# Ecological Validity in Virtual Reality–Based Neuropsychological Assessment

C

**Thomas D. Parsons**
*University of North Texas, USA*

## INTRODUCTION

Over 25 years ago, Paul Meehl (1987) called for clinical psychologists to embrace the technological advances prevalent in our society: "It would be strange, and embarrassing, if clinical psychologists, supposedly sophisticated methodologically and quantitatively trained, were to lag behind internal medicine, investment analysis, and factory operations control in accepting the computer revolution" (p. xv). Ten years later (15 years ago), Sternberg (1997) described the ways in which clinical psychologists failed in meeting Meehl's challenge as is apparent in the discrepancy between progress in cognitive assessment measures like the Wechsler scales and progress in other areas of technology. Sternberg used the example of the now obsolete black and white televisions, vinyl records, rotary-dial telephones, and the first commercial computer made in the United States (i.e. UNIVAC I) to illustrate the lack of technological progress in the standardized testing industry. According to Sternberg, currently used standardized tests differ little from tests that have been used throughout this century. For example, while the first edition of the Wechsler Adult Intelligence Scale appeared some years before UNIVAC, the Wechsler scales (and similar tests) have hardly changed at all (aside from primarily cosmetic changes) compared to computers. Although one may argue that innovation in the computer industry is different from innovation in the standardized testing industry, there are still appropriate comparisons. For example, whereas millions of dollars spent on technology in the computer industry typically reflects increased processing speed and power; millions of dollars spent on innovation in the testing industry tends to reflect the move from multiple-choice items to fill-in-the-blank items. Sternberg's statements are as true now as they were 15 years prior to the publication of this manuscript. While clinical psychology emphasizes its role as a science, its technology is not progressing in pace with other clinical neurosciences. Sternberg also points out cognitive testing needs progress in ideas, not just new measures, for delivering old technologies.

Over the course of the last several decades, clinical neuropsychology has gained increasing recognition as a discipline with relevance to a number of diverse practice areas (e.g., neurology, neurosurgery, psychiatry, and family medicine) as well as neuroscience specific research areas (e.g., behavior, learning, and individual differences). Although today's neuropsychological assessment procedures are widely used, clinical neuropsychologists have been slow to embrace technological advancements. Two essential limitations have resulted from this refusal of technological adaptation: First, current neuropsychological assessment procedures represent a technology that has barely changed since the first scales were developed in the early 1900s. Second, while the historical purpose of clinical neuropsychology was differential diagnosis of brain pathology, technological advances in other clinical neurosciences have changed the neuropsychologist's role to that of making ecologically valid predictions about the impact of a given patient's neurocognitive abilities and disabilities on everyday functioning.

Recently, scholars have been discussing the potential for a paradigm shift in clinical neuropsychology (Bilder, 2011; Dodrill, 1997; Green, 2003; Parsons and Courtney, 2011; Parsons, 2011; 2012; Puente, 1992; Perry, 2009). The historical development of neuropsychology has resulted in a "normal science" that is informed by developments in psychology, neuroscience, neurology, psychiatry, and computer science. Each of these "informing disciplines" has gone through changes that challenge theory and praxes of neuropsychological assessment. These changes are what Kuhn (1962/1996) describes as paradigm shifts, in which new assumptions (paradigms/theories) require the reconstruction of prior assumptions and the reevaluation of prior facts. For psychology, the paradigmatic shifts are found in

DOI: 10.4018/978-1-4666-5888-2.ch095

the move from mentalism (i.e., study of consciousness with introspection) to behaviorism (Watson, 1912), and then cognition (Miller, 2003) as now understood through connectionist frameworks (Bechtel & Abrahamsen, 1990). Further, in clinical psychology, shifting paradigms are seen in the incorporation of innovative technologies in treatment delivery (Dimeff et al., 2010). Neurorehabilitation has undergone a paradigm shift as a result of influences from basic and clinical research (Nadeau, 2002). For psychiatry (e.g., neuropsychopharmacology) the "paradigm shift" has been found in an understanding of psychiatric disorders and molecular biology models that account for gene/ environment/ development interaction (Meyer, 1996). Likewise, neuroscience has seen a shift related to the understanding of communication between nerve cells in the brain—shift from predominant emphasis upon electrical impulses to an enhanced model of chemical transmission (Carlsson, 2001). For neurology (and a number of related branches of neuroscience) a shift is found in new ways to visualize the details of brain function (Raichle, 2009). Finally, we are seeing shifts in computer science in the areas of social computing (Wang, 2007), information systems (Merali and McKelvey, 2006), and even the video game industry (Zackariasson & Wilson, 2010).

Dodrill (1997) has discussed the lack of progress in clinical neuropsychology. According to Dodrill, neuropsychologists are making much less progress than would be expected in both in absolute terms and in comparison with the progress made in other clinical neurosciences. Dodrill offers evidence for this assertion through pointing out that clinical neuropsychologists are using many of the same tests that they were using 30 years ago (in fact close to 50 years ago given the date of this publication). Dodrill points out that if neuroradiologists were this slow in technological development, then they would be limited to pneumoencephalograms and radioisotope brain scans—procedures that are considered primeval by current neuroradiological standards. According to Dodrill, the advances in neuropsychological assessment (e.g., Weschler scales) have resulted in new tests that are by no means conceptually or substantively better than the old ones. The full scope of issues raised by Dodrill becomes more pronounced when he compares progress in clinical neuropsychology to that of other neurosciences. For example, clinical neuropsychologists have historically been called upon to identify focal brain lesions. When one compares clinical neuropsychology's progress with clinical neurology, it is apparent that while the difference may not have been that great prior the appearance of computerized tomographic (CT) scanning (in the 1970s), the advances since then (e.g., magnetic resonance imaging) has given clinical neurologists a dramatic edge. What options are available for clinical neuropsychogists to move beyond an outmoded approach to their field?

According to Bilder (2011), Clinical neuropsychology is ready to embrace technological advances and experience a transformation of its concepts and methods. For Bilder the theoretical formulations of neuropsychology are represented in three waves. In Neuropsychology 1.0 (1950–1979), clinical neuropsychologists focused on lesion localization and relied on interpretation without extensive normative data. In Neuropsychology 2.0 (1980-present), clinical neuropsychologists were impacted by technological advances in neuroimaging and as a result focused on characterizing cognitive strengths and weaknesses rather than differential diagnosis. For Neuropsychology 3.0 (a future possible Neuropsychology), Bilder emphasizes the need to leverage advances in neuroimaging that Dodrill discussed. Further, he calls on clinical neuropsychologists to incorporate findings from the human genome project, advances in psychometric theory, and information technologies. Bilder argues that a paradigm shift toward evidence-based science and praxes is possible if neuropsychologists understand the need for innovations in neuropsychological knowledge bases and the design of Web-based assessment methods.

For the current chapter, the focus will be upon three "modalities" found in the practice of "Neuropsychological Assessment" that reflect the three waves found in theoretical formulations of neuropsychology (see Bilder, 2011). The organization of this chapter is as follows. In Section One: "Neuropsychological Assessment 1.0" a brief overview will be given of the historical development of clinical neuropsychology's normal science and the crisis state that is leading to a paradigm shift. In Section Two: "Neuropsychological Assessment 2.0," current applications of computer-based neuropsychological assessment are described. In Section Three: "Neuropsychological Assessment 3.0" a discussion is proffered of the utility of simulation technology for ecologically valid neuropsychological assessments that make use of current technological advances. Obstacles and limitations are discussed in section four. A discussion of future directions is given in section five.

## BACKGROUND

The neuropsychological assessment has historically been characterized as both a refinement and an extension of the neurological examination (Benton, 1985). Much of what is now considered part of neuropsychological assessment originated from localizationist attempts of late nineteenth and early twentieth century physicians to improve evaluation of the cognitive capacities of persons with brain disease (e.g., Broca and Wernicke aphasics). Part of this has to do with the fact that many widely used neuropsychological tests in Neuropsychological Assessment 1.0 were constructed before the advent of neuroimaging and emergence of much of the currently available information relating altered behavior to brain dysfunction. During Neuropsychological Assessment 1.0's pre-neuroimaging era localization required clinical neuropsychologists to establish standardized assessment measures for a normal science capable of identifying the neurocognitive effects of brain dysfunction. Unfortunately, many clinical neuropsychologists continue to rely on "localization" as the chief basis for validating neuropsychological tests. As Ronald Ruff has contended, although neuroimaging caused the role of neuropsychology to shift from localization to documentation of neuropsychological deficits for prediction of real world functioning, clinical neuropsychologists many times fail to develop ecologically oriented assessments and continue to use localizationist-developed test batteries (Ruff, 2003).

In "Neuropsychology Assessment 2.0," clinical neuropsychologists have begun making use of advances in computer technology for cognitive assessment and return to work decisions. Computer automated neuropsychological assessments offer a number of advantages: increased standardization of administration; increased accuracy of timing presentation and response latencies; ease of administration and data collection; and reliable and randomized presentation of stimuli for repeat administrations. One example of this is the use of computer-automated neuropsychological assessments over the past decade: CogSport (1999), ImPACT (Lovell et al., 2000), ANAM (Johnson et al., 2008), and HeadMinder (Erlanger et al., 1999). Since the neurocognitive sequelae of sports-related concussion often present as relatively mild symptoms, baseline computerized testing may have import for the sports-concussion arena. Computerized assessment of athletes' neurocognitive performance has been shown to be a powerful assessment tool for comparing "return-to-play" decisions. This repeated measures assessment allows the neuropsychologist to establish changes in neurocognitive status as a result of the concussion and evaluate the degree of symptom resolution (Parsons, Notebaert, & Guskiewicz 2000). Hence, it offers an index for return to real-world activities. Likewise, military clinicians are increasingly being asked to make statements regarding a military service member's ability to return to active duty. Current "Return-to-Duty" assessments are based upon the "Return-to-Play" guidelines found in Sports Medicine. Both have incorporated automated neuropsychological assessments to aid in decisions related to resuming activities following a concussion. Although the computer automation of neuropsychological assessments represents progress toward developing a technologically advanced application for real-world decisions, it falls short of offering an enhanced assessment methodology that taps into real-world function. As Sternberg has contended, neurocognitive testing needs progress in ideas, not just new measures, for delivering old technologies.

An unfortunate limitation of Neuropsychological Assessment 1.0 and 2.0 is that clinical neuropsychologists are increasingly being asked to make prescriptive statements about every-day functioning (Long, 1996). This new role for neuropsychologists has resulted in increased emphasis upon the ecological validity of neuropsychological instruments. As a result, neuropsychologists have been experiencing a need to move beyond the limited generalizability of results found in Neuropsychological Assessment 1.0 and 2.0 to measures that more closely approximate real world function. To establish ecological validity of neuropsychological measures, neuropsychologists in Neuropsychological Assessment 1.0 and 2.0 focus on demonstrations of either (or both) verisimilitude and veridicality (Franzen & Wilhelm, 1996). By verisimilitude, ecological validity researchers are emphasizing the need for the data collection method to be similar to real life tasks in an open environment. For the neuropsychological measure to demonstrate veridicality, the test results should reflect and predict real world phenomena (Chaytor & Schmitter-Edgecombe, 2003). In addition to the controversy related to whether or not current indices found on commonly used paper-and-pencil neuropsychological tests give us sufficient detail for prediction of the potential everyday difficulties likely to be faced by patients (Wilson, 1993), a dearth of research has addressed the degree to which neuropsychological testing is ecologically valid (Nussbaum et al., 1995). Review of the ecological validity of neuropsychological tests has provided support for the superiority of verisimilitude tests as the results from these measures tended to be more consistently related to the outcome measures than the traditional paper-and-pencil tests. However, a problem for the verisimilitude approach is that these instruments do not appear to be migrating from research laboratories into the applied settings of clinical neuropsychologists (Rabin et al., 2007). An additional problem for this approach is that although these neuropsychologists have developed instruments that more closely approximate skills required for everyday functioning, have not made use of advances in computer technology. As a result, they are in danger of continuing the negative trend that deemphasizes psychology's role as a science.

While standard neuropsychological measures found in Neuropsychological Assessment 1.0 and 2.0 have been found to have adequate predictive value, their ecological validity may diminish predictions about real-world functioning. Traditional neurocognitive measures may not replicate the diverse environment in which persons live. Additionally, standard neurocognitive batteries tend to examine isolated components of neuropsychological ability, which may not accurately reflect distinct cognitive domains (Dodrill, 1987; Parsons et al., 2004; 2005; Wilson, 1993) Although today's neuropsychological assessment procedures are widely used, neuropsychologists have been slow to adjust to the impact of technology on their profession. While there are some computer-based neuropsychological measures found in Neuropsychological Assessment 2.0 that offer a number of advantages over the traditional paper-and-pencil testing found in Neuropsychological Assessment 1.0, the ecological validity of these computer-based neuropsychological measures is less emphasized. Only a handful of neuropsychological measures have been developed with the specific intention of tapping into everyday behaviors like navigating one's community, grocery shopping, and other activities of daily living. Of those that have been developed, even fewer make use of advances in computer technology.

Neuropsychological Assessment 3.0 involves the use of virtual environments. The virtual environments found in Neuropsychology 3.0 offer an advanced computer interface that allows humans to become immersed within a computer-generated simulation. Potential virtual environment use in assessment and rehabilitation of human cognitive processes is becoming recognized as technology advances. Since virtual environments allow for precise presentation and control of dynamic perceptual stimuli, they can provide ecologically valid assessments that combine the veridical control and rigor of laboratory measures with a verisimilitude that reflects real life situations. Additionally, the enhanced computation power allows for a range of the accurate recording of neurobehavioral responses in a perceptual environmental that systematically presents complex stimuli. Such simulation technology appears to be distinctively suited for the development of ecologically valid environments, in which stimuli are presented in a consistent and precise manner. As a result, subjects are able to manipulate three dimensional objects in a virtual environment that proffers a range of potential task demands.

Virtual environment applications that focus on treatment of cognitive (Parsons, 2009a) and affective disorders (Parsons et al., 2008a), as well as assessment of component cognitive processes are now being developed and tested: attention (Law et al., 2006; Parsons, et al., 2007; 2011) spatial abilities (Beck et al., 2010; Parsons et al., 2004b), retrospective memory (Parsons & Rizzo, 2008b), prospective memory (Knight & Titov, 2009), spatial memory (Astur et al., 2004); and executive functions (McGeorge et al., 2001; Parsons et al., 2012). The increased ecological validity of neurocognitive batteries that include assessment using virtual scenarios may aid differential diagnosis and treatment planning. Within a virtual world, it is possible to systematically present cognitive tasks targeting neuropsychological performance beyond what are currently available using traditional methods (Parsons, 2011; 2012). Reliability of neuropsychological assessment can be enhanced in virtual worlds by better control of the perceptual environment, more consistent stimulus presentation, and more precise and accurate scoring. Virtual worlds may also improve the validity of neurocognitive measurements via the increased quantification of discrete behavioral responses, allowing for the identification of more specific cognitive domains (see Gaggioli et al., 2009). Virtual environments could allow for neurocognition to be tested in situations that are more ecologically valid. Participants can be evaluated in an environment that simulates the real world, not a contrived testing environment (see Gorini et al., 2008). Further, it offers the potential to have ecologically valid computer-based neuropsychological assessments that will move beyond traditional clinic or laboratory borders.

It could be argued that the challenge for neuropsychologists using VEs is to develop techniques that simultaneously satisfy the demands of internal validity, external validity, and ecological validity. Hence, the development of an ecologically valid VE should include psychometric rigor (i.e. internal validity, external validity) as well as verisimilitude and veridicality (i.e. ecological validity). Parsons (2011) has proffered considerations for achieving such standards: 1) Correspondence: the tasks performed within VEs should correspond to the pertinent aspects of real-world activities and environments; 2) Representativeness: the tasks developed should be representative of persons who are performing the tasks; 3) Expedience: research problems should have practical consequences on real-world functioning if they are to be components of verisimilitude and veridicality; and 4) Relevance: outcome measures need to have relevance to the practical problem being investigated.

## FUTURE RESEARCH DIRECTIONS

There are some relatively obvious practical and technical limitations of virtual world-based assessment that will cause clinical neuropsychology to be slow in adopting computerization on a large scale. For example, synchronization between the user's computer processor and the user's Internet connection occurs with varying amounts of delay, or error, in timing. As a result, it will be difficult to standardize or control this delay with a degree of consistency. At one time this was an issue for any computerized testing. However, researchers have since developed software solutions that provide near-millisecond accuracy (Westall et al., 1989). Hence, there is a need for both the development of Internet-based measures and "measure development" software. Further, there is the issue of crucial sources of error in computerized neuropsychological assessment (Cernich et al., 2007). For example, various configurations and operating systems are in use. A further example may be found in real-time versus store-and-forward Internet-based assessment. These issues emphasize the need for technology standardization in which Internet-based information may be exchanged. At minimum, researchers should use the American Psychological Association's (APA) established guidelines for the development, administration, and interpretation of computerized assessments (APA, 1986, 1987). Given the many changes that have occurred in the years since these guidelines were developed, there is need for a documented standard beyond those recommendations offered by the APA. There is a need for neuropsychology to update such guidelines and maintain a professional and guiding presence. Clinical practice is increasingly being impacted by the Internet's ability to disseminate rapidly vast amounts of information and facilitate the instantaneous exchange of ideas.

Another issue is that the automated nature of virtual world measures does not allow an examiner to interrupt or stop the assessment and "test the limits" or be more flexible with their evaluation. Further, virtual world assessments may not provide as much qualitative information as standard evaluations in which a clinician examines the type of errors a patient makes and the strategies a patient might use to arrive at his or her answers (Woo, 2008). Hence, any computerized assessment should not remove a clinician from the equation. Instead, virtual worlds, like automated neuropsychological assessments, should be viewed as a tool to be used by a clinician, and not a replacement of the clinician.

## CONCLUSION

The historical development of neuropsychology has resulted in a "normal science" that is informed by developments in psychology, neuroscience, neurology, psychiatry, and computer science. Each of these "informing disciplines" has gone through changes that challenge theory and praxes of neuropsychological assessment. Developments in the area of Neuropsychological Assessment parallel several of Kuhn's observations concerning the nonlinear trend of progress in the history of science. For example, the naive assumption that traditional neuropsychological assessment procedures would continue to maintain prominence following the advent of neuroimaging characterized an earlier status quo, a period Kuhn referred to as normal science. The untenable presumption that traditional paper-and-pencil batteries (or automated computerized versions) were generally capable of forming accurate judgments about the everyday functioning (i.e., ecological validity) of persons tested on the basis of observation was another received belief that characterized this soon to be archaic era of practice. A further development of this emerging paradigm for clinical neuropsychologists may be found in the expanding use of virtual environments. Within virtual environments, it is possible to systematically present cognitive tasks targeting neuropsychological performance beyond what are currently available using traditional methods. Reliability of neuropsychological assessment and treatment of affective and cognitive disorders can be enhanced in virtual environments by better control of the perceptual environment, more consistent stimulus presentation, and more precise and accurate scoring. Virtual environments may also improve the validity of neurocognitive measurements via the increased quantification of discrete behavioral responses, allowing for the identification of more specific cognitive domains. Virtual environments could allow for cognition and affect to be assessed and treated in situations that are more ecologically valid.

## REFERENCES

American Psychological Association. (1986). *Guidelines for Computer-Based Tests and Interpretations*. Washington, DC: American Psychological Association.

American Psychological Association Committee on Professional Standards & Committee on Psychological Tests and Assessment. Division 40. (1987). Task force report in computer-assisted neuropsychological evaluation. *Clinical Neuropsychologist*, *2*, 161–184.

Astur, R. S., Tropp, J., Sava, S., Constable, R. T., & Markus, E. J. (2004). Sex differences and correlations in a virtual Morris water task, a virtual radial arm maze, and mental rotation. *Behavioural Brain Research*, *151*, 103–115. doi:10.1016/j.bbr.2003.08.024 PMID:15084426

Bechtel, W., & Abrahamsen, A. (1990). *Connectionism and the mind*. Cambridge, MA: Blackwell.

Beck, L., Wolter, M., Mungard, N. F., Vohn, R., Staedtgen, M., Kuhlen, T., & Sturm, W. (2010). Evaluation of spatial processing in virtual reality using functional magnetic resonance imaging (FMRI). *Cyberpsychology, Behavior, and Social Networwing*, *13*, 211–215. doi:10.1089/cyber.2008.0343 PMID:20528281

Benton, A. L. (1985). Some problems associated with neuropsychological assessment. *Bulletin of Clinical Neurosciences*, *50*, 11–15. PMID:3842080

Bilder, R. M. (2011). Neuropsychology 3.0: Evidence-Based Science and Practice. *Journal of the International Neuropsychological Society*, *17*, 7–13. doi:10.1017/S1355617710001396 PMID:21092355

Brennan, D. M., Mawson, S., & Brownsell, S. (2009). Telerehabilitation: enabling the remote delivery of healthcare, rehabilitation, and self management. *Studies in Health Technology and Informatics*, *145*, 231–248. PMID:19592797

Carlsson, A. (2001). A paradigm shift in brain research. *Science*, *294*, 1021–1024. doi:10.1126/science.1066969 PMID:11691978

Cernich, A., Brennana, D., Barker, L., & Bleiberg, J. (2007). Sources of error in computerized neuropsychological assessment. *Archives of Clinical Neuropsychology*, *22*, 39–48. doi:10.1016/j.acn.2006.10.004 PMID:17097851

Chaytor, N., & Schmitter-Edgecombe, M. (2003). The Ecological Validity of Neuropsychological Tests: A Review of the Literature on Everyday Cognitive Skills. *Neuropsychology Review*, *13*, 181–197. doi:10.1023/B:NERV.0000009483.91468.fb PMID:15000225

(1999). *CogSport*. Parkville, Victoria, Australia: CogState, Ltd.

Dimeff, L. A., Paves, A. P., Skutch, J. M., & Woodcock, E. A. (2011). Shifting paradigms in clinical psychology: How innovative technologies are shaping treatment delivery. In D. H. Barlow (Ed.), *The Oxford handbook of clinical psychology* (pp. 618–648). New York, NY: Oxford University Press.

Erlanger, D. M., Feldman, D. J., & Kutner, K. (1999). *Concussion Resolution Index*. New York: HeadMinder, Inc.

Franzen, M. D., & Wilhelm, K. L. (1996). Conceptual foundations of ecological validity in neuropsychological assessment. In R. J. Sbordone, & C. J. Long (Eds.), *Ecological validity of neuropsychological testing* (pp. 91–112). Boca Raton, FL: St Lucie Press.

Gaggioli, A., Keshner, E. A., Weiss, P. L., & Riva, G. (Eds.). (2009). *Advanced Technologies in Rehabilitation - Empowering Cognitive, Physical, Social and Communicative Skills through Virtual Reality, Robots, Wearable Systems and Brain-Computer Interfaces*. Amsterdam: IOS Press.

Gorini, A., Gaggioli, A., Vigna, C., & Riva, G. A Second Life for eHealth: Prospects for the Use of 3-D Virtual Worlds in Clinical Psychology. *Journal of Medical Internet Research*, *10*(21). PMID:18678557

Green, P. (2003). Welcoming a paradigm shift in neuropsychology. *Archives of Clinical Neuropsychology*, *18*, 625–627. doi:10.1016/S0887-6177(03)00094-5

Hare, R. M. (1984). Supervenience. *Aristotelian Society*, *58*, 1–16.

Johnson, D. R., Vincent, A. S., Johnson, A. E., Gilliland, K., & Schlegel, R. E. (2008). Reliability and construct validity of the Automated Neuropsychological Assessment Metrics (ANAM) mood scale. *Archives of Clinical Neuropsychology*, *1*, 73–85. doi:10.1016/j.acn.2007.10.001 PMID:18031982

Knight, R. G., & Titov, N. (2009). Use of Virtual Reality Tasks to Assess Prospective Memory: Applicability and Evidence. *Brain Impairment*, *10*, 3–13. doi:10.1375/brim.10.1.3

Kuhn, T. S. (1996). *The structure of scientific revolutions* (3rd ed.). Chicago: University of Chicago Press. doi:10.7208/chicago/9780226458106.001.0001

Law, A. S., Logie, R. H., & Pearson, D. G. (2006). The impact of secondary tasks on multitasking in a virtual environment. *Acta Psychologica*, *122*, 27–44. doi:10.1016/j.actpsy.2005.09.002 PMID:16307711

Lovell, M. R., Collins, M. W., Podell, K., Powell, J., & Maroon, J. (2000). *ImPACT: Immediate Post-Concussion Assessment and Cognitive Testing*. Pittsburgh, PA: Neuro-Health Systems, LLC.

McGeorge, P., Phillips, L., Crawford, J. R., Garden, S. E., Della Sala, S., & Milne, A. B. et al. (2001). Using virtual environments in the assessment of executive dysfunction. *Presence (Cambridge, Mass.)*, *10*, 375–383. doi:10.1162/105474601147023 5

Meehl, P. E. (1987). Foreword. In J. N. Butcher (Ed.), *Computerized Psychological Assessment* (pp. xv–xvi). New York: Basic Books.

Merali, Y., & McKelvey, B. (2006). Using complexity science to effect a paradigm shift in Information Systems for the 21st century. *Journal of Information Technology*, *21*, 211–215. doi:10.1057/palgrave.jit.2000082

Meyer, R. E. (1996). Neuropsychopharmacology: Are we ready for a paradigm shift? *Neuropsychopharmacology*, *14*, 169–179. doi:10.1016/0893-133X(95)00074-N PMID:8866700

Miller, G. A. (2003). The cognitive revolution: A historical perspective. *Trends in Cognitive Sciences*, *7*, 141–144. doi:10.1016/S1364-6613(03)00029-9 PMID:12639696

Nadeau, S. E. (2002). A paradigm shift in neurorehabilitation. *The Lancet Neurology*, *1*, 126–130. doi:10.1016/S1474-4422(02)00044-3 PMID:12849517

Nussbaum, P. D., Goreczny, A., & Haddad, L. (1995). Cognitive correlates of functional capacity in elderly depressed versus patients with probable Alzheimer's disease. *Neuropsychological Rehabilitation*, *5*, 333–340. doi:10.1080/09602019508401476

Parsons, T. D. (2011). Neuropsychological Assessment using Virtual Environments: Enhanced Assessment Technology for Improved Ecological Validity. In S. Brahnam (Ed.), *Advanced Computational Intelligence Paradigms in Healthcare: Virtual Reality in Psychotherapy, Rehabilitation, and Assessment* (pp. 271–289). Germany: Springer-Verlag. doi:10.1007/978-3-642-17824-5_13

Parsons, T. D. (2012) Virtual Simulations and the Second Life Metaverse: Paradigm Shift in Neuropsychological Assessment. In V. Zagalo, T. Morgado. & A. Boa-Ventura (Eds.), Virtual Worlds, Second Life and Metaverse Platforms: New Communication and Identity Paradigms (pp. 234- 250). Hershey: IGI Global.

Parsons, T. D., Bowerly, T., Buckwalter, J. G., & Rizzo, A. A. (2007). A controlled clinical comparison of attention performance in children with ADHD in a virtual reality classroom compared to standard neuropsychological methods. *Child Neuropsychology*, *13*, 363–381. doi:10.1080/13825580600943473 PMID:17564852

Parsons, T. D., Cosand, L., Courtney, C., Iyer, A., & Rizzo, A. A. (2009b). Neurocognitive Workload Assessment using the Virtual Reality Cognitive Performance Assessment Test. *Lecture Notes in Artificial Intelligence*, *5639*, 243–252.

Parsons, T. D., & Courtney, C. (2011) Neurocognitive and Psychophysiological Interfaces for Adaptive Virtual Environments. In C. Röcker, T. & M. Ziefle (Eds.), Human Centered Design of E-Health Technologies (pp. 208 - 233). Hershey: IGI Global.

Parsons, T. D., Courtney, C., Arizmendi, B., & Dawson, M. (2011). Virtual Reality Stroop Task for Neurocognitive Assessment. *Studies in Health Technology and Informatics*, *143*, 433–439. PMID:21335835

Parsons, T. D., Courtney, C., Rizzo, A. A., Edwards, J., & Reger, G. (2012). Virtual Reality Paced Serial Assessment Tests for Neuropsychological Assessment of a Military Cohort. *Studies in Health Technology and Informatics*, *173*, 331–337. PMID:22357013

Parsons, T. D., Larson, P., Kratz, K., Thiebaux, M., Bluestein, B., & Buckwalter, J. G. (2004b). Sex differences in mental rotation and spatial rotation in a virtual environment. *Neuropsychologia*, *42*, 555–562. doi:10.1016/j.neuropsychologia.2003.08.014 PMID:14728927

Parsons, T. D., Notebaert, A., & Guskewitz, K. (2009). Application of Reliable Change Indices to Computerized Neuropsychological Measures of Concussion. *The International Journal of Neuroscience*, *119*, 492–507. doi:10.1080/00207450802330876 PMID:19229718

Parsons, T. D., & Rizzo, A. A. (2008a). Affective Outcomes of Virtual Reality Exposure Therapy for Anxiety and Specific Phobias: A Meta-Analysis. *Journal of Behavior Therapy and Experimental Psychiatry*, *39*, 250–261. doi:10.1016/j.jbtep.2007.07.007 PMID:17720136

Parsons, T. D., & Rizzo, A. A. (2008b). Neuropsychological Assessment of Attentional Processing using Virtual Reality. *Annual Review of Cybertherapy and Telemedicine*, *6*, 23–28.

Parsons, T. D., & Rizzo, A. A. (2008c). Initial Validation of a Virtual Environment for Assessment of Memory Functioning: Virtual Reality Cognitive Performance Assessment Test. *Cyberpsychology & Behavior*, *11*, 17–25. doi:10.1089/cpb.2007.9934 PMID:18275308

Parsons, T. D., Rizzo, A. A., & Buckwalter, J. G. (2004a). Backpropagation and regression: comparative utility for neuropsychologists. *Journal of Clinical and Experimental Neuropsychology*, *26*, 95–104. doi:10.1076/jcen.26.1.95.23932 PMID:14972697

Parsons, T. D., Rizzo, A. A., Rogers, S. A., & York, P. (2009a). Virtual Reality in Pediatric Rehabilitation: A Review. *Developmental Neurorehabilitation*, *12*, 224–238. doi:10.1080/17518420902991719 PMID:19842822

Parsons, T. D., Rizzo, A. A., van der Zaag, C., McGee, J. S., & Buckwalter, J. G. (2005). Gender and cognitive performance: a test of the common cause hy-pothesis. *Neuropsychology, Development, and Cognition. Section B, Aging, Neuropsychology and Cognition*, *12*, 78–88. doi:10.1080/13825580590925125

Perry, W. (2009). Beyond the Numbers. *Expanding the Boundaries of NeuropsychologyArchives of Clinical Neuropsychology*, *24*, 21–29. PMID:19395354

Puente, A. E. (1992). The Status of Clinical neuropsychology. *Archives of Clinical Neuropsychology*, *7*(4), 297–312. doi:10.1093/arclin/7.4.297 PMID:14591285

Pugnetti, L., Mendozzi, L., Attree, E. A., Barbieri, E., Brooks, B. M., & Cazzullo, C. L. et al. (1998). Probing memory and executive functions with virtual reality: Past and present studies. *Cyberpsychology & Behavior*, *1*, 151–162. doi:10.1089/cpb.1998.1.151

Rabin, L. A., Burton, L. A., & Barr, W. B. (2007). Utilization rates of ecologically oriented instruments among clinical neuropsychologists. *The Clinical Neuropsychologist*, *5*, 727–743. doi:10.1080/13854040600888776 PMID:17676540

Raichle, M. E. (2009). A paradigm shift in functional brain imaging. *The Journal of Neuroscience*, *29*, 12729–12734. doi:10.1523/JNEUROSCI.4366-09.2009 PMID:19828783

Ruff, R. M. (2003). A friendly critique of neuropsychology: Facing the chal-lenges of our future. *Archives of Clinical Neuropsychology*, *18*, 847–864. doi:10.1016/j.acn.2003.07.002 PMID:14609580

Sternberg, R. J. (1997). Intelligence and lifelong learning: What's new and how can we use it? *The American Psychologist*, *52*, 1134–1139. doi:10.1037/0003-066X.52.10.1134 PMID:9329294

Wang, F. Y. (2007). Toward a paradigm shift in social computing: The ACP approach. *IEEE Intelligent Systems*, *22*, 65–67. doi:10.1109/MIS.2007.4338496

Watson, J. B. (1912). Psychology as the behaviorist views it. *Psychological Review*, *20*, 158–177. doi:10.1037/h0074428

Westall, R., Perkey, M. N., & Chute, D. L. (1989). Millisecond timing on Apple's Macintosh revisited. *Behavior Research Methods, Instruments, & Computers*, *21*, 540–547. doi:10.3758/BF03202886

Wilson, B. A. (1993). Ecological validity of neuropsychological assessment: Do neuropsychological indexes predict performance in everyday activities? *Applied & Preventive Psychology*, *2*, 209–215. doi:10.1016/S0962-1849(05)80091-5

Woo, E. Computerized neuropsychological assessments. *CNS Spectrums*, *13*, 14–17. PMID:18955954

Zackariasson, P., & Wilson, T. L. (2010). Paradigm shifts in the video game industry. *Competitiveness Review*, *20*, 139–151. doi:10.1108/10595421011029857

## ADDITIONAL READING

Armstrong, C., Reger, G., Edwards, J., Rizzo, A., Courtney, C., & Parsons, T. D. (2013). Validity of the Virtual Reality Stroop Task (VRST) in Active Duty Military. *Journal of Clinical and Experimental Neuropsychology*, *35*, 113–123. doi:10.1080/13803395.2012.740002 PMID:23157431

Courtney, C. G., Dawson, M. E., Schell, A. M., Iyer, A., & Parsons, T. D. (2010). Better than the real thing: Eliciting fear with moving and static computer-generated stimuli. *International Journal of Psychophysiology*, *78*, 107–114. doi:10.1016/j.ijpsycho.2010.06.028 PMID:20600370

Henry, M., Joyal, C. C., & Nolin, P. (2012). Development and initial assessment of a new paradigm for assessing cognitive and motor inhibition: the bimodal virtual-reality Stroop. *Journal of Neuroscience Methods*, *210*, 125–131. doi:10.1016/j.jneumeth.2012.07.025 PMID:22897988

Jovanovski, D., Zakzanis, K. K., Campbell, Z., Erb, S., & Nussbaum, D. (2012). Development of a novel,ecologically oriented virtual reality measure of executive function: the Multi-tasking in the City Test. *Applied Neuropsychology*, *19*, 171–182. doi:10.1080/09084282.2011.643955 PMID:23373603

Macedonio, M., Parsons, T. D., & Rizzo, A. A. (2007). Immersiveness and Physiological Arousal within Panoramic Video-based Virtual Reality. *Cyberpsychology & Behavior*, *10*, 508–516. doi:10.1089/cpb.2007.9997 PMID:17711358

Moffat, S. D. (2009). Aging and spatial navigation: what do we know and where do we go? *Neuropsychology Review*, *19*, 478–489. doi:10.1007/s11065-009-9120-3 PMID:19936933

Parsey, C. M., & Schmitter-Edgecombe, M. (2013). Applications of Technology in Neuropsychological Assessment. *The Clinical Neuropsychologist*, *27*(8), 1328–1361. doi:10.1080/13854046.2013.834971 PMID:24041037

Parsons, T. D. (2014). Virtual Teacher and Classroom for Assessment of Neurodevelopmental Disorders. In S. Brahnam, & L. C. Jain (Eds.), *Serious Games, Alternative Realities, and Play Therapy* (pp. 121–137). Germany: Springer-Verlag. doi:10.1007/978-3-642-45432-5_7

Parsons, T. D., & Courtney, C. (2014). An Initial Validation of the Virtual Reality Paced Auditory Serial Addition Test in a College Sample. *Journal of Neuroscience Methods*, *222*, 15–23. doi:10.1016/j.jneumeth.2013.10.006 PMID:24184058

Parsons, T. D., Courtney, C., & Dawson, M. (2013). Virtual Reality Stroop Task for Assessment of Supervisory Attentional Processing. *Journal of Clinical and Experimental Neuropsychology*, *35*, 812–826. doi:10.1080/13803395.2013.824556 PMID:23961959

Wu, D., Courtney, C., Lance, B., Narayanan, S. S., Dawson, M., Oie, K., & Parsons, T. D. (2010). Optimal Arousal Identification and Classification for Affective Computing: Virtual Reality Stroop Task. *IEEE Transactions on Affective Computing*, *1*, 109–118. doi:10.1109/T-AFFC.2010.12

Wu, D., Lance, B., & Parsons, T. D. (2013). Collaborative Filtering for Brain-Computer Interaction Using Transfer Learning and Active Class Selection. *PLoS ONE*, 1–18. PMID:23437188

## KEY TERMS AND DEFINITIONS

**Ecological Validity:** Focus on demonstrations of either (or both) verisimilitude and veridicality.

**Immersion:** State of consciousness where a person immersed in a virtual environment has diminished awareness of physical self.

**Neuropsychologist:** Persons that apply a working understanding of psychology, physiology, and neurology to assess, diagnose, and treat patients with neurological, medical, neurodevelopmental, psychiatric, and cognitive disorders.

**Neuropsychology:** A branch of psychology and neurology that aims to understand brain-behavior relations.

**Veridicality:** Emphasis on the need for the test results to reflect and predict real world phenomena.

**Verisimilitude:** Emphasis on the need for the data collection method to be similar to real life tasks in an open environment.

**Virtual Reality:** An advanced form of human–computer interaction, in which users are immersed in an interactive and ecologically valid virtual environment.