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REVIEW ARTICLE

Technology meets tradition: a hybrid model for implementing digital tools in neuropsychology

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ABSTRACT

The COVID-19 pandemic has significantly impacted the provision of mental health care services and the ability to provide neuropsychological evaluations. The inability to conduct traditional evaluations has left neuropsychologists with the unprecedented task of determining how to modify existing paradigms while balancing the need to provide services and adhere to safety parameters. The COVID-19 literature suggests clinicians are modifying their evaluations based on the following models: (1) continuing to administer in-person evaluations; (2) discontinuing all evaluations due to issues related to standardization, test security, and patient-specific characteristics; (3) conducting virtual evaluations; and/or (4) adopting a hybrid model incorporating both traditional and technology-based modalities. Given the challenges with models 1–3, along with the modifications in telehealth guidelines and insurance reimbursement rates, neuropsychologists are more poised than ever to solidify the implementation of a hybrid model that lasts beyond COVID-19. We introduce the term Hybrid Neuropsychology, a model for the future of neuropsychological evaluations that includes three Action Items: (1) building a technology-based practice; (2) integrating data science; and (3) engaging with innovators in other fields. Hybrid Neuropsychology will enable clinicians to effectively modernize their practice, improve health care equity, and ensure neuropsychology secures its place in a technology-based world.

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Mental health, neuropsychology and COVID-19

In March 2020, clinics across the United States shuttered in response to the COVID-19 pandemic. The immediate impact of COVID-19 on mental health care and specifically neuropsychology became profound and far-reaching, marking the first time in the history of neuropsychology that neuropsychologists were unable to conduct traditional evaluations. As the COVID-19 pandemic continues and without consensus within the field for translating in-person evaluations to technology-based platforms, neuropsychology has had to forge its own path in an unprecedented way. The aim of this section is to highlight the rapid changes in the mental health field, illustrate how COVID-19 has differentially impacted neuropsychology, and summarise the implementation of teleneuropsychology (TeleNP).

COVID-19 and mental health

It is widely understood that the rampant spreading of COVID-19 has had a significant impact on mental health. According to a mental health survey conducted by The Academy of Medical Sciences (2020), illness anxiety, isolation, lack of access to mental health services, economic downturn, and interpersonal relationships are just some of the many factors impacting perceived mental health. Further, 55% of survivors present with at least one mental disorder, demonstrating that the downstream effects of inflammatory processes associated with COVID-19 withstand beyond the course of the disease itself (Gennaro Mazza et al., 2020). The impact of COVID-19 on in-person mental health services has resulted in the widespread use of telehealth, which was previously a highly debated and less favoured tool for providing these types of services. In a 2019 survey, 66% of consumers were willing to use telehealth, while only 8% had experience using telehealth services. Interest was moderated by age, with millennials requesting that more mental health services become offered through telehealth (American Well, 2019). With the additional mental health challenges both indirectly and directly

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caused by COVID-19, the mechanism by which mental health services are delivered has fundamentally changed. Technology is now an integral part of providing psychotherapy and psychiatric consultations, facilitated by the relaxation of the Health Insurance Portability and Accountability Act (HIPAA) guidelines (Office for Civil Rights, 2020) and comprehensive parity – that is, insurance reimbursements for telehealth visits equal to in-person care (Coronavirus Preparedness & Response Supplemental Appropriations Act, 2020).

Contextualizing challenges in digitizing neuropsychology

While the transition between in-person to remote sessions has been more straightforward for other mental health services, neuropsychology as a field has had greater difficulty adapting to using technology-based platforms. Generally, a neuropsychological evaluation consists of a clinical neurobehavioral interview, the administration of cognitive assessments, interpretation of test scores, synthesizing qualitative and quantitative data into a comprehensive report and providing feedback and recommendations to patients.

Neuropsychological tests batteries are often described as flexible, yet a survey of 2004 individuals who administer these assessments tend to use a combination of the same 40 tests (Rabin et al., 2005). Of those 40 tests, the most widely used are the Wechsler Adult Intelligence Scales (WAIS-R/WAIS-III; Wechsler, 1997a), Wechsler Memory Scales (WMS-R/WMS-III; Wechsler, 1997b), Trail Making Test, California Verbal Learning Test (CVLT/CVLT-II; (Delis et al., 1987; Delis et al., 2000), and Wechsler Intelligence Scale for Children (WISC-III; Wechsler, 1991). There are appropriate reasons for using these tests: they are well-validated, have established normative data, and are sensitive to neurocognitive dysfunction. They are also routinely taught to neuropsychology trainees in practica, internships, and beyond, during which trainees learn to synthesize these data with information collected during the clinical interview to make appropriate diagnoses, recommendations, and referrals.

Neuropsychology's response to COVID-19

At the beginning of COVID-19, neuropsychologists were largely in disarray, as the tests used in the field are generally normed based on results from in-person evaluations. Without normative data that can be used in test interpretation, providing assessments is in many ways futile. Normative data is routinely integrated with qualitative data to substantiate diagnostic conclusions and establish a baseline with which assessments may be compared and rendered below or above the expected level of neuropsychological functioning. The results of two surveys collected relatively early in the COVID-19 pandemic (Marra, Hoelzle, et al., 2020) reported that neuropsychologists were divided on how to proceed given the pandemic-related restrictions, with those in private practice significantly less likely to provide services than those in academic settings. A majority of clinicians continued to conduct the outpatient evaluation (57%), 31.3% of clinicians discontinued seeing any inpatients or outpatients, and when asking about the use of technology, 16.1% of clinicians reported using neither a phone nor video, with no plan to use these services in the future. Neuropsychology also began to fall behind other areas offering mental health services, which were able to switch relatively quickly to using online platforms for the delivery of mental health services, and in fact reported increases in outpatient attendance (Kannarkat et al., 2020).

Perhaps the most striking statistic reported in these studies is that 16.1% of clinicians have no plans to implement digital tools in neuropsychological assessment, emphasizing not only the potentially long-lasting financial burden to those clinicians but also the reduced amount of access patients may have when seeking a neuropsychological evaluation during the pandemic. The rationale behind refusing to use technology in evaluations is well-founded because as discussed, neuropsychological tests were not normed under the conditions they would be administered during a pandemic (i.e. using an online platform or providing items over the phone). Additional concerns may also include a lack of familiarity with technology and issues related to testing security. Overall, the arguments for adopting remote evaluations or abstaining from any neuropsychological testing both deserve merit.

Using teleneuropsychology before and during COVID-19

Prior to the pandemic, the neuropsychology literature provided some useful guidance on using technology in neuropsychology and switching from conducting traditional evaluations to implementing TeleNP (Bauer et al., 2012; Bilder, 2011; Bilder & Reise, 2019; Brearly et al., 2017; Germine et al., 2019; Miller & Barr, 2017). As a result of the COVID-19 pandemic, the InterOrganizational Practice Committee (IOPC) was created to provide guidance on moving forward

with neuropsychological evaluations during and beyond COVID-19. In their statement, they addressed gaining competency in TeleNP, offered guidance on conducting evaluations, and summarized issues relating to licensure and reimbursement by insurance companies (IOPC, 2020). The reader is referred to this paper for greater detail about available resources during COVID-19, which is beyond the scope of the current paper.

To reduce some of the impacts on neuropsychologist's ability to conduct evaluations, test publishing companies, research labs, and private companies also made remote tools available for cognitive assessment. As discussed by the IOPC, many of these assessments that became available were not recommended to replace traditional neuropsychological tests because they did not meet the criteria for using computerized neuropsychological assessments outlined by Bauer et al. (2012). That is, these tests do not meet the minimum psychometric standards for reliability and validity to be incorporated into a neuropsychological battery. Ultimately, neuropsychologists practicing during COVID-19 face a significant burden: having to individually decide which resources to implement, how to engage in best practices as they continue to evolve, and if using unconventional assessments, make sure to acknowledge their limitations.

Evaluation models

In adapting to the changes necessitated by the pandemic, neuropsychologists are challenging existing paradigms by developing and utilizing novel models of evaluation. This section identifies and critiques each of the current evaluation models, proposing that the most successful model is the hybrid model, as it promotes a scientific process, health care equity, and longevity of the field.

Leaping into the 21st century: an argument for change

Neuropsychology is at a crossroads. Given the current state of the pandemic and the available literature on neuropsychology during COVID-19 so far, neuropsychologists may use one or more of these possible evaluation models: (1) continuing evaluations that are fully in-person using appropriate sanitization and social distancing parameters; (2) discontinuing all neuropsychological services, due to the reduced level of standardization when digitizing an evaluation, along with very real ethical and test security issues; (3) carrying out all aspects of the evaluation virtually; or (4) adopting a hybrid model of conducting evaluations, including some aspects that are virtual (interview, some or all tests, and feedback) and some that are in-person.

Because surveys were done in the early months of the pandemic, it is not clear the extent to which neuropsychologists are currently using any one or combination of these models. Indeed, neuropsychologists are trained to be flexible and are likely to use a modality they feel comfortable with while having a specific referral question in mind. There is likely no *perfect* model here, but there are more sustainable ones – that is, one that neuropsychology may continue to utilize and improve upon beyond the pandemic.

Model 1 is the most similar to care-as-usual, and from the surveys completed early on in the pandemic, it was one of the most straightforward options considered. Many neuropsychologists continue to prefer in-person over remote assessments on a case-by-case basis dependent on patient characteristics such as age, language, sensorimotor impairments, and neuropsychological presentation (Koterba et al., 2020). If the in-person assessment can be done safely, then it could mean maximum interpretability of patient scores with respect to norms. The premise that in-person assessments during the pandemic are the same as in-person assessments before the pandemic warrants some scrutiny. Wearing a mask and following social distancing guidelines may reduce rapport (Koterba et al., 2020) and could even be breaking standardization, as normative studies were not conducted with either or both the examiner and participant wearing masks or with social distancing. Future studies may determine the extent to which these new parameters, such as wearing a mask, impact an examinees performance on cognitive tests, as it is unclear the extent to which an examinee relies on, for example, reading an examiners lips for encoding instructions and test-related information (Erber, 1975).

On its face, Model 2, discontinuing all evaluations, seems fundamentally untenable. And yet, this was the default route for many neuropsychologists early in the pandemic. This option considered for many rose out of ambiguity caused by the pandemic and can be attributed to the lack of consensus regarding the use of a standard protocol across the field. It is conceivable that some clinicians are continuing to abstain from conducting evaluations even with appropriate sanitization techniques, as indicated by the significant minority of clinicians who reported having no plans of using phone or video modalities for any part of

evaluation during the pandemic (Marra, Hoelzle, et al., 2020). Given the current level of uncertainty, neuropsychologists discontinuing evaluations may decide to only pursue psychotherapy, downsize their practices, or even retire. Still, others may choose to only conduct remote intakes and postpone testing until in-person evaluations may resume. All of these options are fair for the reasons discussed above, but if every clinician decided to do this, the field would not be sustainable. At the minimum, patients would be missing critical neuropsychological services, and in the worst case, neuropsychology as we know it might cease to exist as an integrated part of medical practice.

Model 3, an entirely virtual model, might seem on its face ideal when considering the continuation of neuropsychological services during the pandemic. However, it was not the preferred method of evaluation early in the pandemic when remote tools were less readily accessible. As discussed and for the reasons mentioned above, it is not clear that even in their current state, remote neuropsychological assessments meet the criteria outlined by Bauer and colleagues (2012) such that neuropsychologists would feel comfortable replacing all current tests with remote ones. A completely virtual evaluation would also not be recommended for individuals who are uncomfortable with technology, or when the referral is for a forensic or disability evaluation, for which the standardization of the tests administered is critical (Marra, Hamlet, et al., 2020). Looking forward, it is possible that Model 3 will become more accepted and commonplace once remote assessments are validated across clinical populations while demonstrating appropriate sensitivity and specificity to neurocognitive diagnoses. While methods for digital neuropsychology are advancing rapidly and hold promise, it is premature to replace in-person evaluations with entirely digital or remote modalities, as these measures are not sufficiently validated and would therefore leave critical gaps.

Models 1, 2, and 3 have potentially more challenges than benefits, with issues related to standardization, a lack of comprehensive norming and validation work, continuity of care, and maintaining the overall relevance of the field. When reviewing these issues, it becomes readily apparent that Model 4, a hybrid model of neuropsychology incorporating both traditional and technology-based modalities, is the most logical choice. A hybrid model offers sustainability in that it can be adapted to the needs of patients during and beyond COVID-19. It is also consistent with pre-pandemic literature (Bilder, 2011; Bilder & Reise, 2019; Germine et al., 2019; Miller & Barr, 2017), which proposed that the future of clinical decision-making in neuropsychology will involve the collection of data from multiple technology-based and traditional sources.

A hybrid model as a launching pad

Some clinicians in academic medical centres are already implementing a hybrid-like model out of necessity during COVID-19. For example, a group of paediatric neuropsychologists reported a number of benefits from using what they refer to as a tiered model of service, which offers either targeted tele-testing or in-person testing based on a child's needs and referral question (Pritchard et al., in press). They reported that using a tiered model allowed them to maintain their financial stability while gaining greater access to patients. We take this tiered model of service a step further and argue that a hybrid model is a useful framework for neuropsychological practice beyond the pandemic, allowing new tools to be implemented in the field and used in increasingly innovative ways that better serve patients.

If in the likely case HIPAA guidelines and parity with insurance company reimbursements become stringent once again, the majority of neuropsychologists may decide to revert to conventional methods of conducting evaluations for the foreseeable future. This could have particularly negative effects on areas such as health care equity, which has been a major focus for health disparity researchers during and beyond during COVID-19. Although the pandemic has brought to the surface egregious health care disparities that Latino and Black individuals face in the United States (Garg, 2020; Hooper et al., 2020; Yancy, 2020), it has also created a unique opportunity for mental health services and neuropsychology, in particular, to effectively reach a greater number of individuals experiencing cognitive difficulties using digital tools, such that those who live in rural or underserved areas with minimal access to neuropsychologists may be able to undergo a comprehensive evaluation and receive the appropriate feedback and recommendations. We argue that the potential to promote health equity within neuropsychology and the mental health field at large far outweigh the potential barriers that arise when implementing digital tools. It is therefore prudent for neuropsychologists to be introspective both individually and collectively as a field. We discuss the ways a hybrid model can last beyond the

pandemic and then propose a model that would pave the path towards more sustainable neuropsychology.

A new neuropsychology

This section proposes that neuropsychology is well-suited to adopt a technology-based approach to evaluation and should not revert to using traditional models during or beyond the current COVID-19 pandemic. We introduce the term Hybrid Neuropsychology to refer to a technology-based neuropsychology practice that incorporates both traditional and novel remote assessments, facilitates the integration of data science into the clinic, and promotes collaboration with innovators in other fields.

Using a hybrid model beyond COVID-19

Neuropsychology can no longer rest on existing paradigms, nor should it if and when the pandemic allows for 'business as usual'. As seen in Table 1, tests most commonly used today are based on assessments created decades ago, during a time when science was perceived in a fundamentally different way than it is now, and before the term 'neuropsychology' existed in the literature (Klove & Forster, 1963). Consistent with this, even revised versions of tests are in many cases are problematic, particularly when considering language/racial/cultural biases and psychometrics (Brickman et al., 2006; Manly & Echemendia, 2007). For example, the most recent version of the Boston Naming Test – 2nd edition (Kaplan et al., 2001) portrays an image of a noose, which is at a minimum, culturally insensitive, and more significantly, may cause patients emotional distress. Additionally, the normative data upon which clinical decisions are based are often limited for certain groups, resulting in those groups performing seemingly more poorly on those tests. For example, Black individuals score significantly lower than White individuals on 10 of the 12 RBANS subtests (Patton et al., 2003), demonstrating that psychometric properties of this test are not sound for Black individuals, who constitute a significant minority of the population and are already a highly disadvantaged group.

In contrast, a remote platform like TestMyBrain, which uses a citizen-science approach, allows for the potential to collect data from a relatively larger, more heterogeneous sample. Normative data have been collected from approximately 2.5 million people over the last 12 years. The utility of these tools is constrained, however, by reliance on a convenience-based normative sample with a likely higher level of functioning than would be expected compared to random sampling from the population. These tools also rely on a minimum level of technical fluency that may make them inappropriate for evaluating individuals from certain populations (e.g. individuals who do not know how to use a computer or smartphone). For these and other reasons, a remote platform like TestMyBrain cannot replace existing neuropsychological assessment tools. However, unlike traditional assessment tools, the growth of normative datasets for remote tools in both size and diversity can be built

Table 1. Development of commonly used adult neuropsychological assessments.

Assessment	Year	References
Wide Range Achievement Test	1941	Jastak and Bijou (1941)
Wechsler Adult Intelligence Scale (WAIS)	1955	Wechsler (1955)
WAIS-R	1981	Wechsler (1981)
WAIS-III	1997	Wechsler (1997a)
WAIS-IV	2008	Wechsler (2008)
Repeatable Battery for the Assessment of Neuropsychological Status (RBANS)	1998	Randolph (1998)
RBANS-Update	2012	Randolph (2012)
Trail Making Test	1944; 1985	Army Individual Test Battery (1944); Reitan, (1958); Reitan and Wolfson, (1985)
Boston Naming Test	1978	Kaplan et al. (1978)
Boston Naming Test-2	2001	Kaplan et al. (2001)
Controlled Oral Word Association Test (COWAT)	1989	Benton and Hamsher (1989)
Wechsler Memory Scale (WMS)	1945	Wechsler (1955)
WMS-R	1987	Wechsler (1987)
WMS-III	1997	Wechsler (1997b)
WMS-IV	2009	Wechsler (2009)
Rey Auditory Verbal Learning Test	1988	Weins (1988)
California Verbal Learning Test (CVLT)	1987	Delis et al. (1987)
CVLT-II	2000	Delis et al. (2000)
CVLT-3	2017	Delis et al. (2017)
Delis-Kaplan Executive Function System	2001	Delis et al. (2001)
Wisconsin Card Sorting Test (WCST)	1948	Berg (1948); Grant and Berg (1948); Heaton et al. (1981); Heaton et al. (1993)
WCST - Computer Version 4	2008	Heaton (2008)
Token Test	1962	De Renzi and Vignolo (1962)
Rey-Osterrieth Complex Figure Test	1941	Rey (1941)
Benton Judgement of Line Orientation Test	1978	Benton et al., (1978)
Grooved Pegboard	1964	Matthews and Klove (1964)
Minnesota Multiphasic Personality Inventory (MMPI)	1951	Hathaway and McKinley (1951)
MMPI-2	1990	Graham (1990)
MMPI-2 Restructured Form (MMPI-2-RF)	2008	Ben-Porath and Tellegen (2008)

into the process of neuropsychological evaluation. This would allow for better evaluation of test psychometric characteristics and precision of normative data. As a comparison, existing tests developed over the last century continue to be revised over the years with largely homogeneous, white, educated individuals that do not represent the increasingly diverse population of the United States.

The path towards maintaining and evolving a hybrid model of neuropsychology is challenging, requiring collaboration within and across neuropsychology practices and training sites. Above all, continuing to pursue novel ways of administering traditional assessments post-pandemic will require clinicians to have a certain amount of steadfastness and vision of what neuropsychology could be like in the future.

Hybrid Neuropsychology

Hybrid Neuropsychology (Table 2) builds upon ideas presented in previous literature (e.g. Bilder, 2011; Bilder & Reise, 2019; Germine et al., 2019; Miller & Barr, 2017) while also addressing the immediate and long-term needs of the field given the current pandemic. It is based upon the fundamental idea that there exists a need for a paradigm shift in neuropsychology, which calls for radical change that might be initially uncomfortable and easier to avoid for many, particularly given the lack of training on developing new tests or implementing technology (Rabin et al., 2016). The pandemic has forced the field to advance beyond what is conventional, and in doing so, has lessened the gap between where neuropsychology is and where it needs to be to maintain technological relevance. Hybrid Neuropsychology, therefore, provides actionable steps the field may pursue to continue shortening this gap. Below and in Table 2 are Action Items, which clinicians may adopt in varying capacities given the resources available to them. If even a fraction of neuropsychologists pursue either one or more of these items, the incremental changes will amount to a fundamental difference in the way neuropsychology will be perceived, studied, and practiced in the future.

Action Item I: develop a technology-based practice

As discussed, neuropsychology is a field traditionally hesitant to adopt digital tools and implement them into evaluations. We posit that having a technology-based mindset is the first step to addressing a lack of innovation within the field. To widen the scope of neuropsychological assessment, Hybrid Neuropsychology involves adopting what we will refer to as a technology-based practice.

A technology-based practice involves collecting patient data using multiple modalities of assessment, combining traditional in-person measures that permit rich clinical observations with novel digital or remote assessments that allow patterns of behaviour to be more precisely quantified (e.g. trial-by-trial reaction times, variability in cognitive function over time). In addition to bringing more data to bear for clinical decision-making, multimodal assessments would enable (1) timely delivery of screening assessments, (2) more accurate and precise triage decisions, (3) monitoring of short-term changes or fluctuations in cognition, and (4) evaluation of both state- and context-dependent neuropsychological functioning (Germine et al., 2020).

Table 2. Hybrid Neuropsychology model.

	Action Item 1	Action Item 2	Action Item 3
Action Item	Develop a technology-based practice	Integrate data science	Engage with innovators in other fields
Goal	Incorporate multiple modalities when collecting patient data	Aggregate data collected across patients and multiple modalities	Collaborate with innovators to develop, share, and implement new digital tools
Benefits	• Timely delivery • Increased precision and accuracy • Ability to monitor changes in cognition • Access to state- and context-dependent functioning • Greater scalability of the field • Improved health equity	• Improved methods for accessing, storing, and sharing patient data • Greater consistency and integration of data points collected across clinics • More straightforward development of a national data repository and new tests	• Better integration with technology-based fields • Ability to fill gaps in evaluations by measuring constructs not currently assessed using traditional tests • Greater exposure to medical and scientific community
Barriers	• Validity of novel digital tools • Resistance to adopt innovative technologies	• Less familiarity with data science • Reaching a consensus regarding types of data management tools to use	• Risk aversion
How to address barriers	• Cross-validate new tools with traditional tests • Ensure validity through empirical studies and strengthen communication within the field	• Collaborate with individuals in information technology and data science • Increase communication within the field regarding best practices	• Recognise that neuropsychology can be innovative without eliminating traditional, trusted measures

Multimodal assessments would also help address basic issues of health care equity and accessibility by extending the scope of evaluations beyond geographically restricted clinic locations.

In this framework, multimodal data collection might include many types of current and emerging digital technologies (e.g. wearables, phones, internet of things). The biggest barrier to the use of these tools is that many of them are either not validated or only validated for very specific applications. The power of a hybrid approach, however, is in the potential for cross-validation. While data from these tools might initially be difficult to interpret, the accumulation of data in patients assessed using both novel and traditional methods will permit an increasingly rich and well-informed characterization of which innovative technologies and alternate data collection modalities provide the most useful diagnostic information.

At the clinician level, this involves the active incorporation of novel assessment tools to address clinical gaps. For example, working in a psychiatric hospital setting, COVID-19 has made it difficult to conduct neuropsychological assessments of perceptual reasoning through a traditional Block Design task or to understand nuances in attention through a local computerized Continuous Performance Test. As a screening tool and way of prioritizing patient evaluations, we have begun to incorporate accessible web-based measures (from our not-for-profit platform, TestMyBrain.org) of perceptual reasoning and sustained attention into clinical practice. For now, these measures fill a gap in neuropsychological evaluations prioritizing individuals for in-person evaluations of the same functions. Ultimately, however, scores from these remote tests will be correlated with scores on similar measures collected before the pandemic, or once patients return to the clinic, and evaluated for convergent validity. Thus, our incorporation of such remote tools allows us to bridge existing gaps in clinical care and provide validation data for the use of these innovative digital assessments in psychiatric care. Similar efforts have shown good concordance between self-administered online assessments and in-person standard neuropsychological assessments (Chaytor et al., in press). Accumulating these data across conditions and contexts will be important for ongoing validation efforts, and provide opportunities for screening, triage, and monitoring that would otherwise not be possible.

At the field level, this process can be extended to any other neuropsychology service that is using a hybrid model, where each remote or in-person test can be collected through multiple modalities and then evaluated in comparison to other modes of assessment. This effectively streamlines the neuropsychological evaluation, so that clinicians may choose to administer only the most efficient and psychometrically appropriate assessments.

With enough such data collected from individuals with known or suspected brain injury, for example, we may find that particular remote or digital cognitive assessments of perceptual reasoning are more sensitive than the commonly used WAIS-IV subtest, and neuropsychologists may feel comfortable replacing the traditional measure with a digital measure that is more broadly accessible. If Hybrid Neuropsychology were to be adopted at scale, many new assessments would be developed and validated based on traditional assessments and dynamic data repositories, which will likely lead to an abundance of data that must be rigorously evaluated. Normative data must be specific to each type of modality (i.e. laptop, phone, tablet), as we know that scores on neuropsychological tests may differ based on the method of administration (Germine et al., 2019; Singh et al., 2020). This potential inundation of information, coupled with a potential hesitation to adopt innovative technologies, could be major potential barriers to adopting a technology-based practice. However, if neuropsychologists can be confident in the data being collected, are given evidence supporting the sensitivity and specificity of different assessment modalities and are provided with continuous communication and guidance on best practices, Hybrid Neuropsychology could be a successful model for implementing digital tools in neuropsychology.

Action Item 2: integrate data science

The potential of a technology-based practice is constrained by our ability to collect and gain insights from data collected across modalities. Thus, a second Action Item that is a central part of Hybrid Neuropsychology is the integration of neuropsychology with data science.

Traditional neuropsychological evaluations are in some ways limited; scores are interpreted based on norms collected at a single time point, with no evolution of evaluative processes based on the collection of more patient data. As outlined in the previous section, Hybrid Neuropsychology, therefore, aims to capitalize on technological advances such that the field may readily evolve as it accumulates greater patient data. This would result in a dynamic process, wherein innovation and patient care simultaneously impact the way neuropsychological evaluations are conducted.

The concept parallels an existing model in the medical system known as the Learning Health System (LHS), which is defined as systems where '*science, informatics, incentives, and culture are aligned for continuous improvement and innovation, with best practices seamlessly embedded in the delivery process and new knowledge captured as an integral by-product of the delivery experience*' (Goolsby et al., 2012). This system has been instrumental in identifying strategies for providing better patient care at lower costs (Menear et al., 2019), and its concepts can be readily implemented in Hybrid Neuropsychology. The infrastructure used to support LHS is transferable to the components of neuropsychological evaluation and consists of the following: (1) converting data to knowledge; (2) applying knowledge to influence performance; and (3) documenting changes in performance to generate new data (Friedman et al., 2017).

At the clinician level, neuropsychologists may identify the appropriate ways of managing data gathered from a variety of different assessment modalities, thinking about how to access, store, and send others their patient data. Neuropsychology is unique in that, unlike an electronic medical record that maintains a record of, for example, blood pressure or blood sugar over time, neuropsychologists themselves are responsible for managing and relying upon their own patient's item-level data not included in the finalized report. Hybrid Neuropsychology allows neuropsychologists to have greater integration across patients and multiple modalities by creating an infrastructure that enables raw data to be saved and aggregated easily and reliably. However, although neuropsychologists are well-versed in managing scientific databases, the lack of emphasis on training in data science for most neuropsychologists makes the development of infrastructure more appropriate at the field-level. We still encourage clinicians to think deeply about their preferred model of data collection and communicate their preferences to the field at-large.

In adopting Hybrid Neuropsychology, the field may decide to create uniformity across clinic databases when collecting, storing, and retrieving item-level assessment data. Consistency across sites would streamline the creation of a national database, from which data collection could enable innovation and inform best practices. Bilder et al. (2020) suggest that individual data collection could also lead to item-level data immediately included in a national neuropsychology data repository, which would be used to create new tests with greater sensitivity and specificity. Working with individuals in information technology and data science would be ideal in developing a national database, as they would be better suited to address clinicians' common concerns, such as privacy and security.

Action Item 2 creates the potential for uniformity in data collection, storage, and retrieval across clinics. This can facilitate ease of access to normative data, allow for more consistency among data points collected across sites, and lay the foundation for test development with greater sensitivity and specificity. Above all, Action Item 2 relies on communication within the field of neuropsychology regarding the preferred models of data management while working with data scientists who could actualize a national database that can be readily implemented in clinics. Potential barriers include neuropsychologists' willingness to implement a database and a lack of consensus among neuropsychologists about the types of data management tools to use. We argue that neuropsychologists have become more familiar with digital tools than ever due to COVID-19 and will therefore appreciate a sustainable method of data management that both simplifies their collection and access to patient data.

Action Item 3: engage with innovators in other fields

Hybrid Neuropsychology is not attainable while neuropsychology remains siloed. Neuropsychologists are therefore encouraged to break out of their silos and interact with innovators in fields like computer science and engineering who can develop other types of assessments for constructs not typically captured by neuropsychological tests. Such assessments may include eye-tracking or pressure sensing from a digital pen, which could both give valuable cognitive and functional data that are not easily accessible and quantifiable through traditional assessment approaches. Consistent with Action Item 1, these assessments could be studied on clinical populations to determine how sensitive and specific they are to particular neurological disorders, and cross-validated with existing neuropsychological measures so that neuropsychologists wanting to implement these measures have a basic understanding of how they might relate to tests typically used in their standard batteries.

As a field, neuropsychology may begin to invite non-neuropsychologists to speak at national conferences so that they may engage in panel discussions about ways their innovative technologies might be useful in any part of a neuropsychological evaluation. Interacting with innovators in other fields should not

be misconstrued as innovation for the sake of innovation; rather, it is a chance to add to the body of knowledge within the field. A potential barrier to interacting with innovators from other fields is risk aversion, which is justified when asking others from different fields to help improve your own. However, it is important to recognize that neuropsychology can evolve and be innovative without eliminating its own trusted measures. Greater engagement with other specialties yields ancillary benefits as well, such as receiving greater exposure to the medical and scientific community at large and possibly more opportunities for referrals.

By developing a technology-based practice, incorporating data science, and breaking silos, we can achieve sustainability in neuropsychology. Hybrid Neuropsychology in particular ensures that the field evolves with the development of innovative technologies instead of against them, such that existing data sources and available assessments become a community resource that can be readily updated by clinicians and researchers. The benefits of implementing this model and taking on these Action Items far outweigh the costs, particularly given that Hybrid Neuropsychology employs a more rigorous scientific approach to data collection and test development while securing the longevity of the field.

Implementing Hybrid Neuropsychology in clinical practice

Hybrid Neuropsychology is appropriate for use in both inpatient and outpatient settings. Clinicians using Hybrid Neuropsychology should continue incorporating factors such as age, education, cultural background, and socioeconomic status when making clinical and diagnostic decisions. Of note, the creation of a data repository in Hybrid Neuropsychology would allow for greater separation and stratification of patient characteristics, which clinicians would also need to take into consideration when conducting evaluations.

Some individual components of neuropsychological evaluations would not change with the implementation of Hybrid Neuropsychology, as clinicians would still choose their preferred method (remote or in-person) for conducting neurobehavioral interviews and feedback sessions. When considering assessment, each existing and novel modality, technology-based or not, would have varying levels of appropriateness for a particular patient. Similar to traditional evaluations, a neuropsychologist will need to use their clinical expertise to determine which modalities of assessment are most valid for the patient that is being evaluated based on data collected and empirical findings. For example, if collaborations with experts in natural language processing methodology yield valuable insights regarding semantic coherence (Corcoran & Cecchi, 2020), but the measures are only sensitive to aberrant speech patterns in older adults, then this type of technology would be limited to evaluating older adults who have suspected and/or reported language deficits.

Given changes in the method of test administration and integration of neuropsychological findings, particularly with the incorporation of multiple modalities, report-writing would need to be updated in Hybrid Neuropsychology. This could be a straightforward process, in which neuropsychologists discuss the new test or modality similarly to the way they typically discuss traditional measures (i.e. 'this assessment measured processing speed … patient performed in the Average range'). Alternatively, the body of reports may separate technology-based and traditional measures and then integrate them in a Summary section. For experimental measures, neuropsychologists may also include a caveat statement delineating the nature of the assessment and justification for using it in the evaluation, consistent with ethical guidelines. There will be variations in these reports just as there are currently, but because Hybrid Neuropsychology aims to increase standardization in the field, it is recommended that there be guidelines discussed for how to interpret and explain new technology-based instruments as they are developed and implemented.

Conclusions

Neuropsychology is a relatively small area of mental health, yet the results from neuropsychological evaluations communicate impactful and even life-changing insights. Board-certified neuropsychologists typically have 2–5 years of neuropsychology-focussed practica, a year-long clinical internship with a focus in neuropsychology, and a 2-year postdoctoral fellowship in clinical neuropsychology. It is important to recognize and acknowledge that only a very small portion of these years of training is focussed on how to administer and score tests; rather, training in neuropsychology is learning to synthesize quantitative and qualitative data and provide patients with invaluable information about their cognitive, emotional, and psychiatric functioning. By not effectively using this potentially transient period wherein many clinicians are utilizing digital tools in evaluations for the first time, neuropsychologists may miss valuable

opportunities to question what it means to be a neuropsychologist and how to adapt to the current era without becoming technologically irrelevant.

Sustainable neuropsychology is certainly attainable through Hybrid Neuropsychology Action Items, which may evolve as neuropsychology continues to embrace new digital tools. Clinicians and researchers are challenged to use the resources available to them to take on one or more Action Items in their own practice, particularly if using a hybrid model where some of these tasks may be more easily implemented. One could try to collect data from a new device and see how it correlates with an existing assessment, consult a data scientist, or encourage trainees to reach out to an innovator in the technology space. Any incremental step promotes a more scientific basis for quantifying cognition and ensures neuropsychology's survival and growth in the era of digital technology.

Disclosure statement

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