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Addressing Cognitive Health: Problems and Solutions

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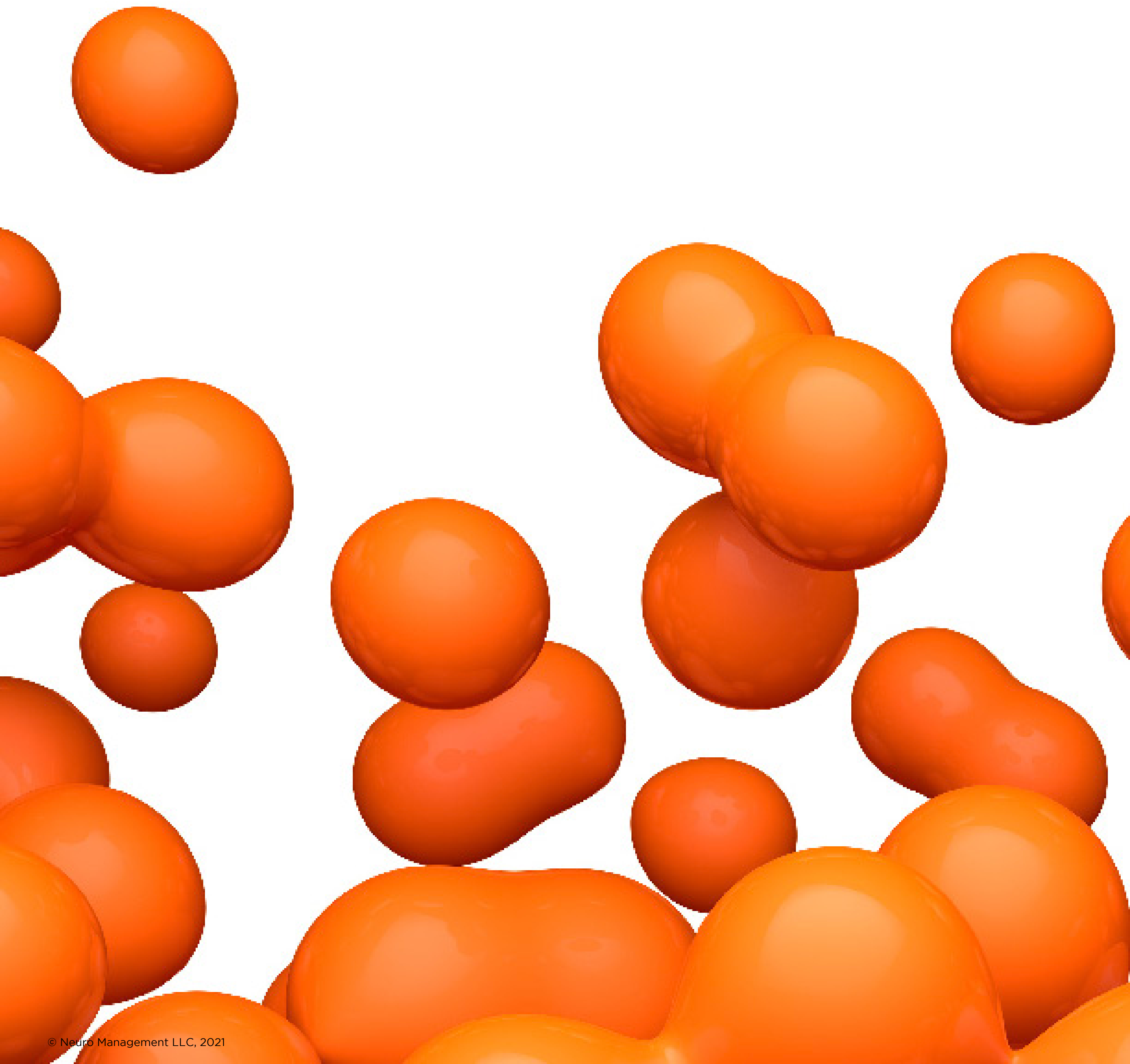

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Abstract

The personal and societal impact of cognitive related health issues is immense, reducing the quality of life for millions of Americans, and costing billions of dollars annually in medical services. The etiology of cognitive impairment is diverse, impacting individuals across the lifespan, and leading to deficits in attention, working memory, inhibitory control, information processing, organization, and planning. Assessment, intervention, and prevention are key areas to help stave off the effects of cognitive decline. The use of valid and reliable psychological and neurophysiological assessment tools aid in the diagnosis and identification of individuals at risk of cognitive decline, selection of appropriate treatments, and evaluation of treatment effects. Emerging interventions such as cognitive brain training and neurofeedback are designed to improve deficits and functioning by directly exercising pre-existing cognitive skills/abilities and/or the underlying neural networks associated with those cognitive processes. Collectively, these interventions have been applied to participant samples with varying degrees of cognitive impairment (e.g. healthy controls, ADHD children, aging adults, etc.), demonstrating performance, clinical, and neurophysiological gains in laboratory settings. However, additional research is needed to further demonstrate the specificity, generalizability, and durability of training effects to support these interventions as frontline treatments for cognitive impairment. Technological advancements have allowed for the development of assessment tools, cognitive brain training games, and neurofeedback protocols that can be delivered through mobile devices, supervised remotely, and seamlessly integrated into existing daily behaviors or interventions. These options are cost effective and user friendly, but require additional research to determine their impact on compliance, generalizability, and efficacy.

Addressing Cognitive Health: Problems and Solutions

As the population of the United States is aging rapidly, the incidence of cognitive impairment is expected to rise. New focus on maintaining brain health has emerged in an effort to reduce age related decline, improve quality of life, and reduce the costs associated with cognitive impairment. However, cognitive impairment and the accompanying changes in mental, physical, and emotional functioning are not limited to a specific age group, disease process, or condition. Individuals with cognitive impairment may experience trouble with memory and learning new things or with concentrating and making decisions in everyday life. Impairment usually presents as difficulty in measurable cognitive skills - like poor memory, weak attention, difficulty concentrating, poor impulse control, and slower processing speed. These impairments create struggles with everyday functioning, learning, and problem solving and range in severity from being a minor nuisance to requiring direct care and supervision.

Impact of Cognitive Impairment

Cognitive health has significant implications on quality of life and economic costs to society (Stoddard, 2014). In 2009, the Centers for Disease Control (CDC) published data collected from 5 states (CA, FL, IA, LA, & MI) that participated in identifying the number of citizens living with some type of cognitive impairment (CDC, 2011). The report indicated the prevalence rate of adults aged 18-49 with some form of cognitive impairment ranged from a low of 4% in Iowa to a high of 8% in Michigan and California. Above the age of 50, the prevalence of cognitive impairment ranged from 9% in Iowa and Louisiana to 15% in Michigan. The Cornell University Employment and Disability Institute published a comprehensive report estimating the 2013 prevalence of cognitive

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impairment among people all ages in the U.S. at 5.0% or roughly 14.6 million individuals (Erickson, Lee, & von Schrader, 2014). The report also indicated lower rates of employment (11.5% vs. 56.8%), decreased annual earnings ($32,200 vs. $43,300), and higher rates of poverty (34.6% vs. 12.5%) among working-age individuals with cognitive disabilities compared to individuals with no disability. Finally, the estimated annual cost of medical treatment for adults with some type of cognitive impairment at approximately $42.5 billion (Courtney-Long, Carroll, & Zang, 2015) and the cost of "unpaid care" for cognitive impairment at approximately $144 billion (Alzheimer's Association, 2010).

While it is clear that the incidence of cognitive impairment increases with age (Ericson et al., 2014) a variety of etiologies have been identified. In the United States, the estimated average annual number of traumatic brain injury (TBI) related emergency room visits is approximately 2.5 million (CDC, 2015). Many of these individuals experience cognitive deficits in attention, learning and memory, planning and decision-making, language and communication, reaction time, and reasoning and judgment. Moreover, many other medical conditions can lead to cognitive impairment. For example, cognitive impairment often accompanies brain tumor, stroke, multiple sclerosis, infections, Parkinson's disease, Huntington's disease, and exposure to neurotoxins (Fatemi & Clayton, 2008). Common psychiatric conditions like depression, generalized anxiety, bipolar disorder (Gualtier & Morgan, 2008), attention deficit hyperactivity disorder (ADHD; van Zomeren & Brouwer, 1994), and chronic stress (McEwen & Sapolsky, 1995) often present with some degree of cognitive impairment.

The previous sections highlight the personal and economic impact of cognitive impairment on society. As a result of these challenges, a focus on cognitive health has developed to assess and improve core cognitive skills and abilities. Greater emphasis has been placed on developing effective tools for assessment and intervention. Proper assessment can lead to a better understanding of cognitive weaknesses, and this understanding can lead to the development of more focused solutions.

Cognitive Components

The presence of cognitive health is viewed as the effective control over one's skills and abilities. This cognitive control has been referred to as executive control or functioning. These terms are used to explain how individuals use general ability to plan and direct activity from beginning to end. Generally, executive functions are considered as the collective input of more specific cognitive processes which include attention, working memory, impulse control, processing speed, and organization and planning. Given the importance of these key cognitive abilities, we will briefly describe each component and highlight its relevance below.

Attention. Attention is the primary glue that holds the cognitive processes together. Attention is generally described as the ability to start focusing, select important targets or elements, and avoid distraction from non-essential details. Attention is also responsible for sustaining focus and shifting focus as needed. Likewise, attention allows people to inhibit or ignore distractions from the environment around them and from their own internal thoughts and feelings that are not related to their present goals (Dosenbach & Peterson, 2009; Riccio, Reynolds, & Lowe, 2001). Researchers have identified a strong positive relationship between attention, working memory, and general intelligence (Ilkowska & Engle, 2010; Shipstead, Redick, Hicks, & Engle, 2012).

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Working Memory. Working memory is generally considered as a complex interplay of systems that allows humans to manipulate and store information during active thinking, active learning, and active problem solving in everyday life. Working memory capacities are strongly related to general intelligence, attentional control, and processing speed (Redick, Unsworth, Kelly, & Engle, 2012; Shipstead, Harrison, & Engle, 2015; Shipstead, Lindsey, Marshall, & Engle, 2014). The most widely cited model of working memory was developed by Alan Baddeley and has been extensively researched and studied for over 40 years. Baddeley proposed that there are four independent components of working memory that work together and with other abilities like attention to allow the performance of complex human behavior (Baddeley, 2007). The model first describes the use of a phonological loop or the ability to rehearse verbally to ourselves. A complementary system, the visuospatial sketchpad, allows us to visually hold onto information to determine its properties and to verbally name the information. A buffer like or holding space allows for the integration of different types of information (as in verbally naming visual information) and the ability to work back and forth from long term memory. Finally, all of these functions operate under the control of a central processing system responsible for utilizing the attention controls towards task completion, while also maintaining the ability to remain flexible (Baddeley, 2007).

Inhibitory Control. Inhibitory control allows for the suppression of actions and the resistance to interference from irrelevant sources. Impaired inhibitory control is related to poor decision making and susceptibility to addiction (Khurana et al., 2012). Furthermore, poor impulse control has been implicated in under-achievement (St-Clair-Thompson & Gathercole, 2006), ADHD (Barkley, 1997), and as a deficient component in a significant number of neuropsychiatric disorders (Pliszka, Carlson, & Swanson, 1999). Overall, the ability to stop responding when needed is a crucial factor for the successful execution of complex social, cognitive, and emotional functioning (Anderson, Jacobs, & Anderson, 2008).

Processing Speed. Processing speed is a measure of an individual's ability to easily perform simple repetitive cognitive tasks. Issues with processing speed are usually more evident when completing previously learned information or tasks than with new learning. Often, despite knowing how to perform a given task, individuals with slow processing find that their recall and thinking are sluggish and require more effort than do their peers. These struggles often lead to stress, anxiety, and rushing to complete tasks, which in turn can lead to frustration and more frequent errors. Research has consistently shown that processing speed is related to working memory and intelligence (Hale & Hale, 1996, Redick et al., 2012). Weak processing speed is common in ADHD and has also been shown to negatively impact reading comprehension and reading fluency (Jacobson et al., 2011). Poor processing speed can have a negative impact on obtained academic achievement, future employment outcomes, and late quality of life (Manard, Carabin, Jaspar, & Collette, 2014).

Organization and Planning. Effective organization and planning require the deployment of the above outlined skills to begin, organize, plan, and monitor various aspects of task completion. For example, task initiation is the ability to get started on something. Individuals who struggle with this skill often have issues with planning and prioritizing as well. Without having a plan for a task, it is hard to know how to start. Planning and prioritizing are the abilities to come up with the steps needed to reach a goal and to decide the order of importance. Organization is the ability to keep track of information. Finally, it is important to self-monitor ongoing performance. People that have difficulty with this process cannot tell if their strategies are working. Problems with organization and planning are often found in ADHD, learning disabilities, cognitive impairment, and many

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neuropsychiatric conditions (Barkley, 1997; Pliszka et al., 1999).

Cognitive Assessment

Given the importance of good cognitive health, cognitive tests and measures have been developed to provide an understanding of an individual's strengths and weaknesses in key skill areas of functioning. The costs of impairment underscore the need for reliable and valid assessments as key determinants in evaluating the state of an individual's cognitive health. Relevant questions range from: "Does someone need help?" and if so, "Is the intervention working and to what extent is a given person's time being used efficiently?". In this way, assessment can help balance the time spent training, against time not spent on other productive activities like reading, socializing, gardening, exercising, or engaging in many other activities shown to benefit cognitive health (Langenbahn, Ashman, Cantor, & Trott, 2013; Rabipour & Raz, 2012; Smith et al., 2010).

Psychological Assessments. Why is there so much emphasis on assessment? Clearly, good assessment is crucial to the identification of deficits, selection of appropriate treatments, and measuring improvement or lack thereof. A variety of assessment tools are available for the evaluation of cognitive function/dysfunction. These include brief screening measures (e.g. Modified Mini Mental Status Exam; Montreal Cognitive Assessment), self-report and third-party (parent, teacher, caregiver) behavioral rating scales (e.g. Conners-3; Functional Activities Questionnaire), intelligence test batteries that include sub-tests to assess for deficits in verbal comprehension, perceptual reasoning, working memory, and processing speed (e.g. Wechsler Intelligence Scale for Children, WISC-V; Wechsler Adult Intelligence Scale, WAIS-IV), and domain specific tests of executive function (e.g. Test of Variables of Attention, d2 Test of Attention, Stroop Task, Wisconsin Card Sorting Test, Trail-Making Test).

Neurophysiological Assessments. Electroencephalography (EEG) measures the electrical activity in the brain utilizing electrodes placed on the scalp at standardized locations according to the International 10-20 system (Klem, Lüders, Jasper, & Elger, 1999). These assessments can be conducted during a variety of tasks including resting state eyes-open and eyes-closed conditions, continuous performance tasks (CPT), math, reading, and working memory tasks. Quantitative EEG (QEEG) analysis, or the mathematical processes of EEG components, has led to the identification of signature brain patterns that are characteristics of attention deficits and cognitive impairment across the lifespan. For example, children with ADHD exhibit elevated theta power, reduced relative alpha and beta power, and elevated theta/alpha and theta/beta ratios over the frontal and central midline regions (Barry, Clarke, & Johnstone, 2003) compared to healthy peers.

Adults suffering with mild cognitive impairment (MCI) exhibit decreased delta and alpha power and enhanced theta power compared to a healthy control sample, and theta power commensurate to values observed in individuals with Alzheimer's disease (Jackson & Snyder, 2008). An event-related potential (ERPs) is the measure of a brain response that is time-locked to specific sensory, cognitive, or motor events. During the EEG recording, these responses can be evoked using specific protocols and averaged over several trials, allowing the administer/researcher to observe the cognitive operations that occur (within milliseconds) before and after the presentation of a stimulus or a behavioral response (Woodman, 2010). A variety of ERP differences have been observed in children with ADHD compared to their healthy peers, with reduced posterior P300 amplitudes being the most robust (Barry, Johnstone, & Clarke, 2003). In adults, P300 latencies

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are prolonged in individuals with MCI compared to unaffected controls, but shortened for individuals with MCI compared to individuals with Alzheimer's disease (Howe, Bani-Fatemi, & De Luca, 2014).

Reliability and Validity. Oversight on the development of assessments has been crucial in stimulating properly constructed and useful tests, while maintaining the safety of the general population. As the use of tests increased, there became a need to develop common standards and guidelines for proper test construction and to demonstrate reliable and valid properties of tests performance. Reliability refers to the ability of a test to produce consistent and stable scores on a given measure over time and validity refers to the ability of a test to accurately measure what it claims to measure. In conjunction with solid reliability and validity, acceptable cognitive tests should include large national samples comprised of individuals from all geographic locations and population demographics. This way, individuals taking the measures can be sure they are comparing their performance to the national standard (American Educational Research Association, 2014). Multi-layered oversight ensures that tests and measures that fail to meet the appropriate standards for general or clinical use are not formally promoted and can be removed and/or mitigated as sources of potential harm to consumers. To this end, the Buros Center for Testing publishes the Mental Measurement Yearbook, provides professional peer critiques of assessments and descriptive information to inform researchers and clinicians on the reliability and validity of a given measure (Carlson, Geisinger, & Jonson, 2014).

Interventions

The remediation of cognitive impairments has strong roots in medical rehabilitation, resulting in a diverse range of treatment approaches, each showing improvement in cognitive and social functioning and emotional control. While a thorough review of available interventions is beyond the scope of this paper, general approaches have ranged from structured pencil and paper activities to meditation, physical exercise, immersion with nature, an language and music training (reviews see, Langenbahn et al., 2013; Rabipour & Raz, 2012; Smith et al., 2010). Cognitive brain training and neurofeedback training are two emerging computer-based treatment interventions designed to improve cognitive functioning by actively exercising specific skills. Training is focused directly in the areas where basic but specific cognitive difficulties occur, with the goal of positively impacting functional and behavioral outcomes. Although the treatment goals are similar, each intervention approaches training in a different way, e.g., top-down vs. bottom-up approaches. The following sections provide a description of cognitive brain training and neurofeedback training, as well as a brief review of the current treatment research and limitations.

Cognitive Brain Training. Cognitive brain training utilizes a predominantly top-down intervention approach, i.e. targets performance/skill deficits observed in cognitive impairment. An individual actively engages in a task or activity that targets a specific pre-existing cognitive skill or ability (e.g. working memory, sustained attention). Through repetition, practice, and increasing challenge, the individual enhances the cognitive and neurophysiological processes required to effectively perform the task, leading to improved cognitive function and/or symptom reduction. On a cognitive level, increased awareness of the cognitive processes and strategies required for the task are hypothesized to generalize from the specific training task and environment to other settings and cognitive functions. On the biological level, skill repetition and practice are hypothesized to promote neuroplastic processes in the brain.

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The efficacy of cognitive brain training, including attention, working memory, and auditory/sensory training, has been investigated in several systematic reviews and meta-analyses for a variety of general health and psychiatric conditions. Post-training improvements on measures of working memory, processing speed, and cognitive function have been observed in healthy older adults (Kelly et al., 2014), producing small to moderate effect sizes for nonverbal memory, verbal memory, working memory, processing speed, and visuospatial skills compared to control conditions (Lampit, Hallock, & Valenzuela, 2014). In healthy younger adults, n-back cognitive training programs led to significant changes on measures of fluid intelligence, producing small effect sizes (Au et al., 2015). For the treatment of children and adolescents with ADHD, cognitive training produced medium effect size for the reduction of total ADHD and inattentive symptoms, and large effect sizes for improvements on visual and working memory (Cortese et al., 2015). For individuals at high risk of cognitive decline (MCI and dementia), training gave rise to improvements in attention, executive function, and memory, along with transfer and maintenance of improvement on psychological measures of depres-sion (Coyle, Traynor & Solowji, 2015; García-Casal et al., 2016). Finally, cognitive training utilizing a mixed (verbal and visuospatial) memory approach produced a medium effect size on pre-posttest performance of verbal short-term memory in individuals with intellectual disabilities (Danielsson, Zottarel, Palmqvist, & Lanfranchi, 2016).

Neurofeedback Training. Neurofeedback training utilizes a predominantly bottom-up intervention approach, i.e. targets brain-based deficits associated with cognitive impairment. Neurofeedback is a specialized form of biofeedback in which the electrical activity of the brain is recorded from the scalp in a region of interest, filtered into the brainwave frequencies of interest, and linked to various forms of visual, auditory, and kinetic feedback displays in a software program (Hammond, 2011). In real-time, the person actively learns to modulate their brainwave activity (e.g. theta, alpha, beta) and feedback components in an a priori direction. Through operant conditioning, behavioral shaping, and reward (Sherlin et al., 2011) the individual enhances neurophysiological and cognitive processes, leading to improved function, performance, and/or symptom reduction. On the biological level, self-regulation of specific brainwave activity is hypothesized to promote neuroplastic processes and flexibility in the brain. On a cognitive level, increased awareness of the cognitive state and strategies required to produce specific brainwave activity are hypothesized to generalize from the training environment to other settings and tasks.

The efficacy of neurofeedback training has also been investigated for the treatment of a variety of conditions. In the treatment of ADHD, neurofeedback training has produced a variety of neurophysiological and behavioral outcomes. In the behavioral domain, neurofeedback has led to improvements in core symptoms of ADHD, with medium effect sizes for overall symptom reduction (Lofthouse, Arnold, Hersch, Hurt, & De-Beus, 2012; Micoulaud-Franchi et al., 2014), and medium (Micoulaud-Franchi et al., 2014) to large (Arns, de Ridder, Strehl, Breteler, & Coenen, 2009) effect sizes on inattention and impulsivity. Neurofeedback led to enhanced improvement on WISC performance and absolute power reductions in delta, theta, alpha, and beta activity among children with learning disabilities (Fernández et al., 2003). Stroke survivors have demonstrated voluntary control of specific brain rhythms during training sessions, with enhancement of SMR activity leading to improvements in visuospatial short-term memory, and enhancement of individualized upper alpha activity leading to improved working memory performance, with comparable gains observed in healthy controls sample (Kober et al., 2015). Finally, neurofeedback training in healthy older adults has also led to improved verbal comprehension and enhanced left hemisphere absolute alpha and beta power following the down-training of theta activity (Fernández et al., 2008), and enhanced cognitive processing and executive function following peak alpha frequency training (Angelakis et al., 2007).

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A Practical Example. While cognitive brain training and neurofeedback training have some similarities, there are important differences. As a practical example, think about going to the gym to work with a personal trainer. The trainer guides you through exercises that work your body to build muscle and increase strength in targeted areas like legs, shoulders, etc. The exercises physically alter your body in a positive way so you can meet pre-established goals, e.g. increase squat max weight. However, if you don't have the muscles necessary to help you complete the task, it won't matter how many repetitions you do. Cognitive training is designed to improve pre-existing cognitive skills like working memory, attention, and impulse control by exercising/practicing an existing skill/task. Conversely, neurofeedback targets the underlying physiology of cognitive processes or impairment. This training is designed to change brain physiology through the operant conditioning of brainwave activity to develop and enhance the cognitive functions associated with and needed for task performance.

State of the Science

Despite the positive treatment outcomes reported above, several independent reviews and meta-analyses highlight methodological issues within the cognitive brain training and neurofeedback research. Additionally, the specificity, generalizability, and durability of treatment effects have been key points of debate (Melby-Lervag & Hulme, 2013; Noack, Lövdén, & Schmiedek, 2014; Shipstead, Redick, & Engle, 2010; Thibault, Lifshitz, Birbaumer, & Raz, 2015; Thibault, Lifshitz, & Raz, 2016). These issues and recommendations for future research are discussed below in greater detail.

Methodological Issues. Collectively, reviewers report that many cognitive brain training studies lack scientific rigor; citing problems with clearly defining target training measures, employing a limited number and type of outcome measures, lack of controlled designs and blinding procedures, small participant samples, and lack of replication and long-term follow-up (Boot & Kramer, 2014; Melby-Lervag & Hulme, 2013; Rabipour & Raz, 2012; Sonuga-Barke, Brandeis, Holtmann, & Cortese, 2014). Neurofeedback research has received similar criticisms, including use of small sample sizes, limited sample demographics, inappropriate use of statistical methods, lack of controlled design or reporting of concomitant treatments, lack of long-term treatment follow-up or monitoring of adverse events, and heterogeneity in protocol design, conditioning methods, and screening procedures (Lofthouse et al., 2012; Loo & Barkley, 2005; Loo & Makeig, 2012; Micoulaud-Franchi et al. 2015; Sonuga-Barke et al. 2013). Due to the large degree of overlap in reviewer criticisms, recommendations for methodological improvements are applicable to both training modalities. Recommendations include the (1) use of power analysis software to determine appropriate sample sizes, (2) use of randomized double-blinded placebo-controlled trials or alternative designs employing partial blinding, additive comparison, treatment dismantling, an interrupted time-series design, counterbalancing or condition crossover, and active or semi-active comparison groups, (3) and independent replication (Green, Strobach, & Schubert, 2014; Vollebregt, van Dongen-Boomsma, Slaats-Willemse, & Buitelaar, 2014).

Specificity. Specificity refers to the ability of an individual to demonstrate task specific learning or mastery that leads to improvement on task specific outcomes, often referred to as near-transfer effects. Task specificity has been well documented in cognitive brain training studies, with participants demonstrating im-provements in attention, memory, and reasoning tasks following training of those specific abilities (Green & Bavelier, 2008). According to Gruzelier (2014b), specificity in neurofeedback research involves demonstration of frequency band specificity,

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topographical specificity, and outcome specificity. Review of frequency band specificity reveals mixed results, as the regulation of protocol specific training bands has been observed within and across sessions and at follow-up (Zuberer, Brandeis, & Drechsler, 2015; Gruzelier, 2014b), as well as non-specific changes observed in flanking frequency bands (Gruzelier, 2014b). Outcome specificity has been observed through the comparison of adjacent band protocols, slow and fast wave protocols, and different neurofeedback methods. For example, augmentation of upper alpha activity correlated with gains in working memory and enhancement of gamma activity correlated with gains in fluid intelligence in healthy training samples (Gruzelier, 2014a), and theta/beta and slow cortical potential (SCP) training led to distinct EEG changes (decreased theta and enhanced alpha and CNV - respectively) that correlated with core symptom improvements in a sample of children with ADHD (Gevensleben et al., 2009).

To further demonstrate the specificity of cognitive brain training and neurofeedback protocols, future investigations should include (1) analysis of within and cross-session EEG regulation performance and assess the impact of self-regulation on clinical outcomes, (2) examination of training characteristics that impact learning and optimize outcomes including the task difficulty, thresholding, type of feedback, rate of reinforcement, and the intensity, frequency, and duration of training, (3) investigation of predictors, mediators, and moderators of training response including age, developmental stage, genetics, neuropsychological functioning, neurophysiological profile, disorder severity, adherence, and compliance and (4) assessment and control of nonspecific factors including motivation, expectancy, emotional state, and client-therapist interaction (Gevensleben, Rothenberger, Moll, & Heinrich, 2012; Green & Bavelier, 2008; Keshavan, Vinogradov, Rumsey, Sherrill, & Wagner, 2014; Micoulaud-Franchi et al., 2015; Strehl, 2014; Zuberer et al. 2015)

Generalizability. While cognitive brain training has repeatedly demonstrated task specificity or near-transfer effects, reviewers are highly critical of the evidence in support of the generalizability of effects from the training task to broader cognitive processes (Boot & Kramer, 2014; Noack et al., 2014; Rabipour & Raz, 2012; Shipstead et al., 2010). Generalizability or far-transfer of training effects impacts performance on tasks that are not of the same nature or appearance as the training task (Shipstead et al., 2010) and may be observed across multiple domains and contexts including sensory modality (e.g. visual, auditory), knowledge base, and physical (e.g. specific setting - lab, home, driving), temporal (e.g. time between training and observed effect), functional (e.g. task to general activities of daily living), and social context (Zelinski, 2014). In a meta-analysis, Au and colleagues (2015) reported that working memory training with an n-back task produced a small but significant effect on fluid intelligence in healthy young adults, demonstrating far-transfer. Similarly, evidence of far-transfer in multiple domains has been reported following executive-control, memory, dual-task performance, and complex task training in healthy aging adults (Karbach & Verhaeghen, 2014; Zelinski, 2009). In a review of working memory training research, Klingberg (2010) reported far-transfer to other cognitive tasks (Stroop, paced auditory serial addition task, continuous performance task, recall of nouns, and mathematical reasoning), and reasoning tasks (Raven colored progressive matrices and Bochumer Matrizen test) in patients with ADHD and stroke. Finally, a mounting body of evidence has demonstrated far-transfer with neurophysiological changes following cognitive brain training (Jaušovec & Jaušovec, 2012; Johnstone, Roodenrys, Philips, Watt, & Mantz, 2010; Klingberg, 2010; Olesen, Westerberg, & Klingberg, 2004; Patel, Spreng, & Turner, 2013; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005; Westerberg & Kling-berg, 2007).

Evidence of generalizability and far-transfer have also been observed following neurofeedback.

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Among individuals with ADHD, neurofeedback training has led to performance improvements on a variety of cognitive assessments including the Test of Variables of Attention (Fuchs, Birbaumer, Lutzenberger, Gruzelier, & Kaiser, 2003; Kaiser & Othmer, 2000; Monastra, Monastra, & George, 2002; Rossiter, 2005; Rossiter & La Vaque, 1995), Counting Stroop (Lévesque, Beauregard, & Mensour, 2006), subtests of the Wechsler Intelligence Scale for Children-Revised (Lévesque et al., 2006; Strehl et al., 2006), d2 Test of Attention (Fuchs et al, 2003), and reaction time and reaction time variability tasks (Mayer Blume, Wyckoff, Brockmeier, & Strehl, 2016). In addition to core ADHD symptoms, behavioral changes have also been observed in the reduction of comorbid anxiety and depression (Mayer, Wyckoff, Schulz, & Strehl, 2012a), sleep related issues (Arns, Feddema, & Kenemans, 2014), and classroom and homework behaviors (Mayer, Wyckoff, & Strehl, 2012b). In the neurophysiological domain, changes in EEG activity have been observed within and across training sessions (Mayer et al., 2012b), pre-post intervention (Bakhshayesh, Hisch, Wyschkon, Rezai, & Esser, 2011; Doehnert, Brandeis, Straub, Steinhausen, & Drechsler, 2008) and during ERP tasks (Arns, Drinkenburg, & Leon Kenemans, 2012; Bakhtdadze, Dzhanelidze, & Khachapuridze, 2011; Egner & Gruzelier, 2004; Mayer et al., 2012a; Wangler et al., 2011).

To promote generalization, researchers recommend that future cognitive brain training and neurofeedback protocols incorporate (1) complexity, novelty, and diversity in training designs to maximize ecological validity, (2) employ transfer trials that require the trainee to practice the training skill without direct feedback or in everyday life settings, (3) integrate training cues from the lab into everyday life situations and vise versa, and (4) promote recognition of situations in which the targeted training task, cognitive process, or brain state are required and assign between session "homework" exercises to practice newly acquired skills in those situations (Gevensleben et al., 2012; Moreau & Conway, 2014; Sonuga-Barke et al., 2014; Strehl, 2014; Vollebregt et al., 2014). To assess for transfer effects, study designs should also incorporate a variety of assessments that measure near-transfer and far-transfer effects, while controlling for test-retest effects, cognitive fatigue, carry-over effects, and the increased probability of Type I errors (Cortese et al., 2015; Green et al., 2014).

Durability. A limited number of cognitive brain training and neurofeedback studies have investigated the long-term persistence of training effects. Within ADHD research, cognitive brain training has led to persistent effects from 9 weeks to 6 month follow-up (Klingberg et al., 2005; Steiner, Frenette, Rene, Brennan, & Perrin, 2014; van der Oord et al., 2014). Similarly, neurofeedback studies have reported the maintenance or continued reduction of core ADHD symptoms, as well as the ability to demonstrate self-regulation skills from six months (Gevensleben et al., 2010; Leins et al., 2007) up to two years post-intervention (Gani, Birbaumer, & Strehl, 2008). Future investigations should include extended follow up periods to investigate the durability of the training effects, as well as potential for training to delay the progression of cognitive impairments (Coyle et al. 2015).

Discussion

The personal and societal impact of cognitive related health issues is immense, reducing the quality of life for millions of Americans, and costing billions of dollars annually in medical services. The etiology of cognitive impairment is diverse, impacting individuals across the lifespan, and leading to deficits in attention, working memory, inhibitory control, information processing, organization, and planning. Assessment, intervention, and prevention are key areas to help stave off the effects of cognitive decline. The use of valid and reliable psychological and neuro-

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physiological assessment tools aid in the diagnosis and identification of individuals at risk of cognitive decline, selection of appropriate treatments, and evaluation of treatment effects. Emerging interventions such as cognitive brain training and neurofeedback are designed to improve deficits and functioning by directly exercising pre-existing cognitive skills/abilities and/or the underlying neural networks associated with those cognitive processes. Collectively, these interventions have been applied to participant samples with varying degrees of cognitive impairment (e.g. healthy controls, ADHD children, aging adults, etc.), demonstrating performance, clinical, and neurophysiological gains in laboratory settings. However, methodological limitations have been identified within this body of work. Additional research is needed to demonstrate the specificity, generalizability, and durability of training effects to support these interventions as frontline treatments for cognitive impairment.

Technological advancements have allowed for the development of assessment tools, cognitive brain training games, and neurofeedback protocols that can be delivered online or via mobile devices, administered and supervised remotely, and integrated into other interventions and activities of daily living. Computerized testing is an efficient and cost effective way to administer standardized cognitive, behavioral, and performance based assessments; decreasing the amount of time needed to administer and score pencil-paper measures, reducing publisher and clinician costs of printing/reordering pencil-paper measures every time an assessment is used, and replacing the need for highly skilled psychometrists. Computerized testing allows clinicians to administer broad baseline assessments to inform the development of adaptive cognitive brain training games that can be tailored to a user's individual cognitive strengths and weaknesses. Similarly, the development and validation of low cost user friendly wireless dry electrode systems (Wyckoff, Sherlin, Ford, & Dalke, 2015) permit clinicians to capture high quality EEG data to monitor neurophysiological treatment outcomes, inform the selection of standardized or individualized neurofeedback protocols, and facilitate training sessions. While these advancements will certainly reduce treatment barriers and enhance accessibil-ity to cognitive brain training and neurofeedback interventions, additional research is needed to determine their impact on compliance, generalizability, and efficacy.

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