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REVIEW

Cognitive Training for Military Application: a Review of the Literature and Practical Guide

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Abstract

In recent years, the potential to improve cognitive skills through training has captured the attention of academic researchers, the commercial market, and the general public. Numerous clinical and healthy populations have been identified as targets for cognitive training, and military personnel are one particular group that may be able to uniquely benefit from cognitive training interventions. Military operations involve a wide range of human performance skills, many of which are cognitive in nature. Use of cognitive training to improve these critical everyday skills for service members represents an untapped potential resource by which to improve operational readiness and warfighter performance. While much of the cognitive training research to date has been circumscribed within basic science pursuits, here we propose ways in which this research may start to be applied in a military setting. In the current review, we examine instances of military operations that may readily lend themselves to cognitive training. Further, we examine the existing literature from academic endeavors and pinpoint areas of exemplary efforts that can serve as a guide for military research to follow, as well as pitfalls to avoid. In particular, we identify and review evidence from the video game, working memory, and executive function training literatures. Finally, the goals of basic and applied science often differ, and that is certainly the case when comparing outcome-based research in a military context with mechanism-based research in an academic context. Therefore, we provide a guide for best practices when conducting cognitive training research specifically in a military setting. While cognitive training has attracted much controversy in both academia and commercial markets, we argue that utilizing near transfer effects in a targeted, outcome-based approach may represent a powerful tool to improve human performance in a number of military-relevant scenarios.

Keywords Cognitive training · Military research · Human performance · Transfer

Military operations stretch the gamut of human performance and tap into many different cognitive abilities. The possibility of using cognitive training to improve those diverse sets of cognitive skills relevant to military operations represents an exciting practical application. Cognitive training represents a substantial opportunity to improve the performance of military service members if the right cognitive training is provided for the right circumstances. For example, inhibitory control has already been linked to the likelihood of inflicting either a civilian casualty (Biggs et al. 2015) or a friendly fire incident (Wilson et al. 2013). One cognitive training study has already demonstrated the potential to improve shooting performance through inhibitory control training by reducing civilian casualties inflicted during simulation (Biggs et al. 2015). Other forms of cognitive training could have widespread military applications, including how visual search training might improve security screening or raw intelligence processing, working memory (WM) training might have applications for high cognitive workload tasks such as flying modern military aircraft, and attention training might have applications for watchstanding duties. The cognitive training opportunities are almost endless given the need for accurate and quick decisions in some of the most high-intensity scenarios imaginable.

Recent reviews have assessed the accumulated empirical evidence and made some detailed recommendations about the

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best cognitive training methods (e.g., Simons et al. 2016). Still, these best case recommendations often discuss the general viability of cognitive training and assume complete experimental control. Cognitive training and field applications face significant uphill challenges when incorporating these best methods into an active duty military population. Some methodology issues become more important, some issues become less important, but all issues can be reviewed with the specific goal of improving human performance for military operations rather than hypothetical generalities. The current manuscript will therefore review the cognitive training literature with the stated and specific intent of evaluating these training initiatives for military purposes. Some examination will touch upon well-covered topics such as near transfer versus far transfer, but this discussion will differ because the focus will be on the relative value for military applications or a military audience—not the general population or specific clinical disorders. The goal is to provide a framework and understanding for any future research initiatives or applications which may seek to provide a military benefit from cognitive training. This review is oriented toward two groups of researchers: basic scientists studying cognitive training who seek to find real-world applications for training and applied researchers working with military populations that seek to develop and test novel methods for improving operational skills. We attest that the successful implementation of cognitive training for improvement of military performance will require a collaborative effort between these two groups. The discussion will begin with a general overview of the cognitive training literature before moving into practical applications and considerations for ongoing and future military operations.

Cognitive Training Overview

The beginning of the twenty-first century has witnessed an explosion of interest in cognitive training both in basic science and applied settings. The overarching goal of cognitive training is to improve specific or broad-ranging cognitive skills and numerous approaches have been examined with this goal in mind, such as video game training (Green et al. 2016; Powers et al. 2013), working memory training (Au et al. 2015; Morrison and Chein 2011; Shipstead et al. 2012), meditation training (Chiesa et al. 2011; Lutz et al. 2008; Tang et al. 2015), non-invasive brain stimulation (Berryhill et al. 2014; Parkin et al. 2015), aerobic exercise (Hillman et al. 2008), and many others (for a comphrensive review see Simons et al. 2016; Strobach and Karbach 2016). However, each of these approaches to cognitive training has been surrounded by some degree of controversy, which typically stems from debate about the effectiveness of training to "transfer" to performance on other untrained tasks. In the context of cognitive training, transfer refers to the potential of training on one task to elicit improvements on another untrained task. This idea of transfer from training originates from Thorndike's theory of identical elements (Thorndike and Woodworth 1901), which proposed that only when the knowledge components between two skills are identical can there be transfer between the two.

Starting with the most rudimentary concept of transfer, there is little doubt that practice improves performance or that practicing one task (e.g., shooting a handgun) will lead to more efficient learning of a closely related skill (e.g., shooting a rifle). From practice, we can move along the transfer spectrum to what is typically referred to as near transfer. A representative example of near transfer comes from the WM training literature. For example, if an individual trains on a spatial n-back task, where the order and locations of stimuli must be remembered, it would be expected that performance following training would improve for an object n-back task, where the order and *identity* of stimuli must be remembered. The logic here is that training on the spatial n-back version improves one's ability to maintain and update visuospatial information in WM and therefore this improved skill will result in better performance on an untrained n-back task that uses different stimuli. Near transfer has great potential for elucidating cognitive mechanisms, as well as practical use in applied settings. Despite the practical value of near transfer, the vast majority of research and its subsequent controversy has surrounded the idea of far transfer.

Far transfer refers to training on a task and seeing improvement on an untrained task that does not necessarily share elements with the trained task. Again, from the WM training literature, the typical example is examining whether training on a WM task like an n-back task will improve performance on matrix reasoning tasks that are considered measures of fluid intelligence (*Gf*). The logic here is that WM capacity is a limiting factor for performing a wide range of cognitive tasks. In particular, WM capacity is highly predictive of *Gf* and therefore improving WM capacity via training may enable individuals to perform better on measures of *Gf* and/or a range of real-world outcomes. While far transfer is the "holy grail" of cognitive training and the marketing foundation of commercial brain training products, evidence has proved inconsistent.

Here, we consider transfer to be a spectrum ranging from practice to far transfer. Thus, there are a variety of "mid" level transfer scenarios one can imagine. For example, WM training has shown mixed evidence for modality specificity, whereby visuospatial WM training may or may not elicit improvement on untrained WM tasks in the verbal domain and vice versa (Buschkuehl et al. 2014; Jaeggi et al. 2014; Schneiders et al. 2011). This type of cross-modality, but intra-skill transfer, may be viewed as mid-level transfer. Alternatively, consider an example where training on a task that requires inhibitory control, such as a go/no-go task, yields improvement on a very different task that taps into an overlapping cognitive mechanism, such as the Stroop task. In this review, our primary focus will be on the spectrum of transfer with the goal of informing the application of cognitive training in military operational outcomes. Human performance is a critical factor in military operations, and cognitive training represents a potential untapped resource for improving that performance.

Task Analysis

One critical consideration in the application of cognitive training to real-world outcomes is that of task analysis. Here, we aim to provide an overview of the cognitive training literature in a basic science setting, as well as provide a guide to using cognitive training in applied settings—specifically the military. Outcomes are of primary importance to military operations, but especially important are outcomes for multifaceted skills, as military operations inevitably require coordination of multiple cognitive abilities. For example, there is not one specific laboratory-based task that encompasses all components of room clearing, piloting a military aircraft, or navigating a ship. With this in mind, determining what knowledge, skills, and abilities are required for a particular job is a critical step in determining what type of cognitive training may be beneficial—otherwise known as a formal task or job analysis. There are several studies which address ways to conduct a formal task analysis (e.g., Brawley and Pury 2016; Morgeson and Dierdorff 2011; Patrick and Moore 1985). However, for researchers conducting applied or "field" research, there are less formal steps that can be taken to integrate some of the principles used in a task analysis.

For example, in a recent study exploring the impact of cognitive training on "shoot/do not shoot" performance, the authors applied task analysis principles to help design a specific training program for military and law enforcement research (Hamilton et al., under review). The researchers conducted interviews with a group of 26 firearms training professionals including active federal Special Agents, special operations military personnel, state and local law enforcement officers, and an elite group of national and world champion competitive shooters. These subject matter experts (SMEs) provided insights into which cognitive abilities might apply to a shoot/do not-shoot decision, and this information was a critical factor in determining not only the cognitive training regimen but the research design as well. Importantly, this method also allowed them to incorporate feedback from experts in nearly every relevant occupation where individuals may be forced to make a "shoot/do not shoot" decision with a firearm. This approach started with the real-world application to create a cognitive training regimen rather than designing a cognitive training regimen and then trying to fit it into a real-world application. It should be noted that, in this situation, the SMEs suggested cognitive tasks that aligned with the limited amount of existing literature regarding shoot/do not shoot performance (e.g., Biggs et al. 2015; Wilson et al. 2013).

In short, after reviewing the relevant literature on a particular application of cognitive training, particularly on a topic where there is very little, a worthwhile next step is to consult with the recognized "experts" in the area that is being studied. This process of starting from the "ground" up and incorporating qualitative data, such as in-depth interviews with SMEs, is one that is often used in grounded theory and/or organizational psychology (Brawley and Pury 2016; Creswell 2007). However, while this technique may be less common in basic cognitive psychology, it may represent a necessary first step in applied research especially when specialized populations are being targeted. This notion may prove especially true in military applications.

Cognition in the Military

Research on the improvement of cognitive function in military populations has been primarily focused on medical interventions for service members recovering from traumatic brain injury (TBI; Bogdanova and Verfaellie 2012; Huckans et al. 2010; Twamley et al. 2014) or psychological disorders such as post-traumatic stress disorder (PTSD; Bogdanova and Verfaellie 2012; Haaland et al. 2016; McDermott et al. 2016). For example, there is a wealth of research on the impact of TBI on cognitive performance in military populations, such as the Vietnam Head Injury Study, which has followed 1221 Vietnam veterans with mostly penetrating brain injuries prospectively (e.g., Grafman et al. 1990; Grafman et al. 1996; Groswasser et al. 2002; Raymont et al. 2011). The prevalence of brain injuries continues to increase in the modern era, as The Defense and Veterans Brain Injury Center estimates that between 2000 and 2017 more than 375,000 service members have been diagnosed with TBI ("DoD Worldwide Numbers for TBI," 2018). TBI is associated with a variety of cognitive impairments that include impaired attention, impaired visuospatial/verbal information processing, memory deficits, communication problems, poor judgment, and impaired executive functioning (Barman et al. 2016). The most common cognitive impairments following TBI are related to attention, memory, and executive functioning (Arciniegas et al. 2002). These deficits represent clear targets for cognitive training as a rehabilitative tool. Further, the deficits seen following TBI demonstrate the utility of potential training programs that elicit near transfer (e.g., improving WM in a population that has suffered WM deficits following TBI).

However, in addition to clinical applications following a physical or psychological injury, improvements or enhancements in cognitive functioning could have several positive preventative implications for service members. Increased combat readiness among healthy service members may help to mitigate some "avoidable" combat injuries. An avoidable combat injury could be described as an injury or incident that results from a cognitive processing error or "mental mistake." Some examples could include friendly fire incidents, preventable civilian casualties, or incorrect relay of grid numbers during communication with air support or artillery units. Furthermore, enhancing cognitive abilities may serve another preventative purpose by improving recovery prognosis following a TBI.

One explanation for why there are differences in how individuals respond to brain injury or disease is cognitive reserve. The assumption underlying cognitive reserve is that preexisting neurological differences underlie the differential response (Stern 2002). Cognitive reserve is broadly classified as either passive or active. Passive reserve refers to gross anatomical differences, such as brain size or cranial volume that serve as protective factors. Active reserve refers to the neural mechanisms, such as more efficient networks or neural flexibility that protect cognitive function (Stern 2009). While neither of these types of cognitive reserve reduce the damage caused by disease or injury, they may allow the individual to compensate for the effects of the damage during recovery. Several studies have shown that pre-injury measures of cognitive reserve are associated with better clinical outcomes. For example, one study that examined cognitive functioning following TBI found that total intracranial volume, a measure of passive reserve, was associated with higher post-injury function (Kesler et al. 2003). Other research that has looked at the effects of active reserve has shown that WM capacity (Sandry et al. 2015), standardized test scores (Kesler et al. 2003), various cognitive tests (Fay et al. 2010), and educational attainment (Schneider et al. 2014) may protect against the effects of brain injury. These results raise the question of whether it may be possible to use training to increase cognitive reserve, thus reducing the impact of a potential future injury. While some factors that influence passive cognitive reserve (e.g., intracranial volume) are fixed, others that affect active reserve might be improved through training. One example of using cognitive training in a preventative manner with military personnel has shown some initial promise. Jha et al. (2010) found evidence that mindfulness training served to protect WM capacity during a high-stress pre-deployment interval. The authors concluded that while stress is known to reduce WM, the service members who received mindfulness training were less susceptible to the functional impairments associated with those high levels of stress during pre-deployment. This approach of boosting cognitive resources and skills prior to insult/injury/stress is in line with the work on cognitive reserve as a protective factor. In addition to serving as a preventative approach, enhancement in cognitive functioning may also represent a method for improving warfighter performance and efficiency in a number of other tasks, scenarios, and domains.

There are several areas of cognitive functioning that likely impact military personnel and specifically apply to the unique situations they encounter. Often the very nature of combat is unpredictable, hectic, and imposes an overload of information on an individual. Battle plans, call signs, routes, frequencies, and grid numbers are only a few of the factors that may change several times over the course of a single mission—and almost certainly change upon contact with a hostile adversary. Keeping track of all these items is extremely taxing to an individual's WM, which is known to be capacity limited (Luck and Vogel 1997). To ensure mission success, it is critical that combat leaders constantly *monitor* and *update* new mission relevant information and discard old, irrelevant information. Individuals in specialty roles, such as medics and forward observers, may be required to *shift* between very different mental tasks or sets such as calling for fire (e.g., radioing information to coordinate an artillery strike) to maneuvering to returning fire to rendering aid. Military personnel are expected to be able to perform these demanding tasks and at the same time exercise enough *inhibition* to appropriately identify and engage the enemy while avoiding friendly fire or inflicting civilian casualties. Cognitively speaking, much is demanded of members of our armed forces, particularly as the battlefield becomes more technologically advanced and complex. Therefore, it is imperative that we investigate how specific cognitive functions impact service members and attempt to find ways to improve their capability in those areas. Unfortunately, this is an area in which relevant research and training is severely lacking.

To illustrate the variety of potential cognitive training opportunities that are relevant to military personnel, consider an example scenario that is often encountered in urban combat: room clearing. Service members are often tasked with going through a building or house and searching it for enemy combatants. This type of situation is dynamic, unpredictable, and extremely dangerous. Individuals must rely heavily on visual and auditory perception to see and hear necessary input. Deployment of visuospatial attention is key, as the entire relevant area must be attended to and then quickly searched for potential threats. Individuals must be able to quickly and accurately identify potential threats as hostile or non-hostile. If a hostile target is identified, that individual must decide on a course of action (e.g., shoot or do not shoot) and then execute the necessary motor response (i.e., aim and pull the trigger). All of this is accompanied by procedural and declarative knowledge that is learned during combat training, such as what order individuals in a team enter a room or building and which individuals are responsible for which specific tasks. Finally, all of these cognitive efforts are compounded by additional variables such as perceptual and attentional distractions (e.g., a dog barking in the background or smoke obscuring one's vision), psychological stress (e.g., anxiety), and physiological stress such as heat or muscle fatigue from carrying a heavy pack. Each of these relevant skills may represent a potential trainable target. While academic endeavors in cognitive training have focused heavily on far transfer, as illustrated in this example, the military may be able to capitalize on near transfer of these specific perceptual, attentional, and higher-order cognitive abilities. In this review, we will focus on the effectiveness of particular forms of cognitive training to elicit near transfer to skills that are operationally relevant to military personnel.

Critical Factors in Cognitive Training Application

When considering application of cognitive training in the real-world, such as use with military personnel, it is critical to not only consider range of transfer but other components of training. In particular, learning theories suggest that both content and context of learning or training are key to a learner's outcome. Content is highly related to the concept of transfer discussed above, as we typically consider content to be the knowledge and skills practiced in a training paradigm. Thus, the degree of similarity or overlap in content between the training task and any untrained task dictates what degree of transfer we might expect. Cognitive training can be designed to focus on a singular task (e.g., spatial n-back), a singular content (e.g., multiple WM tasks), or multiple content areas (e.g., WM, inhibitory control, and task switching tasks). However, it is also important to recognize the influence of *context* on training outcomes as well. The context of training or learning can vary along multiple dimensions, including knowledge domain, physical location and circumstances, intended purpose, and whether the trained skill involves only the individual or involves other people. In a cognitive training environment, additional context variables to consider are motivation (e.g., intrinsic vs. extrinsic) and compliance.

Furthermore, there can be a multitude of interactions between content and context (Barnett and Ceci 2002) that the cognitive training field has only begun to consider—and some of these issues may only arise in military, law enforcement, or security situations. For example, one important issue involves the transfer of effects when using simulators versus live ammunition for training purposes. There is always a push to create realistic circumstances during training, but military operations are often dangerous in nature, which complicates the possibility of creating realistic content and context for transfer. For example, shooting simulators commonly used by military units can only provide a limited amount of realism because eventually a service member must carry a live weapon with live ammunition during the course of his or her duties. Unfortunately, there is no comparable substitute for this context other than placing a live weapon into his or her hands. Meaningful transfer thus becomes a critical issue because transferring the learned training procedures to a combat situation can literally mean the difference between life and death. It also means overcoming the anxiety of using a weapon and the fear involved in facing combat. The challenge becomes how to best ensure the greatest degree of transfer from one context to another, which may require targeting the underlying cognitive mechanisms thereby underscoring the value of cognitive training. In this sense, the value of cognitive training can be seen in the relationship between the Soldier and the combat environment. It is impossible to fully prepare an individual for all possible situational variations that he or she may encounter. This functional challenge makes combat training complicated; however, it is possible to train the cognitive abilities of the individual that are likely to be utilized in combat. Put another way, it may be impossible to train for precisely where an individual will be driving a car—but, we can improve the type of car he or she will be driving.

Meaningful training-related improvements in cognition are almost certainly underscored by neural plasticity. Knowing which conditions are conducive to plasticity helps to establish the circumstances under which we should begin to train and the types of training initiatives to explore. Lovden et al. (2010) argue that a fundamental prerequisite for successful cognitive training is a mismatch or imbalance between environmental demands and actual brain supply. Thus, plasticity denotes a prolonged mismatch between cognitive resources and situational demands. To create this prolonged mismatch, cognitive training tasks must be challenging but manageable with a high degree of effort. This balance between keeping a task difficult enough to ensure the participant is not bored while easy enough to ensure the participant does not get frustrated is typically achieved through adaptive paradigms that keep the effort and feasibility level consistent for each individual participant. Lovden et al. (2010) delineate two manifestations of plasticity: changes to representations and changes to processes and their efficiency. For example, training-induced plasticity could alter representation or knowledge, which is similar to the concept of crystallized intelligence (Horn and Cattell 1966) and relies on procedural or declarative knowledge and abilities. On the other hand, training-induced plasticity could alter the process or efficiency with which one completes a task. WM training relies on the logic that training-induced plasticity will either increase the capacity of WM or enable an individual to more efficiently use their existing capacity (e.g., improving distractor filtering; C. H. Li et al. 2017), which represents an alteration to process or efficiency, which in turn benefits performance on other WM tasks.

Perhaps the greatest challenge in applying cognitive training to the military is the lack of understanding regarding the specific links between cognitive processes and human performance in military operations. Specifically, it is easy to assume that WM is necessary in aviation operations, where a pilot must coordinate information from the control tower, other aircraft in the vicinity, various instruments, and the skies around the aircraft. Some recent evidence has started to explore these links while also using cognitive training to demonstrate that these links are causal in nature rather than purely correlative (e.g., Biggs et al. 2015). Still, these links are more exploratory than anything else. Cognitive training research will need to build upon the most established links or provide foundational efforts first to provide the largest and most efficient expenditure of military resources in pursuit of improved training initiatives.

Lessons from Commercial and Academic Efforts

There has been exponential increase in the for-profit brain training industry in recent years. Unfortunately, there is little—if any—convincing evidence to support the claims made by these brain training companies (e.g., Federal Trade Commission 2016). These companies tend to make claims of vertical, far transfer based on weak or non-existent evidence and with no clear path between training and application (for a detailed review of the commercial brain training literature, see Simons et al. 2016). Conversely, when dealing with a pre-defined area of interest such as specific military operations, the well-defined application provides a rigid standard of comparison in the effectiveness of any cognitive training. Put another way, far transfer is not necessarily the end goal. We are not looking for one single training task or even one group of training tasks that will improve warfighter performance on all job-related tasks. While this one-training-fits-all approach would be ideal, it seems far-fetched and unlikely—especially given that operational military performance can range from room clearing to combat casualty care to aviation operations. Instead, the military has specific tasks and problems that it needs to solve and training could be designed for specific audiences. Previously in this review, we have used shoot/do not shoot performance in the context of room clearing as an example of a singular problem. While this task has many interleaved cognitive processes involved, it is one high-priority task for which the military aims to improve performance. In this context, practice effects or near transfer are appropriate outcomes in improving shoot/do not shoot efficiency. Near transfer is a suitably reliable effect, having been demonstrated in several training formats, and these types of enhancement programs are certainly worth a military investment. Next, we will review these examples of positive near transfer from the basic science literature as models that are useful and may shed light on how training can be used in a military context.

Action Video Game Training

One of the most consistent and robust findings within the cognitive training literature comes from the effects of action video game training on perceptual and attentional skills. The idea that playing video games may serve as a useful tool to improve cognitive and motor functioning dates back to the early 1970s, when the game Pong was first released and researchers tested whether playing Pong could improve functional outcomes following a stroke (Cogan et al. 1977). Modern research has focused specifically on first-person shooter, "action" video games. A seminal paper by Green and Bavelier (2003) showed using both cross-sectional and training study designs that action video game experience was related to enhanced performance on measures of the spatial distribution and temporal resolution of visual attention. This initial paper sparked an explosion of research into the effects of action video game experience.

The most robust and replicated findings surround action video game training (AVGT) improving visual perception and attention. For example, AVGT has been shown to improve visual acuity, contrast sensitivity, and perceptual learning (Bejjanki et al. 2014; R. Li et al. 2009; R. Li et al. 2010). Several studies have found and replicated an enhanced spatial distribution of attention following AVGT as measured by the useful field of view (UFOV) or flanker tasks (Green and Bavelier 2003, 2006, 2007). Further, AVGT has been shown to improve the temporal resolution of attention and visual speed of processing more generally (Dye et al. 2009; Green and Bavelier 2003).

In addition to effects on perception and attention, several studies have found evidence for AVGT improving a broad range of other skills that are mechanistically related to visual perception and attention. For example, AVGT has been shown to increase visual working memory performance (Blacker et al. 2014), to enhance mental rotation ability (Feng et al. 2007), to reduce attentional capture (Chisholm et al. 2010; Chisholm and Kingstone 2012), and to improve selective attention (Mishra et al. 2011). Finally, the effects of action video game experience on higher-order executive functions have been explored but less so, and with less consistent results. These specific findings will be reviewed below in the section on Executive Function training.

The AVGT literature provides a good example of the use of methodologically rigorous experimental designs that include training studies and adequate control groups. While not every action video game study adheres to these standards, there are higher proportions of studies with these designs compared to other areas of cognitive training. Indeed Simons et al. (2016) noted that studies on the benefits of action video game training are "among the best designed" in the cognitive training literature. The inherent qualities of video games (e.g., adaptive, engaging) make them a desirable training vessel for real-world application. AVGT improves a core set of visual perception and attentional skills that are critical in many everyday tasks. One such clinical application of this work is the attempt to improve vision in individuals with amblyopia, which is a developmental disorder that results from physiological alterations in visual cortex early in life (Ciuffreda et al. 1991). Individuals with amblyopia experience a wide range of visual deficits including reduced contrast sensitivity, high levels of spatial uncertainty, spatial disorientation, and impaired reading ability. However, early work has demonstrated that AVGT in individuals with amblyopia can enhance a variety of visual functions compared to a control training group (Vedamurthy et al. 2015a, b). While this work is in its early stages, it represents a practical and focused use for AVGT.

In this review, we have focused on near transfer and quantifiable outcomes following training. Both near transfer and quantification are critical aspects of training with practical value for military applications. The action video game literature is an interesting case in this regard. Is an improvement in visual perception and attention reasonably considered near transfer following AVGT? Indeed, identifying the exact components of action video games that produce transfer is an emerging area of research and will likely be a critical future direction for the field (Dale and Green 2017). However, another potential advantage of AVGT is the likelihood that it is tapping into a range of skills, which are all being trained simultaneously. This notion has led Bavelier et al. (2012) to propose that transfer from AVGT may reflect what is known as “learning to learn” (also reviewed in, Green et al. 2016). The learning to learn model proposes that complex training environments, like action video games, actually foster brain plasticity and learning. The idea here is that training on “Task A” may not necessarily produce immediate transfer to “Task B,” but instead the training on “Task A” allows “Task B” to be learned more quickly. Indeed, several studies have found evidence that action video game players and non-video game players start out at the same performance level, but action video game players improve their performance more rapidly throughout the course of the new task (e.g., Bejjanki et al. 2014; Gozli et al. 2014). This theory of cognitive training, if supported, avoids the curse of specificity whereby learning is typically specific to a single task. This so-called curse of specificity is a primary limiting factor in most practical applications like job training, education, or rehabilitation. Given the myriad duties and tasks that military personnel are asked to learn and execute, a training approach that increases the speed at which new skills can be acquired is particularly appealing.

Indeed, learning to learn is already a high military priority. Admiral John Richardson is the current U.S. Chief of Naval Operations—the senior leader of the U.S. Navy—and he released a document entitled “A Design for Maintaining Maritime Superiority” (Richardson 2016). In this document, he outlined the need to achieve high velocity learning at every level as a key line of effort for current and future naval operations. This need fits with the general challenge of naval service in the high variety of tasks and duties required of so many personnel. Sailors and Marines have to deal with challenges on sea, air, and land, which creates context and content transfer issues among such different environments. Moreover, shipboard duties for Sailors might differ substantially from urban combat duties of Marines, yet some Sailors may have responsibilities that include both shipboard operations and close-quarters combat operations if they have to board an enemy ship. In short, the scope of military duties is complicated, far-ranging, and the same individual may be required to engage in many different types of duties throughout a career. If learning to learn is a primary component of cognitive training in general or AVGT specifically, then these training initiatives offer immense value to current and ongoing military operations.

Working Memory Training

Unlike AVGT, WM training specifically emerged on the scene with the hopes of achieving broad-ranging far transfer. A seminal study in 2008 sparked much excitement and ensuing controversy by demonstrating that training on a dual n-back task improved performance on Raven’s progressive matrices, a measure of *Gf* (Jaeggi et al. 2008). While WM training has been surrounded by the most controversy due to its initial focus on far transfer, it may also bear the greatest potential for informing application of cognitive training. A full review of the entire WM training literature is beyond the scope of this review (however, for reviews see Konen et al. 2016; Morrison and Chein 2011; Shipstead et al. 2012; Simons et al. 2016; also see Au et al. 2015 for a recent meta-analysis). Therefore, here, we will focus on two major aspects of WM training: the logical link between training and outcome and near transfer effects.

WM capacity is limited, varies widely across individuals, and is highly related to many other cognitive skills, including *Gf* (e.g., Engle et al. 1999). Many theories have emerged about the nature of the relationship between WM and *Gf*, but consistent evidence for several decades has demonstrated that WM capacity and performance on measures of *Gf* like matrix reasoning tests have a high, positive correlation (e.g., Ackerman et al. 2005; Conway et al. 2003; Kane and Engle 2002; Mogle et al. 2008; Unsworth et al. 2014). The ability to improve *Gf* via training is particularly intriguing because the construct is highly predictive of many real-world skills such as academic performance, creativity, reading comprehension, job performance, and even mortality (Dreary 2008; Kuncel et al. 2004). The logic of WM training states that WM capacity is a limiting factor for performing a wide range of cognitive tasks, including *Gf*, and thus if WM capacity can be improved with training, then all of these other related skills may also reap the benefits. While WM training’s efficacy in eliciting far transfer to *Gf* has been inconsistent (for reviews and recent meta-analyses, see Au et al. 2015; Morrison and Chein 2011; Shipstead et al. 2012; Simons et al. 2016), the logical link between WM and *Gf* represents a laudable approach. The goal is to find a process or system that (a) underlies cognitive skills and abilities, (b) is malleable or sensitive to training, and (c) may benefit other skills if it can be improved.

While far transfer associated with WM training has been inconsistent, near transfer effects have been far more consistent. A number of recent meta-analyses and reviews agree that WM training produces significant improvements to untrained WM tasks across the lifespan (e.g., Karbach and Verhaeghen 2014; Melby-Lervag and Hulme 2013; Schwaighofer et al. 2015). For example, training on one type of n-back task transfers to improvements on untrained versions of the n-back task (Blacker et al. 2017; Colom et al. 2013; Jaeggi et al. 2010; S. C. Li et al. 2008). Similarly, training on one type of complex span WM task transfers to improvements on other complex span tasks (Chein and Morrison 2010; Richmond et al. 2011). Given the critical nature of WM to everyday functioning, this evidence of near transfer represents a promising step in utilizing WM training in an applied setting such as the military. Further, there are also other methods for improving WM itself through training that would be considered near transfer. For example, a commercial training program called NeuroTracker can be used to have participants complete adaptive 3D multi-object tracking training, which heavily involves WM storage and updating processes. In fact, one study in particular has demonstrated in a military population that this form of training can improve WM span performance (Vartanian et al. 2016). We propose that the military value of this type of near transfer is clear and overwhelming. In a military setting, any human performance improvement could translate to lives saved on the battlefield and thus the distance of transfer from training task to outcome measure becomes less of a concern. This outcome-focused approach stems from the inherent need for military operations to achieve tangible goals for the safety of our population. Thus, military training may be able to utilize WM training itself, which has shown reliable near transfer results or use WM training as a model training approach that yields consistent improvements on a critical cognitive skill.

One interesting aspect of WM training is the relative obscurity of what general behavioral or neural mechanisms underlie training-based improvement or transfer to untrained tasks. Two general and not mutually exclusive mechanisms are typically discussed. First, it may be the case that WM training simply enhances the capacity of WM, meaning it allows for more information to be stored than prior to training. Second, it may be that WM training enhances the efficiency with which information is stored in WM. This second option could be achieved through strategy use, such as rehearsal or chunking, or through an improvement in underlying processes, such as selective attention. For example, individual differences in the ability to select task-relevant and filter out task-irrelevant information is highly predictive of individual WM capacity (Vogel et al. 2005). Improved WM efficiency could take the form of better distractor filtering, faster encoding speed, and/or higher precision of maintained representations. It is also a possibility that WM training improves both capacity and efficiency. To use an oversimplified analogy, if WM were a suitcase, training could allow you to increase your "physical capacity" by using the extra expandable zipper; training could simply provide you with a method for more efficiently packing your items into the same, non-expanded space; or finally, training could achieve both, more space by use of the expandable zipper plus a more efficient packing approach. Understanding how WM training influences performance on this mechanistic level is of great interest in laboratory-based investigations of cognitive training and surely represents a critical next step in advancing the field. However, in a real-world application such as military training, the end goal of packing more items into that suitcase is sufficient and how it occurs is less pertinent as long as human performance is improving. These distinct goals embody the difference between basic science done in academia and applied work done in military research. Both lines of research and communication between entities will help to move the entire field forward as a whole.

A particularly relevant example of the use of WM training near transfer comes from clinical application. In a clinical setting, both rehabilitation (e.g., from stroke) and psychotherapy rely on the engagement of viable and healthy systems to compensate for or re-innervate function that is lost due to illness or injury (Light and Swerdlow 2015). Understanding an individual's assets, in turn, can be leveraged in the service of therapy or treatment. For example, individuals with schizophrenia often exhibit a deficit in WM (e.g., Goldman-Rakic 1994; Lee and Park 2005; Silver et al. 2003), but cognitive-behavioral therapies used to treat schizophrenia place demands on WM with the goal of helping the individual to develop compensatory strategies for learning and applying information. Indeed, previous work has shown that WM training can produce significant near transfer and changes to neural activity in prefrontal cortex among individuals with schizophrenia (Haut et al. 2010).

A future step in this line of research may be to test the efficacy of WM training or other types of cognitive training as a supplement to typical cognitive-behavioral therapy. By boosting one's initial ability, subsequent training or therapy may end up being more effective or result in a faster rate of improvement. This notion, while untested to the best of our knowledge, bears resemblance to Bavelier and colleagues "learning to learn" model from the action video game literature. Perhaps boosting a critical ability like WM will allow an individual to benefit more from a subsequent learning or therapy opportunity. For example, cognitive training that focuses on WM improvement prior to training on a specific operational task like aviation could dramatically reduce the time needed to train a new pilot or immediately increase his or her operational efficiency. Pilot training costs millions of dollars and takes months or years—per pilot—which makes any improvements to the training process highly advantageous. Training that increases the spatial distribution of attention prior to training could likewise aid pilots in reducing spatial disorientation, which is the number one cause of Class A mishaps in military aviation. These predictions have yet to be tested but may reflect critical and practical ways for cognitive training to be applied to standard military training procedures.

Executive Function Training

While WM is considered a higher-order executive function in many influential models, training WM has received more attention than all other forms of executive function training combined. Here, we will briefly review the state of the training literature for executive functions other than WM that have not yet been covered. Different theories propose different categories of executive functions, but here we will adhere to the theory put forth by Miyake et al. (2000). Thus, we will consider WM or "updating" as already discussed above and continue our discussion focused on the remaining two functions: shifting and inhibition. Although there is also a burgeoning literature on training of dual task performance, we will not include this topic here as it was not identified as one of the three core components of executive function by Miyake and colleagues (however, for a review on dual task training see, Strobach et al. 2014). Finally, we will review of a specific form of inhibition training that may be particularly relevant to the military, response inhibition training. These different forms of executive function training may represent an untapped potential for improving human performance in the military. Notably, these executive functions control one's behavior when performing in demanding and/or complex situations in which the management of different tasks or task sequences is required.

Shifting Mental set shifting or task switching involves switching back and forth between multiple discrete tasks, operations, or mental sets (Monsell 2003). Throughout this review, we will simply refer to this function as "shifting." Shifting is a critical skill for service members, particularly those in an infantry or maneuver role. Some examples of this are first line leaders coordinating movements, a forward observer calling for artillery support, or a combat medic rendering aid. These individuals must be able to not only perform these specialized roles but to also shift their focus to another task—such as someone calling in for artillery support may need to return small arms fire until the artillery strike is completed. This type of shifting may occur dozens or even hundreds of times during a prolonged engagement with the enemy.

Two major approaches have been used in the training of shifting in basic science: video game training and direct shifting training. In the gaming literature, action video game players have demonstrated smaller task-switching costs (Colzato et al. 2010; Green et al. 2012; Strobach et al. 2012). However, in a separate study, these smaller costs were attributed to action gamers' specific benefit in controlling selective attention, rather than better task switching-related cognitive control processes (Karle et al. 2010).

The second approach has typically compared training that involves switching between two disparate tasks in random or predictable order and training that involves the same two tasks but practiced in single blocks or sessions where no shift or switch must occur (Minear and Shah 2008). This rigorous design allows for strong conclusions on the effects of training the skill of shifting specifically. There is substantial evidence for the successful improvement of shifting following this type of training in a range of populations, including older adults (for a meta-analysis, see Karbach and Verhaeghen 2014), children and adolescents (for a review, see Karbach and Unger 2014), and in individuals with ADHD (Kray et al. 2011). These findings typically involve practice effects, whereby the cost shifting between tasks is reduced as training progresses. However, there is also promising evidence for near transfer following shifting training, whereby training on one shifting task also reduced switch or shift costs in an untrained task (Blacker et al. 2017; Karbach and Kray 2009; Minear and Shah 2008). For example, after 4 weeks of training on an adaptive, rapid rule learning and switching task, participants saw a significant reduction in switch costs on an untrained task that used distinct stimuli, compared to two active control groups that completed four weeks of WM training (Blacker et al. 2017). Thus, training shifting through action video games or directed training seems to produce robust and consistent practice and near transfer effects that may be useful to military personnel who are consistently placed in environments that require rapid and numerous shifts between key operational tasks.

Inhibition Inhibition or inhibitory control refers to the ability to deliberately inhibit or stop a dominant, automatic, or prepotent response (e.g., Hallett 1978; Logan 1994; Stroop 1935). In the basic science realm, tasks that are often used to measure inhibition broadly include go/no-go (GNG), stop signal reaction time (SSRT), flanker tasks, and Stroop tasks. Fratricide, or "blue on blue" incidents, is one readily apparent military implication for this category of executive functioning. Interestingly, despite tremendous advances in military technology, the rate of these incidents has increased since WW2 (Rasmussen 2007). Even as individual weapons systems become more advanced and more effective, they are still machines that lack the ability to discern or discriminate between targets. Ultimately, the role and efficacy of the weapon relies on decisions made by the individual employing it. With that in mind, the most effective way to mitigate fratricide seems to be increasing the individual performance of military operators as it pertains to their ability to make accurate friend or foe decisions. Importantly, recent research suggests that a lack of inhibitory control may contribute to friendly-fire or other incidents of unintended casualties (Biggs et al. 2015; Wilson et al. 2015). This important issue for military personnel makes the possibility of improving inhibitory control via training an exciting avenue for exploration.

Studies examining inhibitory control training are scarce and mostly done in young children. For example, Thorell et al. (2009) trained preschoolers on three different inhibition tasks (i.e., GNG, SSRT, and a flanker task) and found significant practice effects on two of the three training tasks, but found no evidence of near transfer to untrained inhibition tasks. On the other hand, an earlier study of inhibitory control training in 4–6 year olds found that training yielded far transfer to a matrix reasoning test that is thought to measure *Gf* (Rueda et al. 2005). Further, studies with younger and older adults have typically involved training on a Stroop task, which a body of work has demonstrated that training results in practice effects whereby response times (RT) are reduced for incongruent trials, effectively decreasing the magnitude of the interference effect (i.e., incongruent RT–congruent RT; reviewed in Strobach et al. 2014). However, evidence for transfer tends to be non-existent or highly stimulus-specific (e.g., Reisberg et al. 1980). While this area of research does not provide many leads in the effective use of inhibitory training in applied settings, there is a related but notably distinct area of research that specifically examines *response* inhibition training as it relates to appetitive stimuli such as unhealthy foods, alcohol, and drugs.

Response Inhibition Training Response inhibition training techniques include cognitive tasks that require a stopping action or elicit an avoidance response. This approach is frequently used for intervention with individuals exhibiting overindulgence and impulsive behaviors such as those struggling with obesity and/or addiction. GNG and SSRT paradigms are examples that have been used for this form of response inhibition training. A common strategy is to use cue-specific stimuli, such as pictures of snack foods for those dieting or photos of glasses of beer for those attempting to control drinking.

The GNG task, when designed to include stimulus-specific stopping responses, has shown to be effective in dietary inhibition treatment for decreasing chocolate intake (Houben and Jansen 2011, 2015), decreasing portion sizes (van Koningsbruggen et al. 2014), resisting unhealthy foods (Veling et al. 2013), devaluation of food items (Chen et al. 2016), decreasing food intake (Lawrence et al. 2015), as well as overall weight loss (Veling et al. 2014). Further, similar efforts have demonstrated that alcohol intake can be reduced with a GNG task modified to include a no-go response to photos of alcohol (Houben et al. 2012; Houben et al. 2011), but the converse was also supported whereby participants reported drinking more following training that involved a go responses to photos of alcohol (Houben et al. 2011).

The SSRT task differs from a traditional GNG task in that every trial begins with a go signal and may or may not change to a stop signal at a variable duration. This stop signal delay varies based on an individual's performance and allows for an individualized measure of how long it takes for one to stop an initiated response. This type of task has also been used as a training paradigm with the goal of improving inhibitory control. However, Allom and Mullan (2015) were unsuccessful in producing a difference in eating behavior for a food-specific stimuli condition. Likewise, Jones and Field (2013), when using photos of beer, showed no difference in consumption rate for heavy drinkers. Guerrieri et al. (2012) adjusted the SSRT to compare different proportions of go and stop trials and the results indicated no change in caloric intake for the inhibitory (more no-go stimuli) group, but resulted in an increase in intake for the impulsivity (more go stimuli) group. As such, it is possible that inhibition training from the SSRT task does not apply well to a stimulus-specific training design such as reducing consumption behaviors.

Verbruggen and Logan (2008) argued against distinct functionality of cognitive tasks attributed to top-down inhibition (SSRT) and bottom-up control (GNG) respectively, and others have suggested that combinations of training might work best (Jones and Field 2013). In general, there seems to be a consensus that inhibition training using stimuli associated directly with the targeted inhibitory action elicits better results than using general stimuli. Although the SSRT obtains a measure of individual differences in stopping time, the GNG task has yielded more consistent results in training inhibition.

Indeed, at least one recent training study has directly examined the effects of inhibitory training on an operationally relevant issue—specifically, shoot/do not-shoot performance. Using a simulated shoot/do not-shoot scenario via a video game, Biggs et al. (2015) tested participants' performance before and after response-inhibition training (i.e., GNG and SSRT tasks) or a visual search training paradigm. The response inhibition training group showed a significant reduction in civilian casualties post-training compared to the active control group (i.e., visual search training). Moreover, these findings have been replicated—albeit using a different training design—by having trained police officers fire live ammunition at images holding either guns or cell phones (Hamilton et al., under review). Both training studies demonstrated significant improvement in shoot/do not-shoot decision making through inhibitory control training, and each did so with varying degrees of realism in the shooting tasks.

These findings are potentially relevant to military personnel when engaged in room clearing. As mentioned previously, room clearing is one of the most dangerous and dynamic tasks that a soldier can participate in and is often unavoidable in urban warfare. Perhaps unsurprisingly, in an urban environment, the most dangerous areas are generally those that are more densely populated by enemy fighters. However, the enemy fighters themselves are not the only risk. Research done by Wilson et al. (2015) suggests that this type of "target rich" environment can also lead to a prepotent response to fire that is very difficult to inhibit. Obviously, failure to withhold an inappropriate response (such as firing at friendly personnel) places coalition forces at great risk to one another. In Wilson and colleagues' study, increased speed and high proportions of foe targets during friend-foe room clearing tasks had a significant, negative impact on performance. This issue is of particular concern when enemy combatants may be mixed among civilian non-combatants and other friendly forces. Friend-or-foe or shoot/do not-shoot training research among military populations is scarce. Given the urban nature of modern warfare combined with constant increases in weapon lethality, it is more important than ever that soldiers are equipped to mitigate collateral damage and friendly fire incidents. Response inhibition training, like that used by Biggs et al. (2015), may represent a viable method for improving friend-foe decision making in room clearing scenarios often encountered in urban warfare. With these ideas in mind, it is critical that research into cognitive training application in the military build on the existing basic science and utilize the best practices for experimental design and evaluation of training efficacy.

Practical Considerations for Military Application

Thus far in this review, we have detailed many potential areas of cognitive training that might be useful for military application. The ultimate goal involves improving warfighter performance, but doing so requires rigorous experimental design and evaluation of efficacy. In a recent thorough review of the cognitive training literature, Simons et al. (2016) included several best practices or suggestions for conducting and evaluating cognitive training research for researchers, reviewers, policymakers, and funding agencies. However, the goals of the military are often different from those of basic scientists in academia or individuals working in for-profit commercial or industrial settings. There are also numerous practical considerations when evaluating cognitive training or implementing cognitive training designs into active duty military training. Under normal circumstances, cognitive training for clinical issues can be carefully designed and controlled when administered to a clinical population. An ineffective training method primarily risks wasting time. For military training, especially as far as combat training is concerned, there are rigorous schedules to consider and wasted time could mean wasted alternative training opportunities—in combat, the consequence of wasted training opportunities is that a lesser prepared unit could mean increased battlefield casualties. The grave importance of these field applications makes it necessary to consider all potential aspects of cognitive training so that the eventual training opportunities provided to military personnel will fully prepare them for the challenges to be faced.

Here, following the suggestions of Simons et al. (2016) and other cognitive scientists, we outline what we view as the most critical best practices for military researchers investigating potential cognitive training uses to improve human performance. We also describe some salient individual differences that may influence training efficacy especially in a military population such as baseline performance and motivation. These discussions will also address the advantages of using each method to evaluate cognitive training for military purposes, and potential workarounds for those instances when the best empirical controls cannot be implemented. Finally, we end this section with a brief description of methods that may be able to boost the effects of traditional cognitive training approaches.

Control Groups and Expectations

Standard cognitive training designs need to differentiate between simple practice or placebo effects and tangible improvements due to cognitive enhancement. Military training benefits are no different—particularly if one objective is to determine whether the finding involves only a practice effect, or a sufficient warfighter performance improvement to justify significant military investment. Adequate control groups are one critical step to evaluation of training efficacy. Control groups are generally approached one of two ways: passive or active control groups. In passive control designs, the control group does not receive any training and generally does not have any contact with the experimenters. For example, participants might not be contacted during the data collection period, or they may be told that they are on a waitlist and will receive training when it becomes available. While these designs provide a comparison group to detect any effects of test-retest practice effects or the passage of time, they do not equate contact with the experimenters or the expectations of the two groups. Simply participating in some form of training may cause the experimental group to expect that they should see an improvement in performance, much like a placebo.

Active control groups are one way to better match the groups' expectations. In these designs, the control group performs a similar task as the experimental group but without the critical component of the training. Active control groups come in several forms. Two groups may receive identical training tasks, but the experimental group will experience adaptive training that gradually gets more difficult, whereas the active control group will perform the same task at the same (easy) difficulty level throughout training. As an example, a task that trains visual search might present increasingly difficult arrays as a participant improves (e.g., more distractor objects, increased spatial jitter). The active control group would perform the same task for the same amount of time but without any increase in difficulty. Another approach is to have an active control group that trains on a similar task that simply lacks the critical "ingredient(s)" thought to drive the experimental training. An example of this approach comes from the video game training literature. It has been proposed that action video game training improves visual cognitive skills at least in part because of the fast-paced nature of the games and the use of first-person perspective. For example, a typical study might compare training on an action game that is fast-paced and first-person perspective with a strategy game that is slower paced and third-person perspective. Use of active control groups helps to equate participants' expectations about the outcome of training, as well as the amount of contact participants have with experimenters. This type of design is particularly useful in elucidating mechanistic features of training paradigms in elicited transfer. A final approach is to choose an active control training program that is expected to improve a different set of skills. For example, a WM training group would be expected to improve on an untrained WM task, whereas a task shifting training group, the active control, would not be expected to improve on the WM task. Similarly, in the same design, the task shifting training group would be expected to improve on an untrained shifting task, whereas the WM training group would not be expected to improve (for an example of these results, see Blacker et al. 2017). This type of outcome allows for a robust interpretation of the results that reduce the possibility of external effects like expectations and practice effects. We would argue that this design is most effective at evaluating training efficacy and therefore is most suitable for military research, which focuses on outcome more often than mechanism. This design also has the potential to test two distinct forms of training with two distinct operationally-relevant outcomes in one single study, thus conserving military personnel's time and research funds.

As cognitive training continues to pervade public awareness, the need to control for and be aware of the effects of expectations becomes critical. One recent study related to video game training required participants to view clips of two video games, one game that is typically used as an experimental training game (e.g., an action game) and the other a typical control training game (e.g., a non-action game). Even after a relatively short exposure, people expected differences in performance on measures of visual attention following training on each of the two types of games (Boot et al. 2013). While the action video game training literature is lauded for its rigorous use of active control groups, expectations remain an important area to be explored. A related point is that the way participants are recruited may also effect expectations. For example, two groups were recruited with flyers that contained either suggestive content (e.g., referred to "cognitive enhancement" and "fluid intelligence") or neutral content (e.g., "Participate in a study") and then received the same training on a dual n-back task. Those who responded to the suggestive flyer showed a significant improvement on two measures of *Gf*, but those who responded to the neutral flyer did not (Foroughi et al. 2016). These points may be particularly salient when using a military population who may have very specific and deep-rooted expectations about their training—be it cognitive, or otherwise. Our recommendation for best dealing with expectations in a military population is two-fold: (1) when possible, record subjective measures of expectations before and after training has occurred as basic scientists are starting to do in laboratory-based cognitive training, and (2) attempt to maintain similar expectations for cognitive training as a service member would have when completing any other required training (e.g., physical training, marksmanship training, etc.).

Blinding

The gold-standard approach in intervention research is to utilize a double-blind study design, which involves having both the participants and the experimenters unaware of what condition or training group each participant is enrolled. However, in cognitive training research, it is not possible to completely blind a participant to their training because they are actively engaged in it and therefore know what it entails. While a drug study can give a participant a pill and keep them unaware whether it is an active dose or a sugar pill, cognitive training research does not allow this level of blinding. Thus, it is prudent for experimenters to be blind to group assignment in order to ensure equal treatment and reduce any potential demand characteristics. On the participant's end, it is possible to ensure that any one participant is at least unaware of the alternative training program being used and if possible, unaware that there is any other training group.

In a military setting, this is particularly relevant because if a training study is implemented within a unit or group of service members that work closely together, it may be tempting for individuals to discuss their training with other members of the group, which can undermine the blinding procedure. Military participants should be given strict instructions to not discuss their study participation or the nature of their training with other members of the group until everyone has completed the study. Still, the assumption should be that all training participants will be discussing the training despite experimenter instructions. One important workaround may be to use units from different bases—but with the same basic training—when comparing active and control groups. The point is that some further consideration will be necessary to ensure that participants are not discussing study procedures. Finally, one recommendation that can alleviate the lack of blinding of participants in cognitive training studies is to assess expectations whenever possible (Boot et al. 2013). If a full blinding procedure is not possible, then expectations management becomes the next reasonable mitigation technique.

Randomization and Sample Size

Random assignment is imperative for a controlled design. Each individual enrolled in a training study should have an equally likely chance of being assigned to any one training group in that study. One goal of randomization is to ensure that all training groups have equivalent baseline performance. Acquiring a large sample size increases the effectiveness of this procedure. The military has the benefit of utilizing collaboration of research units if only small samples are available at each location. Further, when multiple locations are being used to achieve a larger sample size, every effort should be made to equate study procedures and expectations across locations and testing site should always be included as a covariate in any analyses. When selecting a sample size, it is important to consider the number of measures implemented so that after correcting for multiple outcomes there is sufficient statistical power to observe the expected effect size.

Still, several practical challenges exist with respect to sample size and expectations. It is a defining aspect of elite forces that there are fewer elite operators than regular operators. For example, an infantry unit may have sufficient numbers to provide training groups and control groups, but a special operations unit may not have the sample sizes necessary unless every member of the unit agrees to participate in training. In these instances, the population itself might be an issue to consider—where both groups receive the same training, but one group includes special operations personnel, and one group includes regular infantry personnel. The critical issue is that an experimenter simply may not be able to design a fully double-blind, randomized-controlled design with limited numbers of potential participants with results that may or may not apply to operators outside of special forces. Likewise, expectations management is a critical consideration about how individuals regard the training and how experimenters interpret the value of said training. For example, a cognitive training design may induce nothing more than a placebo effect that improves confidence among personnel and improves post-test performance. This outcome would lead many cognitive scientists to dismiss the training as nothing important or valuable, yet for military purposes, a sustainable and repeatable placebo effect could prove invaluable. The difference again becomes an emphasis on the end state performance. The goal is to improve human performance, and even training that merely improves confidence could be of substantial use in military training. Whether sample size issues or expectations management, it is important to remember that operational circumstances may prevent a perfectly designed training experiment, sample sizes may complicate training designs, and even placebo effects may have significant value if those effects can be sustained.

Our suggestion for achieving adequate sample sizes when addressing operationally relevant questions about training efficacy is two-fold. First, if care is taken to equate experimental procedures across locations and times, then multiple units can be tested. This may involve using separate groups of individuals who rotate through a training facility and collecting data over multiple time periods. It also may involve recruiting volunteers from disparate military groups, including all branches of the military, both standard operators and special forces. A second recommendation is to consider non-military populations that often engage in the same task of interest. For example, in studying lethal force decision making, a law-enforcement group could be used in addition to a military group. Furthermore, groups such as air traffic controllers or commercial airline pilots may have overlapping duties with those of interest to military operations.

Outcome Measures and Multiple Comparisons

The outcome measures utilized by military researchers may be very different from those used by basic scientists. For example, a study may include a form of neurofeedback training to improve a pilot's ability to identify symptoms of hypoxia during flight. This type of outcome measure is very different than assessing improvement on a computer-based n-back task following WM training. However, some of the same principles apply to these real-world outcome measures. Outcome measures should be reliable, meaning that if you test someone on that measure multiple times, the end results should be comparable. In the example here, hypoxia symptoms are known to be reliable, meaning that each individual tends to experience the same symptoms each time they are hypoxic (i.e., a hypoxia signature). While there is wide inter-individual variability in symptoms, intra-individual differences are small, making it a reliable outcome measure to study in a training study (Singh et al. 2010; Smith 2008). The improvement tasks should incorporate some operational aspect to gauge the training effectiveness. For example, some assessments may include pure cognitive tasks to assess changes in the underlying cognitive mechanism, but these tasks should be paired with operationally relevant tasks based upon the intended field improvement. Cognitive training to improve RTs may then want to include simple vigilance task measurements as well as marksmanship tasks to determine the time needed to fire the first shot. This operational link will improve any evaluation of the training efficacy and help training officers make determinations about when and how to utilize these training opportunities. One concrete suggestion for choosing appropriate training tasks that are likely to improve the specific outcome measure of interest is using a task analysis approach, as detailed above. Consulting SMEs and breaking down a complex outcome measure into its constituent tasks or jobs is a recommended first step for applied researchers.

The use of multiple outcome measures is also an issue that needs to be taken into consideration. Some researchers argue that cognitive training outcomes should be evaluated at the construct level, where multiple tests of one cognitive construct should be used. For example, instead of simply administering Raven's Progressive Matrices before and after a training intervention, a study should administer multiple tests all thought to assess *Gf*, and then the outcome should be evaluated for the construct of *Gf*, not the individual tests (Shipstead et al. 2012). While this may be a robust approach to elucidating mechanism and degree of transfer, this approach does not fit particularly well with the goals of military research. It may be useful to evaluate a specific training paradigm on multiple measures of operational readiness, such as friend-or-foe shooting performance, marksmanship, and performance in prolonged room clearing simulations, but these measures are distinct from looking at construct level transfer in basic science. One consideration that military researchers should note is the need to correct for multiple comparisons when using multiple outcome measures. While military outcomes tend to be more specific, it is still possible that multiple outcome measures will be tested. Given this stringent need to correct for multiple outcome measures, these measures should be chosen carefully based on operational relevance and reliability of the measure.

Individual Differences

The current approach used in the cognitive training field is to implement a "one-size-fits-all" training program and have a sizable group of participants train on that program, and then compare group level improvement pre- and post-training compared to an active control group. However, as this review and others have detailed, these results can be inconsistent or weak. These shortcomings have initiated a recent turn toward understanding individual-level effects and responsivity to training. As with physical exercise, psychotherapy, or any other formal intervention, it may be unreasonable to expect that every individual will respond in the same way to a cognitive training intervention. Indeed, there is a rich literature spanning multiple decades focusing on individual differences in a number of cognitive functions like WM, attention, and cognitive control (e.g., Braver et al. 2007; Cantor and Engle 1993; Daneman and Carpenter 1980; Machizawa and Driver 2011; Shamosh et al. 2008; Tuholski et al. 2001; Vogel et al. 2005). Thus, individual differences like baseline performance, motivation, and expectations may be key to applying cognitive training in the real world. The individual differences consideration is especially important when considering the wide array of training needs of military missions. Drone operators have different training needs from combat medics and front line infantry. Differences between roles should be considered with an eye toward how wide a particular training can be administered. Likewise, there could be issues of homogeneity with certain populations. The particular concern here is among special operations forces, where the requirements become so extreme that individual skills and competencies are more homogenous than among the general military population. However, the corresponding advantage is that training can be tailored to specific populations if special operations personnel are the intended training recipients.

Baseline Performance Baseline performance is likely the area that has received the most attention in cognitive training because it can be investigated without any additions to the typical study design. In a cognitive training study, individuals perform an assessment task or often a battery of tasks before training, then train for a period of time, and then are re-tested on those assessment tasks to look for improvement. However, there is great individual variation at baseline before training begins (e.g., Blacker et al. 2017; Jaeggi et al. 2014). Let us consider a typical WM training study that measures *Gf* as a transfer measure to illustrate two influences of baseline performance. There are at least two possible scenarios for seeing improvement following training: magnification or compensation. Magnification is often conceptualized as the "rich get richer" outcome, whereby individuals who have higher initial *Gf* scores will show the most improvement following training (assuming they are not at or near ceiling during baseline assessment). The notion here is that individuals with more resources will either learn more or learn more quickly during training, thereby magnifying the effects of training. For example, in a study with older adults using WM training paired with transcranial direct current stimulation (tDCS), there was evidence that more educated participants experienced greater benefits from training and brain stimulation than those with less education (Berryhill and Jones 2012).

On the other hand, compensation represents a scenario where individuals with lower initial *Gf* show greater improvements because they have more "room to improve." Indeed, several studies have shown evidence for compensation, such as two studies by Zinke and colleagues demonstrating that individuals who performed worse at baseline across multiple training paradigms experienced larger training gains on the training tasks themselves (Zinke et al. 2012; Zinke et al. 2014). Similarly, multiple studies have shown that the amount of improvement on the training task itself is related to the amount of transfer gains seen following training (Chein and Morrison 2010; Jaeggi et al. 2011; Schmiedek et al. 2010). However, none of these studies directly tested or manipulated how baseline performance on an untrained task influences training transfer. Blacker et al. (2017) found that low WM individuals, as measured by a pre-training untrained n-back task, improved more following training on that same task following both dual n-back training and complex span training, compared to their high WM counterparts. On the other hand, Foster and colleagues recently showed that individuals with high WM at baseline showed greater gains from training compared to their low WM counterparts (Foster et al. 2017). These opposite findings may result from differences in study populations (e.g., where the study was conducted, whether all undergraduates were used, age of the sample). Finally, there is evidence that the type of training used matters, whereby process-based training results in greater gains for individuals with lower initial performance, but strategy-based training results in greater gains for individuals with higher initial performance (Karbach and Unger 2014). These findings suggest that baseline performance can have a wide range of effects on the outcome of training.

This issue is particularly salient in a general military population, which is more diverse than the typical university undergraduate sample. For example, the first formal requirement for applying to enlist is to complete the Armed Forces Qualification Test (AFQT), which is comprised of four tests from the Armed Services Vocational Aptitude Battery (ASVAB), including Arithmetic Reasoning, Mathematics Knowledge, Word Knowledge, and Paragraph Comprehension. The ASVAB was renormalized in 2004 (Moore et al. 2000) and the minimum percentile score needed to enlist is a 31 (Chu 2007). However, there are exceptions, whereby individuals who score between the 10th and 30th percentile may be admitted if they have completed a high school diploma. All of this is to say that any particular military sample recruited for a cognitive training study could potentially span 90% of the population as it relates to performance on this standardized test, which we would speculate encompasses a much larger range of cognitive skills than a typical academic study conducted on undergraduate students. Further, it has been suggested that the ASVAB is largely a measure of crystallized intelligence and that the battery would benefit from the addition of tests that tap into *Gf* and/or WM (National Research Council 2015). The ASVAB also serves as a method for personnel selection for specific jobs. For example, there is evidence that WM capacity and multitasking ability are linked (Redick 2016) and thus jobs that require multitasking may benefit from a measure of WM capacity as a means of personnel selection. One such attempt to broaden the scope of skills assessed in military personnel was the development of the Enhanced Computer-Administered Test (ECAT) battery, which aimed to improve the validity of the ASVAB. The ECAT is comprised of nine tests designed to measure non-verbal reasoning, spatial ability, psychomotor skill, and perceptual speed (Alderton et al. 1997). One such measure, the Mental Counters test (MCt), was accepted for possible inclusion in the ASVAB with the goal of increasing the validity of predictors for military occupations and minimizing minority difference in testing performance (Alderton et al. 1997; Larson and Saccuzzo 1989; Russell et al. 2014; Sager et al. 1997). However, a hurdle to implementing the MCt was that one of the requirements of the ASVAB is that any assessment that is included must not be susceptible to cheating, compromise, practice, or coaching. As we have detailed in this review, there are numerous methods for improving WM skills through practice and training. To date, the MCt has been included in the ASVAB, but only for Navy applicants. The state of the ASVAB and its inclusion/exclusion of measures of fluid cognitive skills have the potential to change personnel selection criteria and ultimately the applicability of cognitive training for specific jobs within the military. Baseline performance levels can influence training outcome and further work into their effects would benefit from more nuanced methods of personnel selection criteria.

Both magnification and compensation represent important considerations in cognitive training, and either could have military use. Magnification could mean that special operations personnel are the ideal recipients of the training. Compensation could mean that cognitive training is a potential method to prevent individuals from washing out during training (i.e., failing to complete the necessary training requirements). Either could create useful training opportunities, but each potential would alter the manner in which the training opportunities are provided. A hybrid possibility is that cognitive training could help individuals who may want to become special operators, but they may narrowly fail a particular training requirement. This possibility is especially important given the high costs involved in selecting and training special operators and the operational value they bring to ongoing military operations. For example, consider a special operations group, like the U.S. Navy SEALs. Like other special operations groups, they substantially contribute to operational efficiency of the military, but among those individuals who qualify to train as a SEAL, fewer than one in five complete the training (Waller 1994). If cognitive training can help reduce the attrition rate, then it could prove to be an invaluable asset to special operations training.

In sum, the variability in individual differences in cognitive ability in a military population is bound to be greater than that of a typical university sample. Given this consideration, research into cognitive training effectiveness in military populations should consider both group-level and individual-level analysis approaches. While group-level improvements may be of greater interest to the military, identifying individual factors that interact with training may allow for personnel selection criteria and further refinement of training for specific subgroups of service members.

Motivation Potentially one of the most salient factors to consider when applying cognitive training to a military population are contextual factors such as compliance, motivation, and expectations about outcome or efficacy of training. The types of real-world tasks that military personnel encounter often have life or death consequences. This fact along with the mandated nature of military training make it likely that motivation and compliance may be much higher than a typical study in an academic setting. However, there are still several factors to consider such as beliefs about the flexibility of cognition and expectations about whether training will benefit real-world performance. For example, Jaeggi et al. (2014) found that individuals who endorsed the malleability of intelligence showed more transfer to *Gf* following WM training compared to individuals who endorsed the fixed nature of intelligence.

Motivation certainly impacts military training efficacy, but similar to the magnification and compensation issues, motivation challenges may differ based upon the personnel involved. The motivation challenges may also differ from standard cognitive training investigations. It may be necessary to incorporate cognitive training into other training (e.g., physical training) to either increase motivation to train, increase transfer effects, or ensure that the training itself is completed on a regular basis. A larger issue involves how any cognitive training would be implemented on a long-term basis, particularly if any training is to be done during deployments. For example, motivation is a challenge when trying to have any population complete computer-based training (Mohammed et al. 2017). Different platforms use gamification to increase motivation and willingness to engage in the training tasks (Deveau et al. 2015). During a military deployment, increased stress and workload are likely to lower an individual's motivation to do even more training, particularly if the task is boring. Gamification may be one method to increase motivation to engage in the training tasks when individual willingness to participate is especially likely to wane (Deveau et al. 2015; Mohammed et al. 2017).

Methods for Boosting Cognitive Training

Two major limitations have blocked the immediate application of cognitive training in real-world settings: inconsistent findings and small effects. Here, we have addressed some of the inconsistencies, which primarily surround the potential of training to elicit far transfer, such as improving *Gf*. Instead, we have focused on the mostly consistent effects of training on near transfer because near transfer represents a sufficient outcome for a real-world application like human performance in military operations. However, the second limiting factor of small effect sizes plagues both near and far transfer attempts alike. While improvements on untrained WM tasks following WM training are consistently demonstrated, the degree or size of improvement may not be meaningful in the real world. Interestingly, there have been several other areas of research that have tested alternative methods for improving cognitive function that may be able to be combined with cognitive training to produce meaningful advances. There is evidence that non-invasive brain stimulation techniques, neurofeedback, and pharmacological interventions may boost the effects of cognitive training. While an extensive review of each of these topics is beyond the scope of this review, we will briefly discuss these three methods for enhancing the effects of cognitive training and point the reader toward more topic-specific literature.

Each of the following methods can be used in conjunction with cognitive training in an attempt to boost or enhance the efficacy of cognitive training or to speed up the learning process. First, the most common form of non-invasive brain stimulation that has been used in this capacity is transcranial direct current stimulation (tDCS), which involves passing a small electrical current through the scalp that alters the resting state of underlying neural populations (Nitsche and Paulus 2000, 2001; Stagg and Nitsche 2011). Pairing tDCS with cognitive training has been shown to be effective in a number of cognitive domains (for reviews see, Berryhill et al. 2014; Kuo and Nitsche 2012; Parkin et al. 2015). Second, neurofeedback has also been used in conjunction with training, whereby individuals learn to control their own brain activity via systematic feedback regarding their own internal states (Sherlin et al. 2011). This approach is most commonly done using EEG paired with a variety of cognitive training tasks including declarative learning, episodic memory retrieval, mental rotation, and others (e.g., Enriquez-Geppert et al. 2014; Gruzelier 2014; Hanslmayr et al. 2005; Hoedlmoser et al. 2008; Keizer et al. 2010; Klimesch et al. 2005; Zoefel et al. 2011). Finally, efforts have been made to boost the effects of cognitive training with pharmacological interventions. For example, drugs such as Ritalin (e.g. Agay et al. 2010) or Modafanil (e.g., Battleday and Brem 2015; Gilleen et al. 2014), and the amino acid tyrosine (Jongkees et al. 2015) have all been shown to enhance the effects of cognition and cognitive training, specifically. These enhancing methods may be of particular interest to military application insofar as they may allow for faster or more effective results following cognitive training.

Conclusions

As modern warfare continues to evolve and change with the advent of new technological, biological, and nuclear threats, one aspect of military performance persists: the ability of our service members to perform their operational tasks under a myriad of circumstances is critical. While technological advances now may allow for us to send in a drone instead of a manned-aircraft, that drone still requires a human operator. The foreseeable future still has human performance as a key element for military effectiveness and as new threats arise, our service members will be asked to juggle increasing cognitive demands in a variety of operational settings. Cognitive training may represent an exciting future step for improving operational readiness and effectiveness in our military personnel.

To date, the majority of cognitive training research has been centered in basic science settings in academia, or in for-profit settings like commercial brain training. As we detailed in this review, lessons can be learned from both of these settings and can be harnessed to begin to develop an area of applied research. A key factor to keep in mind is that the goals of the military differ greatly from those of academic or commercial entities. Military research is often focused on outcome-based measures and improving warfighter performance. For this reason, we have argued that many of the instances of near transfer in the cognitive training literature may be of great value to military application. Near transfer has received very little attention in basic science, likely because of the heightened focus and controversy surrounding far transfer results. However, when performance outcomes become the key measure of training success, near transfer has the potential to be a very powerful tool.

Here, we have made several concrete suggestions that will be critical in translating basic science into military application, as it relates to cognitive training interventions. First, the use of active control groups can have two important implications: (1) an active control group provides a rigorous and acceptable control by which to compare effects in the experimental group and (2) if a second training effort is used as the active control, two distinct training programs can be tested simultaneously in the same study preserving military personnel's time and resources. Second, the role of expectations in cognitive training has been receiving much attention and is particularly salient in a military population who may hold very firm beliefs about the nature of their physical and mental training. We recommend that all training evaluations include measures of expectations (i.e., what expectation(s) does a participant enter a study with and how does that change, if at all, through the course of the training intervention). Third, given the close interaction of military personnel who are likely to be enrolled in the same training study, strict instructions should be given to participants to not discuss the training group activities that have been assigned to them. The goal of these instructions is to maintain blinding to other groups of the study. Fourth, to attain adequate sample sizes, it may be necessary to collect data over multiple time points, multiple groups of participants in separate locations, and/or use non-military personnel with similar skills to fill in the gaps. Fifth, the use of task analysis via SMEs is critical in determining appropriate outcome measures that will relate back to the real-world tasks that service members are performing. Finally, individual differences are bound to be greater in a military population compared to a typical university sample. These differences can be harnessed by using individual-level analyses in addition to typical group-level analysis approaches. Together, these recommendations provide a practical approach that can be used to drive efforts forward in testing and implementing cognitive training for military application.

The notion that we might be able to improve human cognition through training is not a novel idea that arose in the twenty-first century. At least as long as modern psychology has existed, the idea has been discussed and empirically tested. However, the modern era of cognitive training research has built to a point where application may now be a reasonable expectation. Military application in particular has great potential to not only improve the performance of our service members but also to test the bounds of how far these skills can be improved. The parallel investigation of basic questions about the mechanisms driving cognitive training effects and the applied questions of how far cognitive performance can be enhanced is likely to move the field forward in a fast-paced and exciting way.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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