealing to many, reducing the number of obstacles many face in seeking and receiving proper care.

In addition to overcoming barriers related to proximity, a systematic review and narrative analysis of studies on telemedicine identified several other advantages that have been linked to high patient satisfaction. A multitude of studies have shown not only improved and increased communication between patients and practitioners with the use of telemedicine, but also similar or improved outcomes compared to face-to-face care. Telemedicine has also been shown to be cost-effective, another appealing advantage to both clinicians and patients. While patients are able to alleviate the burden of costs associated with traveling to appointments, clinicians are also able to potentially expand their practice beyond the services they offer face-to-face (Kruse et al., 2017). These benefits together likely contribute to the positive perspectives of telemedicine that have been reported by patients who receive care via technology.

Although telemedicine offers many advantages for numerous populations, there are several limitations that individuals must consider before making the transition to remote health care services. First, the practice of telemedicine is not possible without home technology. For those in lower socioeconomic strata, the costs associated with adequate technology are too large of a burden and may outweigh the potential benefits of receiving care via telemedicine. For those with adequate technology to receive virtual services, individuals must be familiar with navigating the technology, which can pose limitations for those who are not technologically-savvy, or who are cognitively or physically impaired. Other environmental factors that may interfere with the ability to provide quality care over telemedicine include unstable connections (i.e., internet or phone reception) and noisy environments (Cullum et al., 2019). Altogether, telemedicine presents with numerous advantages and disadvantages, which must be considered to determine if the patient is a suitable candidate for telemedicine.

In regards to the functionality of telemedicine, its services can be categorized into several domains ranging from consulting with patients, providing diagnoses, monitoring the status of patients, and mentoring. Moreover, communication between a practitioner and patient can be asynchronous or synchronous. Asynchronous communication refers to the exchange of information (i.e., diagnostic imaging, examinations, surveys) between the practitioner and patient while not connected at the same time via platforms such as email and text messaging. On the other hand, synchronous communication pertains to active communication between the practitioner and patient while connected at the same time, typically occurring via videoconference (Walker & Stoler, 2018). For the purpose of the present review and study, synchronous communication and services were reviewed.

As telemedicine has increased in use, it has been increasingly studied. A literature search using the terms “telemental” and “telehealth” on PubMed in February of 2018 revealed 26,857 publications across numerous medical specialties, with the highest volumes of publications in radiology (1,968), pathology (1,007), dermatology (595), psychiatry (484), and surgery (294). A second literature search on PubMed using the same terms in November of 2019 showed a substantial increase in research activity pertaining to telemedicine, with a total of 32,809 publications and the highest volumes of literature in the same specialties reported in the 2018 review (Cullum et al., 2019). Given the substantial increase in telemedicine in response to the COVID-19 pandemic in 2020, it is inevitable that research in this area will follow a similar trend and shed light on the use of telemedicine in specialties that are less-studied.

Totten and colleagues (2016) synthesized the existing literature on telemedicine and identified 1,494 studies on telemedicine, including 58 systematic reviews. Their comprehensive overview of the current knowledge of telemedicine revealed several key findings. A significant volume of research reported that the best positive outcomes were observed when telemedicine interventions were used for remote patient monitoring for several chronic conditions including cardiovascular and respiratory disease. A large body of evidence in the literature was also found to support remote psychotherapy, with the exception of one review that found insufficient evidence for the use of virtual platforms for forensic and correctional psychiatry. The authors also identified gaps in the literature and areas in which research on telemedicine should shift its focus to. Research on maternal health, complex pediatrics, as well as the use of telehealth for urgent care has limited evidence and requires further study. Altogether, the research and practice of telemedicine is growing exponentially across several fields, and in general, has been found to be supported across various populations with various health conditions.

Telepsychology

In alignment with the growth of telemedicine, telepsychology, a subdomain of telemedicine, has grown exponentially as rapid advancements in technology have occurred. The Joint Task Force for the Development of Telepsychology Guidelines for Psychologists (2013) defines telepsychology as "the provision of psychological services using telecommunication technologies". Telepsychology encompasses a wide range of services including interviews, psychological testing, consultation, psychotherapy, feedback, and rehabilitation, over a variety of formats such as therapy via telephone, videoconference, internet-based platforms, and even social media and video games used as a supplement to therapy (Varker et al., 2018).

Practitioners are increasingly incorporating telepsychology to their practices, and a survey conducted by Glueckauf and colleagues (2018) provided insight to the current state of using telecommunication technology by psychologists. A sample of 164 professional psychologists were surveyed and 48% reported delivering some of their services online. Of those who reported using online modalities, 37.5% reported that 1 to 9% of their services were performed online, and 10% reported that 10 to 100% of their services were through the use of telepsychology. Interestingly, more than half of the sample (51%) indicated they would like at least 10% of their services to be online in the future.

The use of telepsychological services is most popular with adult populations, with over half of psychologists in the sample (55%) reporting delivering services to those older than 18, and only 12% providing services to adolescents, 3% providing services to children, and 9% providing services to older adults. The technologies found to be most commonly used in the practice of telepsychology were landline telephone (63%), mobile telephone (51%), email (38%), and videoconferencing (26%). These findings show there appears to be significant variability not only between the amount of time practitioners dedicate to delivering services via technology, but also between the populations that are served and the devices used to connect with patients. Moreover, while the majority of psychologists at the time of the survey did not employ telepsychology in their practices, the majority endorsed a desire to incorporate online services in the future, indicating that an increasing number of clinicians are recognizing the value of telepsychology and are considering the shift to delivering services virtually.

The use of telepsychology has been shown to be attractive to both clinicians and patients for several reasons. The most prominent appeal for telepsychological services is the ability to reach populations who may not otherwise have access to mental health services, such as individuals in underserved, rural areas. Like services via telemedicine, telepsychological services have been shown to have high patient satisfaction, related to the reduction of the burden on families, costs, and elimination of distant travel to receive services for those who are geographically isolated (Backhaus et al., 2012; Benavides-Vaello et al., 2012; Martin et al., 2020; Varker et al., 2019; Wade et al., 2019). In addition to the barrier of being geographically isolated, another common barrier to seeking and receiving mental health services is stigma (Wrigley et al., 2005). The availability of mental health services over virtual platforms may increase accessibility to services for those who are concerned about stigma, due to the ability to receive services from the privacy of their home.

While telepsychology shares the same benefits of virtual services as other medical specialties, there are numerous, appealing advantages over face-to-face services specific to telepsychology. A recent survey of 17 clinicians reported that clinicians perceived telepsychology to be superior to face-to-face therapy for scheduling appointments, attendance, understanding family and home environments, and reducing stigma associated with mental health services. The survey also found patient’s adherence to homework to be equivalent to face-to-face settings. Of note, therapeutic alliance, a common concern with virtual services due to the removal of in-person, and perhaps more intimate communication, was also found to be equivalent over virtual platforms to face-to-face settings (Wade et al., 2019). It is clear that a wide range of benefits accompany telepsychological services for both patients receiving care and clinicians offering care, and can explain the largely positive perspectives of virtual services from both parties.

Due to the benefits and increased use of telepsychological services, as well as rapid advances in technology, researchers and clinicians have questioned whether virtual services are efficacious for interventions. The literature has generally shown the benefits of telepsychology outweigh the risks and limitations of telepsychology. O'Reilly and colleagues (2007) reported remote psychotherapeutic interventions and traditional face-to-face interactions produced similar clinical outcomes. Consistent with these findings, Varker and colleagues (2018) explored the efficacy of synchronous telepsychological services for individuals specifically with anxiety, depression, posttraumatic stress disorder (PTSD), and adjustment disorder by conducting a review of 24 randomized controlled trials (RCTs). These platforms included telephone, videoconference, and the internet for the delivery of interventions. Of the 11 studies reviewed regarding the efficacy of psychological intervention via telephone, all but one study supported the use of telephone-delivered therapy, which was shown to be as effective or better than standard in-person services or treatment as usual on various outcomes for patients with these psychological conditions. Of the 12 studies reviewed on the efficacy of psychological intervention via videoconference, five high-quality randomized control trials were included, and revealed high strength, high consistency, and moderate to high generalizability of evidence across studies supporting videoconferencing telepsychology.

The researchers also reviewed 3 studies on internet delivered, text-based treatments, which included the use of communication via web chats between clinicians and patients. Results revealed low to moderate consistency between the two RCTs reviewed, and moderate generalizability. Thus, there was little evidence for the use of internet-based interventions for conditions such as anxiety, PTSD, and adjustment disorder due to the lack of information and high risk of selection bias in the three studies that examined this platform. However, the existing research supported the use of internet-delivered interventions for individuals with depression, with the two RCTs showing services via web chat to be superior to waitlist control for this population. Overall, it appears telepsychology via telephone and videoconference currently have the strongest evidence for effective treatment for individuals with anxiety, depression, PTSD, and adjustment disorder. Further research is needed with more robust methodologies to understand the efficacy of internet-based interventions.

For the treatment of substance use disorders via telepsychology, the literature on the efficacy of interventions for this population have been mixed. A literature review concerning the matter was conducted including 50 studies, half of which were RCTs, and 36 of which reported the effect of telemedicine intervention with individuals with substance use disorders. The interventions (via internet platforms [44%], exclusive use of telephone [34%], interactive voice response systems [18%], and text messaging, videoconferencing, and electronic monitoring [4%]), as well as populations (alcohol [24%], various or multiple/ unspecified substances [26%], opioids or heroin [8%], cocaine [4%], and prescription drugs [2%]) varied across studies. The content of interventions, technological platforms, and exposure and follow-up intervals also varied significantly across studies; thus, effect sizes were not utilized to form conclusions. Due to this, support for treatment via telepsychology for each category was evaluated by comparing its anticipated result to the outcomes observed across studies.

The researchers found 18% of studies to be unsupportive of telemedicine for substance abuse populations, 27% of studies were supportive and reported the intervention to be beneficial, and 56% were partially supportive. Across studies, the most common barrier to effective treatment was the lack of use of telemedicine services by patients with severe substance use disorders. Significant negative correlations were also observed between the length of the intervention and its level of benefit in outcomes. Studies that examined the use of asynchronous communication interventions showed the best participation results, and the least popular interventions from the patient's perspectives included those with a telephone or videoconference component. However, the interventions that were found to be most efficacious included synchronous communications and were shorter in length. Overall, the results generally support the use of telepsychology as a substitute or supplement to traditional, face-to-face treatment (Young, 2012). The lack of consistency across studies; however, warrants further research in this area to investigate how outcomes may differ across different interventions, different study designs, different outcomes measured, as well as other components such as the type of communication (i.e., synchronous or asynchronous) and severity and type of substance use.

Following the literature review conducted by Young (2012), Benavides-Vaello and colleagues (2013) further examined the use of telepsychology for substance abuse treatment. The research supports the use of telepsychology for individuals with substance abuse, and has shown to produce higher completion rates of treatment compared to traditional, in-person services. Researchers have posited that the higher rates of adherence to treatment in substance use populations may be explained by the increased confidentiality associated with telepsychological services, as well as the convenience of receiving treatment from one's home.

Overall, the literature concerning telepsychological services yields several important findings in regards to the current knowledge of the efficacy of technological platforms used, and the effectiveness of treating specific populations. Synchronous methods including psychological interventions via telephone and videoconference have robust evidence for their efficacy in treatment of individuals with a variety of mental health conditions. Other methods, such as internet-based services, are limited in high-quality RCTs and thus, less is known in regards to their efficacy for treatment. Specific populations, such as those with substance use disorders, may not only benefit from remote services and have shown greater outcomes than standard, in-person treatment. Contrarily, some studies have also shown telepsychology to be ineffective for individuals with substance use disorders, but the majority of studies reported evidence for effectiveness with this population (Young, 2012).

Ultimately, the existing literature supports the use of telepsychology, and virtual methods for treatment are continuing to grow in popularity. The use of telepsychological services substantially increased as a result of the global COVID-19 pandemic and mandated social isolation, and will likely impact the practice and literature regarding telepsychology in significant ways. It is therefore expected that these circumstances will provide important information to aid in filling the current gaps in the literature pertaining to treatment with specific populations, treatment over a variety of different platforms, and the efficaciousness of delivering services via technology compared to traditional, in-person settings.

Teleneuropsychological Assessment

Similar to telepsychological services, teleneuropsychological assessment has become increasingly popular. Like those considering the transition to medical and psychological services via technology, individuals must weigh the benefits and limitations associated with teleneuropsychological assessment. While virtual neuropsychological assessment offers the same benefits as other medical specialties including the ability to reduce geographic, economic, and travel-related barriers to receive quality care, teleneuropsychological assessment presents unique challenges that must be considered.

As highlighted by the Joint Task Force for the Development of Telepsychology Guidelines for Psychologists (2013), one area psychologists must account for when conducting and interpreting teleneuropsychological evaluations are the psychometric properties of the test. Psychologists must make an effort to preserve the integrity of the assessment while administering it via technology to ultimately maintain the reliability and validity of the assessment. The guidelines encourage psychologists to consider modifying the patients' testing environment and make necessary adaptations to preserve the reliability and validity of the administration. Moreover, clinicians must be cognizant and make accommodations for individuals of diverse populations, including but not limited to those with language or cultural issues, cognitive deficits, sensory or physical impairments, or old age, who may be limited in their capacity to complete testing at their maximal ability. As a result of the limitations of teleneuropsychological testing, it is imperative for clinicians to address these limitations when documenting results of testing. The differences between results obtained over teleneuropsychological testing and in-person assessment must be explained and clearly outline the potential limitations that may have implications on the interpretation of results.

Despite these challenges, virtual assessment has received predominantly positive feedback. A review of the literature by Brearly and colleagues (2017) noted that across multiple studies, patients reported appreciation for the ability to avoid challenges associated with travel for specialized care by receiving remote services. Acceptance of teleneuropsychology have been observed in both impaired and non-impaired populations, which was examined in a sample of 40 adults, 21 of which were impaired (i.e., Mild Cognitive Impairment [MCI] or Alzheimer's Dementia [AD]), and 19 were control (i.e., no MCI or AD). The authors reported 63% of impaired, and 57% of non-impaired participants had no preference in regards to in-person or videoconference assessment (Parikh et al., 2013). Altogether, the use of teleneuropsychology appears to be a viable method of assessment from the patients' perspective, in both clinical and research settings.

The benefits of teleneuropsychology go beyond alleviating the burden of seeking and receiving services for some populations. The use of digital platforms for neuropsychological assessment can capture data that is more precise than the degree of precision humans can capture. For example, computers have the capability to capture more precise measures of reaction time than humans can with the use of a stopwatch. The use of technology for administering standardized verbal and visual tasks can also reduce the variability that may occur between examiners as well as the potential for administrator error (Miller & Barr, 2017). Presenting verbal or visual stimuli via digital platforms can also allow for clinicians and researchers to gather a greater degree and quality of behavioral observations during testing, as the platforms can assist with the administration of instructions and items during testing. In addition to gathering more reliable data via testing with technology, computerized tests provide the benefit of automated scoring, which can also reduce the potential for scoring errors.

Arguably one of the most significant areas of teleneuropsychological assessment that is in crucial need of further study is the validity of virtual assessments. Brearly and colleagues (2017) conducted the first systematic review and meta-analysis investigating whether scores acquired during remote neuropsychological test administration varied from those acquired during in-person administration. Twelve studies published between 1997 and 2016 included in the analyses met the following criteria: no direct examinee assistance during the remote administration; the use of a cross-over design; the use of videoconference for administering assessments; and the assessment of adult participants (greater than 17 years old).

Results revealed little effect of administration setting on test scores. The mean effect size attributing to videoconference administration was small ($g = -.03$ [$SE = .03$, $p = .253$]), which did not yield a significant change in test scores between videoconference and on-site testing. However, large heterogeneity between studies was observed [$Q(11) = 55.67$, $p < .001$] as well as inconsistent findings regarding the direction of effects for mean scores in each testing condition: of 79 scores analyzed from the included studies, 26 were higher in the videoconferencing condition, 48 were higher for the on-site condition, and five mean scores were equal between the two conditions.

The systematic review and meta-analysis also revealed small, but significant effects for time-dependent tests or tests where a disruption of stimulus presentation may affect results, such as digit span and list-learning tests, ($g = -0.10$ [$SE = 0.03$, $p < .001$]). Test effects for those that are both visually and verbally mediated (i.e., the Boston Naming Test [BNT], Clock Drawing, and MMSE tests), were also found to be significant, but small, with in-person testing performance approximately 1/10 of a standard deviation greater than virtual test performance. Overall, the systematic review and meta-analysis provided support for videoconference administration as there was not a clear trend towards significantly different performance between assessments given on-site and assessments given virtually ($g = -.03$). One exception was reported (i.e., the BNT); however, the effect size was small. Other important findings were reported, such as a lack of variation in test scores as the result of disruptions in technology (i.e. connectivity difficulties or loss of sound), and significant, high correlations between videoconference and on-site administered tests that require verbal responses from participants.

Following the COVID-19 outbreak, the use of teleneuropsychology in clinical settings increased, and as well as the body of published research using teleneuropsychology. One survey of 372 board-certified neuropsychologists at the beginning of the COVID-19 pandemic (March 2020) indicated two-thirds of respondents were conducting or planning to conduct teleneuropsychological services including clinical interviews, feedback, or testing. One month later (April 2020), researchers reevaluated the use of teleneuropsychology in a larger sample of neuropsychologists across the world. Within this sample, 52% of respondents indicated they used virtual platforms for clinical interviewing, 41% reported providing feedback virtually, and 36% used virtual platforms for intervention. However, only 15% of neuropsychologists reported using teleneuropsychology for testing services and expressed concern regarding the ethics of providing services remotely, given the published teleneuropsychological literature is still in its infancy (Hammers et al., 2020).

In response, researchers are actively attempting to navigate this new paradigm of neuropsychological assessment due to restrictions on in-person testing during the COVID-19 pandemic. Following the outbreak, one research group attempted to better understand the validity of teleneuropsychological assessment with older adults to build upon the literature review conducted by Brearly and colleagues in 2017. Nine studies from a literature review conducted by Brearly and colleagues, as well as 10 studies published following 2016 that examined older adults with concerns for neurodegenerative conditions were included. Consistent with findings reported by Brearly and colleagues (2017), Marra and colleagues (2020) found additional evidence to support the validity and use of teleneuropsychological assessments with older adult populations. Additionally, in alignment with the review conducted by Brearly and colleagues (2017), Marra and colleagues (2020) also reported the Clock Drawing Test was an exception as there are currently discrepancies in the literature regarding the validity of the task when administered virtually. Overall, the study showed good evidence for the validity of teleneuropsychological assessment with most measures except executive functioning and processing speed measures. This presents a significant limitation to forming diagnostic conclusions when conducting neuropsychological testing virtually as measures of executive functioning and processing speed are often crucial components of differential diagnosis (Marra et al., 2020).

Researchers have also compared neuropsychological assessments that have been adapted to digital forms from their original, paper-pencil versions to determine if they measure the same constructs. One test that has been adapted from its original paper-pencil based test to a digital version is the Trail Making Test (TMT). Researchers compared the paper-pencil based test to its digital variant for both Parts A and B in a sample of 81 healthy older adults. Correlation analyses conducted to evaluate the concordance between the paper and digital versions of the test revealed a significant, moderate correlation between versions of Part A ($r_s = .530$, $p < .001$) and a significant, strong correlation between versions of Part B ($r_s = .795$, $p < .001$). The authors further explored the digital version of the TMT to better understand the cognitive processes underlying performance on this measure, and found differing processes to be important for Parts A and B. For the digital version of Part A, the researchers identified visual-scanning and psychomotor processing speed to be the most significant cognitive processes involved, while the digital version of Part B involved more complex visual sequencing and inhibitory control. Notably, these processes align with the findings that on the paper version of the TMT, Part A is primarily predicted by visual-scanning and processing speed, while Part B is largely associated with processing speed and more complex cognitive abilities (Fellows et al., 2017). These results support the use of the digital form of the TMT for the purpose of measuring similar cognitive processes as measured in the paper version of the TMT. However, other important factors must still be considered when interpreting results from the digital platform such as the platform used (i.e., tablet with the use of a stylus pen or without), or the individual's familiarity with electronic devices, that may cause variation in performance that would not be observed with the paper version of the TMT.

Teleneuropsychological batteries

Researchers have shown support for the administration of certain individual neuropsychological measures via virtual platforms, but it remains unclear as to whether there are optimal measures or batteries to assess specific clinical populations remotely. Numerous web-based and computerized testing platforms have been considered to supplement remote testing, but have not been supported by the Inter Organizational Practice Committee (IOPC) for clinical use. Computerized and web-based assessments currently lack validation studies and normative data that would be equivalent to those of traditional, in-person neuropsychological assessments. It has been noted validation studies conducted by the developers of some of these online measures are not true reflections of remote testing as they were validated using in-laboratory methods. As a result, the IOPC has cautioned the clinical use of these platforms (Inter Organizational Practice Committee, 2020).

While the available computer based assessment platforms have not been supported for clinical use, several not-for-profit batteries have been developed for research purposes. For example, the NIH Toolbox is a battery of measures assessing cognitive, sensory, motor, and emotional functioning that overlap with tests traditionally administered in-person. The University of Pennsylvania Computerized Neurocognitive Battery (CNB) was also designed for neuropsychological research. Though it has extensive normative data, it is not intended for diagnostic purposes. The TestMyBrain (TMB) Digital Neuropsychology Toolkit was also developed for research and education. The tests in the TMB Digital Neuropsychology Toolkit have been empirically evaluated, but currently lack conventional normative or validity data that supports the use of these tests for diagnostic purposes.

Finally, in response to the COVID-19 pandemic, several commercial publishers have made tests readily available for remote on-screen administration. Publishers have provided guidance on the use of tele-assessment and reinforce the considerations that must be taken into account while interpreting results of a remote administration of their tests that were adapted to virtual platforms.

Limitations of teleneuropsychological assessment

As indicated by the IOPC, there are currently no formal guidelines published regarding the practice of teleneuropsychology (Inter Organizational Practice Committee, 2020). Thus, the IOPC recommended clinicians refer to the existing literature on teleneuropsychology to inform clinical practice. Unfortunately, the literature to date on teleneuropsychological assessment is sparse. Studies have generally supported the use of testing via virtual platforms as comparable scores have been observed between tests administered face-to-face and tests administered remotely. However, it is difficult to generalize the current teleneuropsychological literature and assure psychometric equivalence between in-person and remote neuropsychological assessment due to several limitations. First, the number of published studies that have examined teleneuropsychological testing is less than adequate (i.e., 22 individual studies and three reviews). Of the studies that do exist, the samples are also less than adequate to generalize findings: all but three studies include a sample with a mean age of 65 or greater, and clinical samples primarily consist of patients with memory disorders, with few evaluating patients with movement disorders (3.01%), stroke/ cerebrovascular accident (8.39%), psychiatric conditions (3.22%), and mixed clinical groups (3.65%) (Marra et al., 2020). There is also more to be learned about the reliability and validity of testing populations such as children, in which the literature is severely limited (Cullum et al., 2019).

In addition to the sample-related limitations of the existing teleneuropsychological literature, limitations also exist regarding the specific assessments administered in the study. All neuropsychological assessments and batteries that have been examined are restricted in length, and can be administered in less than two hours. The tests that have been examined are far from comprehensive, with considerable heterogeneity across studies, as well as limited investigation of many commonly used neuropsychological tests. For example, the reviews conducted by Brearly and colleagues (2017) and Marra and colleagues (2020) identified the following neuropsychological tests that have been examined in the literature for use over virtual platforms: MoCA (Lindauer et al., 2017; Abdolahi et al., 2016; Chapman et al., 2019; Stillerova et al., 2016), BNT (Vestal et al., 2006), BNT-15 item (Cullum et al., 2006; 2014; Wadsworth et al., 2016; 2018), Digit Span (Cullum et al., 2006; 2014; Grosch et al., 2015; Jacbosen et al., 2003; Vahia et al., 2015; Wadsworth et al., 2016; 2018), Hopkins Verbal Learning Test (HVLT) (Cullum et al., 2006; 2014; Vahia et al., 2015; Wadsworth et al., 2016; 2018), Brief Visuospatial Memory Test – Revised (BVMT-R) (Vahia et al., 2015), Mini-Mental Status Exam (MMSE) (Carotenuto et al., 2018; Cullum et al., 2006; 2014; Grosch et al., 2015; Loh et al., 2004; 2007; Montani et al., 1997; Park et al., 2017; Vahia et al., 2015; Wadsworth et al., 2016), Phonemic Fluency (Cullum et al., 2006; 2014; Hildebrand et al., 2004; Vahia et al., 2015; Vestal et al., 2006; Wadsworth et al., 2016; 2018), Semantic Fluency (Cullum et al., 2006; 2014; Vahia et al., 2015; Wadsworth et al., 2016; 2018), Token Test (Vestal et al., 2006), Picture Description (Vestal et al., 2006), Aural Comprehension of Words and Phrases (Vestal et al., 2006), Clock Drawing Test (Cullum et al., 2006; 2014; Grosch et al., 2015; Hildebrand et al., 2004; Montani et al., 1997; Vahia et al., 2015; Wadsworth et al., 2016; 2018), RBANS (Galusha-Glasscock et al., 2016), Brief Test of Attention (BTA) (Hildebrand et al., 2004), Wechsler Adult Intelligence Scale (WAIS) Matrix Reasoning (Hildebrand et al., 2004), Vocabulary (Hildebrand et al., 2004; Jacobsen et al., 2003) Grooved Pegboard (Jacobsen et al., 2003), Symbol Digit Modalities Test (Jacobsen et al., 2003), Benton Visual Retention Test (Jacobsen et al., 2003), Visual Object and Space Perception Battery Silhouettes (Jacobsen et al., 2003), Wechsler Memory Scale (WMS) Logical Memory (Jacobsen et al., 2003), Adult Memory and Information Processing Battery (AMIPB) (Kirkwood et al., 2000), National Adult Reading Test (Kirkwood et al., 2000), Quick Test (Kirkwood et al., 2000), Multilingual Aphasia Examination (Vestal et al., 2006), and Oral Trails A & B (Wadsworth et al., 2016).

Ultimately, it appears the most commonly studied assessments in the existing teleneuropsychological literature are the MMSE (n = 9), Digit Span (n = 7), Clock Drawing Test (n = 8), and Phonemic Fluency (n = 7). Results of these studies are hard to generalize to clinical, non-research settings where neuropsychological batteries are less restricted and use a variety of different measures that have yet to be studied. For example, no published studies exist regarding the validity administration of computerized neuropsychological assessment devices (CNAD's) virtually. One important consideration of CNAD's is the computer software that is required to administer tests of this nature that would need to be downloaded to the patients' computer prior to the appointment. This raises obstacles to administering tests via CNAD's to patients in their home environment and inhibits the examiner's ability to troubleshoot difficulties that arise during testing.

Finally, the existing literature is limited in providing a true understanding of remote neuropsychological testing as most studies have examined "remote administration" using teleconferencing technology in a controlled testing environment such as a research lab or within the same clinic, but in separate rooms using video-conferencing methods. These findings may not reflect scores that would be obtained in a true, naturalistic, remote home environment where potential confounds may exist that are not present in a research lab. When providing in-home teleneuropsychological services, clinicians are unable to control problems that arise during testing that would be managed in the context of in-clinic teleneuropsychological assessment (i.e., troubleshooting technological difficulties or ensuring an environment free of distraction). Ultimately, numerous limitations exist regarding the current literature on teleneuropsychological assessment which does not allow for firm conclusions to be made regarding the efficacy of testing individuals remotely.

Any modification to standardized neuropsychological test administration can impact test results, and currently, the impact of testing remotely on an individual's performance is unclear. Future research is necessary to provide clinicians and researchers a comprehensive understanding of this new paradigm of neuropsychological assessment.

More importantly, this knowledge is essential to increase the confidence that treatment recommendations and diagnostic conclusions made after teleneuropsychological assessment are congruent with those that would be made from in-person testing (Postal et al., 2020).

Outside of the lack of robust literature available to inform clinical practice, several other challenges are associated with teleneuropsychological assessment. Common to all services delivered via telemedicine, patient populations with reduced access to technology are unable to receive care using this platform. For example, a Pew Research study (2015) reported 15% of Hispanic Americans and 12% of Black Americans do not have internet access, and Americans with disabilities are less likely to have internet access in addition to computers or smartphones. Moreover, the study indicated 16 percent of individuals in the United States aged 16-65 are not digitally literate, and therefore, would not be viable candidates for teleneuropsychological assessment. The appropriateness of teleneuropsychological assessment with cultural groups outside of English speaking, American individuals is also unclear due to the lack of studies investigating these populations.

Teleneuropsychological assessment poses risks to privacy and confidentiality. It can limit the opportunity for gathering qualitative data compared to the data that would be obtained in traditional neuropsychological settings, which can have implications on the clinical decisions made following testing. It is essential the patient is made aware of these limitations prior to testing in an informed consent document to clearly outline the costs and benefits associated with teleneuropsychological assessment prior to testing.

Neuropsychologists have also endorsed ethical and legal issues as factors that may limit the benefit of teleneuropsychological assessment. The Joint Task Force for the Development of Telepsychology Guidelines for Psychologists noted "psychologists must make every effort to ensure that ethical and professional standards of care are met" (2013) while providing services remotely, causing ethical concerns for neuropsychologists considering the use of teleneuropsychological services. Specifically, issues related to test security, emergency management, and lack of standardization while testing in remote environments must be considered when weighing the costs and benefits of providing teleneuropsychological services. 56% of respondents in a survey of neuropsychologists in April 2020 expressed ethical concerns serving as a barrier to testing remotely, and it appears the vast majority of neuropsychologists have determined the potential negatives related to teleneuropsychological assessment outweigh the benefits as evidenced by only 15% of respondents who endorsed the use of teleneuropsychological services for testing at the beginning of the COVID-19 pandemic.

Despite this, neuropsychologists have reported a promising future for teleneuropsychological services. It was reported that 90% of neuropsychologists intended to use teleneuropsychology for clinical interviews, 88% for feedback, 70% for intervention, and 59% for testing following the survey in April 2020 (Hammers et al., 2020). Due to this, it is essential the numerous limitations of teleneuropsychological assessment be addressed in future studies as clinicians increasingly incorporate these services into their practice.

Purpose

The purpose of the study was to compare the factor structures of two neuropsychological batteries: The Driving Study neuropsychological battery, administered to participants in-person, and a teleneuropsychological test battery administered remotely to participants. The teleneuropsychological test battery included neuropsychological tests from the Driving Study, as well as an online standardized neuropsychological test battery (the TMB Digital Neuropsychology Toolkit [TestMyBrain.org]); a not-for-profit, web-based testing environment developed by the Vision Sciences Lab at Harvard University). The tests included in the teleneuropsychological test battery, including the subtests of the TMB battery, were adapted from measures standard paradigms of neuropsychological assessment. This study aimed to determine whether virtual versions of tests that were adapted from measures traditionally administered in-person measure similar or different constructs, to increase the current understanding of how virtual versions of traditional neuropsychological tests compare to the tests in which they were derived from. This will ultimately aid in the interpretation of results from remote neuropsychological assessment.

Hypothesis One

It was hypothesized an EFA using PCA method of the subtests from in-person testing (i.e., the Driving Study) would reveal three primary factors. Specifically, the analysis would yield general intelligence, auditory memory, and verbal comprehension factors.

Justification One

The factor structures of the WAIS and the WMS have been published for decades and have generally yielded consistent results. For the editions of the WAIS, including the most recent, fourth edition, there is robust evidence that a four-factor model consisting of verbal comprehension, perceptual reasoning, working memory, and processing speed describes the latent structure of general intelligence (Dickinson, Iannone, & Gold, 2002; Holdnack et al., 2011, Taub, McGrew, & Witta, 2004; Wechsler 2003, 2008). Researchers have also found support for general intelligence to correspond with the WAIS-IV Full-Scale IQ and the Delayed Memory Index of the WMS-IV, which combines visual and auditory measures (Holdnack et al., 2011). The majority of the subtests included in the factor analysis in the present study from the neuropsychological battery administered in-person (i.e., the Driving Study battery) were subtests of the WAIS-IV that comprise the Full-Scale IQ, and subtests of the WMS-IV that comprise the Delayed Memory Index. Considering this, it was expected the highest variance would be accounted for by a general intelligence factor, with the Vocabulary, Similarities, Information, Digit Span, Arithmetic, Coding, and Matrix Reasoning subtests of the WAIS-IV, and the Logical Memory II, Verbal Paired Associates II, Visual Reproduction II, and Designs II subtests of the WMS-IV loading onto this factor.

It was hypothesized the second highest amount of variance would be accounted for by auditory memory. Wechsler (2009) confirmed a five-factor model of the WMS-IV by factor analysis including the auditory memory index, comprised of the Logical Memory I and II, and Verbal Paired Associates I and II subtests. Moreover, as highlighted above, factor analytic studies of the WAIS-IV and WMS-IV batteries have yielded six and seven-factor models also including auditory memory as one of the primary factors (Tulsky and Price, 2003; Holdnack et al., 2011). Within the auditory memory factor, the immediate and delayed conditions of the Logical Memory and Verbal Paired Associates subtests load highly on the factor. The authors also found one other factor, Working Memory, to be divided into two separate factors of auditory and visual working memory factors. It was reported the Digit Span and Arithmetic subtests of the WAIS-IV loaded on the auditory working memory factor. It was therefore expected that an overarching auditory memory factor, including tests measuring auditory working memory that have been reported in the literature, would be extracted due to several subtests of the in-person neuropsychological battery being well-established to measure auditory memory. Specifically, the subtests that were expected to load onto this factor are Logical Memory I, Logical Memory II, Verbal Paired Associates I, and Verbal Paired Associates II of the WMS-IV. The Digit Span and Arithmetic subtests of the WAIS-IV were also expected to load onto this factor due to prior research reporting such correlations with auditory working memory.

It was also expected that the third primary factor extracted in the factor analysis would be verbal comprehension based on the existing literature. Researchers have explored the factor structure of the WAIS-IV and WMS-IV Adult batteries combined without a hierarchical general ability factor, which revealed a seven-factor model comprised of verbal comprehension, perceptual reasoning, processing speed, auditory working memory, visual working memory, auditory memory, and visual memory factors (Holdnack et al., 2011). These results replicated the results of a previous factor analytic study of the combined WAIS-III and WMS-III batteries, which yielded a six-factor model with the same factors with the exception of auditory and visual working memory subtests not being separated into two indices (Tulsky and Price, 2003). A similar study investigated the factor structure of the Wechsler Adult Intelligence Scale- Revised (WAIS-R) and Wechsler Memory Scale- Revised (WMS-R) and reported a six-factor model representing the latent abilities of verbal comprehension, perceptual organization, working memory, verbal memory, visual memory, and processing speed (Bowden et al., 2004). Of these factors, investigators have noted verbal comprehension is regarded as one of the most stable latent factors reported in all models across the literature (Holdnack et al., 2011). This index, comprised of Vocabulary, Similarities, and Information subtests of the WAIS-IV, has also shown correlations with the Arithmetic subtest (Tulsky and Price, 2003; Canivez and Watkins, 2010; Holdnack et al., 2011). Considering the Driving Study battery was primarily composed of subtests of the WAIS-IV, it was expected results of the present study would be consistent with prior research that examined the factor structure of this assessment. Specifically, considering verbal comprehension is one of the most consistent latent factors observed across studies, it was hypothesized this latent factor would also be observed in the present study. The Vocabulary, Similarities, Information, and Arithmetic subtests of the WAIS-IV were expected to load onto this factor.

Hypothesis Two

It was hypothesized a second EFA using PCA method, including the subtests from remote testing, would reveal three primary factors. Specifically, the analysis would yield general intelligence, attention/ working memory, and verbal comprehension factors.

Justification Two

Similar to the factor analysis conducted on subtests from the in-person neuropsychological battery, it was expected the greatest amount of variance would be accounted for by general intelligence. As outlined in justification one, it is well-established in the literature the 10 primary subtests of the WAIS-IV yield a four-factor model comprised of verbal comprehension, perceptual reasoning, working memory, and processing speed to describe the latent structure of general intelligence (Dickinson, Iannone, & Gold, 2002; Holdnack et al., 2011, Taub, McGrew, & Witta, 2004; Wechsler 2003, 2008). The teleneuropsychological battery in the present study consisted of five of the ten primary subtests of the WAIS-IV that would contribute to the general intelligence factor. As highlighted in justification one, evidence exists supporting the WAIS-IV Full-Scale IQ and the Delayed Memory Index of the WMS-IV to correlate with a general intelligence factor (Holdnack et al., 2011). While the present teleneuropsychological battery did not include the Visual Reproduction II and Designs II subtests that contribute to the Delayed Memory Index of the WMS-IV, the Logical Memory II and Verbal Paired Associates II subtests were included in the present battery and were expected to load onto the general intelligence factor.

Moreover, the virtual subtests from the TMB Digital Neuropsychology Toolkit that were administered remotely were developed based on existing neuropsychological measures typically administered in-person. Specifically, the Digit Span subtest was adapted based on the WAIS-IV Digit Span, the Digit Symbol Matching subtest was developed based on the WAIS-IV Coding, and the TMB Matrix Reasoning was adapted to a virtual version based on the WAIS-IV Matrix Reasoning. While further research is needed to better understand whether virtual versions of WAIS-IV subtests measure the same constructs as those administered in-person, the creators of the TMB Digital Neuropsychology Toolkit provided evidence for the good reliability and validity of these measures. Research on the TMB Digital Neuropsychology Toolkit also reported the TMB Matrix Reasoning subtest to measure general intelligence (Passell et al., 2019). Thus, because the present teleneuropsychological battery consisted of seven subtests of the WAIS-IV that were adapted to virtual versions, and because a general intelligence factor has been consistently found in factor analytic studies of the WAIS and WMS batteries combined, it was hypothesized the same factor would account for the greatest amount of variance in the present study. The Vocabulary, Similarities, Information, Arithmetic, and Digit Span subtests of the WAIS-IV from remote testing; the Logical Memory II, Verbal Paired Associates II subtests of the WMS-IV from remote testing; and the Digit Span, Digit Symbol Matching, and Matrix Reasoning subtests of the TMB Digital Neuropsychology Toolkit were expected to load onto the general intelligence factor.

It was hypothesized the second highest amount of variance would be accounted for by working memory/ attention. As reported by the developers of the TMB Digital Neuropsychology Toolkit, several subtests have been shown to measure aspects of working memory and attention. Specifically, the TMB Digit Span subtest was adapted from the Digit Span subtest administered in-person, which is well-established in its assessment of working memory and attention. Research on the Digit Symbol Matching subtest has also shown to measure aspects of working memory, specifically, visual working memory. The developers of the TMB Digital Neuropsychology Toolkit reported the Verbal and Visual Paired Associates tests measure aspects of Working Memory, and the Matrix Reasoning subtest measures attention (Passell et al., 2019). Moreover, the neuropsychological battery from remote testing in the present study contained the two subtests that comprise the Working Memory Index of the WAIS-IV (Digit Span and Arithmetic). These subtests did not require adaptations from the in-person administration due to their administration method (i.e., verbally without any presentation or manipulation of stimuli). It was therefore hypothesized the remote administration of these subtests would measure the same construct, working memory, as the in-person administration of these subtests.

Research has also revealed attentional skills play a significant role in learning new information, such as during the Logical Memory I subtest of the WMS-IV, as well as the ability to display a fund of knowledge, such as during the Information subtest of the WAIS-IV (Smith et al., 1992). Thus, due to the remote administration of measures from the TMB Digital Neuropsychology Toolkit and the WAIS-IV Working Memory Index that have been shown to measure working memory, and measures that require attentional skills such as Logical Memory I and Information, it was expected working memory/ attention would account for the third highest amount of variance in the factor analysis conducted on the remote neuropsychological battery. Specifically, the Digit Span, Digit Symbol Matching, Matrix Reasoning, Verbal Paired Associates, and Visual Paired Associates subtests of the TMB Digital Neuropsychology Toolkit; the Digit Span, Arithmetic, and Information subtests of the remote administration of the WAIS-IV; and the Logical Memory I subtest of the remote administration of the WMS-IV were hypothesized to load onto this factor.

Based on the existing literature regarding the subtests of the neuropsychological battery administered remotely, it was expected a verbal comprehension factor would account for the third highest amount of variance. As highlighted in justification one, the published literature regarding the factor structure of the combined WAIS and WMS battery has shown verbal comprehension to be one of the most stable factors reported across studies (Holdnack et al., 2011). The present study contained three subtests that comprise the Verbal Comprehension Index of the WAIS-IV (Vocabulary, Similarities, and Information), as well as Arithmetic, which has been shown to also correlate with a verbal comprehension factor. Moreover, research has shown verbally-mediated tasks that are typically administered in-person are not affected by videoconference administration, and produce similar results (Brearly et al., 2017).

Because these subtests of the WAIS-IV required verbal administration and responses, and therefore were not modified to be administered virtually, it was expected the remote battery would yield similar scores on verbal assessments to scores on verbal assessments from the neuropsychological battery administered in-person. As a result, because a verbal comprehension factor was expected for the in-person administration of these subtests, it was hypothesized a verbal comprehension factor would also be extracted from the teleneuropsychological battery. Consistent with hypothesis one, the Vocabulary, Similarities, Information, and Arithmetic subtests of the WAIS-IV from remote testing were expected to load onto the verbal comprehension factor.

Chapter III: Method

Participants

The sample consisted of neurologically and psychiatrically healthy volunteers (i.e., no history of traumatic brain injury [TBI]), cerebral injury not due to TBI, psychiatric or psychological treatment, or DSM diagnosis) aged 18 – 90. Participants were divided into two groups dependent on test condition (i.e., in-person or remote). Individuals in the in-person test condition group were selected from a sample of individuals who were assessed in-person in a previous archival study (The Driving Study; *n* = 100). This group had an average age of 27.43 years (SD = 9.04), an average education of 16.08 years (SD = 1.91), was 61% female, and was 61% Caucasian. Individuals in the remote testing condition group were assessed in-home via teleneuropsychology (Remote Neuropsychological Battery; *n* = 100). This group had an average age of 28.57 years (SD = 10.48), an average education of 16.27 years (SD = 1.64), was 57% female, and was 69% Caucasian. Informed consent was obtained from all participants who were eligible for the current study in accordance with the guidelines set by the Institutional Review Board at Nova Southeastern University.

To assess for group demographic differences, an ANOVA was conducted to determine if there were significant differences in age, gender, and education between groups. The groups did not significantly differ in age F(24, 75) = 0.89, p = 0.61), gender F(1, 98) = 2.79, p = 0.09), or education F(7, 92) = 1.08, p = 0.39). A chi-square analysis was also conducted to assess race differences between groups. Results revealed the groups significantly differed in race $\chi^2(9) = 160.77$, $p < .001$.

Measures

Participants in the remote testing condition were administered tests virtually, including subtests from the TMB Digital Neuropsychology Toolkit, subtests from the Wechsler Adult Intelligence Scale – Fourth Edition (WAIS-IV) Verbal Comprehension Index and Working Memory Index, and subtests from the Wechsler Memory Scale – Fourth Edition (WMS-IV) Auditory Memory Index. Testing was conducted using a HIPAA compliant platform provided by the administrator (i.e., Zoom) after obtaining informed consent from the participant. Screen sharing of the participant's computer screen was requested by the administrator to allow the administrator to read the instructions for each test and to observe the participant throughout testing. All participants were required to complete testing on a computer (i.e., laptop or desktop) with up-to-date software (i.e., updated within the past 5 years) and a stable internet connection.

Teleneuropsychological Battery

The neuropsychological battery administered remotely consisted of four portions: the TMB Digital Neuropsychology Toolkit, subtests from the Verbal Comprehension Index of the WAIS-IV, subtests from the Working Memory Index of the WAIS-IV, and subtests from the Auditory Memory Index of the WMS-IV.

TMB Digital Neuropsychology Toolkit. TestMyBrain.org is a not-for-profit, web-based testing environment developed in the Vision Sciences Lab at Harvard University for research purposes. The digital platform offers cognitive assessments for remote administration. The neuropsychological tests from the digital platform included in the present study were Matrix Reasoning, Trail Making Test (Parts A & B), Forward

Digit Span, Backward Digit Span, Digit Symbol Matching, Verbal Paired Associates, and Visual Paired Associates. These tests were chosen based on their psychometric properties, ease of remote administration, and their similarities to measures traditionally administered in face-to-face neuropsychological settings in which they were adapted from.

TMB Digit Span. The TMB Digit Span module was adapted based on the Digit Span subtest of the WAIS, which has been widely used in neuropsychological testing for decades. Similar to the version of Digit Span traditionally administered face-to-face, the TMB Digit Span requires participants to recall sequences of digits of increasing length. First, participants are asked to recall sequences of digits presented visually on their screen in the same order as they are shown (i.e., "Remembering Numbers Forward" on TMB, based on "Digit Span Forward" on the WAIS). Next, participants are asked to recall sequences of digits presented visually on their screen in the opposite order in which they were shown (i.e., "Remembering Numbers Backward" on TMB, based on "Digit Span Backward" on the WAIS). This test measures attention and working memory.

TMB Digit Symbol. The Digit Symbol test is based on a well-validated and widely used measure of processing speed that has been used in neuropsychology for decades (i.e., WAIS Digit Symbol Coding). Comparable with the version of Digit Symbol Coding administered in-person, the TMB Digit Symbol test requires participants to match symbols and numbers as fast as possible using a symbol-number key shown on the screen. The outcome measure for this test is the number of items correctly completed in 90 seconds. The test measures processing speed and visual short-term memory.

TMB Matrix Reasoning. The Matrix Reasoning module is based on a well-validated and widely used assessment in the field of neuropsychology for decades (i.e., WAIS Matrix Reasoning). In accordance with the Matrix Reasoning subtest traditionally administered face-to-face, the TMB Matrix Reasoning test requires participants to identify the image on their screen that best completes the pattern in a series, based on a logical rule. The TMB Matrix Reasoning test has similar reliability to the WAIS Matrix Reasoning test (Chronbach's alpha=0.77) (Passell et al., 2019). The test measures nonverbal reasoning and fluid cognitive ability.

TMB Trail Making Test (TMT). The TMB TMT was adapted from the widely-used TMT traditionally administered face-to-face in paper-and-pencil format. In accordance with the paper-and-pencil TMT, the virtual version of the TMT consists of two parts: Part A and Part B. Part A requires the participant to connect a series of numbers in ascending order with the pointer on the screen by dragging their mouse or finger on their trackpad. Part B requires the participant to connect numbers and letters in alternate ascending order with the pointer on the screen by dragging their mouse or finger on their trackpad. Part B measures cognitive flexibility, and both Parts A and B measure visual scanning, processing speed, and task switching. The participant's score for both Parts A and B reflects how long it took the participant to connect all items in milliseconds.

TMB Verbal Paired Associates. The Verbal Paired Associates Memory test was adapted from a widely-used, well validated test measuring verbal memory and episodic memory that is traditionally given in standard neuropsychological paradigms of face-to-face testing (i.e., WMS-IV Verbal Paired Associates). The TMB Verbal Paired

Associates Memory test also measures verbal memory and episodic memory, and requires participants to learn and then recognize a set of word pairs. The test shows the participant 25 sets of word pairs individually on their screen, then prompts the participant to complete a brief two-to-three-minute task. Following the delay, the participant is asked to recall the corresponding word from each of the 25 word pairs previously presented.

TMB Visual Paired Associates. The Visual Paired Associates test requires participants to learn and then recognize a set of picture pairs of scenery images. This test measures visual memory and episodic memory. The subtest includes an approximate three-minute delay between the memorization of the pairs and the test, during which other tasks can be completed.

WAIS-IV Verbal Comprehension Index. The Verbal Comprehension Index of the WAIS-IV consists of three subtests: Vocabulary, Similarities, and Information. These three assessments reflect an individual’s verbal abilities, including their ability to understand, use, and think with spoken language. This index also assesses an individual’s ability to retrieve information from long-term memory and is influenced by the quality of education and knowledge an individual acquires from their environment. The remote administration of subtests from this index mirrors the administration in-person, as the examiner asks the participant questions verbally, and the participant responds verbally.

WAIS-IV Vocabulary. Similar to the in-person administration of the Vocabulary subtest, the examiner asks the participant to define up to 30 words during the remote administration of this measure. This subtest measures language development, expressive language skills, educational experiences, the ability to use words appropriately, and the retrieval of information from long-term memory.

WAIS-IV Similarities. During the remote administration of the Similarities subtest, the examiner asks the participant to identify the qualitative relationship between up to 18 word pairs. This subtest assesses abstract thinking skills, concept formation skills, and verbal reasoning.

WAIS-IV Information. The Information subtest consists of up to 26 questions regarding general knowledge. During the remote administration of this subtest, the examiner asks the participant to verbally answer these questions based on the knowledge they have accumulated from their environment and academic experiences. This assessment reflects the participant's quality of education, retrieval of information from long-term memory, the ability to learn and recall facts, and intellectual curiosity.

WAIS-IV Working Memory Index. The Working Memory Index of the WAIS-IV consists of two subtests: Digit Span and Arithmetic. This index measures an individual's ability to hold information and simultaneously manipulate the information mentally. The remote administration of subtests from this index mirrors the in-person administration such that the participant is required to respond to the examiner verbally without utilizing a pencil and paper for assistance.

WAIS-IV Digit Span. In accordance with the in-person administration, the remote administration of the Digit Span subtest of the WAIS-IV consists of three parts. First, the examiner asks the participant to repeat a series of digits that are read verbally in the order they were read. Next, Digit Span Backwards requires the individual to repeat a series of digits backwards. Third, the participant is required to repeat digits read by the examiner in ascending order. These assessments measure auditory recall, short-term memory, and working memory.

WAIS-IV Arithmetic. Similar to the in-person administration, the remote administration of the Arithmetic subtest consists of 22 timed arithmetic problems read by the examiner. The participant is required to solve each problem without the use of a pencil and paper. This subtests measures calculation skills, problem-solving skills, mental manipulation of number operations, and working memory.

WMS-IV Auditory Memory Index. The Auditory Memory Index of the WMS-IV consists of four subtests, divided into immediate and delayed conditions: Logical Memory I, Logical Memory II, Verbal Paired Associates I, and Verbal Paired Associates II. The remote administration of these subtests mirror the in-person administration such that the participant is required to recall verbal information that was presented by the examiner both immediately and following a delay.

WMS-IV Logical Memory I. Logical Memory I consists of two stories that are read to the participant. The participant is required to retell each story from immediate memory immediately after it is read to them. This subtest assesses narrative memory under a free recall condition.

WMS-IV Logical Memory II. Logical Memory II requires the participant to retell both stories previously read to them by the examiner in the immediate condition. This subtest measures an individual's long-term narrative memory and free recall abilities.

WMS-IV Verbal Paired Associates I. During this subtest, the examiner reads 14 word pairs to the examinee. Immediately after the examiner reads the word pairs, the examiner reads the first word of each pair, and the participant is required to recall the corresponding word. The subtest consists of four trials in which the words pairs are read to the participant in different orders. This subtest reflects an individual's verbal memory abilities.

WMS-IV Verbal Paired Associates II. Verbal Paired Associates II requires the participant to recall information that was presented to them during the immediate condition. The examiner presents the first word of each pair and the participant is asked to provide the corresponding word. This subtest measures long-term recall abilities for verbally paired information.

In-Person Neuropsychological Battery

The in-person neuropsychological battery (i.e., the Driving Study) is a component of a research study designed to predict driving ability through a series of neuropsychological tests administered in a traditional, face-to-face setting. Assessments from this battery were not directly administered to participants as data was extracted from an archival database. The neuropsychological tests from the battery included in the present study include subtests from the Verbal Comprehension Index of the WAIS-IV, subtests from the Working Memory Index of the WAIS-IV, WAIS-IV Coding, WAIS-IV Matrix Reasoning, Trail Making Test (Parts A & B), subtests from the Auditory Memory Index of the WMS-IV, and subtests from the Visual Memory Index of the WMS-IV. These tests were chosen due to their similarities with the subtests from the teleneuropsychological battery, including the TMB Digital Neuropsychology Toolkit, which are tests adapted to virtual versions based on the original format of the test.

WAIS-IV Vocabulary. During the Vocabulary subtest, the examiner asks the participant to define up to 30 words. This subtest measures language development, expressive language skills, educational experiences, the ability to use words appropriately, and the retrieval of information from long-term memory.

WAIS-IV Similarities. The Similarities subtest of the WAIS-IV asks the participant to identify the qualitative relationship between up to 18 word pairs. This subtest is given orally by the examiner, and assesses abstract thinking skills, concept formation skills, and verbal reasoning.

WAIS-IV Information. The Information subtest consists of up to 26 questions regarding general knowledge. The examiner asks the participant to answer these questions based on the knowledge they have accumulated from their environment and academic experiences. This assessment reflects the participant's quality of education, retrieval of information from long-term memory, the ability to learn and recall facts, and intellectual curiosity.

WAIS-IV Digit Span. The in-person administration of the Digit Span subtest of the WAIS-IV consists of three parts. First, the examiner asks the participant to repeat a series of digits that were read orally in the order that they are read. Next, Digit Span Backwards requires the individual to repeat a series of digits backwards. Third, the participant is required to repeat digits read by the examiner in ascending order. These assessments measure auditory recall, short-term memory, and working memory.

WAIS-IV Arithmetic. The Arithmetic subtest consists of 22 timed arithmetic problems that are read by the examiner. The participant is required to solve each problem without the use of a pencil and paper. This subtests measures calculation skills, problem-solving skills, mental manipulation of number operations and working memory.

WAIS-IV Coding. The paper-and-pencil version of the Coding subtest requires the individual to record associations between different symbols and numbers. The participant is asked to match as many symbols and numbers as fast as possible using a symbol-number key, by writing the numbers that correspond to a series of symbols. The outcome measure for this test is the number of items correctly completed in 90 seconds. This subtest reflects psychomotor speed, the ability to absorb new material, visual motor speed, and drive for achievement.

WAIS-IV Matrix Reasoning. The Matrix Reasoning subtest of the WAIS-IV is a nonverbal reasoning task in which individuals are asked to identify patterns in designs. This subtest measures non-verbal reasoning skills, broad visual intelligence, and perceptual organization skills.

WMS-IV Logical Memory I. Logical Memory I consists of two stories that are read orally to the participant. The participant is required to retell each story from immediate memory immediately after it is read to them. This subtest assesses narrative memory under a free recall condition.

WMS-IV Logical Memory II. Logical Memory II requires the participant to retell both stories previously read to them by the examiner in the immediate condition. This subtest measures an individual's long-term narrative memory and free recall abilities.

WMS-IV Verbal Paired Associates I. During this subtest, the examiner reads 14 word pairs to the examinee. Immediately after the examiner reads the word pairs, the examiner reads the first word of each pair, and the participant is required to recall the corresponding word. The subtest consists of four trials in which the words pairs are read to the participant in different orders. This subtest reflects an individual's verbal memory abilities.

WMS-IV Verbal Paired Associates II. Verbal Paired Associates II requires the participant to recall information previously presented to them during the immediate recall condition. The examiner presents the first word of each pair and the participant is asked to provide the corresponding word. This subtest measures long-term recall abilities for verbally paired information.

WMS-IV Visual Reproduction I. During the administration of Visual Reproduction I, the examiner shows the participant a series of five designs, for ten seconds each. After each design is presented, the participant is required to draw the design that was shown to them from memory. This subtest assesses an individual's memory for nonverbal visual stimuli.

WMS-IV Visual Reproduction II. Visual Reproduction II asks the participant to draw the designs shown to them during the immediate condition following a delay. The delayed condition assesses an individual's long-term visual-spatial memory.

WMS-IV Designs I. The administration of the Designs I subtest consists of the examiner showing the participant a grid with four to eight designs on a page, for ten seconds each. Following the presentation of the stimuli, the participant is required to select designs from a set of cards, and place the cards on a grid in the same place in which they were previously shown. This subtest measures spatial memory.

WMS-IV Designs II. The delayed condition asks the examinee to recreate the pages shown in the immediate condition by placing the same cards in the same location on the grid. Designs II assesses long-term spatial and visual memory.

Trail Making Test (TMT). The TMT (Parts A & B) measures cognitive flexibility, sequencing ability, and visual-motor speed. Trails A is a measure of visual scanning and motor speed. The examinee is asked to draw connecting lines between numbered circles in sequential order (1 to 2, 2 to 3, etc.). Trails B is similar to Trails A but also measures the ability to shift between different kinds of sequencing tasks. The examinee is asked to alternate between numbers and letters, in order, while connecting the circles (1 to A, 2 to B, 3 to C, etc.).

Statistical analysis

Two Exploratory Factor Analyses (EFA) using Principal Component Analysis (PCA) method were conducted on the T-scores and scaled scores of each subtest to compare the internal factor structures of two neuropsychological batteries, one of which was administered in person, and the other administered remotely, adapted from tests traditionally administered in-person. An oblique rotation was specified to allow for expected correlations between factors. While evidence supports the use of orthogonal rotation because it produces more easily interpretable results, the use of this rotation results in a loss of valuable information when factors are correlated (Osborne, 2014). In the present study, moderate correlations among factors were expected due to existing literature reporting overlap between cognitive processes. Researchers have posited a functional overlap of neural circuitry correlates with an overlap of cognitive processes (Kovacs & Conway, 2016). Factors extracted in the present study that represent cognitive domains were therefore expected to be correlated. Thus, the use of an oblique rotation would produce more accurate results. Given orthogonal and oblique rotations typically produce nearly identical results, the choice of an oblique rotation was more appropriate

(Osborne, 2014). In regards to the specific oblique rotation used in the present study, a Promax rotation was conducted as it has been reported to be the more desirable oblique rotation compared to Direct Oblimin (Thomson, 2004).

To select the number of components to extract, a parallel analysis using the Monte Carlo Simulation Technique was conducted. Parallel analysis is considered the most robust and accurate method for determining the number of factors to extract (Ledesma & Mora, 2007; Velicer et al., 2000). The parallel analysis was used to generate a random sample of data sets of the same size from the original data set, and an EFA using PCA method was employed on each of the data sets. The eigenvalues obtained for each factor was then calculated and compared to the eigenvalues of the original data set. Factors were retained if their eigenvalues exceeded the 95^{th} percentile of the simulated eigenvalues (Ledesma & Mora, 2007).

The criterion used as a cutoff to determine which items loaded on a factor was a value of 0.40. While there is no universal standard reported in the literature regarding a cutoff level, as suggested by Pituch & Stevens (2016), a common threshold used is at least 0.32 as it corresponds to approximately 10% variance explained. A cutoff of 0.40 was chosen as this threshold allowed for a clearer solution than a cutoff of a lower threshold and was recommended by Hair and colleagues (1998) for practical significance.

Chapter IV: Results

Preliminary Analyses

Preliminary analyses were conducted to determine if the normality assumption of PCA was tenable by examining skewness and kurtosis. Cutoffs of -2 and 2 for skewness and kurtosis were established (Pituch & Stevens, 2016). Descriptive statistics including the means, standard deviations, skewness, and kurtosis of performance on each subtest of the traditional neuropsychological battery administered in-person are recorded in Table 1.

Table 1. *Descriptive Statistics for In-Person Battery*

Subtest	Mean (SS)	SD	Skewness	Kurtosis
WAIS-IV Vocabulary	13.53	2.47	.16	.71
WAIS-IV Similarities	13.25	2.56	-.32	.26
WAIS-IV Information	13.19	2.86	.35	-.49
WAIS-IV Digit Span	12.04	2.65	.42	-.25
WAIS-IV Arithmetic	11.33	2.54	.48	.55
WAIS-IV Matrix Reasoning	12.21	2.13	.22	-.05
WAIS-IV Coding	12.10	2.40	.80	.59
WMS-IV Logical Memory I	12.17	2.42	-.23	1.19
WMS-IV Logical Memory II	12.55	2.51	.54	.50
WMS-IV Verbal Paired Associates I	12.71	2.68	.38	.10
WMS-IV Verbal Paired Associates II	12.49	1.25	-1.63	2.82
WMS-IV Visual Reproduction I	11.21	2.30	-.43	-.64
WMS-IV Visual Reproduction II	13.17	2.54	.03	-1.06
WMS-IV Designs I	11.97	2.58	-.01	-.75
WMS-IV Designs II	12.25	2.63	.09	-.35
Trails A (T-score)	47.09	14.51	-.44	-.06
Trails B (T-score)	51.19	10.10	.19	.16

The examination of the descriptive statistics from the traditional neuropsychological battery revealed no evidence of extreme skewness defined by cutoff scores of -2 and 2, within the distribution of the data. However, kurtosis for WMS-IV Verbal Paired Associates II was outside the expected range (2.82). This subtest was still included in the analyses given its importance in the neuropsychological battery.

Pearson correlations were conducted on the scores of each subtest to evaluate the relationship between the independent variables. Results are listed in Tables 2, 3, and 4.

Table 2. *Correlations Between WAIS-IV Subtests of In-Person Battery*

	1	2	3	4	5	6	7
1. VC	1.00	.583**	.526**	.167	.297**	.182	.167
2. Sim	.583**	1.00	.490**	.103	.237*	.240*	.121
3. Info	.526**	.490**	1.00	.111	.215*	.189	.219
4. DS	.167	.103	.111	1.00	.445**	.129	.023
5. Ari	.297**	.237*	.215*	.445**	1.00	.356**	.200*
6. MR	.182	.240*	.189	.129	.356**	1.00	.259**
7. CD	.167	.121	.219*	.023	.200*	.259**	1.00

Note. VC, WAIS-IV Vocabulary; Sim, WAIS-IV Similarities; Info, WAIS-IV Information; DS, WAIS-IV Digit Span; Ari, WAIS-IV Arithmetic; MR, WAIS-IV Matrix Reasoning; CD, WAIS-IV Coding. * $p < .05$; ** $p < .01$; *** $p < .001$.

WAIS-IV Vocabulary was significantly correlated with WAIS-IV Similarities, WAIS-IV Information, WAIS-IV Arithmetic at $p < .01$. WAIS-IV Similarities was significantly correlated with WAIS-IV Arithmetic and WAIS-IV Matrix Reasoning at $p < .05$. At $p < .01$, Similarities was significantly correlated with WAIS-IV Information. WAIS-IV Information was significantly correlated with WAIS-IV Arithmetic at $p < .05$.

WAIS-IV Digit Span was significantly correlated with WAIS-IV Arithmetic at $p < .01$. WAIS-IV Arithmetic was significantly correlated with WAIS-IV Coding at $p < .05$. At $p < .01$, WAIS-IV Arithmetic was significantly correlated with WAIS-IV Matrix

Reasoning. At p < .01, WAIS-IV Matrix Reasoning was significantly correlated with WAIS-IV Coding.

Table 3. *Correlations Between WAIS-IV, WMS-IV, and Trails of In-Person Battery*

	8	9	10	11	12	13	14	15	16	17
1. VC	.373**	.364**	.261**	.030	.142	.058	.058	.032	-.027	.002
2. Sim	.240*	.256*	.204*	-.026	.190	.070	.061	.127	.001	.081
3. Info	.184	.164	.060	-.122	.160	.090	-.086	.053	.009	.075
4. DS	.127	.013	.022	-.061	.128	.112	.101	.120	.049	.002
5. Ari	.275**	.256*	.247*	.168	.250*	.140	.179	.191	-.047	.097
6. MR	.144	.146	.125	.097	.205*	.135	.113	.172	-.125	.058
7. CD	.384**	.404**	.151	.017	.265**	.345**	.092	.110	.338**	.314**

Note. VC, WAIS-IV Vocabulary; Sim, WAIS-IV Similarities; Info, WAIS-IV Information; DS, WAIS-IV Digit Span; Ari, WAIS-IV Arithmetic; MR, WAIS-IV Matrix Reasoning; CD, WAIS-IV Coding. * *p < .05; ** p < .01; *** p < .001.*

WAIS-IV Vocabulary was significantly correlated with WMS-IV Logical Memory I, WMS-IV Logical Memory II, and WMS-IV Verbal Paired Associates I at p < .01. WAIS-IV Similarities was significantly correlated with WMS-IV Logical Memory I, WMS-IV Logical Memory II, and WMS-IV Verbal Paired Associates I at p < .05.

WAIS-IV Arithmetic was significantly correlated with WMS-IV Logical Memory II, WMS-IV Verbal Paired Associates I, and WMS-IV Visual Reproduction I at p < .05. At p < .01, WAIS-IV Arithmetic was significantly correlated with WMS-IV Logical Memory I.

WAIS-IV Matrix Reasoning was significantly correlated with WMS-IV Visual Reproduction I at p < .05. WAIS-IV Coding was significantly correlated with WMS-IV Logical Memory I, WMS-IV Logical Memory II, WMS-IV Visual Reproduction I, WMS-IV Visual Reproduction II, Trails A, and Trails B at p < .01.

Table 4. *Correlations Between WMS-IV and Trails of In-Person Battery*

	8	9	10	11	12	13	14	15	16	17
8. LMI	1.00	.829**	.369**	.129	.246*	.236*	.217*	.174	-.005	.136
9. LMII	.829**	1.00	.426**	.203*	.261**	.258**	.246*	.297**	.000	.204*
10. VPAI	.369**	.426**	1.00	.491**	.290**	.284**	.247*	.351**	.083	.147
11. VPAII	.129	.203	.491**	1.00	.241*	.270**	.243*	.272**	.011	.090
12. VRI	.246*	.261**	.290**	.241*	1.00	.634**	.277**	.251*	.116	.223*
13. VRII	.236*	.258**	.284**	.270**	.634**	1.00	.302**	.292**	.173	.207*
14. DesI	.217*	.246*	.247*	.243*	.277**	.302**	1.00	.737**	.113	.242*
15. DesII	.174	.297**	.351**	.272**	.251*	.292**	.737**	1.00	.129	.174
16. TmtA	-.005	.000	.083	.011	.116	.173	.113	.129	1.00	.444**
17. TmtB	.136	.204*	.147	.090	.223*	.207*	.242*	.174	.444**	1.00

Note. LMI, WMS-IV Logical Memory I; LMII, WMS-IV Logical Memory II; VPAI, WMS-IV Verbal Paired Associates I; VPAII, WMS-IV Verbal Paired Associates II; VRI, WMS-IV Visual Reproduction I; VRII, WMS-IV Visual Reproduction II; DesI, WMS-IV Designs I; DesII, WMS-IV Designs II; TmtA, Trails A; TmtB, Trails B. * $p < .05$; ** $p < .01$; *** $p < .001$.

WMS-IV Logical Memory I was significantly correlated with WMS-IV Visual Reproduction I, WMS-IV Visual Reproduction II, and WMS-IV Designs I at p < .05. At p < .01, Logical Memory I was significantly correlated with WMS-IV Logical Memory II, and WMS-IV Verbal Paired Associates I.

WMS-IV Logical Memory II was significantly correlated with WMS-IV Verbal Paired Associates I, WMS-IV Designs I, and Trails B at p < .05. At p < .01, Logical Memory II was significantly correlated with WMS-IV Verbal Paired Associates I, WMS-IV Visual Reproduction I, WMS-IV Visual Reproduction II, and WMS-IV Designs II.

WMS-IV Verbal Paired Associates I was significantly correlated with WMS-IV Designs I at p < .05. At p < .01, Verbal Paired Associates I was significantly correlated with WMS-IV Verbal Paired Associates II, WMS-IV Visual Reproduction I, WMS-IV Visual Reproduction II, and WMS-IV Designs II.

WMS-IV Verbal Paired Associates II was significantly correlated with WMS-IV Visual Reproduction I and WMS-IV Designs I at $p < .05$. At $p < .01$, Verbal Paired Associates II was significantly correlated with WMS-IV Visual Reproduction II and WMS-IV Designs II.

WMS-IV Visual Reproduction I was significantly correlated with WMS-IV Designs II and Trails B at $p < .05$. At $p < .01$, Visual Reproduction I was significantly correlated with WMS-IV Visual Reproduction II and WMS-IV Designs I. WMS-IV Visual Reproduction II was significantly correlated with Trails B at $p < .05$. At $p < .01$, Visual Reproduction II was significantly correlated with WMS-IV Designs I and WMS-IV Designs II.

WMS-IV Designs I was significantly correlated with Trails B at $p < .05$. At $p < .01$, Designs I was significantly correlated with Designs II. Finally, Trails A was significantly correlated with Trails B at $p < .01$.

Preliminary analyses were conducted to determine if the normality assumption of PCA was tenable by examining skewness and kurtosis. Cutoffs of -2 and 2 for skewness and kurtosis were established (Pituch & Stevens, 2016). Descriptive statistics including the means, standard deviations, skewness, and kurtosis of performance on each subtest of the teleneuropsychological battery are recorded in Table 5.

Table 5. *Descriptive Statistics for TeleNP Battery*

Subtest	Mean (SS)	SD	Skewness	Kurtosis
TMB Forward Digit Span	49.82	8.59	.16	-.17
TMB Backward Digit Span	50.68	9.16	.18	.36
TMB Digit Symbol	48.90	7.81	.21	-.32
TMB Matrix Reasoning	49.33	7.44	-.33	.47
TMB Trails A	52.31	5.26	-1.37	1.36
TMB Trails B	52.36	5.93	-.29	1.75
TMB Verbal Paired Associates	50.59	9.33	-.91	.18
TMB Visual Paired Associates	52.48	9.68	-.31	-.43
WAIS-IV Vocabulary	14.37	2.34	-.22	.35
WAIS-IV Similarities	14.21	2.53	-.31	-.13
WAIS-IV Information	13.56	2.73	-.11	-.26
WAIS-IV Digit Span	11.96	2.85	.29	-.54
WAIS-IV Arithmetic	11.71	2.60	.03	-.23
WMS-IV Logical Memory I	12.18	2.26	-.30	.31
WMS-IV Logical Memory II	12.18	2.85	.00	-.08
WMS-IV Verbal Paired Associates I	12.47	2.78	.01	-.07
WMS-IV Verbal Paired Associates II	12.18	1.83	-.92	.68

The examination of the descriptive statistics from the teleneuropsychological battery revealed no evidence of extreme skewness or kurtosis, defined by cutoff scores of -2 and 2, within the distribution of the data.

Pearson correlations were conducted on the scores of each subtest to evaluate the relationship between the independent variables of the teleneuropsychological battery. Results are listed in Tables 6, 7, and 8.

Table 6. *Correlations Between TMB Subtests of TeleNP Battery*

	1	2	3	4	5	6	7	8
1. FDS	1.00	.357**	.259**	.225*	.020	.305**	.086	.273**
2. BDS	.357**	1.00	.387**	.244*	.109	.362**	.200*	.284**
3. DSym	.259**	.387**	1.00	.345**	.247*	.454**	.227*	.444**
4. TmbMR	.225*	.244*	.345**	1.00	.167	.285**	.263**	.362**
5. TmbA	.020	.109	.247*	.167	1.00	.255*	.075	.203*
6. TmbB	.305**	.362**	.454**	.285**	.255*	1.00	.222*	.262**
7. VerbPA	.086	.200*	.227*	.263**	.075	.222*	1.00	.414**
8. VisPA	.273**	.284**	.444**	.362**	.203*	.262**	.414**	1.00

Note. FDS, TMB Forward Digit Span; BDS, TMB Backward Digit Span; DSym, TMB Digit Symbol; TmbMR, TMB Matrix Reasoning; TmbA, TMB Trails A; TmbB, TMB Trails B; VerbPA, TMB Verbal Paired Associates; VisPA, TMB Visual Paired Associates. * $p < .05$; ** $p < .01$; *** $p < .001$.

TMB Forward Digit Span was significantly correlated with TMB Matrix Reasoning at $p < .05$. At $p < .01$, TMB Forward Digit Span was significantly correlated with TMB Backward Digit Span, TMB Digit Symbol, TMB Trails B, and TMB Visual Paired Associates. TMB Backward Digit Span was significantly correlated with TMB Matrix Reasoning and TMB Verbal Paired Associates at $p < .05$. At $p < .01$, TMB Backward Digit Span was significantly correlated with TMB Digit Symbol, TMB Trails B, and TMB Visual Paired Associates.

TMB Digit Symbol was significantly correlated with TMB Trails A and TMB Verbal Paired Associates at $p < .05$. At $p < .01$, TMB Digit Symbol was significantly correlated with TMB Matrix Reasoning, TMB Trails B, and TMB Visual Paired Associates.

TMB Matrix Reasoning was significantly correlated with TMB Trails B, TMB Verbal Paired Associates, and TMB Visual Paired Associates at $p < .01$. TMB Trails A was significantly correlated with TMB Trails B and TMB Visual Paired Associates at $p < .05$. TMB Trails B was significantly correlated with TMB Verbal Paired Associates and TMB Visual Paired Associates at $p < .01$. TMB Verbal Paired Associates was significantly correlated with TMB Visual Paired Associates at $p < .01$.

Table 7. *Correlations Between TMB, WAIS-IV, and WMS-IV of TeleNP Battery*

	9	10	11	12	13	14	15	16	17
1. FDS	.044	.035	.064	.483**	.265**	.022	-.006	.018	.129
2. BDS	.019	.080	.080	.419**	.353**	.013	.066	.115	.226*
3. DSym	.061	-.074	.042	.322**	.201*	.193	.256*	.173	.350**
4. MR	.248*	.233*	.196	.191	.213*	.095	.165	.267**	.119
5. TmtA	.176	-.043	.010	.024	-.021	.094	.132	.094	.112
6. TmtB	.034	-.023	.116	.278**	.241*	.171	.247*	.106	.105
7. VerbPA	.052	.213*	.224*	.090	.187	.128	.194	.525**	.462**
8. VisPA	.181	.195	.104	.217*	.312**	.281**	.335**	.458**	.416**

Note. FDS, TMB Forward Digit Span; BDS, TMB Backward Digit Span; DSym, TMB Digit Symbol; MR, TMB Matrix Reasoning; TmtA, TMB Trails A; TmtB, TMB Trails B; VerbPA, TMB Verbal Paired Associates; VisPA, TMB Visual Paired Associates. * $p < .05$; ** $p < .01$; *** $p < .001$.

TMB Forward Digit Span was significantly correlated with the remote administration of WAIS-IV Digit Span and WAIS-IV Arithmetic at $p < .01$. TMB Backward Digit Span was significantly correlated with the remote administration of WMS-IV Verbal Paired Associates II at $p < .05$. At $p < .01$, TMB Backward Digit Span was significantly correlated with the remote administration of WAIS-IV Digit Span and WAIS-IV Arithmetic.

TMB Digit Symbol was significantly correlated with the remote administration of WAIS-IV Arithmetic and WMS-IV Logical Memory II at $p < .05$. At $p < .01$, TMB Digit

Symbol was significantly correlated with the remote administration of WAIS-IV Digit Span and WMS-IV Verbal Paired Associates II.

TMB Matrix Reasoning was significantly correlated with the remote administration of WAIS-IV Vocabulary, WAIS-IV Similarities, and WAIS-IV Arithmetic at $p < .05$. At $p < .01$, TMB Matrix Reasoning was significantly correlated with the remote administration of WMS-IV Verbal Paired Associates I.

TMB Trails A was not significantly correlated with any subtests of the teleneuropsychological battery. TMB Trails B was significantly correlated with the remote administration of WAIS-IV Arithmetic and WMS-IV Logical Memory II at $p < .05$. At $p < .01$, TMB Trails B was significantly correlated with the remote administration of WAIS-IV Digit Span.

TMB Verbal Paired Associates was significantly correlated with the remote administration of WAIS-IV Similarities and WAIS-IV Information at $p < .05$. At $p < .01$, TMB Verbal Paired Associates was significantly correlated with the remote administration of WMS-IV Verbal Paired Associates I and WMS-IV Verbal Paired Associates II.

TMB Visual Paired Associates was significantly correlated with the remote administration of WAIS-IV Digit Span at $p < .05$. At $p < .01$, TMB Visual Paired Associates was significantly correlated with the remote administration of WAIS-IV Arithmetic, WMS-IV Logical Memory I, WMS-IV Logical Memory II, WMS-IV Verbal Paired Associates I, and WMS-IV Verbal Paired Associates II.

Table 8. *Correlations Between WAIS-IV and WMS-IV Subtests of TeleNP Battery*

	9	10	11	12	13	14	15	16	17
9. VC	1.00	.417**	.542**	.234*	.330**	.115	.146	.130	-.060
10. Sim	.417**	1.00	.433**	.110	.443**	.179	.150	.161	.009
11. Info	.542**	.433**	1.00	.256*	.308**	.082	.054	.127	-.028
12. DS	.234*	.110	.256*	1.00	.376**	.089	.100	.186	.311**
13. Ari	.330**	.443**	.308**	.376**	1.00	.291**	.324**	.153	.039
14. LMI	.115	.179	.082	.089	.291**	1.00	.836**	.320**	.141
15. LMII	.146	.150	.054	.100	.324**	.836**	1.00	.431**	.260**
16. VPAI	.130	.161	.127	.186	.153	.320**	.431**	1.00	.641**
17. VPAII	-.060	.009	-.028	.311**	.039	.141	.260**	.641**	1.00

Note. VC, WAIS-IV Vocabulary; Sim, WAIS-IV Similarities; Info, WAIS-IV Information; DS, WAIS-IV Digit Span; Ari, WAIS-IV Arithmetic; LMI, WMS-IV Logical Memory I; LMII, WMS-IV Logical Memory II; VPAI, WMS-IV Verbal Paired Associates I; VPAII, WMS-IV Verbal Paired Associates II. * $p < .05$; ** $p < .01$; *** $p < .001$.

The remote administration of WAIS-IV Vocabulary was significantly correlated with the remote administration of WAIS-IV Digit Span at $p < .05$. At $p < .01$, the remote administration of WAIS-IV Vocabulary was significantly correlated with the remote administration of WAIS-IV Similarities, WAIS-IV Information, and WAIS-IV Arithmetic. The remote administration of WAIS-IV Similarities was significantly correlated with the remote administration of WAIS-IV Information and WAIS-IV Arithmetic at $p < .01$. The remote administration of WAIS-IV Information was significantly correlated with the remote administration of WAIS-IV Digit Span at $p < .05$. At $p < .01$, the remote administration of WAIS-IV Information was significantly correlated with the remote administration of WAIS-IV Arithmetic.

The remote administration of WAIS-IV Digit Span was significantly correlated with the remote administration of WAIS-IV Arithmetic and WMS-IV Verbal Paired

Associates II at $p < .01$. The remote administration of WAIS-IV Arithmetic was significantly correlated with the remote administration of WMS-IV Logical Memory I and WMS-IV Logical Memory II at $p < .01$.

The remote administration of WMS-IV Logical Memory I was significantly correlated with the remote administration of WMS-IV Logical Memory II and WMS-IV Verbal Paired Associates I at $p < .01$. The remote administration of WMS-IV Logical Memory II was significantly correlated with the remote administration of WMS-IV Verbal Paired Associates I and II at $p < .01$. The remote administration of WMS-IV Verbal Paired Associates I was significantly correlated with the remote administration of WMS-IV Verbal Paired Associates II at $p < .01$.

Hypothesis One

For hypothesis one, it was hypothesized an EFA using PCA method of the subtests from the in-person neuropsychological battery would reveal three primary factors: general intelligence, auditory memory, and verbal comprehension. The Parallel Analysis indicated a three-factor solution for the in-person neuropsychological battery. The analysis yielded three factors explaining a total of 47.17% of the variance for the entire set of variables. Results of the factor analysis, including the factor loadings and communalities of each item of the traditional neuropsychological battery are presented in Table 9.

Factor 1 explained 25.11% of the variance. Items that exceeded the factor loading cutoff of 0.40 were WAIS-IV Vocabulary (.847), WAIS-IV Similarities (.756), WAIS-IV Information (.733), WAIS-IV Arithmetic (.539), WMS-IV Logical Memory I (.527), WMS-IV Logical Memory II (.473), WAIS-IV Matrix Reasoning (.432), and WAIS-IV

Digit Span (.326). Due to the high loadings of Vocabulary, Similarities, Information, Arithmetic, Logical Memory I, Logical Memory II, Matrix Reasoning, and Digit Span, Factor 1 was labeled as *general intelligence*. Inconsistent with hypothesis one, three subtests of the WMS-IV Delayed Memory Index (i.e., Verbal Paired Associates II, Visual Reproduction II, and Designs II) did not load on Factor 1.

Factor 2 explained 12.79% of the variance. Items that exceeded the factor loading cutoff of 0.40 were WMS-IV Designs I (.753), WMS-IV Designs II (.751), WMS-IV Verbal Paired Associates II (.721), WMS-IV Verbal Paired Associates I (.604), WMS-IV Visual Reproduction II (.453), and WMS-IV Visual Reproduction I (.409). Due to the due to the high loadings of Designs I, Designs II, Verbal Paired Associates I, Verbal Paired Associates II, Visual Reproduction I, and Visual Reproduction II, Factor 2 was labeled as *general memory*. WMS-IV Logical Memory I and Logical Memory II did not meet the cutoff of 0.40, which is inconsistent with what would be expected for a general memory factor.

The variance explained by Factor 3 was 9.27%. Items that exceeded the factor loading cutoff of 0.40 were Trails A (.833), Trails B (.736), and WAIS-IV Coding (.676). The third factor derived was labeled as *processing speed* due to the high loadings of Trails A, Trails B, and Coding.

Table 9. *Factor Loadings and Communalities for PCA of In-Person Battery*

Subtest	Factor 1	Factor 2	Factor 3	Communality
WAIS-IV Vocabulary	**.847**	-.141	-.087	.642
WAIS-IV Similarities	**.756**	-.149	-.024	.522
WAIS-IV Information	**.733**	-.361	.123	.556
WAIS-IV Digit Span	.326	.085	-.121	.115
WAIS-IV Arithmetic	**.539**	.267	-.173	.392
WAIS-IV Matrix Reasoning	**.432**	.162	-.119	.226
WAIS-IV Coding	.233	-.067	**.676**	.569
WMS-IV Logical Memory I	**.527**	.249	.115	.481
WMS-IV Logical Memory II	**.473**	.335	.142	.515
WMS-IV Verbal Paired Associates I	.216	**.604**	-.053	.463
WMS-IV Verbal Paired Associates II	-.108	**.721**	-.166	.450
WMS-IV Visual Reproduction I	.150	**.409**	.290	.407
WMS-IV Visual Reproduction II	-.006	**.453**	.382	.456
WMS-IV Designs I	-.119	**.753**	.036	.545
WMS-IV Designs II	-.040	**.751**	-.004	.547
Trails A	-.269	-.111	**.833**	.609
Trails B	-.123	.053	**.736**	.528

Notes. Extraction method; Principal Component Analysis. Rotation method; Promax. Factor loadings > 0.40 are in boldface.

Hypothesis Two

For hypothesis two, it was hypothesized an EFA using PCA method of the subtests from the teleneuropsychological battery would reveal three primary factors: general intelligence, attention/ working memory, and verbal comprehension. The Parallel Analysis indicated a three-factor solution for the teleneuropsychological battery. The analysis yielded three factors explaining a total of 49.59% of the variance for the entire set of variables. Results of the factor analysis of the teleneuropsychological battery are presented in Table 10.

Factor 1 explained 26.19% of the variance. Items that exceeded the factor loading cutoff of 0.40 were TMB Verbal Paired Associates (.540), TMB Visual Paired Associates (.524), and the remote administration of WMS-IV Logical Memory II (.818), WMS-IV Verbal Paired Associates I (.806), Logical Memory I (.733), and Verbal Paired Associates II (.632). Due to the high loadings of these variables, Factor 1 was labeled as *general memory*. Though it was hypothesized a general intelligence factor would be extracted, the items that exceeded that loaded on Factor 1 better fit a general memory factor as they have been shown measure verbal memory, visual memory, immediate and delayed story memory, and immediate and delayed memory for word pairs.

Factor 2 explained 12.03% of the variance. Items that exceeded the factor loading cutoff of 0.40 were TMB Backward Digit Span (.752), TMB Forward Digit Span (.746), TMB Digit Symbol (.632), TMB Trails B (.614), and the remote administration of WAIS-IV Digit Span (.673). Factor 2 was labeled as *attention* due to the high loadings of these variables. However, WAIS-IV Arithmetic and TMB Trails A did not meet the cutoff of 0.40 which is inconsistent with what would be expected for an attention factor. Although it was hypothesized an attention/ working memory factor would be extracted, working memory was not an adequate label for Factor 2 as WAIS-IV Arithmetic did not meet the factor loading cutoff.

The variance explained by Factor 3 was 11.37%. The third factor derived was labeled as *verbal comprehension* due to the high loadings of the remote administration of

WAIS-IV Vocabulary (.767), WAIS-IV Similarities (.764), WAIS-IV Information (.758), WAIS-IV Arithmetic (.577). These results are consistent with hypothesis two.

Table 10. *Factor Loadings and Communalities for PCA of TeleNP Battery*

Subtest	Factor 1	Factor 2	Factor 3	Communality
TMB Digit Span Forward	-.231	**.746**	.041	.500
TMB Digit Span Backward	-.086	**.752**	.002	.529
TMB Digit Symbol	.246	**.632**	-.177	.543
TMB Matrix Reasoning	.157	.388	.231	.314
TMB Trails A	.188	.201	-.088	.098
TMB Trails B	.086	**.614**	-.049	.412
TMB Verbal Paired Associates	**.540**	.138	.032	.371
TMB Visual Paired Associates	**.524**	.342	.047	.531
WAIS-IV Vocabulary	-.009	.001	**.767**	.587
WAIS-IV Similarities	.108	-.119	**.764**	.601
WAIS-IV Information	-.060	.058	**.758**	.576
WAIS-IV Digit Span	-.101	**.673**	.215	.504
WAIS-IV Arithmetic	.086	.298	**.577**	.523
WMS-IV Logical Memory I	**.733**	-.242	.168	.535
WMS-IV Logical Memory II	**.818**	-.189	.119	.641
WMS-IV Verbal Paired Associates I	**.806**	-.044	-.011	.624
WMS-IV Verbal Paired Associates II	**.632**	.225	-.298	.544

Notes. Extraction method; Principal Component Analysis. Rotation Method; Promax. Factor loadings > 0.40 are in boldface.

Two subtests of the teleneuropsychological battery did not load on any of the three primary factors. Although it was hypothesized TMB Matrix Reasoning would load on a general intelligence factor, the subtest did not meet the factor loading cutoff for any of the factors. TMB Trails A also did not meet the factor loading cutoff for any of the three primary factors. This is inconsistent with what was expected for the attention factor.

Comparison of the Factor Structures

Results of the two EFAs using PCA method revealed both similarities and differences between the two factor structures. Both batteries extracted a memory factor. WMS-IV Verbal Paired Associates I and II were administered in both batteries and loaded highly on this factor. Moreover, the memory factor extracted from the in-person battery included measures of visual memory that loaded highly (WMS-IV Visual Reproduction I and II; WMS-IV Designs I and II). This is consistent with a measure of visual memory administered virtually (TMB Visual Paired Associates) which loaded highly on the memory factor of the teleneuropsychological battery. On the other hand, the memory factor extracted from the teleneuropsychological battery included Logical Memory I and II of the WMS-IV, whereas the memory factor extracted from the in-person battery did not. The memory factor extracted from the in-person battery may be better labeled as a visual/ verbal memory factor as opposed to general memory because it did not include measures that assessed story memory abilities. Alternatively, the memory factor extracted from the teleneuropsychological battery is best labeled as a general memory factor as measures of visual memory, verbal memory, and story memory loaded highly on this factor.

The factor structures of each battery contained more differences than similarities. The in-person battery extracted a general intelligence factor which was not observed in the teleneuropsychological battery. The in-person battery also included a processing speed factor, which was not captured in the teleneuropsychological battery. The teleneuropsychological battery extracted attention and verbal comprehension factors, which were not found to be primary factors in the in-person battery. Altogether, results of the two factor analyses do not indicate the batteries measured the same underlying cognitive skills.

Chapter V: Discussion

The goal of this study was to examine the factor structures of a traditional neuropsychological battery, administered in-person, and a teleneuropsychological battery, administered remotely. This study sought to add to the existing literature on teleneuropsychological assessment and increase the current understanding of the implications of administering tests virtually that were adapted from traditional neuropsychological measures administered face-to-face.

Hypothesis One

It was hypothesized an EFA using PCA method of the subtests from the traditional neuropsychological battery administered in-person would reveal three primary factors: general intelligence, auditory memory, and verbal comprehension. Hypothesis one was not fully supported as a general intelligence factor was extracted, but auditory memory and verbal comprehension factors were not extracted.

Consistent with hypothesis one, the in-person neuropsychological battery revealed a general intelligence factor. These findings have implications on cognitive abilities that are measured using a traditional neuropsychological battery administered in-person. It is well established in the literature that the WAIS-IV measures general intelligence. Factor analytic studies consistently show the factor structure of the WAIS-IV containing verbal comprehension, working memory, perceptual reasoning, and processing speed factors. Thus, when administering a battery such as the in-person battery in the present study with measures of the WAIS-IV including subtests projected to measure verbal comprehension, working memory, perceptual reasoning, and processing speed, a general intelligence factor is expected. The factor structure of the in-person neuropsychological battery, which contained a general intelligence factor, further supported the existing literature.

The loadings of the subtests that loaded highly on this factor have clinical implications. WAIS-IV Vocabulary loaded the highest on this factor (0.84) suggesting this subtest is a good measure of general intelligence. The other two subtests of the WAIS-IV Verbal Comprehension Index also loaded higher on this factor than the other subtests that exceeded the 0.40 cutoff (Similarities= 0.75; Information= 0.73). This suggests an individual's performance on the WAIS-IV Verbal Comprehension Index correlates well with their overall general intelligence. This can be beneficial in measuring an individual's intelligence level in clinical settings, particularly when estimating premorbid level of intelligence in clinical populations that do not have a baseline measure of intelligence.

An auditory memory factor was expected to be extracted due to most measures of memory involving an auditory component in the present battery. However, a general memory factor better explained the subtests that loaded on factor two. Most measures that involved learning and encoding information (i.e., WMS-IV Visual Reproduction I, WMS-IV Verbal Paired Associates I, and WMS-IV Designs I) as well as consolidating and retrieving information (i.e., WMS-IV Visual Reproduction II, WMS-IV Verbal Paired Associates II, and WMS-IV Designs II) loaded on to this factor, which included measures that involved auditory components as well as visual components. This shows memory is a broad construct that involves numerous cognitive abilities. Although each measure of memory in the present study has been shown to measure different aspects of memory functioning, they all assessed the examinee's ability to store and retrieve information. This explains why these measures loaded on to a single factor despite their differences.

The factor structure of the in-person battery suggests this battery measures an individual's memory broadly. It is well established in the literature that the WMS-IV measures memory, specifically immediate and delayed auditory memory, and immediate and delayed visual memory. These findings further support the existing literature that the WMS-IV measures memory functioning. However, only a general memory factor was extracted, and the ability of the neuropsychological battery administered in-person in the present study to measure specific kinds of memory (i.e., auditory memory, story memory, visual memory) is therefore less known.

The subtests that loaded highest on the general memory factor were WMS-IV Designs I, Designs II, and Verbal Paired Associates II with factor loadings above 0.70. These findings suggest these tasks are good measures of memory in the context of other subtests in this specific battery.

On the other hand, WMS-IV Logical Memory I and II were the only subtests of the WMS-IV in the in-person battery that did not load on to the general memory factor. This was surprising considering these subtests have been consistently shown in the literature to measure story memory and long-term story memory under a free recall condition. It is possible Logical Memory I and II did not load on to this factor highly due to other cognitive processes involved in these subtests (i.e., receptive language abilities and the ability to understand logical-grammatical structures) that are not as highly involved in the other subtests that loaded on to this factor. The use of these cognitive skills in addition to the methodology used to assess memory in the Logical Memory I and

II subtests may affect an individual's ability to store and retrieve information. This can affect the relationship of these measures to other measures of memory that loaded on the general memory factor.

Although Logical Memory I and II did not load highly on the general memory factor, it did load highly onto the general intelligence factor. This indicates Logical Memory I and II was more strongly associated with measuring an individual's intelligence level than broad memory abilities in the present battery. This suggests that including WMS-IV Logical Memory I and II in a battery of tests that aim to measure an individual's general intelligence may be beneficial in clinical settings. These subtests can add useful information over and above the information provided by the WAIS-IV pertaining to an individual's general intelligence by providing additional information about an individual's memory abilities in relation to one's general intelligence.

Inconsistent with hypothesis one, the factor structure of the in-person neuropsychological battery also included a processing speed factor. It has been consistently shown that Trails A and B and WAIS-IV Coding measure processing speed, and these results further support the existing literature. Of the three subtests that exceeded the 0.40 cutoff, Trails A loaded the highest on the processing speed factor (0.83). Trails B and WAIS-IV Coding did not load as highly as Trails A, but exceeded the 0.40 cutoff. This may be due to the other cognitive processes involved in Trails B (i.e., cognitive flexibility and set shifting) and WAIS-IV Coding (i.e. memory and sustained attention). This suggests that of the three tests that loaded on to the processing speed factor, Trails A may best reflect an individual's processing speed abilities. However, including Trails B and WAIS-IV Coding in a neuropsychological battery can provide useful information regarding an individual’s processing speed abilities in the context of using other cognitive abilities simultaneously that are required to complete these specific tasks.

Moreover, the three measures that loaded on to the processing speed factor were administered in paper-pencil format and required the participant to work as fast as they can under timed conditions. Results of the factor analysis elucidate specific cognitive abilities, particularly processing speed, underlying the paper-pencil versions of these three measures. These findings have implications on assessing clinical populations as measures of processing speed are sensitive to a wide range of neurological and psychiatric conditions. Processing speed is also associated with other complex cognitive abilities and the utilization of these measures in an in-person battery can aid in identifying cognitive processes that are clinically relevant.

Overall, results of the EFA using PCA method of the in-person neuropsychological battery indicate general intelligence, general memory, and processing speed are underlying dimensions of this specific battery. In clinical settings, this relatively short battery of tests can be administered to generate a better understanding of an individual’s memory functioning, speed at which they process information, and expected level of functioning as a whole. Assessing these underlying cognitive processes are particularly important in characterizing an individual’s cognitive abilities and how these abilities affect their functional impairment. This can aid in differential diagnoses of neurological and psychiatric conditions which can ultimately facilitate an understanding of an individual’s functional outcome and guide treatment planning.

Hypothesis Two

It was hypothesized a second EFA using PCA method, including the subtests from remote testing, would reveal three primary factors: general intelligence, attention/ working memory, and verbal comprehension. However, the factor analysis yielded general memory, attention, and verbal comprehension factors.

The factor structure of this battery has implications on the use of teleneuropsychological testing. First, the factor structure suggests this battery measures an individual's broad memory abilities. All subtests of the WMS-IV administered in the teleneuropsychological battery loaded highly on this factor. These findings support factor analytic studies of the WMS-IV that have shown this measure to evaluate memory functioning and show support for the use of these subtests to evaluate memory functioning via teleneuropsychology.

The subtests that loaded highest on the general memory factor were WMS-IV Logical Memory II (0.81), Verbal Paired Associates I (0.80), and Logical Memory I (0.73) with factor loadings above 0.70. These results suggest these tasks are strong measures of memory in the context of other subtests in a virtual battery.

The finding that the teleneuropsychological battery extracted an attention factor reveals attentional abilities are highly involved in teleneuropsychological testing. In the present study, the participant was required to attend to a computer screen to complete measures of the virtual battery. It is possible attentional abilities are more highly involved in virtual testing due to the necessity to attend to a screen while testing. This finding has implications on teleneuropsychological testing in general. If the examinee is required to expend more energy to attend to a task that is being completed over technology, the examinee may be more vulnerable to fatigue. This can negatively impact the examinee's performance throughout teleneuropsychological testing and must be considered when interpreting scores.

Of the measures that loaded highly on the attention factor, TMB Digit Span Backward (0.75) and Forward (0.74) loaded the highest. WAIS-IV Digit Span also loaded highly on this factor (0.67). It is well established that the measure in which TMB Digit Span was adapted from (WAIS-IV Digit Span) requires attentional abilities to be able to remember, mentally manipulate, and recall digits read by an examiner. It was therefore expected that TMB Digit Span would also require attentional abilities. Unlike the traditional measure of Digit Span, the TMB Digit Span subtest requires the examinee to recall digits presented to them visually on a computer screen rather than recall digits presented to them verbally. The added component of attending to a computer screen while completing TMB Digit Span may require higher levels of attention, over and above the attentional abilities needed to complete WAIS-IV Digit Span in both the in-person and teleneuropsychological batteries.

It can also be concluded that verbal comprehension abilities are easily measured over virtual platforms. This finding is not surprising considering subtests of the WAIS-IV that comprise the verbal comprehension index did not require significant alterations to be administered virtually as no visual stimuli were involved. All subtests of the verbal comprehension index loaded highly on the third factor, with factor loadings greater than 0.70. This suggests administering tests that measure verbal comprehension abilities virtually, particularly the subtests of the WAIS-IV verbal comprehension index, is efficacious and comparable to administering these measures during in-person testing.

These findings have several implications on teleneuropsychological testing and the clinical utility of administering measures virtually that were adapted from measures traditionally administered in-person. Despite the administration of similar measures from the WAIS-IV that were adapted to virtual versions (i.e., TMB Digits Forward and Backward, Digit Symbol, and Matrix Reasoning) in addition to the remote administration of subtests of the WAIS-IV verbal comprehension and working memory indices, a general intelligence factor was not extracted from the teleneuropsychological battery. This suggests general intelligence is more difficult to measure through virtual testing. These subtests were adapted from the measures traditionally administered in-person and intended to measure the same cognitive domains. The factor structure of the teleneuropsychological battery suggests these measures do not assess the same cognitive abilities as the measures given in-person in which they were adapted from.

However, measures that were administered verbally in the teleneuropsychological battery that did not require significant alterations from their traditional administration in-person appear to measure the same cognitive domains using both traditional and virtual administration methods. These findings show support for the use of these subtests in teleneuropsychological testing. The teleneuropsychological battery in the present study can therefore be beneficial in assessing general memory, attention, and verbal comprehension abilities in clinical settings. This is particularly relevant during a time in which in-person testing is limited due to a global pandemic, and clinicians can utilize this battery to assess these specific cognitive domains.

It should be noted that less is known regarding the assessment of other cognitive domains via teleneuropsychology. At this time, clinicians should consider supplementing teleneuropsychological testing with in-person testing to obtain a comprehensive understanding of an individual's cognitive functioning. A comprehensive neuropsychological battery is essential when evaluating neurological and psychiatric conditions to best understand an individual's current level of functioning, and ultimately guide treatment planning. Thus, the incorporation of additional measures that have been well-established to assess other domains of neuropsychological functioning would be necessary to add to the teleneuropsychological battery administered in the present study.

General Discussion

Results revealed the teleneuropsychological battery and the in-person battery did not extract the same primary factors, indicating they did not measure the same cognitive domains. This suggests different cognitive skills are utilized when some measures, traditionally administered in person, are administered virtually. Several factors can cause these differences and can be explained by minute changes in tests when they are adapted to virtual versions, even if the measures were not significantly altered to be administered virtually (e.g., measures that are administered verbally that do not require the presentation or manipulation of stimuli).

Within this study specifically, the differences between virtual and in-person versions of certain measures can contribute to the discrepancies observed between the two batteries. First, TMB Digit Span Forward and Backward presents digits visually, whereas the WAIS-IV Digit Span traditionally administered in-person presents digits to the participant verbally. Although both subtests require attention and working memory skills, TMB Digit Span requires the use of attention and working memory skills to visual stimuli rather than verbal stimuli. The variation between the presentation of digits between the virtual and in-person format likely contributes to the differences observed in the factors extracted from each battery.

TMB Digit Symbol was adapted from the WAIS-IV Coding subtest traditionally administered in-person. Several differences exist between the presentation of stimuli in version of this measure as well as the method in which the participant completes each test. During the virtual subtest, the participant is required to match nine symbols and numbers as fast as possible within 90 seconds. The nine symbols are labeled 1 through 3, with three symbols labeled as 1, three symbols labeled as 2, and three symbols labeled as 3. When the symbol is presented on the screen, the participant presses the corresponding number (1, 2, or 3) on their keyboard as fast as they can. On the other hand, WAIS-IV Coding is administered in paper-pencil format. The participant is also required to match nine symbols as fast as possible, but within 120 seconds. The nine symbols are labeled 1 through 9 and are different symbols than the symbols presented in the virtual version of this subtest. The participant completes the subtest by writing the corresponding symbol in a box below each number. The numerous variations between the in-person and virtual format (i.e., differences in platform used, time, labeling of symbols, and specific symbols used) clearly require different cognitive skills and contribute to the differences in factor structures of each battery.

TMB Matrix Reasoning was adapted from the WAIS-IV Matrix Reasoning traditionally administered in-person. Both measure nonverbal reasoning by requiring the examinee to identify patterns in designs. The stimuli are presented visually in both the in-person and virtual versions, and the examinee is required to choose one response out of five options in multiple choice format that best completes the pattern. However, the specific patterns and matrices in the in-person and virtual versions of Matrix Reasoning differ, which may contribute to some of the differences observed between the two batteries.

TMB Verbal Paired Associates also contains similarities and differences compared to the WMS-IV Verbal Paired Associates administered in-person. Both measures assess declarative memory, particularly verbal memory of pairs of words. Additionally, both are scored based on the number of word pairs recalled correctly after they are presented to the examinee.

With regard to differences, the Verbal Paired Associates test administered virtually presents 25 word pairs visually, whereas the version administered in-person presents the word pairs verbally to the examinee. The examinee therefore encodes the word pairs using different cognitive skills due to the stimuli being presented in different manners. Moreover, the TMB Verbal Paired Associates contains 25 sets of word pairs whereas the WMS-IV Verbal Paired Associates presents 14 word pairs to the participant. The word pairs presented in each version also differ. Finally, the retrieval of the word pairs varies between each version. During the virtual administration of Verbal Paired Associates, the examinee is required to learn and memorize the set of word pairs, is then presented a two-to-three-minute task that serves as a distractor to increase difficulty in learning the word pairs, then requires the examinee to choose one word out of four options that completes the word pair. The in-person version of this assessment also involves a delay before the examinee is asked to recall the corresponding word from each of the 14 word pairs presented to them. However, the delay is 20 to 30 minutes and involves different tasks to serve as distractors. Finally, the in-person version of Verbal

Paired Associates involves a free-recall condition compared to the multiple-choice format in the virtual version of this measure.

TMB Visual Paired Associates is similar to standard measures that assess visual memory (WMS-IV Visual Reproduction I and II; WMS-IV Designs I and II) due to the utilization of similar cognitive skills involved in encoding and retrieving visual stimuli. Each of these measures also involve a set of distractors to increase the difficulty of learning the visual information, but the length of the delay between the presentation and recall of stimuli varies (i.e., an approximate three-minute delay for the virtual assessment and a 20 to 30-minute delay for the in-person measures).

There are notable differences between the virtual and in-person measures, such as the type of visual information learned. The TMB Visual Paired Associates involves learning a set of image pairs of scenic photos (i.e., pictures of barns, landscapes, and interiors of buildings). The WMS-IV Visual Reproduction involves learning five designs, and the WMS-IV Designs involves learning four to eight designs in addition to their location on a grid. The format in which the examinee recalls the visual information also varies between the virtual and in-person subtests. In the virtual subtest, the examinee is asked to choose one image of six images that corresponds to the image pair that was shown previously. In the WMS-IV Visual Reproduction, the examinee is required to draw the visual design that was presented to them. In the WMS-IV Designs subtest, the examinee is asked to place cards of different designs in the same places on a grid that was shown to them on a grid in the stimulus book. Considering the numerous variations between the ways in which the visual stimuli were presented and the ways the examinee is required to recall the visual information between these measures of visual memory, differences in the cognitive skills used vary between each measure.

Although there are clear differences between the virtual and in-person measures of verbal and visual memory, both batteries extracted a general memory factor. Different cognitive processes may have been involved in learning and recalling information on these subtests due to their differences in the presentation of stimuli, the type of information learned, the length of delay, distractor tasks, and condition of recalling information (i.e., free recall or recognition), but they ultimately assessed the examinee's ability to remember information. This suggests assessing general memory abilities can be done over virtual platforms despite significant variations in the test adapted from its original format. However, memory is a complex construct that encompasses other cognitive abilities (i.e., encoding, consolidation, retrieval) and contains numerous forms (i.e., auditory memory, verbal memory, visual memory, visual working memory, immediate memory, delayed memory, recognition memory). Assessing these components of memory in-person compared to virtually is outside of the scope of this study and warrants further investigation.

The virtual and traditional Trail Making Test both contain parts A and B. Both versions of part A assess visual scanning and processing speed and require the examinee to draw connecting lines between numbered circles in sequential order. Both versions of part B also measure visual scanning, processing speed, and cognitive flexibility as the examinee is asked to switch between connecting numbers and letters in sequential order. The most notable difference between the two formats pertain to the way in which the examinee completes the subtest. The virtual version requires the examinee to connect the circles by dragging their mouse or finger on their trackpad, and the in-person version involves connecting the circles using a paper and pencil. In addition, the placement of the numbers and letters on both parts A and B differ between the virtual and in-person tests. The extent to which these differences contribute to differences in performance is unknown.

In addition to the variations between the tests administered virtually and in-person, the instructions differed despite the virtual measures being adapted from the traditional in-person measures. Because the instructions are not standardized, the way in which the participant approaches the subtest may differ between the format in which the test is administered. This can also cause differences in cognitive skills used to complete each test, therefore impacting performance.

Despite these differences, some measures were administered virtually that did not require any changes from the in-person administration. For example, WAIS-IV Vocabulary, Similarities, Information, Digit Span, and Arithmetic, as well as WMS-IV Logical Memory I, Logical Memory II, Verbal Paired Associates I, and Verbal Paired Associates II were administered in both batteries. These subtests are administered verbally by the examiner that do not require visual stimuli, with the exception of sharing the examiner's screen for the WAIS-IV Vocabulary subtest to display the words the examiner asked the participant to define. A general intelligence factor and verbal comprehension factor were therefore expected in both batteries due to these measures being administered in both batteries without any alteration to the administration of the test. However, a general intelligence factor was only extracted in the in-person battery and a verbal comprehension factor was only extracted in the teleneuropsychological battery. This suggests subtle differences, such as the format of the administration (i.e., face-to-face in-person or virtual) can cause differences in the cognitive domains being measured by the same subtests.

The results of the present study also revealed processing speed was captured in a factor analysis of the in-person battery, but not the teleneuropsychological battery. Subtests that measure processing speed such as the Trail Making Test and Coding were administered in both batteries and thus, it would be expected that a processing speed would be extracted from both batteries. Although the virtual versions of the Trail Making Test and Coding were adapted from in-person measures, the adaptions made clearly decreased the test’s sensitivity in assessing processing speed abilities. The fine motor skills involved in using a paper and pencil to complete a subtest in-person differs from the fine motor skills required for completing tests on a computer, which can explain the present results. This further suggests virtual tests adapted from measures traditionally administered in-person may not necessarily assess the same cognitive domains.

The factor analyses also showed an attention factor was extracted from the teleneuropsychological battery but not the in-person battery. Subtests that involve attentional skills were administered in both batteries, such as Digit Span, Arithmetic, Coding, and the Trail Making Test, but only loaded highly on a factor extracted from the teleneuropsychological battery. This may be explained by adapted versions of Digit Span, Coding, and the Trail Making Test requiring greater attentional skills when administered via technology. The virtual versions of these subtests all involve the examinee to attend to a computer screen and process visual stimuli. Alternatively, the in-person administration of these subtests does not require the examinee to attend to a screen and other forms of attention are involved (i.e., attention to auditory information for WAIS-IV Digit Span; attention to visual information on paper for WAIS-IV Coding and the Trail Making Test). This suggests that completing tasks over the computer require a different level of attentional abilities compared to tasks administered in-person.

These findings have several implications on the use of teleneuropsychology, particularly administering measures that were adapted from assessments traditionally administered in-person. The interpretation of results obtained from testing using virtual platforms must be altered as it cannot be assumed that virtual assessments measure the same cognitive domains as tests administered in-person. Due to this, it is essential for clinicians to be cognizant of the differences between virtual and in-person batteries and incorporate this knowledge while conceptualizing an individual's performance. Clinicians should openly acknowledge this limitation and be cautious in their ability to form definitive conclusions from virtual testing.

It is important to note testing in the present study attempted to control for extraneous factors during virtual testing that may have altered performance. When testing clinical populations virtually, clinicians may not be able to test patients in a controlled environment. This can negatively influence performance and interfere with capturing a patient's true cognitive abilities. For example, the present study ensured the participant completed testing in a quiet, controlled room that was comparable to the controlled environment in which the in-person battery was administered. Unfortunately, some patients may not have the ability to test in quiet, controlled environments and this must be considered when interpreting results of teleneuropsychological testing with clinical populations.

However, the clinical implications of these results during the COVID-19 pandemic warrant discussion. When clinicians are unable to resume in-person testing to protect from potential spread of the virus, teleneuropsychological testing may be the only option to provide services to patients. Results of the present study do not indicate that teleneuropsychological testing should not be used, but rather, clinicians must be cautious in their approach of interpreting scores and acknowledge that virtual measures may not measure the same domains as in-person measures.

Limitations

Though the present study adds to the limited research on teleneuropsychology, it is not without limitations that warrant discussion. A notable limitation in the present study was the variability in testing conditions. A cornerstone of neuropsychological assessment is testing in a standardized and controlled environment to limit the influence of extraneous factors on test performance. The teleneuropsychological battery in the present study was administered remotely to participants in their home environment which varied between each participant. On the other hand, data from the in-person neuropsychological battery was archival and was previously administered in a standardized neuropsychological testing environment (i.e., at a community mental health clinic at an academic institution). The lack of consistency in testing conditions may a have contributed to the differences observed between performance on the battery in each testing condition.

Within the teleneuropsychological testing condition, the inability to control for specific environmental factors in each participant’s home during testing may have also impacted performance on the teleneuropsychological battery. Because participants in the teleneuropsychology battery group were administered the battery from their homes, they were instructed prior to the initiation of testing to take measures to help eliminate distractions such as ensuring the participant is in a quiet environment, placing a sign indicating "testing" on their door if possible, cellular phones are turned off and out of sight, and notifications on both the participant's and examiner's computer are turned off (i.e., software updates, messaging, and sounds from emails). Despite this, interruptions still occurred. Poor internet quality and loss of connection during the videoconference also disrupted testing on a few occasions. These factors may have negatively impacted participant's performance, and the extent to which these factors affected the accuracy of test results are unknown. Environmental and technological issues have been noted as primary limitations of teleneuropsychological assessment in general by researchers and clinicians, and these limitations were further presented in this study.

Variability in testing environment within the teleneuropsychological battery was also associated with variations in testing times. A benefit of teleneuropsychological testing is the ease of administering measures to participants from their home environment, which does not require travel and is not limited by hours of operation of settings where testing typically occurs in-person. Participants were administered the teleneuropsychological battery at varying times during the day given the flexibility. The variable testing times of each participant may limit the accuracy of results considering attentional abilities have been shown to progressively decline throughout the day. Some participants in the teleneuropsychological testing condition indicated they were completing testing following a full work day which can certainly impact an individual's ability to perform at their optimal level. Attentional abilities are required for any cognitive task, and sustained attention is necessary for completing testing on a web-based platform. The variation in testing times and attentional capacities of participants are limitations of the data as it is unknown whether each participant's performance during remote testing was a true reflection of their level of cognitive functioning.

Numerous sample characteristics limit the generalizability of the results of the present study. First, the sample consisted of healthy participants without any history of TBI, cerebral injury not due to TBI, psychiatric or psychological treatment, or DSM diagnosis. Participants were excluded from the study if they endorsed any history of these factors given their influence cognitive performance, which has been frequently cited in the literature. The exclusion criteria therefore limits the generalizability of these findings to clinical populations.

The generalizability is also limited considering the nature of the sample tested, which likely had a higher level of cognitive functioning compared to the performance that would be expected from a random sample of the general population. For example, the average level of education of participants in the in-person testing condition was 16.08 years, and 16.27 years for the teleneuropsychological battery, suggesting most participants attended or completed college at a minimum. The normative sample of the TMB Digital Neuropsychology Toolkit also consists of a population that does not represent the diverse population of the United States and was normed on individuals with a higher level of education and cognitive functioning compared to the average population. Given the higher level of education in the present sample and sample in which the TMB normative data was developed, the results of this study are limited in the generalizability to populations with lower levels of education.

It is important to consider teleneuropsychological testing requires a level of competency using technology. This may inhibit individuals of lower socioeconomic from being represented in the normative data of teleneuropsychological assessments due lack of access to smartphones, tablets, or computers, causing less familiarity and fluency using technology. Altogether, a limitation of the present study and teleneuropsychological testing broadly pertains to the limited generalizability of these results due to the lack of research on these measures with populations diverse in socioeconomic status, level of education, race, and other demographic factors. This includes non-English speaking individuals as well, as proficiency in English was required for the present study.

The length of the teleneuropsychological battery was a notable limitation. The battery was designed to be brief and included measures that did not require major adaptations, material manipulation, or stimulus books. Because most neuropsychological assessments involve these factors, the battery was limited in the number of tests that could be included. The battery was also designed to be administered in approximately three to four hours for the purposes of participant recruitment, maintaining participant attention, and reducing fatigue and sensory burden associated with hours of looking at a computer screen. Thus, a comprehensive neuropsychological profile of each participant was not captured. The teleneuropsychological battery utilized in the present study showed promising results for assessing general memory, attention, and verbal comprehension using a virtual platform, but it is likely the factors extracted from each battery may have differed if additional neuropsychological measures were added.

Individuals factors such as current levels of depression, anxiety, and sleep were not assessed or considered in the analyses. This study was conducted amidst the COVID-

19 pandemic, and participants completed testing from their home as a result of self-quarantine to limit the risk of contagion. Various factors related to the pandemic and self-quarantine have caused a multitude of negative emotional and psychosocial consequences affecting a large percentage of the general population. This includes, but is not limited to grief associated with the death of a loved one, financial and occupational stressors, limited social interaction, illness anxiety, and development of unhealthy lifestyle habits. These factors can certainly impact an individual's mood, and it has been widely reported that the prevalence of depression and anxiety significantly increased during the COVID-19 pandemic. Depression and anxiety are also well known to impact an individual's quantity and quality of sleep, which has negatively affected many during unprecedented times.

It has been well-established in the literature that depression, anxiety, and poor sleep can negatively influence an individual's performance on neuropsychological testing. However, the present study did not include measures or screeners that assess for these factors. It is therefore unknown whether participants were experiencing heightened psychological distress or sleep difficulties at the time of testing, which is likely considering the trends in the general population during the COVID-19 pandemic. Because these factors were not controlled for, it is possible the present study did not evaluate each participant's optimal level of cognitive functioning.

Future Research

Future research is essential given the clinical utility of teleneuropsychology, particularly during the wake of a global pandemic that limits in-person testing. Research regarding teleneuropsychological assessment remains limited, which has caused hesitation for a large percentage of neuropsychologists to incorporate remote testing into their practice. This new paradigm of testing therefore warrants further investigation considering the immediate need of virtual testing and potential for widespread use beyond the COVID-19 pandemic.

Given the sample size of 200 healthy participants in the present study, the generalizability of these findings is limited for numerous reasons. This preliminary study contained a relatively small sample size and more robust research is needed with larger samples to determine whether the teleneuropsychological and in-person batteries measure the same constructs that were observed in the present study. Additionally, participants were excluded from the study if any history of TBI, cerebral injury not due to TBI, psychiatric or psychological treatment, or DSM diagnosis was reported. Researchers have begun to explore the use of teleneuropsychology with various clinical populations, and a hypothetical future study could compare diagnostic groups using the battery in this study. This would provide a deeper understanding of the clinical utility of this specific battery beyond what was found in the present study, as the goal was to compare the factor structures of the in-person and teleneuropsychological batteries.

Researchers could further study teleneuropsychological testing in clinical populations by comparing performance within the remote testing battery specifically. The teleneuropsychological battery consisted of both traditional neuropsychological assessments administered verbally and measures administered on a web-based platform. Future studies should compare performance on traditional measures administered virtually and measures of the web-based platform. This would provide a better understanding of whether the method in which measures are administered remotely (i.e., verbally or online) are better at diagnosing different neurological and psychiatric populations.

In this study, the average age of the teleneuropsychology testing condition was 28.57 years, and the average age of the in-person testing condition was 27.43 years. Thus, less is known regarding the generalizability of these results to younger and older age cohorts. Previous studies have noted the challenges pertaining to testing older adults via teleneuropsychology for various reasons including, but not limited to, less familiarity and comfortability with technology. Similar challenges have been conveyed regarding teleneuropsychological assessment of pediatric populations and future research should be conducted specifically with these age groups.

As highlighted in the limitations, the current knowledge on teleneuropsychological testing is limited and may not be representative of a random sample of the United States population. Virtual assessments, including those administered in the present study, have not yet been robustly validated with diverse populations. Future research should aim to investigate the use of teleneuropsychological testing with lower socioeconomic groups, and those with lower levels of education. This remains a limitation of traditional neuropsychological assessments as well which are commonly normed with homogeneous, white populations with higher levels of education and socioeconomic status that likely would not represent a random sample of the general population. Validation of virtual measures with diverse populations is therefore warranted before the widespread use in clinical settings.

Researchers should also explore the use of teleneuropsychological testing with non-English speaking populations. The present study was limited to English speaking individuals due to lack of access to interpreters and limited knowledge regarding the use of the measures in the present batteries using other languages. Considering the increasingly diverse population of the United States, future research should study teleneuropsychological testing with linguistically diverse samples.

Although the two groups did not significantly differ in age, sex, and education, the groups significantly differed in race. To minimize group differences, future researchers should consider a within-subjects design, administering both the teleneuropsychological battery and traditional in-person neuropsychological battery to each participant. This would assist in better understanding individual differences between test performance in each setting. Additionally, should interruptions or distractions occur during teleneuropsychological testing, administering the in-person battery to the same participant can aid in identifying the extent to which confounding variables may have negatively impacted performance by comparing results of both testing conditions.

Validation of teleneuropsychological assessments using different modalities of technology is also needed. The present study involved the use of laptops or computers to complete the measures on the web-based platform and to administer traditional measures verbally over videoconference. However, smartphones and tablets have also begun to be used by clinicians to conduct neuropsychological testing. It has been noted by the publishers of the web-based platform in the present study that device variance can pose a significant threat to test validity, particularly on measures that assess reaction time. Preliminary data has been collected regarding differences in performance between testing on each technological device. Future research should further explore these differences not only on tests of reaction time, but across all cognitive domains. Comparing healthy controls to clinical populations using each modality can also be beneficial to determine whether corrections for specific technological devices should be made when using virtual platforms for testing in clinical settings.

Given the limitation of the present study that factors such as mood, anxiety, and sleep were not controlled for, future research should include measures that assess these aspects of functioning to include in the analyses. This is particularly important considering the present study was conducted during the COVID-19 pandemic, a time in which significant variations in mood, anxiety, and sleep have been documented. Researchers should carefully consider these factors in future studies and potentially include exclusion criteria dependent on a participant's score on screenings of these factors given that they have been shown to influence neuropsychological performance. On the same note, it would be beneficial for researchers to conduct a study involving a within-subject, repeated measures design, comparing performance of participants during the COVID-19 pandemic, and post-COVID-19 pandemic. This would allow for a better understanding of the influence of these factors on both teleneuropsychological and traditional in-person neuropsychological testing during a global pandemic.

A future hypothetical study should expand the present teleneuropsychological battery to include additional measures. The batteries administered in the present study produced a limited neuropsychological profile and published studies on teleneuropsychological testing thus far have also consisted of relatively brief teleneuropsychological batteries. Comprehensive testing is essential to understand patterns of scores and identify cognitive impairment in patients, and creating a more comprehensive teleneuropsychological battery is necessary to evaluate the clinical utility of virtual testing. Unfortunately, neuropsychological tests traditionally administered in-person have not yet been normed using virtual testing platforms. This has caused some neuropsychologists to be hesitant to conduct comprehensive remote evaluations, or even implement teleneuropsychological testing in general in their practice. To overcome this, expand the use of teleneuropsychological assessment, and build upon the brief teleneuropsychological batteries that are currently being used, future research is needed on virtual testing to establish norms, validate remote assessments, and show adequate sensitivity and specificity.

Many traditional neuropsychological measures have not been adapted to virtual versions due to significant variations needed to administer the test, or due to test security (i.e., the need to send blocks to participants prior to the testing session to administer Block Design of the WAIS-IV, or sending protocols for measures that require the use of a paper and pencil). Future investigators should consider designing a study in which virtual testing is augmented with the administration of some measures in-person. This method, often referred to as the "hybrid model" (i.e., conducting some testing in-person and some virtually) is becoming increasingly popular. The hybrid model of neuropsychological testing would benefit from further study to evaluate which assessments are most appropriate for in-person versus remote testing, as well as which specific measures should be included in the battery to evaluate various neurological and psychiatric populations.

Summary

In conclusion, conditions created by the COVID-19 pandemic have forced clinicians to transition to alternative methods of providing services beyond what is traditionally provided in-person. Remote testing has become increasingly popular and has provided the field of neuropsychology with an opportunity to evolve from its traditional practices to incorporate advanced technology to conduct testing. The shift to remote testing that clinicians have been forced to make may reflect an even broader transition in neuropsychology as a whole, and has shed light on a new paradigm of the provision of psychological services.

Given the immediate need and potential for long-term use of remote assessment, the present study aimed to provide a better understanding of how of how virtual versions of traditional neuropsychological tests compare to the tests in which they were derived from. The results of the present study indicated that when comparing a teleneuropsychological battery to a neuropsychological battery administered using traditional in-person methods, there were more differences than there were similarities. The teleneuropsychological battery was designed to measure the same cognitive constructs as a traditional neuropsychological battery. However, results showed while both batteries measured general memory, the other factors extracted in each battery differed. This suggests different cognitive skills are used for tests administered virtually that were adapted from measures traditionally administered in-person.

These results can be explained by numerous factors, and the variations between the two batteries must be noted. Though some subtests in the teleneuropsychological battery did not require adaptation to be administered virtually, some tests required notable modifications to be administered via a digital platform. Because these tests were not identical, it would be expected that some variations in the cognitive abilities used to complete measures in the teleneuropsychological battery compared to the traditional in-person administration of the measures would be present. Results of the present study confirmed this, and factor analyses of the two batteries suggested general intelligence, general memory, and processing speed were measured in the in-person battery, while general memory, attention, and verbal comprehension were assessed in the teleneuropsychological battery.

Altogether, results of the present study suggest that adaptations must be made when interpreting results from teleneuropsychological assessment. The literature on the validity and clinical utility of teleneuropsychological assessment is in its early stages, and it cannot yet be concluded that virtual assessments can be interpreted with the same conceptualization of assessments administered in-person. Further research is needed to better understand similarities and differences between remote and in-person measures, and future studies should continue to investigate the validity, specificity, and sensitivity of teleneuropsychological assessments.

On the other hand, these results illuminate the potential benefits of teleneuropsychological testing and extending neuropsychological services to patients in their home environment. Though the interpretation of results of teleneuropsychological testing must be altered and require further understanding, this study showed valuable information can still be acquired regarding an individual's cognitive abilities through virtual testing. Implementing teleneuropsychological testing can help reduce numerous barriers for patients who would not otherwise have access to healthcare.

Finally, implementing teleneuropsychological testing is especially relevant during the COVID-19 pandemic. Conducting neuropsychological evaluations virtually can offer patients the opportunity to be evaluated who may not otherwise be able to due to being in an at-risk medical or age group, being unable or reluctant to use mass transit to attend appointments due to social distancing measures, or are uncomfortable testing in a room with an examiner for multiple hours due to fear of exposure to the virus. This also pertains to clinicians who may be unable or hesitant to resume in-person testing services due to being in a high-risk group identified by the CDC or in attempt of minimizing the risk of contagion. For patient populations who are unable to be tested in-person during this time but are in urgent need of testing (e.g., pre-surgical evaluations; inpatient populations) teleneuropsychological testing may be the best alternative and may outweigh the risk of withholding from conducting a neuropsychological evaluation.

Clinicians and patients must therefore assess the risks and benefits of undergoing or foregoing testing during a global pandemic. At this time, the benefits of teleneuropsychological testing appear to outweigh the risks and limitations. For clinicians who remain hesitant to incorporate remote testing into their practices, a hybrid model (i.e., incorporating both in-person and virtual testing) at the minimum may be the most logical choice when in-person testing remains limited to minimize the risk of contagion of a viral disease. This can allow for the provision of services while the literature on teleneuropsychological assessment of healthy and pathological individuals continues to grow.

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