


# Cognitive Rehabilitation After Traumatic Brain Injury: A Reference for Occupational Therapists

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## Abstract

Nearly 1.7 million Americans sustain a traumatic brain injury (TBI) *each year*. These injuries can result in physical, emotional, and cognitive consequences. While many individuals receive cognitive rehabilitation from occupational therapists (OTs), the interdisciplinary nature of TBI research makes it difficult to remain up-to-date on relevant findings. We conducted a literature review to identify and summarize interdisciplinary evidence-based practice targeting cognitive rehabilitation for civilian adults with TBI. Our review summarizes TBI background, and our cognitive remediation section focuses on the findings from 37 recent (since 2006) empirical articles directly related to cognitive rehabilitation for individuals (i.e., excluding special populations such as veterans or athletes). This manuscript is offered as a tool for OTs engaged in cognitive rehabilitation and as a means to highlight arenas where more empirical, interdisciplinary research is needed.

## Keywords

TBI, evidence-based practice, cognition, rehabilitation, occupational therapy, interdisciplinary systematic review

## Introduction

Imagine this scenario: An occupational therapist (OT) at a rehabilitation hospital receives the schedule for the day. From this list of names, the OT has 30 min to complete a chart review and make treatment plans. For clients with physical injuries, the treatment plan is clear. These patients will work with the OT to increase their limb flexibility, strength, and utility. The OT will provide adaptive equipment to compensate for the physical deficits that cannot be remediated. However, there is one client listed who has a traumatic brain injury (TBI). She needs cognitive rehabilitation so she can return home safely. The OT recognizes that rehabilitation should focus on improving the client's attention, learning, and memory, but it is not always clear what approach is optimal. The client's injury is internal and invisible. The OT wants to believe that the activities the client completes will lead to meaningful improvements to her brain function. But is there any certainty of this? Do improvements during acute therapy translate to real-life functionality? At what time point does an OT assume that remedial approaches are futile, and compensatory interventions are best practice? What factors regarding patient management from other intervention stages must be considered to predict optimal cognitive outcomes? When should rehabilitation end? What literatures can be tapped to address unexpected issues?

This vignette depicts some of the challenges facing OTs involved in the cognitive rehabilitation of people with TBI.

TBI is defined as brain damage that disrupts cognitive function in variable ways with diverse consequences (*The Merck Manual of Diagnosis and Therapy*, 2006). Nearly 1.7 million Americans sustain a TBI *each year*, prompting 275,000 hospitalizations (Faul, Xu, Wald, & Coronado, 2010). Acutely, TBI severity is assessed using the Glasgow Coma Scale (GCS; Teasdale & Jennett, 1974). GCS scores can be grouped according to TBI severity: mild (13+), moderate (8-12), or severe (<8; Decuyper & Klimo, 2012). GCS scores can be predictive of future cognitive dysfunction, which is associated with future disability (Skandsen et al., 2010). Perhaps, surprisingly, there is no “gold standard” for cognitive rehabilitation (Gordon, 2011) and, consequently, no systematic approach to cognitive remediation. Therapists, of course, use theoretical models to guide interventions, but empirical evidence can help expedite interventions and maximize gains. Without a systematic, evidence-based approach, a patient with TBI may receive varied cognitive interventions until one works, or worse, until reimbursed rehabilitation ends. Cognitive rehabilitation, by nature, results in gains, losses, and plateaus. It is estimated that at least 300 hr of appropriate

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therapy are needed to promote optimal outcomes. Therefore, it is essential that OT and other therapists use those hours effectively (Leon-Carrion, Dominguez-Morales, Barroso y Martin, & Leon-Dominguez, 2012). In this review, we sought to identify evidence-based cognitive rehabilitation interventions that exist within TBI literature.

Unfortunately, there is no single, uniform TBI literature to support the development of comprehensive best practices. Instead, physicians, nurses, neuropsychologists, therapists, researchers, and other professionals publish relevant findings in field-specific journals. This makes it challenging to stay current with the literature(s). This criticism was highlighted in a recent paper that described the heterogeneity of both TBI patients and TBI literature (Maas et al., 2013). The authors noted that clinical research is often derailed by non-standardized data collection and insufficient multidisciplinary collaboration. The purpose of this article is to summarize relevant findings across the TBI literatures for an OT readership. In short, this review is intended as an “update” for busy OTs conducting cognitive rehabilitation. Our secondary goal is to expand cross talk between related fields as TBI is inherently interdisciplinary and to encourage OTs to promote research that will supply much-needed empirical basis for refining evidence-based practices. We review issues that influence and improve cognitive recovery from the moment of the TBI itself. These topics include successful early medical interventions, assessment, and empirically based cognitive rehabilitation strategies.

There are systematic, broad review papers of evidence-based cognitive rehabilitation (see Carney et al., 1999; Cicerone et al., 2000; Cicerone et al., 2005; Rees, Marshall, Hartridge, Mackie, & Weiser, 2007). This review adds to these papers by focusing on the recent literature and explicitly targeting an audience of OTs. Using the search term *TBI cognitive rehabilitation* in humans in PubMed, we found 932 articles published between 2006 and 2014. We focus on cognitive rehabilitation for the non-veterans/athletes adult TBI population, and therefore excluded articles specific to other populations, and articles that did not explicitly describe effective cognitive treatment strategies.<sup>1</sup> The remaining relevant articles were used to create this review. We also used additional search engines (e.g., Cochrane Library, PEDro, Google Scholar) to ensure that the cognitive rehabilitation section provided as close to *comprehensive* coverage of recent empirical articles as possible.

Although grant funding and research programs target TBI in veterans and athletes, our goal was to highlight the consequences of TBI in adult non-veterans/athletes. Recently, falls have replaced motor vehicle accidents as the leading cause of TBI. In the United States, the older adult population is rapidly growing, and older adults are particularly vulnerable to TBI from falls (Wick, 2012). Therefore, it is essential that research also focus on rehabilitation for everyday individuals who sustain TBI. As stated above, our goal was to provide a targeted integration across multiple fields to support OTs

engaged in cognitive rehabilitation. At the end of each segment is a brief statement recapitulating the direct relevance of the section to the occupational therapy interventions for TBI. In closing the review, we provide a breakdown of the empirical evidence by cognitive domain to promote our view that increased research is needed. Finally, as a textual note, to avoid excessive qualification (given the variability inherent in TBI), we acknowledge that there can always be exceptions to the general patterns of results described below.

## **Early Interventions: Intubation, Diagnosis, and Surgical and Pharmaceutical Treatment**

Early TBI management can predict the success of later cognitive rehabilitation. A major cause of death and secondary brain injury in TBI is the first responders' difficulty establishing, securing, or maintaining an airway (Bauer, 2012), or performing resuscitation (Bernard et al., 2010). Air medical crews are responsible for safe and rapid intubation under difficult, often complicated circumstances (e.g., cervical spine instabilities; Bauer, 2012). Efficient endotracheal intubation, such as by video laryngoscopy, reduces complications such as hypoxia, hyper- or hypo-capnia, or hypertension (Bauer, 2012). A recent review that examined 30 years of TBI interventions verified that pre-hospital intubation promoted significantly better outcomes (Lu, Gary, Neimeier, Ward, & Lapane, 2012). OTs should note whether intubation took place in pre-emergency settings because complications like hypoxia can exacerbate cognitive deficits, and early intubation predicts better outcomes.

Once in the emergency room, quick and correct diagnosis of TBI is essential. In some hospital settings, trauma nurses and physicians receive specific TBI training (Appleby, 2008). The nursing literature emphasizes that training should include diagnostic criteria, treatment instructions, and symptom management at discharge from the emergency room (Bay & Strong, 2011; Bergman & Bay, 2010). For example, it is easy to overlook pupillary changes that may indicate subdural bleeding, which can be fatal. Other abnormal pupillary responses should be noted because they can indicate a range of abnormal brain function (Adoni & McNett, 2007). Other diagnostic techniques include use of spiral computer tomography (CT; Barrett et al., 2009), scheduled repeat brain CT (Thomas et al., 2010), biomarker signature evaluation (Jeter et al., 2013), or simply, the use of targeted questions to determine the mechanism of injury (Powell, Ferraro, Dikmen, Temkin, & Bell, 2008). After a TBI diagnosis, a range of interventions may be necessary including craniotomies, craniectomies or surgical evacuations (Y. J. Kim, 2011), therapeutic hypothermia (Dietrich & Bramlett, 2010; McIntyre, Fergusson, Hebert, Moher, & Hutchison, 2003; Wright, 2005), administration of statins (Rosenfeld et al., 2012), tranexamic acid, nimodipine (Lei, Gao, & Jiang, 2012), erythropoietin (Rosenfeld et al., 2012), or progesterone (Lei et al.,

2012). A recent TBI review indicated that acute surgical interventions produce mixed outcome and acute pharmacological interventions result in no effects or even adverse effects for patients who have sustained a TBI (Lu et al., 2012). It is important for OTs to know how their patients were initially diagnosed and treated after a TBI, as these early interventions can impact future recovery. For more detail on the acute medical management of TBI, please see Koliass, Guilfoyle, Helmy, Allanson, and Hutchinson (2013).

In the past, interventions had the primary goal of preventing death. Now, providers consider a patient's long-term prognosis (Livingston, Tripp, Biggs, & Lavery, 2009). Interventions are used when they can facilitate *both* survival and meaningful holistic recovery. This has significant implications for OTs, as they will now treat patients with less severe injuries who possess greater potential for recovery.

## Cognitive Assessment

Typically, in acute care and inpatient rehabilitation hospitals, rehabilitation nurses are responsible for managing and assessing patients' medical status and needs (Murphy & Carmine, 2012). A therapy team evaluates and treats these patients once stabilized. When available, neuropsychologists conduct thorough initial cognitive evaluations to clearly identify impaired domains. These assessments provide objective normed data that are essential for monitoring change over time (Michels, Tiu, & Graver, 2010). However, these assessments do not always relate to the "real-world" functioning potential of patients as these tests may not have strong ecological validity (Gordon, 2011).

Speech and language pathologists (SLP) also work closely with neuropsychologists who perform extensive cognitive testing of patients (Constantinidou, Wertheimer, Tsanadis, Evans, & Paul, 2012; Wertheimer et al., 2008). Many validated cognitive assessments are used throughout the course of TBI recovery (for a review on cognitive assessments for adult TBI, see Podell, Gifford, Bougakov, & Goldberg, 2010; Tate, Godbee, & Sigmundsdottir, 2013).

When appropriate assessment is completed, rehabilitation strategies can be effectively used throughout the continuum of TBI recovery (Tsaousides & Gordon, 2009).

## Contributions From Cognitive Neuroscience

Research findings from cognitive neuroscience remain underutilized for cognitive rehabilitation. Neuroscientists seek to understand brain structure–function relationships, occasionally in patient populations, and often engage in translational research with clear relevance to occupational therapy. In the TBI literature, these contributions are often diagnostic or prognostic in nature. Magnetic resonance imaging (MRI) can be used to predict functional outcomes and identify the location of TBI damage (Moen et al., 2012; Palacios et al., 2013).

Moen and colleagues used MRI to objectively classify the degree of traumatic axonal injury and repair over time. They found that early MRI (injury to 3 months post injury) of traumatic axonal injury associated with TBI predicted the patient's cognitive outcome (Moen et al., 2012).

In a functional MRI study (fMRI), Bonnelle and colleagues (2011) found that patients with TBI can have increased activation of the default mode network. Interestingly, this increased activity can predict which patients will show sustained attention deficits. This pattern of activation is often present before any behavioral manifestation. Finally, Kohl, Wylie, Genova, Hillary, and DeLuca (2009) found neural correlates of cognitive fatigue in individuals with TBI. Their fMRI data demonstrated increased brain activity, which was believed to represent increased cerebral effort. This increased effort is thought to be associated with the subjective complaint of cognitive fatigue. These data are synchronous with rehabilitation research that indicates that subjective cognitive fatigue can be highly debilitating and negatively impact processing speed (Johansson, Berglund, & Ronnback, 2009). Diffusion MRI (dMRI) can be used to identify diffuse axonal injury and subsequently classify how structural and functional networks are impaired (Gillebert & Mantini, 2013; Raffin & Dyrby, 2013; Sharp, Scott, & Leech, 2014; Voelbel, Genova, Chiaravalotti, & Hoptman, 2012; Yallampalli et al., 2013). One study showed that dMRI has been used to accurately predict which individuals who had sustained a TBI would benefit from a specific memory rehabilitation program (Strangman et al., 2012).

These cortical network data could assist in diagnostics and prognostics after TBI *and* could inform therapeutic interventions. MRI from the acute TBI stage is strongly recommended to maximize predictive power for long-term prognosis. As an example, Farbota and colleagues (2012) observed progressive axon myelination changes that were related to decreases in working memory performance suggesting the progressive, rather than isolated, nature of TBI. These data are complementary to longitudinal rehabilitation studies that examine changes in TBI over time (see Himanen et al., 2006) and a positron emission tomography (PET) study which demonstrated that inflammatory processes can persist for up to 17 years following a TBI (Ramlackhansingh et al., 2011). Future research of this type could have important implications for professionals, like OTs, who provide cognitive rehabilitation.

Electrophysiological measures, including direct recordings from human neurons *in vivo* via electrocorticography (eCog), can also be used to predict outcomes after TBI, although it is not available in all hospital settings. Specifically, in an eCog study, Hartings and colleagues (2011) recorded activity from patients' neurons and observed spreading mass neuronal depolarizations post TBI. These abnormal, mass neuronal depolarizations corresponded to worse cognitive outcomes.

Results from various neuroimaging techniques can help OTs create realistic expectations for rehabilitative outcomes for some patients, and alternatively, encourage others to achieve maximal functionality. Not only are these tools useful for diagnosis and prognosis but they can also be used to test the efficacy of interventions. As an example, fMRI research has helped to identify neural mechanism associated with attentional training (Y. H. Kim et al., 2009). In this study, all participants completed a visuospatial attention task in conjunction with fMRI. Following the intervention, individuals with TBI demonstrated behavioral improvement and patterns of cortical activity that better resembled the activity of healthy control. These results not only support the attentional training intervention but also support the concept that rehabilitation progress is made due to neural plasticity. Similarly, fMRI can successfully predict the effectiveness of memory rehabilitation in patients with TBI, in indicating who benefited most from the intervention (Strangman et al., 2008). While fMRI cannot feasibly be used to identify maladaptive cortical patterns in individual patients, it can be used to identify which types of rehabilitative interventions instantiate more neurotypical patterns of cortical activity. Electroencephalography (EEG) and fMRI could be monitored acutely and post intervention to objectively quantify cortical changes due to rehabilitation interventions.

Research in cognitive neuroscience is also actively identifying new rehabilitation interventions. Transcranial direct current stimulation (tDCS), a type of non-invasive electrical neurostimulation, applied to the left prefrontal cortex can improve performance of attention tasks for individuals with TBI (Kang, Kim, & Paik, 2012). Repeated transcranial magnetic stimulation (rTMS), another form of non-invasive neurostimulation using magnetic fields, has been successfully used to improve physiological and behavioral characteristics after TBI (Pachalska, Lukowicz, Kropotov, Herman-Sucharska, & Talar, 2011). Finally, functional electrical stimulation (FES) has been used to effectively improve brain perfusion in individuals with cranial trauma (Amorim et al., 2011). These interventions and the diagnostic possibilities of neuroscience tools illustrate the potential of a symbiotic relationship between research and clinical fields that should be further developed to enhance evidence-based practice and rehabilitation.

### **Cognitive Rehabilitation: Remediation Approaches**

Typically, in early stages of recovery, OTs apply remediation approaches, with a shift toward compensation approaches during later stages of recovery. Early intervention after TBI significantly improves outcomes when compared with interventions that occur temporally later (Leon-Carrion, Machuca-Murga, Solis-Marcos, Leon-Dominguez, & Dominguez-Morales Mdel, 2013). Cognitive rehabilitation operates on the principle that enriched and enhanced learning

environments can promote gains via neuronal plasticity (Dash, Orsi, & Moore, 2009). There are some data that suggest, however, that there may be a trade-off between motor and cognitive gains in TBI recovery (Green et al., 2006). In other words, neuronal plasticity is limited; similar neural mechanisms may be competing for resources in motor and cognitive recovery; therefore, identifying the most important rehabilitation goals is essential. In addition, the cognitive deficits patients experience may negatively affect their physical recovery. As an example, patients with cognitive deficits are less likely to comply with constraint-induced therapy schedules designed to improve upper limb function (Morris et al., 2006). Therefore, targeting cognitive improvement may be most important for holistic recovery.

In general, greater cognitive improvement occurs within the first 5 months of recovery when compared with the subsequent 7 months (Christensen et al., 2008). However, significant gains in motor and visuospatial areas can happen beyond the initial window. Importantly, motor and visuospatial therapy should be remedial in nature for significantly longer than therapy that targets other domains. This recommendation modifies current practice, where therapists use remediation approaches in the acute stages (<5 months) of rehabilitation and shift to compensatory strategies in the later stages. It is clear that extending the use of remediation strategies may be advantageous in some recovery domains. The following sections describe existing and emerging interventions to improve cognitive outcomes.

### **Self-Awareness**

TBI survivors often have deficits in self-awareness and subjective well-being; they may be unaware of their acquired deficits (Sasse et al., 2013). Impaired self-awareness reduces the motivation to participate in rehabilitation activities, as they are deemed unnecessary; this imposes significant challenges for recovery (Bivona et al., 2013; Boosman, Visser-Meily, Winkens, & van Heugten, 2013; Evans, Sherer, Nick, Nakase-Richardson, & Yablon, 2005; Kelley et al., 2014; Spikman et al., 2013).

Improving self-awareness is essential for improving other cognitive domains, as patients must first recognize their deficits to improve them. A common practice, and usually effective strategy, in rehabilitation settings is for therapists to set goals with patient input, for a “client-centered” approach (Dalton et al., 2012; Grant, Ponsford, & Bennett, 2012; Hart & Evans, 2006; McPherson, Kayes, & Weatherall, 2009). Not surprisingly, researchers have found that cognitive goal setting with patients with TBI is often unsuccessful when patients have self-awareness deficits (Bouwens, van Heugten, & Verhey, 2009).

One promising approach uses a combination of video and verbal feedback to improve self-awareness in patients without increasing emotional distress (Schmidt, Fleming, Ownsworth, & Lannin, 2013). In addition, Goverover,

Johnston, Togli, and DeLuca (2007) successfully improved self-awareness by using a five-step process during instrumental activities of daily living (IADL) tasks. They instructed individuals with TBI to first identify task goals, predict task performance, prepare for errors or difficulties, choose a strategy to manage errors or difficulties, and finally assess how much assistance will be needed for successful completion. In addition, group therapy programs can help individuals recognize the consequences of their cognitive deficits. These programs successfully increase patients' degree of self-awareness and promote improved use of behavioral strategies for managing deficits (Lundqvist, Linnros, Orlenius, & Samuelsson, 2010). While TBI literature often focuses on identifying deficits in self-awareness after TBI, the three listed strategies—using video/verbal feedback, completing a five-step self-awareness process, and implementing group-based sessions—are successful evidence-based interventions that can improve self-awareness in patients with TBI.

## Learning and Memory

Individuals with TBI have difficulty with learning and memory because they struggle with being active participants in their own recovery (Aadal & Kirkevold, 2011) and often experience encoding deficits (Goverover, Arango-Lasprilla, Hillary, Chiaravalloti, & DeLuca, 2009). Here, classic memory research from psychology may be beneficial.

Strategies that promote deeper memory encoding and slower information presentation facilitate learning in healthy individuals. One deep encoding technique, self-generation, asks individuals to create their own examples to understand new material. Individuals with TBI are able to use this strategy and subsequently enhance their learning ability (Goverover, Chiaravalloti, & DeLuca, 2010; O'Brien, Chiaravalloti, Arango-Lasprilla, Lengenfelder, & DeLuca, 2007). Spacing out information is another technique where small amounts of new information are presented in multiple short time periods. This technique can enhance recall in TBI populations (Goverover et al., 2009). A related approach is spaced retrieval, where information is retrieved from memory over progressively longer periods of time. Therapists have used this treatment technique to enhance memory for individuals with chronic TBI, and importantly, this treatment was successfully provided over the phone (Bourgeois, Lenius, Turkstra, & Camp, 2007).

Another study used *testing*, such that responses require active memory retrieval, as a remediation approach for learning and memory because it improves memory performance in healthy adults (Roediger & Karpicke, 2006). Regular testing helped to facilitate gains in both learning and memory in survivors of severe TBI (Pastotter, Weber, & Bauml, 2013). Another analogous study found that retrieval practice, or explicit quizzing of to-be-remembered information, can improve later recall in patients who have sustained a severe TBI (Sumowski, Coyne, Cohen, & DeLuca, 2014). Finally,

“self-imagining” (visually imagining oneself engaged in a particular event) can enhance memory of that event in healthy individuals. For individuals with memory deficits following TBI, using “self-imagining” serves as a useful mnemonic device for remembering events for which recognition was previously difficult (Grilli & Glisky, 2011).

In summary, OTs should encourage individuals with TBI to use established memory encoding strategies like self-generation, spacing, retrieval practice, testing, and self-imagining to enhance learning and memory of new information. For additional information regarding memory rehabilitation, see Elliott and Parente (2014).

Individuals with TBI also have deficits in prospective memory (PM), the ability to remember to perform activities at a designated moment in the future (e.g., remembering to take the trash to the curb every Monday). Researchers investigated why this was a consequence of TBI. Again, encoding difficulties combined with deficits in self-awareness may make individuals with TBI less likely to use external memory aids (Roche, Moody, Szabo, Fleming, & Shum, 2007). Individuals with TBI benefit from applying strategies associated with the use of visual imagery to assist with PM. The intervention used graded complexity in naturalistic settings and improved PM by strengthening the memory trace and facilitating recall of the intended action (Potvin, Rouleau, Senechal, & Giguere, 2011). In a similar study, participants used a “self-imagining” technique to view themselves completing the desired PM task, which significantly improved task performance (Grilli & McFarland, 2011). Researchers have also used virtual reality PM training in a virtual convenience store and successfully improved both virtual reality and real-life PM performance in adults with TBI (Yip & Man, 2013). Another effective strategy for improving PM is to train individuals with TBI to associate a cue phrase (e.g., “Stop”) with pausing their present activity and monitoring their goals (e.g., a goal to complete a PM task). These cued interruptions were delivered to individuals' cell phones on five randomly selected days, and significantly improved PM task completion (Fish et al., 2007).

OTs in rehabilitation settings can encourage patients to use visual imagery (e.g., picturing themselves taking out the garbage on Tuesday) or virtual reality training (when available) in preparation of completing their daily activities in their own naturalist settings. In addition, OTs could teach clients to establish “cued” interruptions to help them monitor their PM task performance and completion.

## Executive Function

Executive functioning (EF) is the ability to plan, organize, strategize, and focus attention. Deficits in EF following TBI can be profound and debilitating, and EF deficits have the strongest effect on functional outcomes (Spitz, Ponsford, Rudzki, & Maller, 2012). Interestingly, EF deficits can occur even in mild TBI (Erez, Rothschild, Katz, Tuchner, &

Hartman-Maeir, 2009). There is some variability in *how* EF deficits are managed. Researchers and therapists often target EF deficits by relying on theoretical models of treatment. These varied approaches are described below.

The *cognitive orientation to occupational performance* model (CO-OP) encourages individuals to use metacognitive strategies to identify and strengthen weak areas of cognition (Dawson, Binns, Hunt, Lemsky, & Polatajko, 2013; Dawson et al., 2009). Metacognition is the ability to recognize one's cognitive capacity. If a patient recognized, for example, that he had trouble remembering verbally presented information, he could use a metacognitive strategy of requesting written information (Dawson et al., 2009). Telerehabilitation, such as videoconferencing between patients and therapists, can also support this approach (Ng, Polatajko, Marziali, Hunt, & Dawson, 2013).

Classic neuroscience approaches are also used to target EF. One study used a cognitive neuroscience working memory training paradigm to improve EF in a pilot population of adults with TBI. The paradigm chosen was based on the paced auditory serial addition task (PASAT). The PASAT task includes presenting a series of digits after which participants must add each new number to the immediately preceding number (e.g., "4," "3" becomes 7). A Months task and Words task were modeled from this design (for full details, see original paper). These working memory training tasks successfully enhanced EF, which translated to improvement in everyday life performance (Serino et al., 2007).

Researchers have also used intact cognitive abilities to promote EF recovery. Because individuals with TBI occasionally have difficulty planning unstructured novel tasks, like moving to a new home, researchers trained participants with TBI to think about past autobiographical events (e.g., the last time they moved) to support planning of a future event. This training technique successfully improved planning performance (Hewitt, Evans, & Dritschel, 2006).

Goal management training (GMT) developed by Robertson (1996) is used for a variety of clinical populations. Researchers have also used this protocol to manage executive function deficits following TBI. GMT includes a five-stage process of identifying an objective or goal, defining the task to reach the objective, listing and learning the steps of the task, executing the task, and then evaluating whether or not the task was completed correctly. In this study, authors propose using GMT with errorless learning. Errorless learning occurs when a therapist guides the participant through the above steps but provides cueing and assistance to prevent occasions of errors or guessing. The authors are presently empirically testing this combined approach with individuals with TBI (Bertens, Fasotti, Boelen, & Kessels, 2013).

Finally, ecologically valid interventions can also be used to target EF. Jacoby and colleagues used a virtual supermarket to successfully train EF skills needed for grocery shopping in adults with TBI (Jacoby et al., 2013).

Remediation approaches OTs might adopt for improving EF include using metacognitive strategies, classic neuroscience research—including working memory training, improving EF using intact cognitive abilities, use of the GMT protocol, and adopting virtual reality environments to prepare for community reintegration. For more detail on deficits, assessment, and treatment, please see recent reviews specific to EF (Chung, Pollock, Campbell, Durward, & Hagen, 2013; Cicerone, Levin, Malec, Stuss, & Whyte, 2006).

## Attention

Attentional deficits are relatively common after TBI and exist in realms of selective, sustained, and divided attention. Foley, Cantagallo, Della Sala, and Logie (2010) studied 86 adults with TBI and found significant attentional deficits in one fourth of the participants. Systemic reviews of earlier papers addressing attention rehabilitation after TBI are helpful (see Cicerone, 2002; Park & Ingles, 2001). This article provides an update on recent literature, so the following section refers to more recent findings.

Attention process training (APT) is shown to improve selective attention in individuals with TBI by progressively increasing attentional demands (Pero, Incoccia, Caracciolo, Zoccolotti, & Formisano, 2006). APT is currently being applied in a longitudinal study with the goal of enhancing the understanding of how to rehabilitate attention in early phases (i.e., first year) of acquired brain injury recovery (Bartfai, Markovic, Sargenius Landahl, & Schult, 2014)

Recent work in patients with severe TBI has found success using tactile feedback in a virtual environment to facilitate recovery of sustained attention on visuo-motor tasks (Dvorkin et al., 2013). Training in tasks of divided attention can specifically improve performance on the trained tasks, but this improvement does not transfer to other cognitive tasks (e.g., EF; Couillet et al., 2010). In summary, rehabilitation practitioners have found that APT, providing tactile feedback, and training divided attention can successfully ameliorate attention deficits.

## Generalized Strategies and Approaches

Certain strategies and therapeutic approaches can implicitly target some or all of the aforementioned cognitive domains. As an example, aerobic exercise and music therapy are evidenced based interventions that can improve cognitive performance. A recent review paper indicated that aerobic exercise is associated with increased production of brain-derived neurotrophic factor, which facilitates neurogenesis (Lojovich, 2010). Furthermore, exercise may promote angiogenesis—the formation of new blood vessels in the brain. This can improve cortical oxygen use and significantly affect brain function, specifically cognitive abilities like memory (Lojovich, 2010).

Music-based therapy is also shown to improve cognitive functioning by altering and restoring brain functions. Another recent review highlighted a study that used neurologic music therapy (NMT; Hegde, 2014). NMT is a therapeutic use of music for sensory, cognitive, or motor recovery. The study highlighted in Hedge (2014) used four sessions of NMT in group therapy sessions. Each session targeted a different cognitive domain and used music to enhance the therapy. This intervention significantly improved executive function, mental flexibility, and reduced anxiety and depression (Thaut et al., 2009). Although aerobic exercise and music-based therapy do not target specific cognitive domains (e.g., memory), OTs can use these strategies to help promote gains across various cognitive abilities.

## Daily Cognition

In addition to targeting specific cognitive domains, rehabilitation research examines ways to improve overall cognitive function, or daily cognition. One daily cognitive activity that is difficult for individuals with TBI is using technology—including electronic, technical, and mechanical equipment. Participants reported that technology use was difficult because it required sequencing and remembering codes and passwords, and finding assistance could be challenging (Engstrom, Lexell, & Lund, 2010). OTs can successfully address these difficulties with interventions that promote improved technology use.

Another activity that is difficult for individuals with TBI is recognizing faces. This ability is essential for daily social interactions. Cognitive neuroscientists targeted this deficit by modifying how they showed novel faces. In this study, participants saw caricature faces (i.e., simplified with target features, like eyes, enhanced), typical pictures with semantic information (e.g., this is Mary; she is a doctor) information, or typical pictures with feature identification (e.g., this is Bob; he has large eyes). All of these approaches were successful in improving face recognition when compared with simple exposure (e.g., just viewing the face; Powell, Letson, Davidoff, Valentine, & Greenwood, 2008).

TBI literature also supports the concept that re-learning of daily tasks in a natural setting leads to greater functional gains, particularly for patients with cognitive deficits (Dawson et al., 2009; H. Kim & Colantonio, 2010). However, virtual reality environments can be exceptionally useful when OTs cannot work with patients in their natural environment (e.g., when a patient must remain in the hospital due to medical need). Retrieving money from an ATM is a daily cognition activity that can be challenging following TBI. Fong and colleagues (2010) used a simulated ATM in a virtual reality environment, and successfully facilitated ATM use improvements in a population of adults with acquired brain injuries. Virtual reality training is an evidence-based option for improving performance prior to natural environment participation.

It is often in a naturalistic setting that a patient's functional potential becomes apparent. There are emerging data showing that transfer effects are possible between technology and the real world. Randomized computer-based practice for about an hour per day for 13 days facilitated transfer effects to everyday skills in adult men with TBI (Giuffrida, Demery, Reyes, Lebowitz, & Hanlon, 2009). Two separate studies found that a computerized working memory training could facilitate improvement in daily cognition. In one study, participants reported fewer cognitive problems after completing the Cogmed QM training software (Johansson & Tornmalm, 2012). In another study, participants with TBI demonstrated improvement on both trained computer tasks and untrained transfer tasks, and reported improved occupational performance and satisfaction with their occupation performance (Lundqvist, Grundstrom, Samuelsson, & Ronnberg, 2010).

A substantial amount of TBI literature is allocated to individuals' ability to return driving (D'Apolito, Massonneau, Paillat, & Azouvi, 2013; Klonoff et al., 2010; Lundqvist, Alinder, & Ronnberg, 2008; Ortoleva, Brugger, Van der Linden, & Walder, 2012; Rapport, Bryer, & Hanks, 2008) and gainful employment (Andelic, Stevens, Sigurdardottir, Arango-Lasprilla, & Roe, 2012; Benedictus, Spikman, & van der Naalt, 2010; Hart et al., 2006; Hofgren, Esbjornsson, & Sunnerhagen, 2010; Klonoff et al., 2007; Kolakowsky-Hayner, Wright, Shem, Medel, & Duong, 2012; McCrimmon & Oddy, 2006; Rietdijk, Simpson, Togher, Power, & Gillett, 2013; Sela-Kaufman, Rassovsky, Agranov, Levi, & Vakil, 2013). Both of these areas of occupational performance require integrated cognitive and physical skills. Furthermore, performance can also be improved with environmental modifications (e.g., less distracting work space) and social support (e.g., an encouraging spouse) Because both driving and returning to work require holistic approaches including cognitive, physical, social, and environmental interventions (Dawson, Schwartz, Winocur, & Stuss, 2007), we did not include a comprehensive section on this type of rehabilitation. For a review on driving rehabilitation after TBI, see Tamietto et al. (2006); for a review on return to work after TBI, see Fadyl and McPherson (2009) and Wehman, Targett, West, and Kregel (2005). To facilitate return to driving and work following TBI, OTs can use the approaches described above to target the *cognitive* skills that are needed for future engagement in these activities.

In summary, daily cognition can be improved by providing therapy in patient's natural environment or a virtual reality environment, using technology to train skills needed for daily functioning and by applying interventions developed by cognitive neuroscientists, like face recognition improvement techniques and working memory training paradigms.

The sections above describe empirically based interventions to *remediate* cognitive deficits following a TBI. As stated earlier, some of these interventions (i.e., those used in neuroscience research) are not yet available for clinical use

as they are in development stages. Nevertheless, OTs should be aware of developing remedial approaches, as many are likely to reach clinical settings in the future.

### **Cognitive Rehabilitation: Compensation Approaches**

With time, even the best remedial approaches fail to promote functional gains and rehabilitation turns to compensatory approaches. The goal of compensation approaches is to find ways to offset degrees of impaired functioning. Difficulties performing daily activities can arise from deficits in any of the cognitive domains listed above. Therefore, most compensatory strategies attempt to facilitate improvements in daily activities without specifically targeting a cognitive domain. Typically, compensatory strategies involve the use of assistive technology (AT). AT can improve daily task performance in adults who have sustained a TBI and, with training and education, health professionals become more receptive to use of AT (de Joode, van Boxtel, Verhey, & van Heugten, 2012). AT can include personal digital assistants (PDAs) that remind individuals to complete daily activities (Gentry, Wallace, Kvarfordt, & Lynch, 2008; Lannin et al., 2014), electronic aids that improve daily activity performance and memory (Boman, Tham, Granqvist, Bartfai, & Hemmingsson, 2007; Dry, Colantonio, Cameron, & Mihailidis, 2006), and augmentative and alternative communication (ACC) technology (Fager, Hux, Beukelman, & Karantounis, 2006; Fried-Oken, Beukelman, & Hux, 2011).

Boman, Lindberg Stenvall, Hemmingsson, and Bartfai (2010) used a training apartment to determine where patients would likely exhibit memory lapses upon discharge from a rehabilitation setting. In this study, a computer registered the number of times they forgot to complete a predefined set of activities. Patients made the greatest number of errors when using the refrigerator and the stove. Following this assessment, all participants received training using electronic memory aids and collectively demonstrated improvement in their ability to use the aids to complete daily tasks. Determining which electronic aids will be useful can be facilitated by use of a training apartment (Boman et al., 2010). However, it is important to note that some individuals who have sustained a TBI have difficulty using everyday technology, even ones they had previously used (e.g., tablets). It is important for OTs to address this difficulty for both newly introduced and previously used technology (Engstrom et al., 2010). Another barrier to AT use is that health insurance reimbursement for AT is limited. This makes widespread use less likely, even though it is an evidenced based way of improving daily functioning. Increased AT reimbursement by health insurance companies is possible and could be accomplished by more research supporting the successful use of AT in various populations by demonstrating improved management of medical issues. Improved medical management results in reduced need for additional medical services and, therefore, reduced overall cost.

### **Implications for Occupational Therapy**

Cognitive disabilities after TBI are assessed and treated by occupational therapy using the best information they have. In general, scientists seek to understand the basic science surrounding TBI. Expediting translational success via enhanced communication between scientists and OTs would likely improve cognitive outcomes for people with TBI. The interdisciplinary nature of TBI means that different groups are targeting different problems using different techniques, and publishing in field-relevant journals, making communication across disciplines a real challenge.

There is a clear need for more research in cognitive rehabilitation for the everyday citizen who has sustained a TBI. Since 2006, 37 empirical articles from rehabilitation and neuroscience journals identified remedial or compensatory approaches for the TBI population (Bartfai et al., 2014; Bertens et al., 2013; Boman et al., 2010; Boman et al., 2007; Bourgeois et al., 2007; Couillet et al., 2010; Dawson et al., 2013; Dawson et al., 2009; de Joode et al., 2012; Dry et al., 2006; Dvorkin et al., 2013; Engstrom et al., 2010; Fager et al., 2006; Fish et al., 2007; Fong et al., 2010; Fried-Oken et al., 2011; Gentry et al., 2008; Giuffrida et al., 2009; Goverover et al., 2009; Goverover et al., 2010; Goverover et al., 2007; Grilli & Glisky, 2011; Grilli & McFarland, 2011; Hegde, 2014; Hewitt et al., 2006; Jacoby et al., 2013; Johansson & Tornmalm, 2012; H. Kim & Colantonio, 2010; Lannin et al., 2014; Lojovich, 2010; Lundqvist, Grundstrom, et al., 2010; Lundqvist, Linnros, et al., 2010; McDonnell, Smith, & Mackintosh, 2011; Ng et al., 2013; O'Brien et al., 2007; Pastotter et al., 2013; Pero et al., 2006; Potvin et al., 2011; Powell, Letson, et al., 2008; Roediger & Karpicke, 2006; Schmidt et al., 2013; Serino et al., 2007; Sumowski et al., 2014; Yip & Man, 2013).

The limited number of empirical articles describing evidence-based rehabilitation may seem surprising. Yet, this pattern has been observed previously. A comprehensive TBI review paper conducted in 2007 began with researchers selecting 1,312 papers drawn from the preceding 25 years. These authors identified a mere 76 empirical articles describing randomized control trials (RCT) for improving cognition after TBI (Teasell et al., 2007). Another comprehensive review examined RCT for cognitive rehabilitation after TBI over a 30-year period. They found 95 RCT and noted that many of these articles did not provide enough detail about treatment, which makes clinical implementation exceptionally difficult (van Heugten, Gregorio, & Wade, 2012). Although we screened more recent papers over a shorter time frame and *did* include both RCT and non-RCT articles (provided they included adequate treatment information), we reached a similar conclusion as previous authors—much more research is needed.

Details for the 37 empirical articles by domain are depicted in Table 1. Increasing the amount of interdisciplinary work for each cognitive domain and enhancing access to these findings is essential and could create the “gold standard” for cognitive rehabilitation. This would improve OTs’



**Table 1.** Summary of Empirical Articles for Each Cognitive Domain.

	N	Intervention	Intensity	Outcome
SA				
Goverver, Johnston, Toggia, and DeLuca (2007)	10	SA training during IADL practice	6 sessions; 2-3/week over 2-3 weeks	Selective ↑ of SA during IADL and functional tasks
Lundqvist, Linnros, Orlenius, and Samuelsson (2010)	21	Group sessions including profession presentations, experience sharing, coping, and problem solving discussions.	11 sessions, 2 hr each for 6 months	↑ SA, understanding of brain injury consequences, & coping strategies
Schmidt, Fleming, Ownsworth, and Lannin (2013)	54	RCT comparing video + verbal feedback, verbal feedback, or experiential feedback following a meal preparation task	4 sessions; 2-4 days b/w each session	Video + verbal feedback was optimal for reducing errors & ↑ SA
Learning and memory				
Bourgeois, Lenius, Turkstra, and Camp (2007)	38	RCT comparing SR or traditional didactic SI	30-min sessions; 4-5 times/week	SR & SI ↑ everyday memory and perceived QOL. SR by phone > SI for strategy mastery.
Fish et al. (2007)	20	Content free cueing (via text message reading "STOP" to aid PM)	8 messages sent on 5 of 10 PM task days	Significant ↑ on PM task
Goverver, Arango-Lasprilla, Hillary, Chiaravalloti, and DeLuca (2009)	10	Spacing—presentation of information over multiple time points—for functional tasks.	3 trials separated by 5-min intervals	Spaced presentation > massed presentation for recall
Goverver, Chiaravalloti, and DeLuca (2010)	10	Generation effect—participants self-generate own examples when learning new functional tasks	1 session: 30 min b/w learning and recall portions	Self-generation > provided for learning
Grilli and Gisky (2011)	14	Selfimagining—imagining events from own perspective to encode neutral and emotional sentences	2 sessions (~1 week apart), 45 min each	Self-imagining > other encoding techniques for recognition memory.
Grilli and McFarland (2011)	12	Selfimagining—imagining completing a PM task prior to starting a computerized PM task	2 sessions; 1 week apart	Self-imagining > to rote rehearsal for PM
O'Brien, Chiaravalloti, Arango-Lasprilla, Lengenfelder, and DeLuca (2007)	18	Self-generated to-be-remembered words by filling in sentences	2 sessions; a learning/immediate recall session and a 1-week post-session	Self-generation > provided for recall
Pastrotter, Weber, and Bauml (2013)	24	Testing—participants learned and were then immediately tested on novel word lists	2 sessions: immediate testing session and distractor session	Immediate testing of learning and memory
Potvin, Rouleau, Senechal, and Giguere (2011)	10	Visual imagery—participants learned to associate cues w/PM tasks	2 eval. sessions (3 hours each) and 10 weekly rehab sessions (90 min)	Visual imagery ↑ memory trace of intention and ↑ PM
Sumowski, Coyne, Cohen, and DeLuca (2014)	10	Retrieval practice—participants quizzed on information shortly after presentation	2 sessions: a 30-min delayed recall session, and 1 week post-session	Retrieval practice > massed or spaced practice for long term recall
Yip and Man (2013)	37	Used virtual reality-based PM training; non-immersive VR for everyday PM tasks (e.g., shopping)	12 sessions; 30-45 min each	Significant ↑ in both VR and real-world PM
EF				
Bertens, Fasotti, Boelen, and Kessels (2013)	64	RCT comparing errorless learning in GMT w/ traditional GMT	1 baseline, 5 training sessions, and 1 post-training	Expected <sup>a</sup> to ↑ daily task completion for EF deficits
Dawson, Binns, Hunt, Lemsky, and Polatajko (2013)	13	Occupation-based strategy training (adapted from CO-OP) during real-world behavior performance	1-hr session; 2/week for 10 weeks	Far transfer effects ↑ performance and satisfaction on untrained tasks
Dawson et al. (2009)	3	Used the CO-OP to manage EF deficits	20 1-hr sessions in participants' environments	↑ self-identified goals immediately and 3 months post-intervention

(continued)

Table 1. (continued)

	N	Intervention	Intensity	Outcome
Hewitt, Evans, and Dritschel (2006)	30	Used <i>autobiographical episodic memory cueing</i> to prompt success in future planning of activities	1 session lasting b/w 60 and 90 min	↑ effectiveness and ↑ no. of correct steps when planning new activities
Jacoby et al. (2013)	12	Compared VR <i>supermarket training</i> with traditional OT for treatment of EF deficits	10 sessions of 45-min OT or VR training	Trend indicating that VR training > OT w/o VR
Ng, Polatajko, Marziali, Hunt, and Dawson (2013)	3	CO-OP delivered via teleconferencing	20 sessions; 2 1-hr sessions/week for 10 weeks	Trend ↑ satisfaction and performance w/daily activities and ↑ community integration
Serino et al. (2007)	9	WMT to targeting CES	16 sessions; 4 sessions/week for 4 weeks	↑ on cognitive tasks that rely on the CES and ↑ daily activity performance
<b>Attention</b>				
Bartfai, Markovic, Sargenius Landahl, and Schult (2014)	120	RCT comparing the use of APT and standard activity based training	20 hr of APT or standard training	Expected <sup>a</sup> changes in functional attention and return to work capacity
Couillet et al. (2010)	12	<i>Dual task training</i> to improve divided attention. Tasks were performed simultaneously & progressively increased in difficulty.	24 sessions; 4 1-hr sessions/week for 6 weeks	Specific ↑ on trained dual tasks/divided attention, but limited transfer effects
Dvorkin et al. (2013)	21	<i>Interactive visuo-haptic environments</i> to train attention for visuo-motor tasks	2 consecutive days; 48 min of training/day	Haptic (tactile/sensory) cues ↑ attention for visuo-motor tasks
Pero, Incoccia, Caracciolo, Zoccolotti, and Formisano (2006)	2	Used APT for comprehensive attention processes rehabilitation	4 cycles of APT; pre-testing before, and post-testing 1 month later.	↑ selective attention, but limited improvement in alertness and vigilance
<b>General strategies</b>				
Hegde (2014) highlighting (Thaut et al., 2009)	31	Review of music-based interventions for TBI highlighting a study using NMT	4 group sessions; 30 min/session. Sessions targeted different cognitive domains	NMT ↑ EF and mental flexibility while reducing depression and anxiety
Lojovich (2010)	N/A	Review of <i>aerobic exercise-based interventions</i> for TBI	N/A (summarized multiple studies)	Exercise may promote angiogenesis resulting in ↑ cortical oxygen use during cognitive activities
<b>Daily cognition</b>				
Fong et al. (2010)	24	<i>Virtual reality environment</i> (non-immersive) simulating an ATM to train real-world ATM use	1-hr sessions; 2/week for 3 weeks	↑ real-world ATM use
Giuffrida, Demery, Reyes, Lebowitz, and Hanlon (2009)	6	Used randomly structured practice to improve processing and fine-motor skills	55 min/day for 13 days	↑ performance of everyday skills
Johansson and Tornmalin (2012)	18	Used a WMT program (QM Cogmed) to improve WM and overall cognition needed for daily activities	30-45 min sessions; 3 times/week for 7 weeks	↑ on trained WM tasks and ↑ daily cognitive problems
Lundqvist, Grundstrom, Samuelsson, and Ronnberg (2010)	21	Used a structured and intense WMT protocol (QM) on personal computers	45-60 min/day, 5 days/week for 5 weeks	↑ cognitive performance: WM and occupational performance improvements

(continued)

**Table 1. (continued)**

	N	Intervention	Intensity	Outcome
Powell, Letson, Davidoff, Valentine, and Greenwood (2008)	20	Used semantic association, caricaturing, and part recognition to enhance learning and recognition of novel faces	4 days w/a different presentation strategy each day	All strategies > simple exposure for novel face recognition
<b>Compensation approaches</b>				
Boman, Lindberg Stenvall, Hemmingsson, and Bartfai (2010)	14	Training on proper use of EMA in a training apartment	5 days, 24 hr a day in training apartment	Patients learned to use the EMA effectively; OT involvement is essential
Boman, Tham, Granqvist, Bartfai, and Hemmingsson (2007)	8	Provided basic or advanced EADL to enhance occupational performance	4-6 months w/in 2 years	Participants learned to use EADL in everyday activities; QOL improved
Fager, Hux, Beukelman, and Karantounis (2006)	25	Provision of high- or low-tech AAC devices	Varied	Adults w/TBI effectively use AAC, but abandon if facilitator support is lost
Gentry, Wallace, Kvarfordt, and Lynch (2008)	23	Training w/PDAs to improve EF	3-6 home visits, 90 min/visits over 30 days	↑ EF performance w/PDA use; OT is essential
Lannin et al. (2014)	42	RCT comparing PDA w/OT training or standard rehabilitation	7 hr, ~8 sessions over 8 weeks	PDA w/OT training > standard rehabilitation

Note. N represents the number of participants with TBI who were included in each study. Some studies also included healthy controls or other patient populations. SA = self-awareness; IADL = instrumental activities of daily living; RCT = randomized control trials; SR = spaced retrieval; SI = strategy instruction; QOL = quality of life; PM = prospective memory; VR = virtual reality; EF = executive functioning; GMT = goal management training; CO-OP = cognitive orientation to daily performance; OT = occupational therapist; WMT = working memory training; CES = central executive system; APT = attention process training; TBI = traumatic brain injury; NIMT = neurologic music therapy; EMA = electronic memory aids; EADL = electronic aids to daily living; AAC = augmentative and alternative communication; PDA = personal digital assistant. The ^ symbol notes articles describing a study protocol for a RCT, but the results are not yet published; they were included so OTs can search for the findings in the near future. The ↑ symbol represents increased or improved performance. The > symbol indicates that one treatment protocol was superior to another.

abilities to select and tailor an evidence-based cognitive rehabilitation program for their patients in a time-efficient and effective manner.

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### Note

1. Excluded articles included those describing pediatric populations (~117 articles; for reviews, see Laatsch et al., 2007; Slomine & Locascio, 2009), single case study articles (~87), combat specific (~63; for reviews, see Carlson et al., 2011; Hoge et al., 2008), sports-related injuries (~51; for reviews, see Johnston, McCrory, Mohtadi, & Meeuwisse, 2001; McCrory, Johnston, Mohtadi, & Meeuwisse, 2001), populations with comorbidities (~12), those specific to particular geographical locations (~27), psychological evaluation and treatment-based articles (~64), pharmacological treatment articles (~27), and articles validating specific assessment (~71). Most importantly, we excluded articles that were unsuccessful in promoting cognitive improvement and articles where intervention techniques were not described adequately for implementation (~16). Please note that these numbers are approximated because of overlap (e.g., pediatric sport injury articles) and the subjective nature of categorizing articles by topic.

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