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ASSESSMENT OF COGNITIVE COMPONENTS OF DECISION MAKING WITH MILITARY VERSIONS OF THE IGT AND WCST

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The U.S. Army is focused on improving leader decision making, yet little is known as to how military officers develop optimal decision making. Two key components of optimal decision making are reinforcement learning and cognitive flexibility. Thirty-four military officers completed military versions of two standard cognitive assessments, the Iowa Gambling Test and the Wisconsin Card Sorting Task, while their eye movements were tracked. Results indicated that the military versions of these tasks successfully provided objective assessments of reinforcement learning and cognitive flexibility. Preliminary analyses of eye movements provide insights into the subjects' decision strategies. Training implications of the results are discussed.

INTRODUCTION

As the U.S. Army focuses on enhancing leader development and decision-making to improve the effectiveness of forces in combat, the importance of understanding how to effectively train decision-makers and how experienced decision-makers arrive at optimal or near optimal decisions has increased (Lopez, 2011). Two cognitive characteristics necessary for military personnel to reach optimal decision making are reinforcement learning, the ability to learn from trial and error, and cognitive flexibility, the ability to recognize when the rules have changed or that the current strategy no longer works (Vartanian & Mande., 2011). Although many laboratory tests of reinforcement learning and cognitive flexibility exist, these tasks may not necessarily capture military decision making due to the high stakes and uncertain environment in which military decisions are made. Assessment tools that leverage wargames, simulations of realistic military scenarios, to evaluate these two cognitive characteristics are needed. We determined that two common psychological tests that measure reinforcement learning and cognitive flexibility, the Iowa Gambling Task (IGT) (Bechara et al., 1994) and the Wisconsin Card Sorting Task (WCST) (Grant & Berg, 1948) could be modified to provide a more realistic military context as a first step towards understanding military decision making.

The IGT was developed to measure prefrontal damage (Bechara et al.1994). Persons with prefrontal damage tend to have difficulty detecting the long-term consequences of their decisions and actions. In this task, subjects receive a loan of $2,000 of play money and are asked to make a series of decisions to maximize the profit on the loan. Each decision entails selecting one card at a time from any of four available decks of cards (decks A–D). All cards give money and some cards also issue a penalty. Decks differ in the amount of money given on a single trial ($50 or $100) as well as the frequency and severity of penalties ($0 to $1250). Healthy subjects should learn through reinforcement learning which decks have the best long term payoffs (decks C and D) (Bechara et al., 1994; Steingroever et al., 2013). Main measures of decision performance are total money won and an advantageous selection bias (the proportion of good decks selected minus the proportion of bad decks selected).

The WCST taps the working memory, shifting and inhibition components of executive function (Grant & Berg, 1948). Subjects view five cards, one card displayed at the top center of the screen, the remaining four displayed across the bottom of the screen. Each card contains symbols that vary in number, shape, and color. Over several trials, participants try to figure out the matching rule that will correctly match the card on the top of the screen with one of the four cards at the bottom of the screen. Unbeknownst to subjects, the matching rule changes once they have 10 consecutive correct matches. For example, after 10 consecutive correct matches based on the color of the symbols, the matching rule could then change to the number or shape of the symbols. Thus, subjects must not only learn and maintain in working memory the correct matching rule while inhibiting irrelevant stimuli, but also exhibit cognitive flexibility in detecting when the rule has changed (Grant & Berg, 1948). The task is complete when subjects either successfully complete two rounds of each matching rule or 128 trials. Main performance measures include total percent correct, percent of perseverative responses (the number of incorrect responses that would have been correct for the previous matching rule), the number of matching rules achieved and total number of trials completed (fewer indicates better performance).

The purpose of this study was to modify two existing cognitive assessments that measured reinforcement learning and cognitive flexibility in order to assess active duty military officers' decision making behavior on these tasks. The convoy task, in which subjects incur or receive enemy or friendly damage is analogous to the IGT, whereas the map task is modified from the WCST. In order to gain further insight into how military decision makers value information, eye tracking data was captured for each subject during each task. Numerous studies indicate that eye movement data via eye tracking technology can provide valuable insights into subjects' attention allocation patterns and underlying cognitive strategies during real-world tasks (Kasarskis et al., 2001; Marshall, 2007; Sullivan et al., 2011). We predicted:

1) Convoy task: Subjects will demonstrate reinforcement learning by having a positive advantageous selection bias, and by correctly reporting which routes are the safest and most dangerous.

2) Map task: Subjects will demonstrate cognitive flexibility by having low rates of perseverative responses, completing at least 3 matching rules, and having at least 70% correct trials.

3) Exploratory analyses from the eyetracking data will provide insights into subjects' prioritization of information.

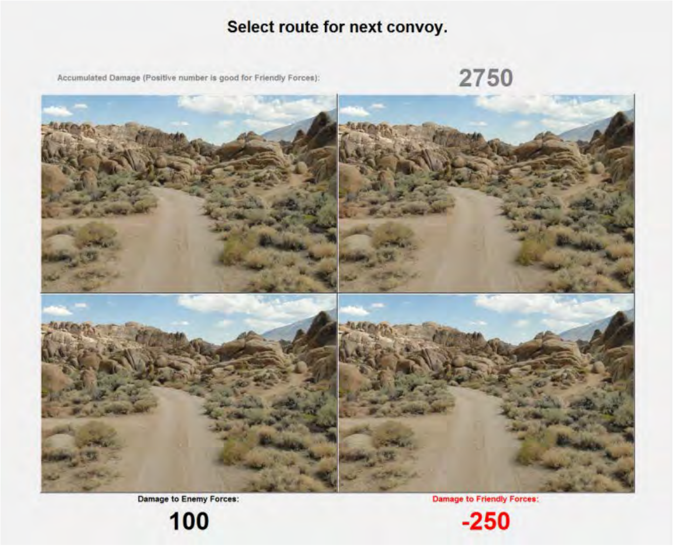
METHOD

Participants

The study collected data from 34 military officers from all branches of service: 9 U.S. Army, 11 U.S.M.C., 10 U.S. Navy, 3 U.S. Coast Guard, and 1 U.S. Air Force. Mean age was 35.11 years (SD 4.9) with a mean time in service of 12.7 years (SD 4.42) of which the average time deployed was 19.57 months (SD 12.12) (note one subject did not report their deployment time). Of the 31 subjects with deployment experience, the mean time since their last deployment was 37.98 months (SD 25.18) and 19 of those deployments were to ground combat zones (Iraq or Afghanistan). A majority of the subjects, n=24, served as staff officers during their most recent deployment. The majority of the subjects were male (30 males, 4 females) and the majority of subjects possessed 20/20 or better visual acuity (n=29).

Measures

Convoy task (Modified IGT). On a computer monitor, subjects see four identical routes (Figure 1). They are instructed that over several trials, they must decide on which route to send convoys and based on each decision, they may incur enemy damage (good outcome) or receive friendly damage (bad outcome). They also are instructed that the pictures of the routes are identical. Their goal is to achieve the highest possible total damage score by maximizing enemy damage and minimizing the friendly damage accrued over all trials. These routes have the same payout format as the decks of the original IGT (see Table 1): routes 3 and 4 are considered good; routes 1 and 2 are considered bad. Subjects receive immediate feedback on each trial on the current total damage score, and enemy damage and friendly damage that occurred on that trial. Based on pilot data, we extended the number of trials from 100 (as in the IGT) to 200, as pilot subjects needed more than 100 trials to detect the long-term payout. Decision performance variables are measured using typical IGT variables: total damage score, frequency with which each route was selected, an advantageous selection bias (proportion of good routes selected minus the proportion of bad routes selected).



Select route for next convoy.

Accumulated Damage (Positive number is good for Friendly Forces): 2750

Damage to Enemy Forces: 100

Damage to Friendly Forces: -250

Figure 1 Screenshot of convoy task. Route 1 is the top left route; route 3 is the bottom left route. On this particular trial, the subject selected route 1 and received 100 enemy damage and - 250 friendly damage.

Table 1 Amount of enemy damage accrued on each trial by route and script of the payout schedule for friendly damage. Here, on the 2nd time that a subject selected Route 1, they would receive -250 in friendly damage.

	Route 1	Route 2	Route 3	Route 4
Enemy damage	100	100	50	50
Friendly damage				
Selection				
1	-350	0	-50	-250
2	-250	-1250	-50	0
3	0	0	0	0
4	-200	0	-50	0
5	0	0	0	0
6	-300	0	-50	0
7	0	0	0	0
8	-150	0	-50	0
9	0	0	0	0
10	0	0	0	0
11	-350	0	-50	-250

Map task (Modified WCST). On a computer screen, subjects see five maps: one map is at the top center of the screen; the remaining four are across the bottom of the screen. Each map contains military graphic control symbols that vary in meaning, color and shape (FM 1-02, Operational Terms and Graphics, United States, 2004). The symbols fall into three different categories: friendly force (blue symbols), type of intended action, such as ambush (black symbols), and type of enemy force (red symbols). Within each category, there are four different possible symbols, each indicating a particular type of friendly force, intended action, or enemy force. Subjects are instructed to match one of the four lower maps to the top one over an unknown number of trials. As in the original WCST, the subject is not told that the matching rule will change following 10 consecutive correct matches. The task is completed when either the subject has successfully completed two rounds of each matching rule for a total of six rounds or until they have completed 128 trials. One small modification from the WCST is that not all maps have all three types of symbols and subjects can match maps based on the absence of a symbol (see Figure 2). Decision performance variables are measured using typical WCST variables: Total number of trials (fewer indicates better performance), percent correct, percent perseverative responses (percent of trials in which subjects incorrectly used the same matching rule as in their previous selection), number of trials to complete the first matching rule, and number of rules achieved (max number = 6)

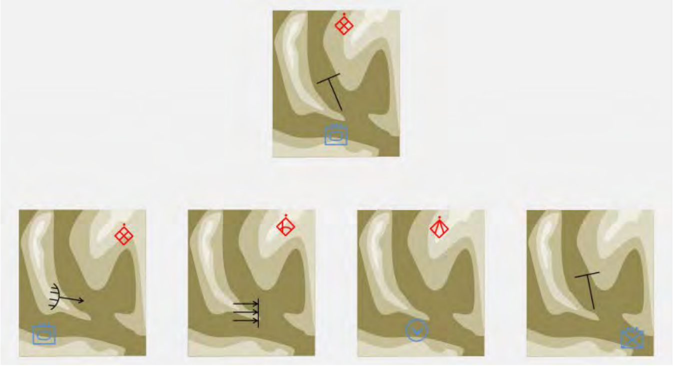


Figure 2 Screenshot of a trial in the map task. On this trial, the subject should sort on intended action graphics (black), and therefore should select the rightmost map.

Demographics Survey. Demographic information regarding age, gender, service branch, rank, and deployment experience were captured in the demographic survey.

Post-task survey. The post-task survey included questions regarding a ranking of the routes in the convoy task from safest to most dangerous, decision strategies, and how quickly they noticed that the matching rule had changed in the map task.

Visual acuity. The Snellen eye chart was administered to verify that all subjects had adequate visual acuity to see the icons and text on the computer screen.

Eyetracking. Subjects' eye movements were measured while they completed the tasks with the use of the FaceLAB eyetracking equipment. Eye movements were measured in number of fixations in each ROIs and percent of time subjects looked at each ROI.

Equipment

The equipment used in this study consisted of a laptop computer, two eye tracking stereo cameras, and a desktop computer. The laptop ran FaceLAB 5.0.7 30 software on a Windows XP operating system. The stereo cameras supplied data to FaceLAB on the laptop. The desktop computer ran the EyeWorks data collection suite on the Windows 7 operating system. The stereo cameras used 12 mm lenses to detect infrared light reflected off the subjects' eyes and face to monitor the position of the head and direction of the eye gaze. This data was fed from the laptop to the EyeWorks Record software on the desktop.

Procedures

This study was approved by the institution's IRB. Subjects first completed the approved consent form, followed by the demographic survey, visual acuity test and eye tracking calibration. Once all calibration steps were satisfied, subjects completed the convoy task and then the map task while their eye gaze was monitored. Finally, subjects answered the post task survey questions.

RESULTS

Convoy task

All analyses utilized a two tailed .05 alpha level. Although mean total damage score was above 2000 and the advantageous selection bias was positive, results were not significant (p's >.05) (see Table 2). As would be expected, total damage score was negatively correlated with the number of high friendly damage, (r = -.87, p < .001), as well as frequency of friendly damage (r =.39, p < .05). Officers also successfully distinguished between safe and dangerous roads, (χ^2 (3) = 23.63, p = .005). In a question asking subjects to rank order the routes from safest to most dangerous, 42% reported route 4 as the safest followed by route 3 (27%), whereas 42% of subjects reported route 1 as the most dangerous, followed by route 2 (33%).

Table 2 reveals that subjects benefited from having 200 trials instead of 100. Results from paired t-tests indicated that the advantageous selection bias improved in trials 101 – 200 compared to trials 1-100 (t(33) = 2.87, p = .007) and a trend for people to learn to avoid high friendly damage (t(33) = 1.85, p =.07) in the second half of the wargame. Improvements in decision performance were due to the decrease in route 2 selection (t(33)=2.70, p = .01), and increase in route 3 selection (t(33) = 1.87, p = .07). Improvements in decision performance over time are captured in Figure 3, which indicates that only after about trial 130 did subjects' total damage, on average, exceed the baseline of. Figure 3 also illustrates the large range of variability in decision performance.

Table 2 Descriptive statistics of convoy task decision variables for the 1st 100 trials, trials 101 – 200, and all 200 trials

Performance variable	First 100 trials Mean (sd)	Trials 101-200 Mean (sd)	All 200 trials Mean (sd)
Total damage score	2077.94 (883.96)	N/A	2402.94 (1725.69)
No. trials with friendly damage	24.5 (6.46)	26.65 (7.44)	51.15 (11.05)
No. trials with heavy friendly damage	3.62 (1.39)	3.06 (1.72)	6.68 (2.59)
Route selection frequency (%)			
Route 1	13.82 (7.88)	12.56 (8.59)	13.19 (7.27)
Route 2	38.91 (14.30)	30.74 (16.84)	34.82 (12.82)
Route 3	21.62 (16.59)	28.77(20.63)	25.19 (15.02)
Route 4	25.64 (12.93)	27.94 (18.48)	26.79 (12.39)
Adv. selection bias	-5.47 (30.73)	13.41 (41.57)	7.94 (62.38)

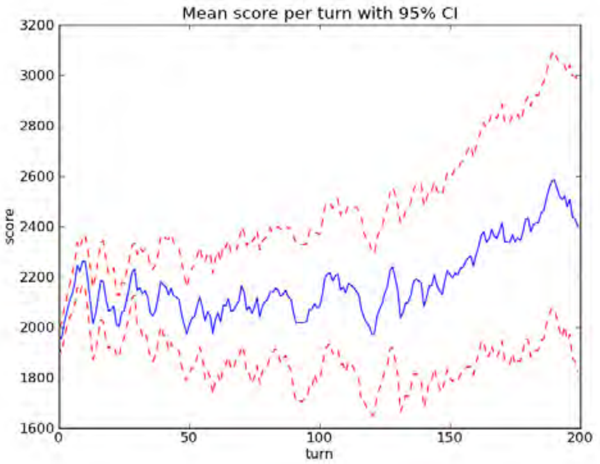


Figure 3 Mean total damage score per trial (blue line) with 95% CI (red dotted line).

Finally, preliminary eyetracking analyses revealed that subjects spent most of the time looking at the routes and relied more heavily on friendly damage information than enemy or total damage (see Table 3).

Table 3 Mean number of fixations and percent time spent in each convoy task ROI.

ROI	Mean (sd), %
Enemy damage	318.53 (355.09), 1.74%
Friendly damage	1545.66 (1678.50), 9.15%
Total damage	141.94 (373.10), 1.03%
Routes	15565.41 (8001.44), 88.56%

Map task results

Results indicate that most subjects were able to determine the matching rules and that the matching rule changed periodically. Total percent correct was not significantly different from 70% (95% CI: 59.81% – 70.58%). Subjects completed an average of 3.21 matching rules (95% CI: 2.53 – 3.88). When subjects committed an error, they tended to be non-perseverative errors: On average, non-perseverative errors occurred on 33.56% (sd = 16.46%) of all trials, whereas perseverative errors occurred on 10% (sd = 8.79%) of all trials. Four subjects never completed the first matching rule. In the post task questionnaire, 44% reported that they “immediately” recognized that the matching rule had changed, 29% “after a few trials,” 15% “after several trials,” and 12% “did not realize matching rule had changed.” There was a positive correlation between how long it took subjects to realize that the matching rule had changed and the total number of trials completed ($r = .46$, $p < .05$) and a negative correlation between this self-reported variable and percent of correct trials ($r = -.53$, $p < .05$). Table 4 outlines subjects’ performance on the main decision performance variables.

Table 4. Descriptive statistics of map task decision variables.

Performance variables	Mean (sd) median, range
No. trials	119.35 (16.52) 128, 76 – 128
% correct	65.19 (15.43) 68.75, 36.72 – 86.25
No. Perseverative responses	11.82 (11.12) 9, 0 – 37
No. Non-perseverative errors	41.85 (22.52) 38, 8 – 81
No. trials to complete 1^{st} rule (n = 30)	42.9 (28.95) 34, 14 – 121
No. categories achieved	3.21 (1.94) 4, 0 – 5
Failure to maintain set	2.32 (1.49) 2, 0 – 5

Preliminary eyetracking results indicate that subjects spent the majority of the time looking at the example card at the top of the screen, and then appear to spend more time looking at the cards in the center of the screen (cards 2 and 3) than cards on the farthest sides of the screen (cards 1 and 4) (see Table 5).

Table 5 Mean number of fixations and percent time spent in each map task ROI.

ROI	Mean (sd), %
Example card	9289.55 (5372.24), 46.95%
Card 1	1360.32 (1146.73), 6.12%
Card 2	3115.29 (2300.53), 14.00%
Card 3	4525.81 (3026.41), 21.77%
Card 4	2425.58 (1434.77), 11.16%

DISCUSSION

Overall, results indicate that the modified tasks successfully captured reinforcement learning and cognitive flexibility. Results from the convoy task were consistent with other studies in which healthy adults completed the IGT (Steingroever et al, 2013). Although the total damage score and advantageous selection bias results were not significant, subjects correctly reported which routes were safe and which were dangerous. Subjects' score on the modified IGT benefited from the additional 100 trials beyond the standard IGT protocol. Subjects’ advantageous selection bias significantly increased due to a shift in route selection patterns, potentially attributable to the occurrence of reinforcement learning. Additionally, preliminary eyetracking results indicate that subjects tended to prioritize information regarding friendly damage over information regarding total damage and enemy damage scores in making their decisions, highlighting the potential impact of the military context. Also consistent with previous studies of the IGT (Steingroever et al , 2013), all convoy measures showed large amounts of variability, suggesting that individual differences occur even among healthy subjects.

Results from the map task were somewhat lower than what is typically found on the WCST for healthy subjects (Shan et al, 2008). However, subjects' perseverative response rates were relatively low, indicating that errors were not due to lack of cognitive flexibility. One reason that subjects may not have performed as well as predicted is because subjects' military experience actually may have made it harder for them to detect the matching rule. Unlike the original WCST, the symbols in the map task are meaningful: each map can be 'read' as a sentence by experienced military personnel: some type of friendly force should do an intended action upon an enemy force. Thus, these experienced military officers may have attempted to match the maps based on meaning, rather than simply on color and shape.

This work holds several future directions that can inform and increase the efficiency of training designed to improve military decision making performance. As mentioned above, a large range of variability in decision performance occurred in both tasks. Thus, one future direction is to examine individual differences in decision performance and prioritization of information. For example, do differences in cognitive function, such as working memory or visual processing speed, explain some of the variability in decision performance in the military decision problems? Additionally, can eye movement patterns predict decision performance? Finally, results from the convoy task demonstrate that at some point over the course of the 200 trials, subjects transitioned from exploring different routes to figuring out each routes' long term damage payout and exploiting that knowledge. By looking at decision and eye movement data on a trial by trial basis, can the moment in which subjects start to exploit their knowledge be pinpointed? Future work will include increasing the complexity of the decision making setting by analyzing decision makers' performance in sequential decision making tasks with delayed rewards and more noisy wargame settings.

Summary

Wargames are a preferred method of training military personnel to make optimal military decisions. However, wargames typically are not assessed objectively and may not focus on training two cognitive functions necessary for optimal decision making: reinforcement learning and cognitive flexibliity. The purpose of this study was to take the first steps to bridge the gap between the study of decision making ability in the field of cognitive psychology and the study of decision making in a military setting. The use of well known objective assessments to assess the effectiveness of training designed to improve reinforcement learning and cognitive flexibility shows great potential. Results demonstrate successful modification of the IGT and WCST into a military context. Future directions focus on explaining individual differences in decision performance and identifying the moment in which subjects' transition from exploration of the environment to exploitation of knowledge obtained about the environment. Future studies will examine military decision making performance in sequential decision making tasks with delayed rewards and more realistic military wargame scenarios.

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