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Effects of Neurocognitive Temporal Training on Weapon Firing Performance

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Abstract

While marksmanship is a critical skill for military personnel, some service members experience difficulty in attaining and maintaining marksmanship qualifications. Temporal training may improve marksmanship performance, since rhythm and timing are critical for coordinated movement. In this study, we examined the effect of neurocognitive temporal training (NTT) on military personnel's marksmanship performance. We randomly assigned 41 active duty U.S. Army service members with prior marksmanship training into an NTT group that received 12 NTT training sessions ($N = 18$) and a Control group ($N = 23$) that received no NTT training. We measured marksmanship at baseline (pretest) and following either NTT (posttest) or, for the Control group, a comparable time period. We quantified marksmanship during 2 tasks of firing 5 self-paced shots at stationary 175 m and 300 m targets (Task 1) and firing at 50 moving and stationary targets of varying distances (Task 2). We recorded three measures of accuracy and three measures of precision (including Total Path Length, a unique measure quantifying shot-to-shot variability) for the first task, and we recorded one accuracy measure for the second task. To determine group differences for pretest versus posttest, we used multivariate analysis of variances for Task 1 and a mixed-model analysis of variance for Task 2. Results revealed significantly reduced variability and improved precision when firing at the 175 m

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target for the NTT group compared with the Control group ($p < .05$), but there were no significant group differences on other measures. While these results suggest the utility of neurocognitive timing and rhythm training for marksmanship precision, additional research is needed and should include varied training regimens, comparisons of expert versus novice shooters, additional outcome measures, and a larger participant sample.

Keywords
timing, rhythm, neurocognitive temporal training, human performance, weapon firing, M16A4

Marksmanship is a critical skill for military forces. Precision shooting requires not only an awareness of environmental and situational parameters but also the integrated use of one's knowledge, experience, and training, along with coordinated musculoskeletal movement, regulated breathing, and emotional control. Rhythm and timing are essential to movement patterns in complex motor tasks such as weapon firing. Temporally structured interventions may facilitate optimal motor performance (MacPherson et al., 2009). The U.S. Army Maneuver Center of Excellence has identified a gap in basic weapon firing proficiency and is taking steps to move military shooters to the expert level (Tan, 2016).

A series of motor and cognitive task sequences requiring rhythm and timing are engaged when a person fires their weapon. Successful execution of weapon firing motor sequences requires precise *motor and cognitive skills*, especially when taking into account uncontrollable factors such as environment, situation, and equipment malfunctions (Chung et al., 2004). In terms of *motor* control, weapon firing performance requires control of posture and weapon alignment (Era et al., 1996; Humphreys et al., 1936; McGuigan & MacCaslin, 1955; Spaeth & Dunham, 1921) as well as coordination of breath with trigger squeeze (Chung et al., 2004). The *cognitive* processes of marksmanship include focusing and sustaining attention on the task (Kelley et al., 2011), comprehending the shooting task requirements (Boyce, 1987; Chung et al., 2004), and making fast, action-oriented decisions (Scribner, 2016). The thoughts and actions involved in weapon firing precision follow a rhythmic, coordinated neurocognitive and visuomotor sequence that first occurs explicitly (with concentrated effort) and later implicitly (spontaneously) as a person moves from being a novice to an expert.

All of these motor and cognitive processes must be properly coordinated for successful marksmanship. Execution of learned movement sequences such as weapon firing or signing one's name on a piece of paper, follow certain temporal, repeatable patterns (Sakai et al., 2004; Viviani & Terzuolo, 1980). Such *motor rhythm* (Sakai et al., 2004) patterns are controlled by complex coordination of higher cortical and lower peripheral structures. Cognitively controlled timing can become automatic through practicing a series of movements (Sakai et al., 2004). Damage to cortical structures thought to be important in timing and rhythm (i.e., cerebellum), can cause impaired motor responses and timing perception (Ivry & Keele, 1989; Wing, 2002). Temporal training with sequential movement patterns may not only improve timing and rhythm but may also generalize to improved weapon firing performance.

Neurocognitive temporal training (NTT) is a short-term instructional method designed to improve an individual's rhythm and timing. NTT teaches individuals to pair physical movement with auditory and visual cues, by using a metronome in synchronized metronome training. Previous NTT work with the Interactive Metronome®; IM, 2004) has largely focused on improving cognitive function such as attention (Baker, 2014; Cosper et al., 2009) and reading efficiency (Ritter et al., 2013). However, timing and rhythm performance with the IM have also been correlated with physical fitness scores on the Army Fitness Test (timed sit-ups and push-ups and a two-mile run; Rice et al., 2007) and performance on complex stepping tasks (Rönnqvist et al., 2018). Individuals who underwent NTT with the IM improved their golf shot accuracy (Libkuman et al., 2002; Sommer, 2014; Sommer & Rönnqvist, 2009) and decreased variability during a soccer ball cross-passing task (Sommer, 2014). In addition, experienced golfers undergoing NTT with the IM decreased golf shot variability (Sommer & Rönnqvist, 2009; Sommer et al., 2014). In terms of fine motor control, NTT with the IM has improved finger dexterity during a Nine Hole Peg Test for older adults (Trujillo, 2017) and improved consistency in timing during golf-putting (requiring some fine motor adjustments for alignment; Kim et al., 2018).

Given the reported improvements in athletic performance (and in other domains) following NTT, temporal training may improve other activities requiring complex motor and cognitive skills such as weapon firing. However, we found no NTT studies related to weapon firing in the literature, leading us to design this study to investigate the effect of NTT on U.S. Army active duty personnel's weapon firing performance, using a weapon firing simulator. We hypothesized that marksmanship precision and accuracy would improve for individuals who underwent NTT to a greater extent than for those individuals assigned to a control group who did not participate in NTT training.

Method

Participants

We recruited a total of 84 active duty army service members from Joint Base San Antonio (JBSA)—Fort Sam Houston as volunteer participants in this research.

We estimated sample size with the Creative Research Systems size calculator (Creative Research Systems, 2014) and effect sizes from previous research that examined the effects of a computer training program on weapon firing (Chung et al., 2009). A sample size of 60 participants (30 in each group) were required to complete the study in order to produce a statistical difference (confidence level [CL] = 95% = 12.64, Population-military available = 33,000). We increased recruitment to account for the larger-than-average dropout rate expected with an active duty military population. Of these 84 individuals, only 41 participants completed the study due largely to military duty changes and reassignment of priorities. Participants were not compensated for their research involvement. All participants were at least 18 years of age, able to speak, read, and write English, had previously received annual M16A4 weapon firing training as part of their military training and gave written informed consent to participate in this research. All participants completed a demographic survey and engaged in pre- and posttest weapons firing assessments. All procedures within this protocol were approved by an institutional review board.

Procedure

We randomly assigned participants into either an NTT group or a Control group that did not undergo NTT training. We measured pre- and posttest weapon firing using a weapon firing simulator, the Engagement Skills Trainer 2000 (EST 2000, Cubic Inc., San Diego, CA, version 7.11). Regardless of group assignment, no participant practiced with the weapon firing simulator between pre- and posttest. Between the pre-and posttest, those in the NTT group underwent NTT on the IM® (described later), supervised by certified IM training research staff. The Control group received no NTT training between the pre- and posttest. We conducted posttesting after NTT completion for the NTT group and a comparable time for the Control group (approximately 3-4 weeks postbaseline assessment). Both groups performed their regular military duties between pre- and posttesting.

NTT with the IM®

As noted, the NTT tool utilized in this study was the IM® (IM, 2004). The IM is a system that utilizes the IM software, a standard laptop computer (for display of the visual cues and task results to the participants), headphones (for the auditory cues), two clapping triggers that are held in each hand, and a foot pad that can be triggered by a tapping a foot. Participants were instructed to match an auditory reference tone and a visual cue on the computer screen by tapping a trigger with their hands, their feet, or both hands and feet. The IM software provides auditory and visual feedback during training sessions, to alert participants to whether their response preceded or followed the reference tone (preset to 54 beats per minute), and whether it was within $\pm$ 15 milliseconds (ms) of the reference tone and visual cue. The visual signal showed three levels of participants *closeness* to the reference tone (measured in ms) for early and late responses. The auditory feedback consisted of three levels of a pleasant tone related to early and late responses within $\pm$15 ms of the reference tone. Participants heard the tone in the left ear when they were early and in the right ear if their response was late. This reflected their visual feedback, where they saw the left circle on the screen light up when they were early, and the right circle light up when the response was late. When the response was $\pm$15 ms of the reference tone, they heard the tone in both ears and saw the center circle light up on the screen. Participants in the NTT group attended 12 IM (NTT) training sessions, varied in time length so that, progressively, they lead up to 45 minutes (IM, 2004). IM-certified research staff were standing by to supervise all those undergoing NTT with the IM.

Weapon Firing

We quantified weapon firing performance with the EST 2000 during the pre and posttests. The EST 2000 is used by U.S. Army to simulate short- and long-range weapon firing, and it has been shown to be an effective measure of rifle marksmanship in an earlier version (Scholtes & Stapp, 1994). Shooting performance on the EST 2000 has been linearly correlated with performance during live-round marksmanship performance (Hagman, 1998). The EST 2000 uses a range of modified shooting weapons, is equipped with a compressed air system to simulate recoil, and includes laser technology to mimic live action firing. For the weapon, we used the mock M16A4 without laser assist. Participants remained in the prone supported position for all shooting tasks. Research precision and accuracy outcome measures were limited to the outputs provided by the EST 2000 software.

Prior to tasks used in the pre- and posttest for the study, participants *grouped* and *zeroed* their weapons. *Grouping* refers to the firing five of six consecutive shots within a 4 cm range from one another, while aiming at the center of mass (COM, a 4-cm zone in the center of the targets) on the 25 m simulated target (United States Army, 2011). Based on the position of their grouping, the EST 2000 software then made adjustments to correct for weapon misalignment so subsequent shots will hit the target in the center, when aimed at the center. *Zeroing* refers to ability to fire five of six consecutive shots inside the COM with the newly adjusted weapon. If participants failed to group and zero within the allotted number of rounds, we did not use their data for the study, as their data would not reflect proper weapon and sight alignment.

All participants performed two main shooting tasks at both pretest and posttest. For Task 1, participants fired five rounds at the COM of a simulated target at a 175 m followed by five rounds at 300 m. The targets were stationary, and time to engage the targets were unlimited. For Task 2, a modified Advanced Rifle Marksmanship task, participants fired 50 rounds at 50 targets, ranging in distance between 35 and 300 m. There were 25 stationary targets and 25 moving targets intermixed (Table 1). Both stationary and moving targets *popped up* individually and sometimes simultaneously in pairs, and all were visible for 3 to 8 seconds. Targets appeared in random order to the shooter, and target order was the same for each shooter and visit.

Data Analysis

Weapon Firing Task 1: Accuracy and Precision Measures on 175m and 300m Targets. Using the EST 2000, we quantified weapon firing marksmanship by the number of successful shots on target and recorded shot position data. For Task 1, the EST 2000 provided the vertical (y axis) and horizontal (x axis) position of each of the five rounds fired with respect to the target's COM (provided in cm). Position location was provided by the EST 2000 for all shots, regardless of accuracy. From the position data, we calculated the accuracy and precision outcome measures detailed in the following paragraphs. Outcome measures of this kind have previously been used to quantify performance in weapon firing literature (Johnson, 2001). We added one additional precision measure, Total Path Length or TPL, which has not previously utilized in weapon firing literature, to capture shot-to-shot realignment, an important component of repeated firing.

Accuracy is a measure of how close the shot came to hitting the COM and was captured in Task 1 with three separate measurements. The first measure, Total Hit Point score, followed a point structure used by Tikuisis et al., (2002).

Table 1. Task 2 Target Description for Pre- and Posttest Weapon Firing Performance.

Target distance	Number of targets	Stationary targets	Moving target
35 m	3		X
50 mm	4	X	
60 m	2		X
75 m	5		X
100 m	5	X	
125 m	8		X
150 m	5	X	
175 m	1	X	
185 m	7		X
200 m	4	X	
250 m	3	X	
300 m	3	X	

Shots were awarded five points when landing in the *lethal zone* (the COM) and three points when landing on the target but outside the COM. Shots that missed the target were awarded zero points. The total possible score for Total Hit Points was 25 (for five shots). Total Hit Point score captured how well participants fired a shot in the designated lethal versus nonlethal zones. The second accuracy measure, Shot Group Distance from Center of Mass (DCM_{SG}), was calculated as the distance between the center of the shot group and the COM. DCM_{SG} reflected the *average error* of a participant's shot group (Johnson, 2001). The third accuracy measurement, Individual Shot Distance from Center of Mass (DCM_S), was the average distance between the individual shots of the shot group and the COM. This measure reflected the *individual error* of each shot fired (Johnson, 2001). A higher Total Hit Point score, a lower DCM_{SG}, and a lower DCM_S indicated a more accurate shot group.

Precision, a reliability measure of shot reproducibility, is defined as how consistent or *tight* the shot group was in terms of location on the target (Johnson, 2001). Precision was quantified using three separate measurements. The first precision measure, the mean radius or MR, was calculated as the overall mean distance of all shots and the center of the shot group or radial spread of the shot group (Johnson, 2001). The second precision measurement, height and width or $H + W$, was calculated as the sum of the horizontal range and vertical range of the shots on the target, indicating the horizontal and vertical spread of shot group (Johnson, 2001). TPL was the third precision measure and was the only measure to take into account shot order. TPL was defined as the sum of distances between each consecutive shot location. Each precision measure differed in terms of sensitivity to aberrant shots, with MR being least sensitive and TPL being most sensitive to aberrant shots. TPL was the only measure that gave information regarding the ability to hit the same location on a shot-to-shot basis (giving information related to shot-to-shot realignment), rather than indicating the spread of the shot group. Measuring TPL enabled researchers to capture subtleties about motor memory, giving a greater understanding of the overall degree of motor control involved in marksmanship. For all three precision measures, the lower the number, the more precise (or tight) the grouping.

Weapon Firing Task 2: Advanced Rifle Marksmanship. For Task 2, EST 2000 software data were limited to the number of successful shots that hit the target, measuring only one aspect of accuracy, at each target distance. For this Task, the software defined successful shots as those shots that made contact with the simulation target, not necessarily in the lethal zone. For the purpose of this research, due to the uneven number of targets offered at each distance (Table 1), we analyzed the overall total number of successful shots on stationary targets and the overall total number of successful shots on moving targets. Exact position data of each shot were not available.

Statistical Tools

For shooting Task 1, we used four separate 2 (Group) $\times$ 2 (Time) mixed-design multivariate analysis of variance (MANOVAs) to determine the effect of NTT on shooting performance accuracy and precision at the 175 m and 300 m static targets. We analyzed the 175 m and 300 m targets separately, since there was a resting break and repositioning between engaging the two static targets. For each target, the first MANOVA included the accuracy dependent variables of Total Hit Points, DCM_{SG}, and DCM_{S} and the independent variables of Group (NTT and Control) and Time (pretest and posttest). The second MANOVA included the precision dependent variables of MR, H + W, and TPL and the independent variables of Group and Time. We investigated significant main effects from the MANOVA with Univariate analysis of variance. We performed a post hoc analysis for significant interactions with paired *t* tests. For Task 2, a 2 (Group) $\times$ 2 (Target Type) $\times$ 2 (Time) mixed-model analysis of variance was used to analyze performance. The dependent variable for Task 2 was the Number of Successful Hits, and independent variables included Group, Target Type (Stationary and Moving), and Time. Independent *t* tests were used to determine group differences in age and time in the military service. We relied on IBM SPSS Statistics for Windows (Version 22, Armonk, NY: IBM Corp, Released 2013) software to perform the analyses. We considered a *p* value of less than .05 significant for all analyses. Data had acceptable normality with nonsignificant skewness (Tabachnick & Fidell, 2007). We applied a log transformation to the TPL measure to correct for a violation of the assumption of equal variances between the two groups from the Levene's Test.

We designated as outliers those variables that were greater or less than three standard deviations from the mean, and for this reason we removed three NTT participants and one Control participant from data analysis. In addition, one NTT and one Control participant failed to zero their weapon in the required number of rounds, and thus, their data were also excluded from further analyses. Finally, we removed one additional Control group member due to self-reported changes in their eyeglass prescription from pre - to post-testing sessions.

Results

Sample Description

Of the 41 active duty military participants who completed the study, 18 were randomly assigned to the NTT group ($M_{age} = 31$, $SD = 9$ years; $M_{time\ in\ service} = 9$, $SD = 7$ years; 16 males and 2 females) and 23 to the Control group ($M_{age} = 26$, $SD = 8$ years; $M_{time\ in\ service} = 7$; $SD = 6$ years; 17 males and

6 females). Neither age nor time in service was significantly different between the two groups.

Effect of NTT on Accuracy and Precision at 175 m: Weapon Firing Task 1a

For the shooting task at the 175 m Target, participants who went through NTT improved in precision, but not accuracy, compared with the Control group (see Tables 2 and 3; Figure 1). Table 2 shows the Weapons Firing Task 1a MANOVA results for all accuracy and precision variables. For the three accuracy measures (Total Hit Points, DCM_{SG}, and DCM_S), there were significant main effects of Group and Time (Table 2, Figure 1A to C). The interaction between Group and Time was not statistically significant for Weapons Firing Task 1a accuracy variables. The univariate analyses revealed that the NTT group scored a higher amount of Total Hit Points overall compared with the Control group (Table 3, Figure 1A). For the three precision measures (MR, H + W, and TPL), there was a significant Group and Time interaction effect but no significant main effect for Group or Time. Further univariate analysis revealed that all three precision variables were significantly dependent upon the interaction between Group and Time (Table 3, Figure 1D to F). A post hoc analyses with paired *t* tests showed that changes (i.e., improvements) between pre- and posttest were significant for the NTT group for MR, H + W, and TPL measurements ($p = .041$, $p = .047$, and $p = .004$, respectively) but were not significant for the Control group.

Table 2. MANOVA for the Marksmanship Accuracy and Precision Variables While Aiming for the Task 1a 175 m Target.

	175 m target MANOVAs		
	Wilks Lambda *F*, *df*(1,3)	*p*	Effect size, η_p^2
Accuracy (Total Hit Points, DCM_{SG}, DCM_S)			
Group	6.02	.002**	.376
Time	5.09	.006**	.337
Group × Time	0.27	.844	.027
Precision (MR, H+W, TPL)			
Group	0.27	.894	.020
Time	1.31	.281	.118
Group × Time	3.72	.015*	.292

Note. MANOVA = multivariate analysis of variances; MR = mean radius; H + W = height and width; TPL = Total Path Length; DCMSG = Shot Group Distance from Center of Mass; DCMS = Individual Shot Distance from Center of Mass.
*$p < .05$. **$p < .01$.

Table 3. Univariate ANOVAs for the Marksmanship Accuracy and Precision Variables While Aiming for the Task 1a 175 m Target.

	F, *df*(1,32)	*p*	Effect size, η_p^2
	175 m target univariate ANOVAs: accuracy		
Total hit points			
Group	5.88	.021*	.155
Time	9.35	.004**	.226
Group × Time	0.78	.385	.024
DCM_{SG}			
Group	1.03	.318	.031
Time	9.51	.004**	.229
Group × Time	0.73	.398	.022
DCM_S			
Group	0.97	.332	.029
Time	11.21	.002**	.259
Group × Time	0.40	.385	.024
	175 m target univariate ANOVAs: precision		
MR			
Group	0.63	.432	.019
Time	3.92	.056	.109
Group × Time	6.50	.016*	.169
H+W			
Group	0.63	.432	.019
Time	4.14	.050	.115
Group × Time	4.85	.035*	.132
TPL			
Group	0.86	.500	.014
Time	2.01	.154	.063
Group × Time	11.89	.001**	.291

Note. ANOVA = analysis of variance; MR = mean radius; H + W = height and width; TPL = Total Path Length.
Note. ANOVA = analysis of variance; DCMSG = Shot Group Distance from Center of Mass; DCMS = Individual Shot Distance from Center of Mass; MR = mean radius; H + W = height and width; TPL = Total Path Length.
*$p < .05$. **$p < .01$.

Effect of NTT on Accuracy and Precision at 300 m: Weapon Firing Task 1b

For the shooting task at the 300 m target, there were no significant pretest to posttest differences on weapons firing performance for participants in the NTT group compared with the Control group. For all three accuracy measures (Total Hit Points, DCM_{SG}, and DCM_S), and all three precision measures (MR, H + W, and TPL), there were no significant main effects for Group, Time, or the Group and Time interaction.

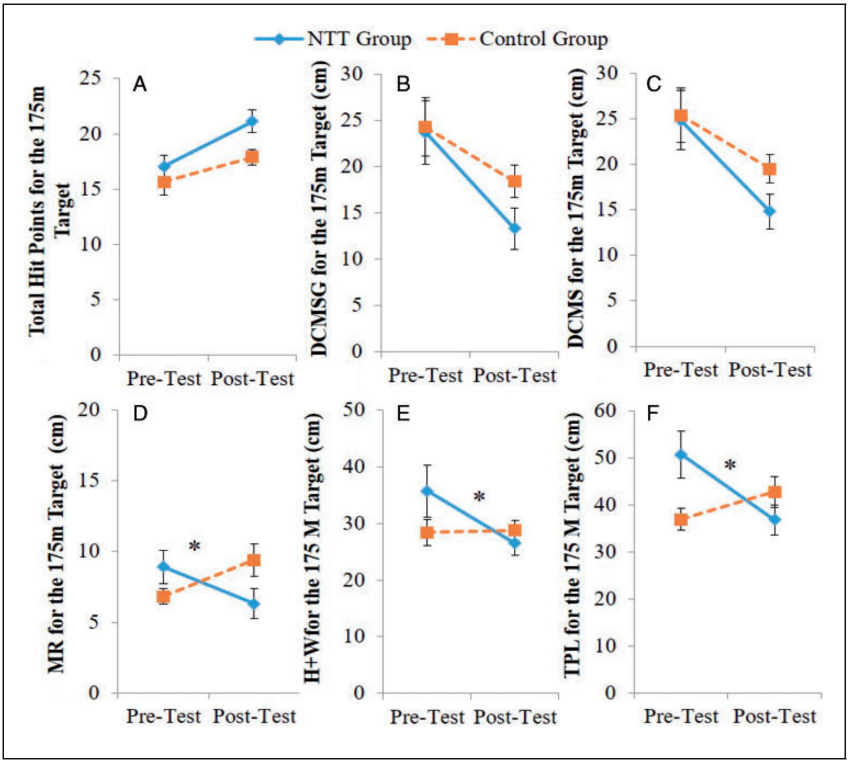

Figure 1. Effect of NTT for Firing at a 175m Target. Mean standard error (SE) for marksmanship variables for Task 1a: 5 rounds, aimed at a stationary 175m target task. The active NTT group and the Control group did not significantly differ in changes between pre- and posttest for the accuracy measures of Total Hit Points, DCMSG, and DCMS (A-C). There was a significant interaction between Group and Time for precision measures of MR, H + W, and TPL. The NTT group significantly improved precision measures from pre- to posttests (D-F). The Control group did not significantly change pre- to posttest. NTT = neurocognitive temporal training; DCMSG = Shot Group Distance from Center of Mass; DCMS = Individual Shot Distance from Center of Mass (DCMS); MR = mean radius; H + W = height and width; TPL = Total Path Length.

Effect of NTT on the Advanced Rifle Marksmanship: Weapon Firing Task 2

Both the NTT group and the Control group significantly improved in Task 2 shooting performance in the posttest as compared with the pretest (Table 4, Figure 2). The total number of successful hits for Task 2 was significantly dependent upon Time and Target Type but was not significantly different depending upon Group or any interaction between Group, Target Type, or

Table 4. Results for the Mixed-Model ANOVA for the Marksmanship Variables for the Task 2: Advanced Rifle Marksmanship.

Total successful hits	F, $df(1,64)$	p	Effect size, η^2
Group	0.76	.386	.012
Time	9.71	.003**	.132
Target type	49.28	.000**	.432
Group × Time	0.78	.380	.012
Group × Target Type	0.01	.921	.000
Time × Target Type	0.17	.679	.003
Group × Time × Target Type	1.67	.201	.025

**$p < .01$.

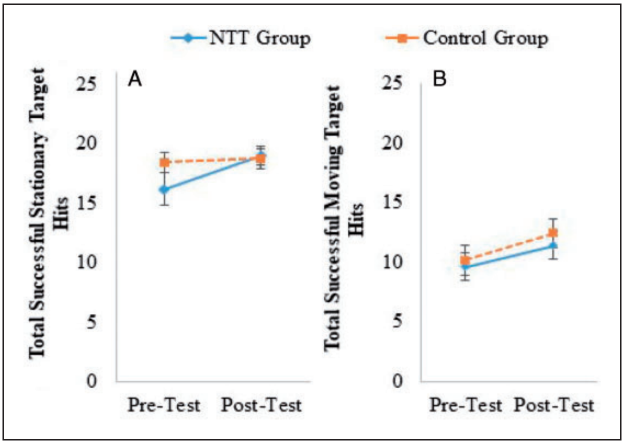

Figure 2. Effect of NTT for Firing at Timed Moving and Stationary Targets. Mean ± SE for total successful stationary and moving hits for Task 2: Advanced Rifle Marksmanship. The active NTT group and Control group did not significantly differ from one another in changes between pre- and posttest for either stationary (A) or moving target hits (B).
NTT = neurocognitive temporal training.

Time (Table 4). For Time, Task 2 performance was significantly better in the posttest as compared with the pretest, and both groups were significantly better when engaging the stationary targets as compared with the moving targets (Table 4, Figure 2).

Discussion

Overall, we found a positive effect of NTT on participants' marksmanship in terms of precision (MR, H + W, and TPL) but not accuracy (compared with the Control group). This improvement was significant for the closer range, 175 m stationary target for shooting Task 1. Thus, our primary hypothesis was only partially supported. Improved precision indicates those who underwent NTT were more consistent in their marksmanship shooting, compared with Controls when aiming at close range, stationary targets (Figure 1D to F). There were no significant differences for any measure in pre- to posttest for either group with the Task 1 300 m stationary target or with the Advanced Rifle Marksmanship task.

The implications of these findings are important for future marksmanship training, especially in terms of marksmanship precision. Precision has been stated to be a true measure of volatility, with errors in precision being more difficult to correct than errors in accuracy (Chapanis, 1999; Johnson, 2001). Since NTT is designed to improve rhythm and timing, it could be that in the case of weapon firing, NTT assists in a smooth transition between initial sighting, shots, shot realignment, and perhaps in motor memory. Improving realignment capabilities and motor memory could be why training with the NTT had a greater improvement effect on participants' precision measures over their accuracy measures. Furthermore, NTT training involves practicing coordinated visual–motor actions, and developing an internal sense of timing and rhythm, aided by visual and auditory biofeedback. Therefore, although not accessed in this study, NTT training may expedite the time it takes for military personnel to reach a proficient, consistent level of marksmanship in terms of precision.

While both precision and accuracy are considered important in marksmanship training, precision may be less emphasized than accuracy in training, thus leaving greater opportunity for improvement to be observed in the precision measures in this study. This can be accomplished by high accuracy and low precision (larger shot group with hits closely surrounding the center of the target). However, training in consistency (precision) in accuracy should also be addressed. Therefore, it might be expected that accuracy develops more rapidly during marksmanship training, than precision due to the training focus itself, thereby leaving greater room for the improvement in precision. Marksmanship is a core skill for military personnel, especially among troops engaging in ground operations. Even small improvements in marksmanship have the potential to impact life and death on a battlefield.

NTT tools, such as the IM, have previously been shown to impact cognitive function and motor control. Motor control and cognitive function are key elements in marksmanship (Chung et al., 2004). There are several working mechanics to how NTT training yielded precision improvements via improved motor control and cognitive function, as detailed in the following paragraphs.

Rhythmic training assists in temporal information processing and improves a person's mental internal clock (Buhusi & Meck, 2005; Taub et al., 2007). Researchers have proposed that improving one's internal clock via NTT has effects on neural efficiency and improves the ability to transfer information during motor and cognitive tasks (Marsh & Hicks, 1998; McGrew, 2013;

Rammsayer, 2007). Improvement in neural efficiency appears not only to influence the specific rhythm and timing task trained by NTT but also creates a cross-training effect to the rhythm and timing of other motor and sensory coordination tasks (Sommer, 2014). For example, NTT improved planned motor control in sporting activities (Kim & Ridgel, 2019; Rönnqvist et al., 2018; Sommer, 2014; Sommer et al., 2014) and stroke patients (Beckelhimer et al., 2011; Malcolm et al., 2009; Yu et al., 2017). NTT has also improved control over unintentional motor movements in children with attention deficit hyperactivity disorder (Cosper et al., 2009; Shaffer et al., 2001). Therefore, even though the motor movements involved in marksmanship appear at first glance to be unrelated to those cyclic movements targeted during NTT (i.e., clapping or stepping to a rhythm), NTT improves a person's timing, which governs rhythm and timing for a myriad of seemingly unrelated sensory–motor tasks (McGrew, 2013; Sommer et al., 2014). This improved internal timing structure could have aided volunteers' ability to coordinate between the important timing elements of target engagement such as aiming, obtaining a proper sight picture, breathing control, squeezing triggers, and resetting for subsequent shots.

In addition, internal timing is important in executive functioning (Brown, 1997, 2006) and improvement in internal timing via NTT could lead to positive effects on working memory and the ability to focus on detail and maintain task attention (McGrew, 2013). NTT has been shown to improve attention (Baker, 2014; Nelson et al., 2013; Shaffer et al., 2001), memory (Nelson et al., 2013), behavioral control (Shaffer et al., 2001), and other related cognitive functions (Shaffer et al., 2001; Taub et al., 2007). Therefore, we suggest that NTT may have positively influenced the cognitive processes involved in marksmanship performance by increasing participants' attention to the verbal instructions of each task, concentration during the tasks, and/or recall of basic shooting techniques learned previously during initial weapon training. Furthermore, if NTT was paired earlier in the weapons firing learning process, there might be an even greater positive impact of NTT on weapon firing. Administering NTT during initial training of weapons firing in basic training could assist Soldiers in learning basic military foundational skills.

NTT may also impact sensorimotor system synchronization and improve feedforward planning. It has been proposed that timing and rhythm training may assist in creating spatiotemporal maps across the motor system (Sommer et al., 2014) and streamline information processing from auditory and visual cues to the motor system in order to allow for the fine tuning of movement. Using NTT to improve this feedback–feedforward system, participants may have improved their ability to make rapid movement adjustments (Malcolm et al., 2009; Sommer et al., 2014) thus improving the coordination of fine motor movements.

Improving sensory–motor synchronization via NTT could also have impacted weapons firing precision by improving individuals' integration of sensory feedback and feedforward control, which is important in coordinating motions such as weapon alignment and timing of trigger squeeze (Ghez et al., 1990; Proske & Gandevia, 2012; Scholz et al., 2000). Since precision (or consistency) of target acquisition was improved following NTT, it is possible that individuals in this group were able to reproduce their previous shot alignment more readily than those in the Control group. This was especially evident in the significant improvement seen in the reduced TPL precision measure. TPL is estimated to be a more fine-tuned precision measure for shot-to-shot variability. Improvement in TPL for those in the NTT group included not only reduction in the overall spread of the shot group, but also a reduction in the distance between each shot and the subsequent shot. This suggests that individuals were able to be more consistent in target acquisition during the realignment period between each shot execution and, potentially, indicating improved recall of their positional previous shot alignment.

Although we found a significant positive effect only on precision at a close range target, our finding suggests that it is possible to augment marksmanship training with NTT. Given the outcomes of our study and those reported previously in literature, training with NTT tools, such as the IM, may have a positive impact on service members' motor control and cognitive function, impacting marksmanship and having a potential impact on other tasks as well.

Limitations

We acknowledge several limitations of this study. Due to participant availability (e.g., temporary duty elsewhere), individual training sessions with the NTT for the NTT group were, in some cases, separated by a significant time gap (~1–2 month) contradicting the suggested time course for NTT (Libkuman et al., 2002; Sommer, 2014). Therefore, participants in the NTT group averaged 64 days to finish the study, whereas those in the Control group averaged 37 days to complete the study. Participant availability also impacted attrition for many participants who were unable to remain in the study. The number of participants to complete this study was less than the desired number from our a priori statistical power analysis ($N = 60$), and this may have increased the possibility of Type 2 errors (i.e., failing to find effects that may have been evident with a larger sample). These limitations were unavoidable in a study with active duty soldiers, as their unit's mission takes priority. An additional complication was participant fatigue due to sleep loss, as a number of participants were also attending advanced individual training that required a rigorous and demanding schedule. Furthermore, our Control group assumed normal duties between pre- and post-testing and did not undergo any alternative training for the study (not considered an *active control group*). Future research of this kind should include an active Control group such as playing a self-paced video game that does not target training in rhythm and timing, perhaps one that would be similar to that used in previous studies investigating IM use for improving motor control and cognitive function in children with Attention Deficit Hyperactivity Disorder (ADHD) (Shaffer et al., 2001).

Significant improvement following NTT in weapon firing performance in our study was limited to the stationary 175 m target and did not significantly impact performance on the 300 m stationary target or the Task 2, modified Advanced Rifle Marksmanship task. This could be due to task design. Since proper alignment and engagement of the 300 m stationary target require a very high degree of fine motor control, NTT may not sufficiently affect this degree of fine motor skill. For Task 2: Advanced Rifle Marksmanship participants were only required to hit the target with no concern to being particularly precise or accurate. Participants may have improved shot placement on the target, but position data on the target were not provided by the software for this task. Overall, we observed a consistent trend toward improvement for both of these tasks for the NTT group, though this improvement was not significantly different from that of the Control group.

Although all participants in the study received prior training in weapon firing, there may be some practice effect regarding the weapon simulator for both groups. We observed that both groups appeared to have improved (non-significantly) on accuracy for the stationary 175 m target and in the moving targets during the Advanced Marksmanship task. In future studies, a practice session held prior to baseline might reduce practice effects with the simulator. This could also reduce the observed group baseline differences, increasing the potential for the NTT group to have improved by chance (Type 1 error), regardless of training. Implementing a practice test would ensure that improvement in weapon firing was due to the NTT intervention and not to group differences at baseline or a practice effect with the simulator.

Conclusions

NTT had a significant impact on participants' precision marksmanship scores when firing at a self-pace to a close range stationary target. However, there was no significant NTT benefit on weapon firing *accuracy* at the close range target, on weapon firing measures at the long distance stationary target, or on firing measures during the mixed-distance pop-up moving and stationary targets. While our findings were mixed, some precision improvements may have occurred due to improved cognitive and motor control via enhanced mental internal clock and/or sensory–motor synchronization. These results show a promising NTT training effect on weapon firing precision, and this study utilized a unique measure, TPL, in addition to MR and H + W, to quantify marksmanship precision. Calculating TPL allowed for greater insight into marksmanship shot-to-shot variability and in tracking individuals' realignment capabilities. We recommend further research on both NTT and TPL to further clarify the impact of this training and new assessment method on military weapon firing.

Highlights

- Neurocognitive temporal training improved weapon firing precision, but not accuracy when acquiring a stationary target set at a 175 m distance.
- Neurocognitive temporal training had a promising effect on marksmanship precision and future research is needed to clarify the overall benefit of such training on military weapon firing.
- A unique measure calculating shot-to-shot repeatability of weapon firing precision, called total path length (TPL) of the shot group, was utilized to capture shot-to-shot variability.

Author's Note

The views expressed in this article are those of the authors and do not reflect the official policy or position of the Department of the Army, Department of Defense, or the U.S. Government.

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