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Source: *The American Journal of Psychology*, Vol. 132, No. 2 (Summer 2019), pp. 179-194

Published by: University of Illinois Press

Stable URL: https://www.jstor.org/stable/10.5406/amerjpsyc.132.2.0179

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Can Cognitive Training Improve Shoot/Don't-Shoot Performance? Evidence from Live Fire Exercises

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Police, security, and military personnel have—at most—seconds to make a shoot/don't-shoot decision despite the life-or-death consequences of their actions. Recent research suggests that shoot/don't-shoot errors (e.g., commission errors of shooting at nonhostile or unarmed civilians) can be linked to specific cognitive abilities, and these errors could be reduced through targeted cognitive training. However, these studies were conducted with untrained personnel, conducted with simulated weapons, or conducted with untrained personnel using simulated weapons. Before integrating cognitive training into real-world police and military firearm training, there should be evidence that training benefits also apply to trained shooters using live weapons and live ammunition. Here we assessed differences following cognitive training for trained law enforcement officers who performed pretraining and posttraining shooting tasks with live ammunition and their service-issued weapons. Our findings provide further support that targeted cognitive interventions can significantly improve firearm safety and efficacy for armed professionals.

KEYWORDS: shooting cognition, guns, attention, response inhibition, shooting performance, live ammunition

Shoot/don't-shoot decisions are some of the fastest and most critical decisions people make. Police, security, and military personnel have—at most—seconds to determine whether lethal force should be used or risk being shot themselves (Banks, Couzens, Blanton, & Cribb, 2015). Unfortunately, this decision can be affected by numerous factors, including racial bias (Correll, Park, Judd, Wittenbrink, Sadler, & Keesee, 2007; Correll, Urland, & Ito, 2006), stress (Nieuwenhuys & Oudejans, 2010; Scribner, 2002, 2016), and

American Journal of Psychology
Summer 2019, Vol. 132, No. 2 pp. 179–194 • © 2019 by the Board of Trustees of the University of Illinois

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relevant training (Aveni, 2002). Thus, it is vital that we identify all possible methods to increase speed and accuracy in the shoot/don't-shoot decision.

Traditional marksmanship training focuses on posture and motor control activities such as orienting the weapon and pressing the trigger (Morrison & Vila, 1998). Recently, simulators have emerged as a safe, reliable means to create a beneficial training environment (Bennell, Jones, & Corey, 2007; Getty, 2014; Hays & Singer, 2012; Jensen & Woodson, 2012; Saus et al., 2006; Söderström, Åström, Anderson, & Bowles, 2014). These platforms provide valid training paradigms, although evidence suggests that deliberate practice alone may not be sufficient to reach a high level of performance (Macnamara, Hambrick, & Oswald, 2014). This issue is particularly relevant for firearms training because practice has limited impact on improving performance in a threat-based scenario (Nieuwenhuys, Savelsbergh, & Oudejans, 2015). Other alternatives have suggested looking at individual differences to improve performance by identifying better candidates for particular roles. For example, marksmanship has been linked to heart rate variability (Thompson, Swain, Branch, Spina, & Grieco, 2015), grip strength (Anderson & Plecas, 2000), and postural balance (Mononen, Konttinen, Viitasalo, & Era, 2007). Cognitive abilities have also been linked to marksmanship performance (Biggs, 2017; Kelley et al., 2011), which presents an intriguing possibility. Specifically, any training scenario is at least partially dependent on repeatedly presenting prespecified stimuli. However, cognitive abilities underlie human performance and could transfer to a wider array of scenarios than repeated training. Cognitive training thus offers a supplementary training procedure that might help military, police, and security professionals surpass certain training limitations.

The key issue becomes how to train cognitive abilities. There is substantial controversy surrounding so-called brain training initiatives (e.g., Simons et al., 2016). One issue involves efficacy when there is no theoretical or empirical support for the transferability of any training improvements. In particular, brain training companies have argued that simple cognitive exercises could prevent Alzheimer's without any theoretical or empirical link between the cause and training (Simons et al., 2016). Firearm use is different in that there is a far more clear and concrete link between cognitive abilities and outcome performance. According to the cognitive cascade hypothesis (Biggs & Mitroff, unpublished manuscript), each step in the act of shooting a firearm can be linked to a particular cognitive ability. Each step must be completed—and completed in the proper order—to ensure a successful outcome. For example, finding a possible target involves visual search, identifying friend-or-foe involves object recognition abilities, taking aim requires perceptual judgments about distance and motion, and pressing the trigger involves response execution (and inhibition) abilities. More importantly, a predictable cascade suggests a predictable link between specific shooting errors and specific cognitive abilities.

One such relationship has already been explored: Poor inhibitory control has been linked to an increased likelihood of inflicting friendly fire casualties (Wilson, Finkbeiner, de Joux, Head, & Helton, 2014; Wilson, Head, & Helton, 2013), and response inhibition training reduced civilian casualties inflicted during gaming simulations (Biggs, Cain, & Mitroff, 2015). However, these promising results should be interpreted with caution because these studies were conducted with untrained personnel, simulated weapons, or untrained personnel using simulated weapons. The issue taps into a larger firearm training challenge because training scenarios can simulate impeding threat (e.g., the threat of being shot), projected threat (i.e., the threat of shooting someone), or some combination of both—but never to the extent that will be encountered in the field. The preferred middle ground appears to be with simulated ammunition (cf. Nieuwenhuys & Oudejans, 2011). These simulated rounds are often low-velocity, plastic projectiles filled with a marking solution that can inflict pain (similar to a paintball gun) depending on clothing, point of impact, and the range at which the projectile is fired. Notably, these types of rounds have been shown to increase the participants' state anxiety because of the potential sensation of pain (Nieuwenhuys & Oudejans, 2010; Oudejans, 2008), thereby allowing participants to experience a level of impending threat and, to a much lesser degree, projected threat.

Overall, this blended training aligns with other paradigms where anxiety has a large impact on performance (Nibbeling, Oudejans, & Daanen, 2012; Nieuwenhuys, Cañal-Bruland, & Oudejans, 2012;

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Nieuwenhuys, Weber, Hoeve, & Oudejans, 2016; Vickers & Lewinski, 2012; Wilson, 2012). All these training issues are important when considering the transferability from cognitive training to lethal force decisions. However, cognitive training benefits have yet to be demonstrated anywhere on this threat continuum.

Taken together, these issues raise several important questions about the relationship between firearms and cognition and the potential to use cognitive training for improved shooting performance. Foremost, transferability becomes a key issue when considering shooting performance. Field use will require live ammunition, whereas a significant portion of training and evaluation would involve the kinds of simulation used in cognitive testing or training. This limitation means that any evaluation of transfer effects must eventually assess performance using live weapons rather than simulators. Additionally, there is limited empirical evidence about the full relationship between cognitive abilities and firearms. Cognitive research is only beginning to elucidate the depth and specificity of these interactions. However, humans have been firing guns for hundreds of years, and expert marksmen know a substantial amount about training marksmanship. The limited cognitive evidence does not mean that no experts exist in the field of firearm performance or lethal force decision making, merely that the experts are not cognitive psychologists. Their different expertise does create a hurdle in designing cognitive training for firearms, but it does not diminish the value of their knowledge.

Thus, the current study involves a cognitive training assessment that differs in two critical ways from most previous cognitive training studies and all cognitive training studies involving firearms. First, the pretest and posttest assessments were conducted with live ammunition and service-issued weapons. This method creates a level of realism that allows better assessment of transfer from the training tasks to the operational performance tasks. Second, because of the lack of empirical cognitive evidence, we took a different approach to the cognitive training design and consulted the existing experts. Numerous subject matter experts (SMEs) provided their opinions about which cognitive abilities might apply to a shoot/don't-shoot decision, and this information became the critical factor in determining the cognitive training regimen. In short, rather than designing cognitive training to fit a real-world application, we used the real-world application to create a cognitive training regimen. This approach is novel and fundamentally different from many existing cognitive training studies.

These ideas and this cognitive training approach therefore required an assessment of cognitive training benefits in a projected threat scenario by creating as realistic a projected threat as possible: live weapons and live ammunition. This approach differs theoretically and practically from the blended impending or projected threat conditions of simulated ammunition, although it does fulfill one of the necessary criteria our subject matter experts suggested would be essential before transitioning this new training to field operators.[1] The current study conducted cognitive training with trained law enforcement officers (LEOs) who performed pretraining and posttraining shooting tasks with live ammunition and their service-issued weapons—the exact same weapons they use on duty. SMEs suggested cognitive tasks that aligned with the existing literature (e.g., Biggs et al., 2015; Wilson et al., 2013). Specifically, increased response inhibition should improve the shoot/don't-shoot decision. Participants were then randomly assigned to either an active training group (ATG) or a control training group (CTG). ATG trained cognitive abilities related to the shoot/don't-shoot decision, whereas CTG trained cognitive abilities unrelated to the shoot/don't-shoot decision. Both training groups were composed exclusively of active duty LEOs. Notably, both training groups completed a 4-week active training regimen designed to improve performance, and both groups received identical briefings and instructions to mitigate expectation differences, which substantially reduces the potential for placebo effects (Boot, Simons, Stothart, & Stutts, 2013).

At pretraining and posttraining assessments, participants performed two different shooting tasks: one threat based (i.e., a shoot/don't-shoot decision), and one marksmanship based (i.e., an always-shoot decision). Our hypothesis is that inhibitory control training should improve performance on a shoot/don't-shoot decision, and so we should see improvement on the threat-based task for ATG participants but not CTG participants. No differences are hypothesized for either group on the marksmanship task because

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the training exercises did not include any tasks related to pure marksmanship. Thus, the marksmanship task serves as a control to identify whether cognitive training yielded specific improvements in performance or whether this training yielded placebo-like effects across all areas of shooting performance. Participants in both training groups used live ammunition and their service-issued weapons for pretraining and posttraining assessments.

EXPERIMENT

METHOD

Participants

Participants were 16 male police officers from a central Virginia urban law enforcement agency. Recruitment involved as many active duty police officers as were willing to participate, and recruitment ended upon the beginning of data collection. Participants were randomly assigned to the ATG or CTG, with 8 participants in each group. The average age for all participants was 38.13 years (SD = 10.76 years). Participants had an average of 10.88 years of law enforcement experience (SD = 7.12 years). All participants had previously attended biannual department-mandated firearm training sessions and received an average score of 96.01% (SD = 3.08%) on their most recent firearm qualification. A score of 80% or higher is considered a passing score for qualification within this agency and is generally consistent with law enforcement standards nationwide.

General Procedure

All testing took place at the host agency's outdoor range facility. The cognitive training period was 4 weeks, and pretraining and posttraining assessment weather conditions were sunny and between 85°F and 92°F. All testing was completed in accordance with guidelines presented to and approved by the Randolph-Macon College Institutional Review Board. Before testing, participants were informed that the study would examine how online cognitive training might affect shooting performance, there were no "fake" exercises in the study, all exercises had been shown previously to have a positive effect on cognition in various ways, participation was completely voluntary, and their choice to participate or not in any way at any point during the study would not affect their standing with their employing agency. Participation briefings were given in a group setting, with no indication that participants were assigned to two separate training groups. This procedure established identical expectations for both training groups and limited the possibility of placebo effects (for full discussion about expectations and placebo effects affecting active training control groups, see Boot et al., 2013; Foroughi, Monfort, Paczynski, McKnight, & Greenwood, 2016; Simons et al., 2016). After the briefing, written informed consent was obtained, and participants were asked to complete a pretraining questionnaire to gather basic demographic information, including age and years of law enforcement experience.

Blinding Procedure

All participants received the same briefing; participants from both groups were intermixed without any knowledge that there were two training groups. Additionally, all participants received the same week-to-week e-mail feedback encouraging them to continue with the training. Thus, all participants received identical treatment from the experimenter during the initial briefing and feedback (they were assigned to groups and given a roster number after the briefing and consent process).

During testing, one experimenter escorted participants to and from the range. That same experimenter scored the participant's performance and did not know the participant's roster number or the experimental group to which the participant was assigned (roster number was recorded by another researcher immediately after the evaluation). The scoring system is also objective and based on the shooting performance without any subjective interpretation from the experimenter.

Cognitive Training Procedure

To design the cognitive training procedure, the experimenters consulted firearm training SMEs about possible cognitive training activities that might relate to shooting performance. The SME group comprised 26 firearm training professionals, including active federal special agents, special operations military personnel, state and local LEOs, and an elite group of national and world champion competitive shooters. Based on these SME interviews, the experimental design included two different training procedures: one designed to improve the shoot/don't-shoot decision and one designed to be unrelated to the shoot/don't-shoot decision. ATG participants completed three cognitive training exercises designed to improve visual processing speed, visual acuity, and impulse

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control. SMEs and researchers hypothesized that improvement in these tasks should produce better performance for the shoot/don't-shoot decision. CTG participants completed three different cognitive training exercises designed to improve visual memory, object tracking, and spatial orientation. SMEs and researchers hypothesized that any improvement in these tasks should not produce improvement for the shoot/don't-shoot decision because the tasks did not directly relate to the shooting error in question. All cognitive training exercises were used with permission from BrainHQ (http://www.brainhq.com/why-brainhq/about-the-brainhq-exercises).

All participants were provided the same initial briefing before training to prevent any expectation differences between participants about anticipated training benefits (cf. Boot et al., 2013). For example, participants in the ATG could demonstrate improved performance at the posttraining session simply because they expect to improve—even if there were no differences between the trainings (Foroughi, Monfort, Paczynski, McKnight, & Greenwood, 2016). Participants were randomly assigned to one of the two training groups and given a unique individual login identification number, although participants were never made aware that some would be completing the primary inhibitory control training and some would be completing an active control version of the training. An online training portal directed participants to the corresponding group exercises based on their unique login number and its associated group. This approach mitigated confusion and prevented participants from inadvertently training on the wrong exercises.

Experimenters instructed participants to complete online training exercises for approximately 10–15 min per day, 5 days per week, over the course of 4 weeks. All participants received the same guidance from experimenters regardless of their performance on the training tasks. Weekly e-mail reminders were sent to encourage participation and to ensure that they were not having any difficulty with the training. Once a week, experimenters checked to see that participants had logged into the online training system and completed the assigned training. All participants logged in to the system and completed some levels of training. However, participants were not sent any additional reminders regardless of their compliance with the assigned training intervals. This approach was maintained to increase ecological validity because it allowed the training to proceed as naturally as possible in the field, with participants completing the computer tasks as they would without constant supervisor intervention. Thus, the focus could remain on the computerized training itself without the additional issue of supervisor intervention or coaching potentially playing a role in any training-related benefits.

After the 4-week training period, participants returned to the hosting agency's range to undergo an identical posttraining shooting assessment. After the final assessment, all participants underwent a post-study debriefing and interview, including questions about whether participants were aware of a control or treatment group. No participants reported any awareness of different training groups during the training process or during the posttraining assessment. Testing took place over the course of two consecutive days with nearly identical weather conditions to the pretraining assessment. Participants completed the experiment on a volunteer basis and were not monetarily or professionally compensated for their time.

ATG EXERCISES.

The three cognitive training exercises for ATG participants were visual sweeps (VS), eye for detail (EFD), and freeze frame (FF) (Figure 1). The ATG participants completed an average of 107 levels of training. See Table 1 for results and Table 2 for descriptions of the training tasks. These exercises, which were selected with SME input, should have an impact on the shoot/don't-shoot decision.

VS is designed to increase visual processing speed through presentation of two spatial frequency sweeps (movements of bars) that sweep inward or outward. Color, luminance, orientation (i.e., vertical, horizontal, and diagonal), and spatial frequency (i.e., thickness of lines) are systematically varied and responses are measured in milliseconds to track progress and provide participants with immediate feedback. For example, two arrays are presented and participants must indicate whether the movement of the bars in each array swept inward or outward by mouse clicking on the appropriate set of directional arrows.

SME input indicated that the ability to recognize the presence of a target quickly is important in determining its location, the type of target, whether it should be engaged, and the speed with which it can be engaged. Faster recognition of a target provides more time to make decisions and allows shorter response execution. The VS exercise was chosen for use in the ATG group because people who are faster in processing randomly presented visual threat/nonthreat targets while making shoot/don't shoot deci-

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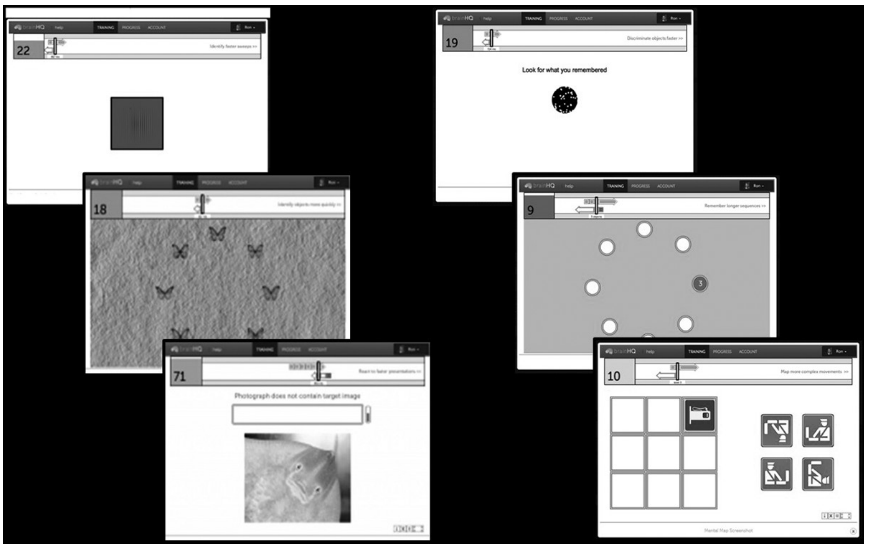

FIGURE 1. Sample displays from the cognitive training exercises for both the active training group (ATG; visual sweeps [VS], eye for detail [EFD], and freeze frame [FF]) and the control training group (CTG; mind's eye [ME], juggle factor [JF], and mental map [MM])

TABLE 1. Descriptive Statistics for Training Levels Completed and Percentage Improvement by Group

	Training levels and improvement		
	Training levels completed (average)	% Improvement between pretest and posttest	Significance
Active training group	170	18.75%	$p < .01$, significant
Control training group	30	4.69%	$p = .22$, not significant

sions would be expected to make a higher percentage of correct decisions. Furthermore, previous efforts have significantly demonstrated the ability to train reflexive attention with directional cues (Dodd & Wilson, 2009; Tang & Posner, 2009). This combined relationship to the shoot/don't-shoot task and related evidence makes the VS task a prime training task to include in the ATG exercises.

EFD is designed to increase attention to subtle details and improve visual processing speed and acuity. In EFD, three to five images briefly appear one at a time in different positions on the screen. Image similarity, speed of presentation, and placement in the visual field are systematically varied. After presentation of each series of images, participants view a set of test images that include identical matches and lure items. Participants are required to identify the identical matches via mouse clicks.

SME input indicated that both the speed with which a potential target could be identified and the discernment of specific discriminating details (e.g., a handgun vs. a cell phone) are important in determining whether a particular target represents a threat and should be engaged or ignored. The EFD exercise was included in the ATG group because it systematically trains people to notice subtle differences in the details of visually presented stimuli under increasingly challenging time constraints. SMEs believed that participants who could notice subtle differences in targets presented in shoot/don't shoot situations with high time constraints would probably make better decisions. Additionally, these key details more directly relate to stimulus-based inhibitory control training, where particular stimuli become paired with either "go" or "no-go" responses (Houben, Havermans, Nederkoorn, & Jansen, 2012; Houben, Nederkoorn, Wiers, & Jansen, 2011; Houben & Jansen, 2015; Lawrence et al., 2015). Because shoot/don't-shoot tasks depend heavily on the interplay between correct identification and inhibitory control, it is important

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TABLE 2. Summary Descriptions of the Training Tasks Used in the Study, the Cognitive Abilities Being Trained, and How These Tasks Either Do or Do Not Relate to a Shoot/Don't-Shoot Decision

Training task	Training to improve	Relation to shoot/don't-shoot performance
Active training group		
Visual sweeps	Processing speed	The ability to perform accurately and extremely quickly is critical to a shoot/don't-shoot situation.
Eye for detail	Attention to subtle details	These snap decisions may often hinge on details such as whether an individual is armed. This task is intended to help identify those subtle details in a speeded task.
Freeze frame	Inhibitory control	Inhibitory control has already been demonstrated as a key factor in shoot/don't-shoot decisions (e.g., Biggs et al., 2015).
Control training group		
Mind's eye	Visual memory	Subtle details may be important, but improving capacity may not directly impact the shoot/don't-shoot tasks administered to shooters in this study.
Juggle factor	Spatial working memory	Spatial working memory could impact larger room clearing scenarios, but maintaining spatial information should not impact the shooting task presented here.
Mental map	Spatial working memory	Spatial working memory could impact larger room clearing scenarios, but maintaining spatial information should not impact the shooting task presented here.

to include tasks designed to improve both identification and inhibitory control.

FF is designed to affect two types of alertness, tonic alertness and phasic alertness, which work together to determine attentional state. Increasing tonic and phasic alertness strengthens the ability to pay attention to what is important and to determine whether to make or withhold a response at the appropriate time. In the exercise, participants are required to discriminate between target images and distractor images of varying similarity at varying speeds and frequency of presentation. Correct choices require demonstration of impulse control (i.e., response inhibition) at the appropriate times. For example, participants pressed the spacebar for all distractor images that are presented but refrained from pressing the spacebar (i.e., "freeze") when the target image was presented.

SME input indicated that one of the most difficult tasks in shoot/don't scenarios is withholding a response, especially after targets have been engaged and additional threat/nonthreat targets appear randomly. The FF exercise was chosen for use in the ATG group because it mimics the task and the behavior needed to function successfully in a shoot/don't shoot situation. Namely, the participant is aware of the types of targets that should and should not be engaged but is presented with a rapid series of mixed stimuli (i.e., threat vs. nonthreat) at ever increasing speeds. The increased ability to demonstrate response inhibition at the appropriate times would logically result in a larger percentage of correct shoot/don't shoot decisions. Moreover, inhibitory control has already been demonstrated as important in shoot/don't-shoot scenarios (Biggs et al., 2015; Wilson et al., 2013, 2014). These theoretical and empirical links make the FF exercise perhaps the strongest link between the training tasks and the shoot/don't-shoot decision tested in the present experiment.

CTG EXERCISES.

The three cognitive training exercises for CTG participants were mind's eye (ME), juggle factor (JF), and mental map (MM) (see Figure 1). These exercises were selected, with SME input and in conjunction with a review of current literature, because they had the least likelihood of significantly affecting shoot/don't-shoot performance. Participants logged into the system and completed the designed tasks in a manner identical to the ATG exercises. This approach simultaneously manages expectations and helps reduce any performance improvements due

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solely to placebo effects (Boot et al., 2013; Foroughi et al., 2016). The CTG completed an average of 30 levels of training. See Table 1 for results.

ME is designed to improve visual memory through practice in sensory discrimination. In ME, participants are asked to remember a target image and determine whether a set of similar images presented contain the target image. Various shapes and images of varying similarity are presented simultaneously to test and expand visual memory but do not emphasize speed of processing or visual acuity. Participants must use the mouse to click on the target image or images they were instructed to memorize.

JF requires participants to recall, compare, and manipulate multiple pieces of information within a limited time. It improves working memory through the presentation of a sequence of numbers placed within moving circles that must be recalled. Sequence length and speed of presentation become more complex as the exercise progresses. Successful performance requires participants to click on the circles in the correct sequence in which the numbers appeared.

MM targets spatial memory and mental manipulation. Participants are required to remember the relative location of objects in a grid and then reconstruct the grid from memory after it has been rotated, flipped, or translated (i.e., moved up, down, right, or left). Complexity of the grid (e.g., number of objects, object similarity) and its movement (i.e., number of movements) increases as the exercise progresses. Participants are required to click on an object and drag it to the proper location in the grid after it has been rotated, flipped, or translated in order to match the original pattern.

Shooting Tasks

Participants from both groups were given two identical pretraining and posttraining assessments of basic marksmanship and decision making. Participants were informed that they would be engaging a stationary bullseye target and then a series of shoot/don't-shoot targets, which would be presented very briefly from behind a visual barrier via a robotic target system. Each shooting task was limited to a maximum of eight rounds per task to accommodate the magazine capacity of the host department.

TARGET SYSTEM.

Input from SMEs indicated that evaluating complex elements of firearm proficiency (e.g., the shoot/don't-shoot decision) would be "ineffective" and "inaccurate" in typical or standard department or agency qualification courses (for further discussion, see Morrison & Vila, 1998). This distinction results from the simplicity of the task and the fact that such a qualification is designed to measure the minimum degree of skill needed by LEOs to operate a handgun effectively. To represent realistic differences in skill and proficiency, SMEs recommended a shooting task that would present the shooter with rapidly appearing targets from unpredictable locations while also requiring them to differentiate between threat and nonthreat targets. Several target systems were evaluated to determine which would be able to provide such a task. Based on consistency and reliability, this study used two Targabot TM-101 Robotic Target Systems (Figure 2).

This task was developed and refined with SME input and beta testing from federal LEOs and firearm instructors. Details such as time and location of exposure were adjusted to reach a level of difficulty that would avoid a restriction of range in task performance (i.e., all participants either receiving maximum scores or being unable to complete the shooting task at all). The final task is described in greater detail in the following sections.

SHOOT/DON'T-SHOOT TASK.

This task was designed to evaluate an officer's ability to quickly and accurately identify and then appropriately engage or not engage a single target. A 19-year-old Caucasian man was used as the model

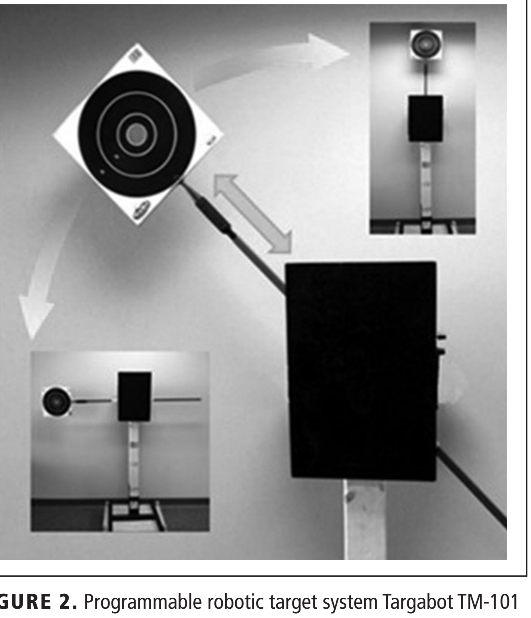

FIGURE 2. Programmable robotic target system Targabot TM-101 Robotic Target System (Targamite; www.targamite.com)

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for the shoot/don't-shoot targets (Figure 3). Two identical photos were taken of the model, with the only difference being either a gun (i.e., threat image) or a cell phone (i.e., nonthreat image) in his right hand. Both photos were printed in black and white using the same model to minimize confounds due to color blindness or any potential racial biases in performance (Correll, Hudson, Guillermo, & Ma, 2014; Correll, Park, Judd, & Wittenbrink, 2007; James, Klinger, & Vila, 2014; Sadler, Correll, Park, & Judd, 2012). Simulated bullet holes were added to identical areas of both the threat and nonthreat target, as recommended by SMEs. Adding these simulated bullet holes prevented shooters from using any actual bullet holes in the target as a cue or an indicator of whether the target was a threat or nonthreat target (Figure 4). These targets were placed on the armature of the Targabot system, which consists of two independently rotating units each of which controls rotation and extension and retraction of an individual target shaft (one threat image, one nonthreat image). New targets were used for each participant.

In this task, participants were informed that they would be engaging a series of threat/nonthreat targets that would appear rapidly from behind the visual barrier. They were instructed that if they identified a threat target, they should fire one round at it. Participants were exposed to a maximum of 8 threat targets and 12 nonthreat targets with a presentation time of 1 s each. All target presentations began hidden from view (behind the barrier) and were then presented one at a time from various locations in a randomized and alternating pattern. The pattern of presentations was randomized initially and then programmed into the targets so that each participant received identical presentations. This process was repeated for the post-training assessment.

Participants began the shoot/no-shoot task with eight rounds of live ammunition loaded in their firearm. Participants assumed a "low ready" position and were given a verbal command of "get ready" 3 s before the target appeared. The task ended when participants went through all 20 possible targets or ran out of ammunition (i.e., fired eight shots before seeing all 20 possible targets). All participants ended the task by running out of ammunition.

Recall that the purpose of the shoot/don't-shoot task was to assess officers' threat identification ability, not their marksmanship skill. Therefore, scores for the shoot/don't-shoot task were based on whether officers shot at threat targets and withheld fire when nonthreat targets were presented. Raw scores ranged from 0 to 8 and were converted to a percentage ranging from 0% to 100% based on the percentage of possible points obtained. Scores reflect a percentage based on number of correct responses divided by the maximum number of possible correct responses. For example, if a participant fired six rounds at threat targets and two rounds at nonthreat targets, his score would be 75%.

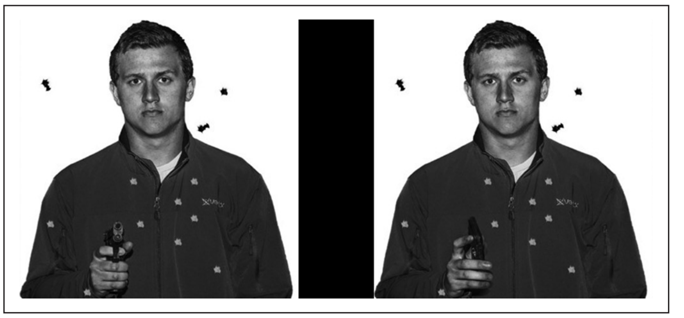

FIGURE 3. Threat and nonthreat targets. Likeness used and reprinted with direct permission and written consent from model. Semiautomatic handgun (left) and cell phone (right)

FIGURE 4. Photograph illustrating the shoot/don't-shoot task as used on the firing range

MARKSMANSHIP TASK.

This task paralleled the marksmanship tasks performed by police officers during regular weapon qualification to determine their field readiness with their service-issued firearms. Participants were asked to fire eight carefully aimed shots at a bullseye target at a distance of 10 yards. Participants proceeded at their own pace and began each shot from a "low ready" position. The marksmanship task used an industry standard, 12″ × 12″ black and white bullseye target with six scoring zones (10, 8, 6, 4, 2, 1) mounted to a stationary target stand (Figure 5). This target was chosen because it is familiar, allows the shooter

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FIGURE 5. Photograph illustrating the marksmanship task with static, bullseye target

to have a clearly defined, central aim point, and does not require a threat assessment (i.e., no shoot/don't-shoot decision). Scoring was based on number of hits per scoring zone, with a possible scoring range of 0–80 points. Raw scores were converted to a percentage ranging from 0% to 100% based on percentage of possible points obtained. For example, if a participant hit the center or "10 ring" of the bullseye with all eight rounds, he would receive 80 out of 80 points and a score of 100%.

Participants also performed another marksmanship task using bullseye targets, but the secondary marksmanship task had a design akin to the shoot/don't shoot task used in the experiment rather than a real-world police weapon qualification task. However, the results and interpretations from this additional marksmanship task were statistically similar and qualitatively identical to the primary experimental marksmanship task (i.e., the one designed to mimic weapon qualification). Given the identical nature of the interpretations and given that the experimental marksmanship task is more similar to current police weapon qualification tasks, only data from the experimental marksmanship task are reported in detail in the *Results* section.

DATA ANALYSIS.

Our primary hypothesis is concerned with a change between groups when comparing pretraining and posttraining performance. This approach depends on a single difference score and a between-group t test. However, we also conducted between-group t tests on the pretraining scores to ensure there were no preexisting group differences. Notably, the experimental design was created based on SME input and previous empirical results. This combination of input and evidence provided a strong rationale for using one-tailed t tests when comparing performance differences between groups because only one training group was specifically designed to yield a benefit on the shoot/don't-shoot task ($\alpha = .05$). Thus, the between-group comparisons used one-tailed t tests. Other analyses included descriptive statistics of group performance, effect size analyses for significant effects, and power analyses. The same statistical analyses were used for both shooting tasks (shoot/don't-shoot and pure marksmanship) (Figure 6).

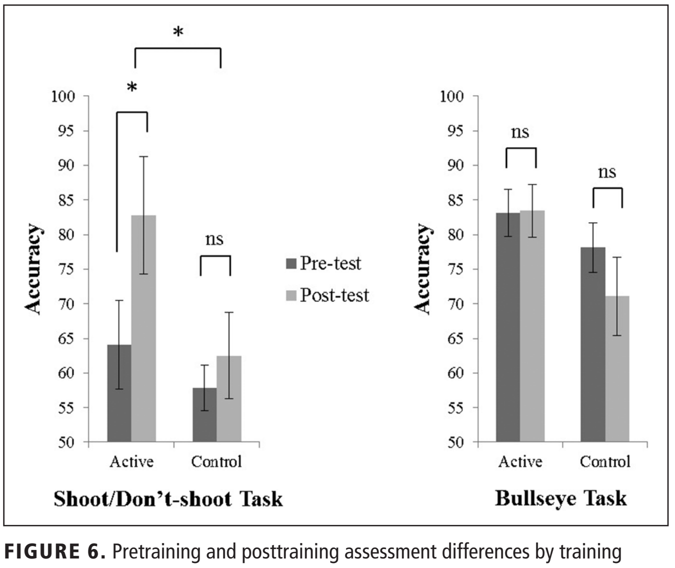

FIGURE 6. Pretraining and posttraining assessment differences by training group for the two live fire shooting tasks

RESULTS

Shoot/Don't-Shoot Task

There were no significant differences between the training groups on pretraining performance in the shoot/don't-shoot task (ATG, mean = 64.06%, SE = 6.44%; CTG, mean = 57.82%, SE = 3.29%), $t(14) = 1.34$, $p = .20$. As hypothesized, ATG participants improved on the shoot/don't-shoot task from pretraining to posttraining (mean change = 18.75%, SE = 4.72%), $t(7) = 4.53$, $p < .01$, whereas the CTG participants did not improve on the shoot/don't-shoot task from pretraining to posttraining (mean change = 4.69%, SE = 5.76%), $t(7) = 1.34$, $p = .22$. Moreover, the pretraining to posttraining change significantly differed by training group on the shoot/don't-shoot task, $t(14) = 2.26$, $p = .04$, $d = 0.94$. This effect size

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exceeds what Cohen (1992) defined as a large effect. Thus, the active training regimen significantly improved performance on the shoot/don't-shoot task, whereas the control training regimen did not significantly improve performance.

Another concern involves the type of error in this task. Participants were scored based on the maximum number of bullets in their magazines, and their eight rounds were intended for the eight threat targets. So, upon seeing all possible threat and nonthreat targets, there were three types of responses: correct shot (fired on a threat target), incorrect shot (fired on a nonthreat target), or incorrectly withheld shot (failed to fire on one of the eight threat targets). The 16 participants had a combined total of 256 rounds between pretest and posttest sessions. However, only a combined total of eight rounds were withheld across all participants, indicating that incorrect responses due to unfired rounds (i.e., participants did not fire on a threat target) accounted for only a small percentage of errors (3.13% of all trials). The primary source of error, and the primary investigation here, thus focused on incorrect shots fired on a nonthreat target (i.e., false alarms). See Figure 7 for results.

There were no significant differences between the training groups on pretraining performance in shots incorrectly fired on a nonthreat target (ATG, mean = 3.13, *SE* = 0.52; CTG, mean = 2.75, *SE* = 0.41), $t(14) = 1.10$, $p = .29$. As hypothesized, ATG participants reduced the number of shots incorrectly fired on nonhostile targets from pretraining to posttraining (mean change = 1.88, *SE* = 0.48), $t(7) = 4.47$, $p < .01$, whereas the CTG participants did not reduce the number of shots incorrectly fired on nonhostile targets from pretraining to posttraining (mean change = 0.25, *SE* = 0.65), $t(7) = 0.99$, $p = .36$. Moreover, the pretraining to posttraining change significantly differed by training group on the shoot/don't-shoot task for number of shots incorrectly fired on nonhostile targets, $t(14) = 2.39$, $p = .03$, $d = 1.01$.

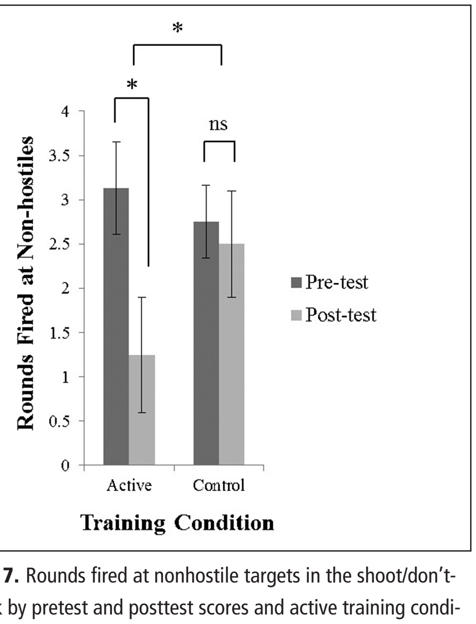

FIGURE 7. Rounds fired at nonhostile targets in the shoot/don't-shoot task by pretest and posttest scores and active training condition versus control training condition

A final issue with these results involves the small sample size. The observed power is 51% for these statistical tests, which yields an increased chance of making a type II error in statistical interpretations. The recommended acceptable level to avoid these errors is 80% statistical power (Cohen, 1988). To achieve 80% statistical power with this effect size, we would have needed 15 participants per group, as calculated within the G*Power program (Faul, Erdfelder, Lang, & Buchner, 2007). However, it should also be noted that the errors likely to occur from this sample size are type II errors that result from a decreased ability to detect an effect or a false negative judgment that there is no effect present. Despite the lower-than-optimal power levels here, we still observed significant effects. This finding is probably due to the very large effect sizes observed and the robust nature of the training effectiveness. Thus, the low statistical power is an issue, albeit not a critical one because the low power made the results less likely to produce a significant effect. The larger issue remains the replicability of this effect, although this study is itself a replication and extension of previous findings to more realistic methods with a trained population.

Bullseye Marksmanship Task

There were no significant differences between the training groups on pretraining performance on the marksmanship task (ATG, mean = 83.13%, *SE* = 3.43%; CTG, mean = 78.13%, *SE* = 3.59%), $t(14) = 1.51$, $p = .15$. ATG participants did not improve on pure marksmanship performance from pretraining to post-training (mean change = 0.31%, SE = 4.16%), $t(7) = 0.76$, $p = .47$, nor did CTG participants improve on pure marksmanship performance from pretraining to posttraining, (mean change = –7.04%, *SE*

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= 6.62%), $t(7) = 1.56$, $p = .16$. There were also no differences in group change from pretraining to posttraining on the marksmanship task, $t(14) = 1.41$, $p = .18$. Thus, neither training regimen had an impact on pure marksmanship performance with a firearm.

DISCUSSION

Previous research demonstrated a clear link between cognition and firearm performance, which implies that cognitive training could produce better shooting performance (Biggs et al., 2015). These previous studies indicate substantial potential, yet they have one significant flaw in adapting the findings for real-world use—that is, these studies were conducted with untrained personnel, conducted with simulated weapons, or conducted with untrained personnel using simulated weapons. Unfortunately, no mock weapon can replicate the inherent danger and accountability involved in firing a live weapon, and no amount of practice or simulation can circumvent the issue of translating findings from an untrained population to a well-trained population. Moreover, during SME interviews, experts strongly insisted that any new training technique would need successful demonstration with live ammunition to be well received and eventually transitioned to the field. Therefore, this study represents an essential step before any novel training ideas can benefit armed professionals in a meaningful way.

The present findings also support the cognitive cascade hypothesis (Biggs & Mitroff, submitted). This general idea suggests that specific cognitive steps can be linked to specific aspects of shooting a firearm. In the present study, the two shooting tasks provide two very different scenarios because of differential reliance on object recognition abilities. The marksmanship task did not require differentiating between targets (i.e., participants always fired at the bullseye), whereas the shoot/don't-shoot task required participants to differentiate between friend and foe when viewing the possible target. Only ATG participants received a targeted intervention designed to improve this specific aspect of shooting performance, which further supports the idea of specific and identifiable links between cognition and shooting performance. The current findings also demonstrate that the specific cognitive interventions can be used to reduce specific errors in shooting performance.

Although this study contributes to the literature and will help transition these ideas to field use, it is important to note continued limitations. For example, there are no definitive answers about the relative contribution of specific cognitive exercises to shooting performance. We are not endorsing BrainHQ as a law enforcement training platform, nor do we guarantee that these exercises are the optimal configuration for inhibitory control training. A full training program will require more targeted interventions into the specific cognitive exercises that increase response inhibition capabilities. Another potential issue involves compliance among the participants. ATG exercises appeared to be more engaging than the CTG participant exercises, as evidenced by the increased compliance among the ATG participants in total time spent training. Previous cognitive training interventions have used watered-down versions of the primary training simply to act as a control for placebos (cf. Klingberg et al., 2005; Klingberg, Forssberg, & Westerberg, 2002); however, this approach comes with its own methodological issues (for a full discussion, see Boot et al., 2013). The critical point, even in light of potential engagement differences between groups, is that placebo-related improvements are not a likely explanation for the results because both groups were treated identically and both groups were provided an adaptive training regimen designed to improve some aspect of cognition. Long-term viability is also a question because posttraining assessments occurred immediately after the training period. Duration of the training benefits is a particularly important point in considering when and how this training should be provided. Among trained military personnel, for example, should this type of training be integrated at boot camp, annually during other training exercises, during predeployment exercises, or for several minutes immediately before patrol? The answer depends entirely on whether the effects last years, months, or days. Both the optimal training exercises and how long the benefits last will need to be evaluated before policy decisions about implementation can be made.

Although there is very little in the current literature about the idea of projected threat with actual firearms, the concept was addressed by nearly all of the SMEs interviewed. *Projected threat* refers to the fear

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or anxiety that may arise from the idea that your actions have the real potential to injure another person. On the surface, it would seem that this issue is completely mitigated by the use of simulated ammunition. The logic would proceed as follows: It hurts when getting shot with a simulated round, and therefore it will hurt someone else if they are shot with the same round. This logic superficially addresses the issue of projected threat. However, SMEs were adamant that this logic was extremely flawed, particularly among highly trained people. First, they noted that trainees quickly become "very comfortable" with simulated rounds, and the seriousness can quickly wear off. Participants are aware that the physical pain involved dissipates quickly and that it is "ok to make mistakes" because they have no permanent consequences. Additionally, the role players (e.g., confederates pretending to be hostile adversaries) are often padded with heavy clothing and protective gear to allow them to go through several scenarios. The trainees, who likewise fulfill the adversarial function, can assume there is little chance of them inflicting pain or harm on a role player that they shoot. This combination lowers the perceived realism and any potential or perceived consequences of shooter actions in these scenarios.

SMEs indicated that this contrived simulation differed significantly from when people conducted scenarios with a live weapon. The mere presence of a live weapon creates the potential for lethal consequences. Although the aspect of a living, thinking adversary (i.e., a human opponent) is lost, the very real aspect of projected threat is gained. Careless weapon handling carries the risk of serious injury or death, including activities such as "sweeping" another teammate with the muzzle. SMEs indicated that this difference is particularly evident in "shoot house" training. When the scenario changes from simulated bullets and live targets to live bullets and simulated targets, participants are much more careful and conservative with shot placement and number of rounds fired. This criticism does not remove the value of simulated rounds under certain circumstances, such as the use of a live role player and more realistic impending threat. Instead, the point is to highlight that live fire, even at paper stationary targets, is an invaluable training component. A future challenge is to examine the extent to which this type of practice transfers to more realistic situations (e.g., using video-based simulation or live role-player scenarios) and how long the benefits of training are retained (Proctor, Yamaguchi, & Miles, 2012).

A primary study limitation, and therefore limitation of transfer effects for our findings to real-world applications, involves the small sample size of the current study. The sample size is small primarily because of the difficulty recruiting and training active duty law enforcement throughout a month-long cognitive training study. The highly specialized inclusion criteria and study length increase the realism and practical extensions of our findings, yet these same criteria vastly restrict the possible participants far beyond the average psychology department subject pool. Even so, any reservations about sample size can be curtailed for several reasons. Foremost, the limited statistical power is more likely to prevent a significant effect from being observed than to observe significant findings where there are none. The difference involves a statistical type I versus type II error, and if anything, the limited statistical power stacks the deck against observing an effect rather than observing a significant finding due to a large effect size. Additionally, this study is not the first demonstration of the idea that cognitive training can be used to improve the shoot/don't-shoot decision. Inhibitory control has already been linked to the shoot/don't-shoot decision (Wilson et al., 2013), and response inhibition training has been shown to improve the shoot/don't-shoot decision (Biggs et al., 2015). This study extends and enhances those findings by demonstrating the effects among trained police officers using live ammunition—the most realistic demonstration ethically possible. Thus, because this study is a replication of an existing concept and extension of the methods, sample size issues are minor given that we were able to replicate previous work and support the underlying concept.

In conclusion, the current study demonstrated that cognitive training can improve shooting performance under the most realistic circumstances ethically possible. This evidence further contributes to the link between cognition and firearms (cf. Biggs, Brockmole, & Witt, 2013; Loftus, Loftus, & Messo, 1987; Witt & Brockmole, 2012) and to the general effectiveness of inhibitory control training (Houben et al., 2011, 2012; Spierer, Chavan, & Manuel, 2013). Moreover, this successful demonstration with trained

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personnel could pave the way for additional forms of cognitive training to improve shooting performance. Systematically identifying optimal cognitive exercises could ultimately lead to the development of more effective firearm training, increased officer survival, and increased public safety.

NOTES

J.A.H. and G.L. applied for and received funding from the Randolph-Macon College 2015 SURF program to fund the study. The study protocol was approved by the Randolph-Macon College Institutional Review Board in compliance with all applicable federal regulations governing the protection of human subjects. J.A.H., along with firing range training officers, collected the data. J.A.H. and G.L. performed primary data analyses. J.A.H., G.L., J.S., and A.T.B. prepared the final manuscript. The authors have no financial or nonfinancial competing interests in this manuscript. The views expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the Department of the Navy, the Department of Defense, or the U.S. government. A.T.B. is a military service member. This work was prepared as part of his official duties. Title 17 U.S.C. §105 provides that "Copyright protection under this title is not available for any work of the United States Government." Title 17 U.S.C. §101 defines a U.S. government work as a work prepared by a military service member or employee of the U.S. government as part of that person's official duties. We thank the following SMEs, who provided a tremendous amount of guidance and insight that was critical in the design and implementation of this study: Bill Rogers, Robert Vogel, Brandon Wright, Scott Reidy, Steve Fisher, James Murray, and numerous federal law enforcement officers and special operations personnel who, for security reasons, cannot be named. Without their knowledge and support, this study would not have been possible.

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1. This information comes from the same group of SMEs interviewed for the current study. This expert group consisted of 26 firearm training professionals, including active federal special agents, special operations military personnel, state and local LEOs, and an elite group of national and world champion competitive shooters. These SMEs were interviewed to help identify which cognitive areas might be involved in a shoot/don't shoot scenario.

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