Acta Psychologica 139 (2012) 146–158

Contents lists available at SciVerse ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

Performance gains from directed training do not transfer to untrained tasks

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ARTICLE INFO

Article history:
Received 25 February 2011
Received in revised form 1 November 2011
Accepted 7 November 2011
Available online 30 November 2011

PsycINFO code:
2340

Keywords:
Directed training
Performance gains
Transfer of training

ABSTRACT

Given the increasing complexity of the tasks and skills needed in modern society, developing effective training strategies is of tremendous practical importance. Furthermore, training that improves performance of both trained and untrained tasks would be highly efficient. In the present study, we examined how directed training contributes to skill acquisition, and more importantly, to engendering transfer of training to untrained tasks. Participants learned a complex video game for 30 h (Space Fortress, Donchin, Fabiani, & Sanders, 1989) using one of two training regimens: Hybrid Variable-Priority Training (HVT), with a focus on improving specific skills and managing task priority, or Full Emphasis Training (FET) in which participants simply practiced the game to obtain the highest overall score. We compared game performance, retention of training gains, and transfer of training to untrained tasks as a function of the training regimen. Compared to FET, HVT learners reached higher levels of mastery on the game and HVT was particularly beneficial for initially poor performing participants. This benefit persisted seven months after training. However, contrary to expectation, both HVT and FET were unsuccessful in producing transfer to untrained tasks compared to a group that received limited game experience, suggesting that directed training and practice can produce task-specific improvements, but improvements do not necessarily transfer from trained to untrained tasks.

1. Introduction

Although computer-based training programs and video games hold great appeal as a means to improve perceptual and cognitive abilities, scientific evidence of their efficacy is mixed. Habitual video game players often outperform non-players on laboratory tasks measuring cognition (e.g., Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Castel, Pratt, & Drummond, 2005; Green & Bavelier, 2006a, 2006b, 2008), and video game training can improve the cognitive abilities of preschool and school children, young adults, and older adults (Basak, Boot, Voss, & Kramer, 2008; De Lisi & Wolford, 2002; Green & Bavelier, 2008; Li, Polat, Makous, & Bavelier, 2009; Smith et al., 2009 for review). However, a recent study featuring 11,000 participants failed to find any transfer from a cognitive training program modeled after commercially available "brain fitness" software to other measures of cognition (Owen et al., 2010). Additional evidence suggests that commercially available brain fitness video games may do little to improve cognition (Ackerman, Kanfer, & Chalderwood, 2010).

While the type of game or computer activity engaged in is likely one explanation for divergent results with respect to the breadth of transfer, it is possible that training strategy may also play an important role. A few previous studies of video game training and transfer effects have manipulated training strategies explicitly (e.g. Boot et al., 2010; Gopher, Weil, & Siegel, 1989), however most computer-based brain fitness and game-based training studies have not. Instead, these studies have mostly tested the effect of practice, not training, which might have contributed to limited generalizability of acquired skills. Given these mixed results, the exact characteristics of training that result in both maximal improvement on the trained tasks, good retention of trained skills and broad, task-independent improvements are still uncertain. The current study explores the effect of directed game training (i.e., training that, throughout the training processes, explicitly asks the learner to master certain game aspects and the coordination of multiple tasks within the game) on these aspects of skill acquisition.

Although practice almost invariably improves performance, explicit training strategies can more effectively enhance the learning and retention of new skills, and can engender broader transfer of training (Carrier,

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doi:10.1016/j.actpsy.2011.11.003

Davidson, & Williams, 1985; Gopher, 2007; Hannafin, 1984; Schmidt & Bjork, 1992). A common method to train complex task performance is *whole-task training*, in which skills are practiced in the context of the full task with performance feedback. In contrast to whole-task training, *part-task training* involves decomposing a complex task into smaller component tasks, which are then practiced in isolation (Fabiani, Buckley, Gratton, & Coles, 1989; Frederiken & White, 1989; Whaley & Fisk, 1993; Wightman & Lintern, 1985). Whole-task training has the advantage of allowing participants to learn how component tasks fit together within the context of the complete task. However, this approach possesses a key disadvantage. Specifically, the complexity and difficulty of the whole task may overwhelm learners, at least early in the training process. Part-task training appears to be more effective at improving performance on tasks composed of difficult and demanding subtasks. By decomposing a complex task into a set of manageable chunks, cognitive demands are reduced during training. An important disadvantage to this approach, however, is that the opportunity to learn how to integrate different task components into the overall task and to coordinate the performance of component subtasks is absent (Briggs & Naylor, 1962; Wightman & Lintern, 1985).

Variable Priority Training (VPT) capitalizes on the advantages of both part-task and whole-task training strategies without succumbing to their disadvantages. In VPT learners emphasize different task components at different times, but do so in the context of the whole task. In such a case learners reap the benefits of concentrating their practice on manageable subcomponents while also learning how these subcomponents function within the context of the whole task.

Some of the best evidence for the superiority of VPT to enhance skill acquisition comes from studies using Space Fortress, a video game designed by cognitive psychologists as a training and research tool that requires cognitive processes such as working memory, resource management, and complex manual control (Donchin, 1989). Comparing the performance of participants who received VPT with the performance of participants who were trained without emphasis manipulation (Full Emphasis Training, FET), VPT showed substantially faster learning and higher levels of mastery (e.g., Boot et al., 2010; Gopher et al., 1989).

Beside the benefit to learning, some previous studies have shown that VPT can lead to transfer to untrained tasks (Bherer et al., 2006, 2008; Fabiani et al., 1989; Gopher, 2007; Gopher et al., 1989; Kramer, Larish, & Strayer, 1995; Kramer, Larish, Weber, & Bardell, 1999). Compared to participants who received whole-task training, participants who received VPT on a complex dual-task showed higher levels of performance on a transfer dual-task, even though participants had no prior experience with this task (Kramer et al., 1995). In another study, 10 h of Space Fortress Training with VPT led to better flight performance among a group of Israeli Air Force flight school cadets compared to a no-contact control group (Gopher, Weil, & Bareket, 1994).

Despite the well-known effectiveness of VPT, it does have a potential disadvantage: early in training participants must complete the challenging whole task with the additional demand of monitoring and adjusting their own performance based on priority instructions and specialized feedback. Thus, the advantage of VPT manipulation may be delayed or minimized until basic proficiency in each subtask is attained. One way to improve VPT is to combine part-task training and variable priority training, and adjust the nature of training over the course of learning (we call this training Hybrid Variable-Priority Training, HVT; see Gopher et al., 1994 for an earlier implementation of a similar strategy). Early in training, component tasks are trained in isolation and gradually increase in complexity, approaching the whole task. This progressive part-task training is included to enhance learning by reducing the complexity of the whole task. After part-task training, blocks of variable priority training (i.e., emphasizing different subtasks in the context of the whole task) are also included to provide learners an opportunity to integrate the skills acquired from part-task training into the whole task. Later in training, once learners have displayed some proficiency, focus is fully shifted to VPT so that they can continue to explore ways to integrate and coordinate subtasks.

The effectiveness of HVT in terms of training and transfer of training, however, has not been systematically investigated. In the present study, we examined the effectiveness of HVT by comparing HVT to Full Emphasis Training (FET, i.e., undirected practice that emphasized all components of the task equivalently in a whole-task context) over an extended training period (30 h). Participants received fifteen 2-hour training sessions. For the HVT group, the first 5 sessions were a combination of Part-task training and VPT. We refer to the first five sessions as Part/Variable-Priority Training (PVP). After the first 5 PVP sessions, participants completed 10 sessions of Variable Priority Training (VPT). For the FET group, participants were always asked to maximize total score, but otherwise received no additional instruction on how to improve. The effectiveness of HVT was measured in terms of game score improvement and retention of training measured approximately 7 months from the last training session. Transfer of training was also assessed with a battery of cognitive tasks ranging from basic laboratory paradigms to complex real-world simulations. We administered the cognitive battery three times (prior to training, after 10 h of training and following the completion of training), in order to measure transfer of training at different levels of skill acquisition.

Furthermore, we included a control group that received only limited game experience, but was assessed on the game itself and all transfer tasks with the same interval between assessments as the HVT and FET groups. This allowed us to address a critical gap in the literature with respect to transfer of training, game experience, and directed training involving emphasis change. Boot et al. (2010) demonstrated that although VPT was successful in accelerating learning compared to FET, transfer of training from VPT to untrained tasks was limited to only specific transfer tasks that were similar to components of the Space Fortress game itself. The conclusion drawn was that directed training did little to engender broad transfer of training. However, since a limited game experience control group was not tested, it is possible that game experience itself engendered broad transfer of training, making it appear as if the effect of VPT was relatively weak. Compare this to the study conducted by Gopher et al. (1994), which contrasted two directed training manipulations (VPT, HVT) to a no-game control group, but did not have a non-directed training condition similar to the FET condition Boot et al. (2010) studied. With respect to the observed broad transfer of training from Space Fortress to jet flight performance, it is unclear how much the transfer of training results were due to directed training or mere experience playing the Space Fortress game. The current study can disambiguate these two potential effects.

By including a limited game-experience control group as a baseline, we can examine both the effect of training strategy and the effect of game experience/practice in general on skill acquisition and transfer of training, in addition to the retention of trained skill. Thus the current study fills a gap in our understanding of the influence of directed training and simple practice on skill acquisition and transfer. Furthermore, potential transfer as a function of game experience and training strategy was assessed with not just one outcome measure, but with a diverse battery of tasks measuring multiple cognitive constructs in addition to complex task performance.

2. Methods

2.1. Participants

Seventy-five participants (ages 18–30, 29 males) were recruited from the Urbana-Champaign community and were paid fifteen dollars an hour for completing approximately 60 h of testing and training including ERP and fMRI sessions.[1] All participants reported normal or corrected-to-normal vision, normal color vision and were right-handed. Twenty-five participants were assigned to the Hybrid Variable-Priority Training group (HVT), twenty-five were assigned to the Full Emphasis Training group (FET), and twenty-five were assigned to the control group. Initially participants were randomly assigned to each group, and halfway through the recruitment processes demographic characteristics of each group were checked and used as a guideline for group assignment to ensure groups did not differ in terms of gender composition or age. Forty-three participants returned for a retention session approximately 7 months from their last training session (57.3%, 12 from the FET group, 16 from the HVT group, and 15 from the control group). Demographics are presented in Table 1.

Potential participants were first contacted through flyers posted in campus buildings and businesses or through advertisements posted to online bulletin boards. Individuals responding to these flyers and advertisements were then asked to complete a survey of their video game habits and to return this survey via e-mail.[2] To determine their final qualification for the study, potential participants were then invited to the lab to complete an in-person interview. This interview assessed detailed video game habits and health status. Individuals with video game experience of more than 4 h per week or with major medical or psychological illness were excluded.

2.2. Apparatus

Space Fortress game data was collected on networked PC computers and game inputs were made using the computer mouse and a Logitech Attack 3 Joystick®. The game was displayed on color 19" LCD monitors. All computer-based cognitive assessment tasks were administered using PC computers with 17" CRT monitors. The majority of assessment tasks were programmed in E-prime. Logitech Attack 3 Joysticks® were used for all tasks in the assessment battery requiring a joystick input.

2.3. Stimuli and procedure

Participants completed a variety of different tasks across multiple sessions. In this section, we first provide the reader with a basic description of the Space Fortress game. We then discuss the cognitive assessment battery that was administered to participants three times. Finally, we discuss the structure of training, transfer and retention sessions. Details of Space Fortress Training Procedures are presented in Table 2.

2.3.1. The Space Fortress game

Space Fortress was developed by cognitive psychologists as a tool to study learning and training strategies (Donchin, 1989). The game requires players to manage multiple demanding and overlapping component tasks and simulates the complexity of many important real-world tasks such as piloting, air traffic control, and radar/sonar monitoring. It incorporates difficult motor, memory, multi-tasking, and visual/attentional components, many of which were taken directly from the cognitive psychology literature. The complexity, difficulty, and well-defined components of the Space Fortress game makes it an ideal research tool to study learning, training, and transfer of training.

Complete details of the Space Fortress game are reported elsewhere (Donchin, 1989), but here we summarize the most important aspects of the game. Space Fortress (see Fig. 1) requires players to navigate their ship with precise control using a joystick. Players can rotate the ship by moving the joystick left or right, or apply a thrust by pushing forward on the joystick. However, the ship moves in a frictionless environment and the ship has no braking system, making control very challenging. In order for players to stop the ship or decrease its speed they must rotate the ship so that it faces the opposite of its current motion and apply a thrust.

The main goal of the game is for players to destroy the Space Fortress (located at the center of the screen) as many times as possible while avoiding damage to their own ship (the fortress rotates and fires back at the player's ship). To destroy the fortress, players must hit it with missiles by aiming their ship towards it and pushing the fire button on the joystick. To make the fortress vulnerable to destruction, it must first be hit with ten missiles. The time between each of these hits must be at least 250 ms. After ten missile hits with the correct timing, the fortress can be destroyed by hitting it with a rapid double shot, that is, with two missile hits with the time between shots being less than 250 ms. If participants hit the fortress with a double shot before it is vulnerable, the vulnerability of the fortress is reset to zero and the player must start accumulating hits all over again. Each time the player's ship is damaged four times it is destroyed, points are lost, and the vulnerability of the fortress is reset to zero.

Mines appear on the screen at regular intervals and actively pursue the player's ship, damaging the ship if contact is made. Critically, as long as a mine is on the screen, the fortress cannot be damaged or destroyed. Thus mines must be dealt with as soon as possible. Each mine has a letter associated with it that is displayed in the instrument panel at the bottom of the screen that identifies it as a friend or foe. At the beginning of each game participants are asked to remember three letters that represent foe mines; all other mines are friends. If the mine that appears is a friend mine, the player can shoot it, and the friend mine will transfer this damage to the fortress. However, if it is a foe mine, it must be flagged as such using the mouse double-clicks and then destroyed with a missile. Responding to mines incorrectly (i.e., identifying a friend as a foe) has important negative consequences, and thus participants must be careful to remember which letters represent foe mines.

In addition to tasks related to the fortress and mines, there is a constant monitoring task imbedded in the game. Symbols appear periodically below the fortress and whenever a dollar sign appears for the second time, players can use the mouse to either select bonus points, or bonus missiles (which are a limited resource). However, if participants incorrectly identify the first dollar symbol as the second, they miss their opportunity to obtain a bonus when the second dollar sign does appear. Thus, participants are always encouraged to monitor this information.

Points are awarded to participants based on their Space Fortress game performance, and different actions add to, or subtract from, different sub-scores displayed in the instrument panel at the bottom of the screen. For example, participants are asked to keep their ship within the two hexagons on the screen. Doing so increases the Control sub-score. Flying the ship outside of the large hexagon or leaving the screen entirely (referred to as “going into hyperspace”) subtracts from the Control sub-score. The Velocity sub-score rewards participants for going slowly and punishes participants for flying at high speeds. The Speed sub-score rewards/punishes participants for how quickly they deal with mines, and the Points sub-score rewards participants for shooting and destroying the fortress, but subtracts points for damage and destruction of the player's ship.

2.3.2. Game orientation

The first session that participants completed was a game instruction session. Participants were taught to play the game by watching a 20-minute instructional video that explained all the details of the Space Fortress game, and then another 5-minute summary movie that summarized the most important rules. Next, participants took a 5-minute pop-quiz about game rules. If participants scored below 80%, they went through the game rules with the experimenter one

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[1] Imaging data (ERP & fMRI) will be presented in separate publications.

[2] The survey can be found on http://spacefortress.blogspot.com.

Table 1
Descriptive characteristics of participants in the three groups (FET, HVT, and the control group), standard deviations are within parentheses.

	Full Emphasis Training (FET)	Hybrid Variable-Priority Training (HVT)	Control group
N	25	25	25
Age	21.91 (2.77)	20.88 (2.06)	21.44 (2.52)
Proportion male	.30	.33	.37
Self-rated health	5	5	5
Year of education	15.52 (2.19)	14.68 (1.85)	15.28 (2.25)
Baseline score	−844.45(2086.81)	−1034.78 (1907.14)	−988.38 (1916.30)
Retention session			
N	12	16	15
Age	22.18 (3.78)	20.25 (1.43)	21.8 (2.95)
Proportion male	.25	.38	.4
Self-rated health	5	5	5
Year of education	15.33 (2.81)	13.96 (1.13)	15.50 (2.58)
Baseline score	−1042.22 (2023.78)	−1115.38 (2106.28)	−970.77 (1992.28)
Last session score	3516.19 (1883.05)	4752.64 (831.87)	1675.64 (2058.96)

Note: For self-rated health, the scale was ranging from 1 for poor to 5 for excellent.

more time. After participants fully understood the game rules, they played 6, 3-minute games to familiarize them with the game.

2.3.3. Cognitive battery

On the second and third visit, participants were administered a battery of assessment tasks over the course of two 2-hour sessions that took place on different days. Two identical batteries of assessment tasks took place after 10 h and after 30 h of Space Fortress training in order to measure transfer at different levels of skill acquisition. These tasks measured memory, attention, visual processing, motor control, reasoning ability, and dual-tasking ability. The duration of each task was between 5 and 30 min and all tasks were completed in a fixed order. Participants were encouraged to take breaks whenever necessary. Table 3 provides a brief summary of each task and the construct it assessed. In general, tasks fell into three categories: 1) Visual and Attentional Tasks, 2) Memory Tasks, and 3) Complex Tasks.

2.4. Visual and Attentional Tasks

2.4.1. Dot Comparison Task

Participants viewed displays containing two 4×4 matrices of dots, one to the left of fixation and one to the right. Dots could be either filled or unfilled. Participants were required to quickly indicate whether the pattern of filled dots on the left was the same as the pattern on the right or whether one filled dot was displaced by one position in the matrix. Participants completed 10 practice trials in which they were given feedback regarding accuracy, then 3 blocks without feedback that increased in difficulty by increasing the number of filled dots.

2.4.2. Attention Blink Task

Participants viewed a rapid sequence of letters (approximately 1° high) on a gray background at the center of the screen and reported two things about each letter sequence: (1) the identity of the one white letter in the sequence of black letters and (2) whether or not an X was present sometime after the white letter (50% of trials). Each letter appeared for 12 ms, followed by an 84 ms blank interval before the next letter. Letter sequences varied in length from 16 to 22 letters. The white letter appeared unpredictably after either the 7th, 10th, or 13th letter. The X could occur 2, 4, 6, or 8 letters after the first target. Participants often fail to report the X when it appears soon after the first target (referred to as the “attentional blink”). Participants completed one practice block of 20 trials in which they only had to detect the white letter, and another practice block of 20 trials in which they only had to detect whether or not an X was present.

Table 2
Details of Space Fortress Training Procedures.

	FET	HVT	Control
2 h	Game Instruction/Mock Magnet, for all groups		
4 h	Cognitive battery 1, for all groups		
3.5 h	ERP 1, for all groups		
2 h	fMRI 1, for all groups		
Session 1	Full Emphasis Training	Part-Task/ Variable Priority Training	Full Emphasis Training
Session 2	Full Emphasis Training	Part-Task /Variable Priority Training	
Session 3	Full Emphasis Training	Part-Task /Variable Priority Training	
Session 4	Full Emphasis Training	Part-Task /Variable Priority Training	
Session 5	Full Emphasis Training	Part-Task /Variable Priority Training	
4 h	Cognitive battery 2, for all groups		
3.5 h	ERP 2, for all groups		
Session 6	Full Emphasis Training	Variable Priority Training	Full Emphasis Training
Session 7	Full Emphasis Training	Variable Priority Training	
Session 8	Full Emphasis Training	Variable Priority Training	
Session 9	Full Emphasis Training	Variable Priority Training	
Session 10	Full Emphasis Training	Variable Priority Training	
Session 11	Full Emphasis Training	Variable Priority Training	
Session 12	Full Emphasis Training	Variable Priority Training	
Session 13	Full Emphasis Training	Variable Priority Training	
Session 14	Full Emphasis Training	Variable Priority Training	
Session 15	Full Emphasis Training	Variable Priority Training	Full Emphasis Training
3.5 h	ERP 3, for all groups		
2 h	fMRI 2, for all groups		
4 h	Cognitive battery 3, for all groups		

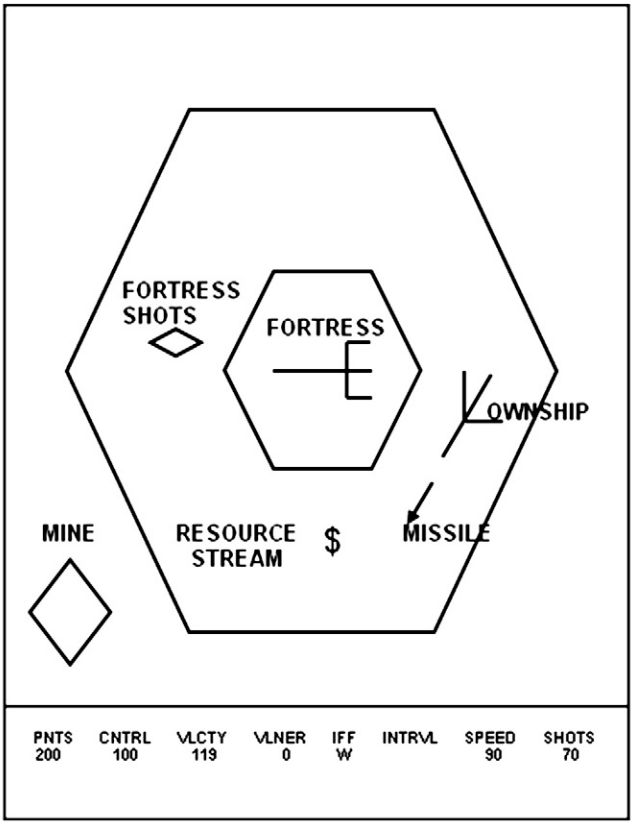

Fig. 1. A schematic representation of the Space Fortress game. From left to right, indicators represent Points score, Control score, Velocity score, the vulnerability of the Space Fortress, the identity of the mine on screen, the mine identification interval (not depicted), Speed Score, and the number of shots the player has remaining.

Finally, participants completed 144 test trials in which they had to detect both the white letter and whether or not an X occurred after the white letter. Of primary interest is the size of the "blink" observed. That is, the difference between when the X was the second letter after the white target (when detection is typically worst) and when it was the 8th letter (when detection is typically good).

2.4.3. Change Detection Task

During each trial, participants viewed a repeating cycle of four displays: an unaltered image of traffic scene (240 ms), gray screen (80 ms), a modified version of first image (240 ms), and then another gray screen (80 ms). The task was to detect and report the difference between the unaltered and altered images. Upon detecting a change, participants pressed a button to terminate the stimulus and described the change. The trial was terminated if participants failed to detect the change within 60 s. Participants completed 24 trials in total with different street scenes, 22 of which were change trials along with 2 catch trials (i.e., with no change between stimuli). A response was considered an error if participants falsely reported a change in catch trials or if the trial ended without a response in the change trials.

2.4.4. Flanker Task

Participants completed a standard Flanker Task in which they responded to the direction indicated by a central arrow while ignoring flanking arrows that could either point in the same direction or different direction as the target. On half of the trials, the flanking arrows were incompatible with the target (pointed in the opposite direction). Participants were required to respond as quickly as possible while maintaining high accuracy. Participants first completed a block of 20 practice trials with accuracy feedback, and then 100 real trials without feedback. Selective attention was assessed by observing the reaction time cost when flankers were incompatible compared to compatible.

2.4.5. Manual Sequence Task

Participants viewed a display with four rectangles. A star could appear in each of the four rectangles and participants had to respond as quickly as possible to the rectangle containing the star by pressing 'v', 'b', 'n' or 'm' on the keyboard (corresponding to the spatial location of the rectangle with the star). A sequence of 10 star locations was randomly generated for each participant with the restriction that no two locations were selected in a row. The fixed sequence of 10 trials was repeated for 20 cycles, generating 200 total trials.

2.5. Memory

2.5.1. Sternberg Memory Task

Participants viewed 3 or 5 random letters presented one at a time at the center of the screen (duration: 1200 ms, inter-stimulus interval 500 ms). After a brief delay (1500 ms), participants heard a beep and saw a letter presented in the center of the screen. Participants had to respond as quickly as possible (but accurately as well) whether this letter was one of the letters viewed in the previously viewed set. Participants completed 32 practice trials with accuracy feedback, then 96 trials without feedback.

2.5.2. N-back Memory Task

Participants viewed displays in which letters appeared one at a time at the center of the screen and pressed one key if the letter was the same as the previous letter (1-back task), or had to respond whether or not it was the same as the letter presented 2 items back (2-back task). Each

Table 3
Sequence and details of the assessment battery of cognitive tasks.

Tasks	Order	Assessment session	Category	Primary measure	Source
Flanker Task	1	1	Visual and Attentional Task	Flanker Cost (Composite Score)	Eriksen and Eriksen (1974)
Manual Sequence Task	2	1	Visual and Attentional Task	Composite Score	Nissen and Bullemer (1987)
Dot Comparison	3	1	Visual and Attentional Task	Composite Score	Salthouse and Babcock(1991)
Attentional Blink	4	1	Visual and Attentional Task	T2 dual cost (lag8–lag2)	Raymond, Shapiro, and Arnell (1992)
N-back Task	5	1	Memory	Dual Cost (Accuracy)	Jaeggi et al. (2003)
Change Detection Task	6	1	Visual and Attentional Task	Accuracy	McCarley et al. (2004)
Sternberg Memory Task	7	1	Memory	Composite Score	Sternberg (1966)
Probability Learning	8	1	Complex Task Performance	Accuracy	Fu and Anderson (2008)
Flight Simulation Task	9	2	Complex Task Performance	RMS Error	X-plane® by Laminar Research
Radar Monitoring Task	10	2	Complex Task Performance	Accuracy	ATC
Dual-Task Manual Tracking	11	2	Complex Task Performance	Dual Cost (RMS Error)	Boot et al. (2010)
Raven's Matrices	12	2	Complex Task Performance	Accuracy	Raven, Raven, and Court (2003)

Note: Due to the limit of testing material, Raven's Matrices were conducted only on the first and third cognitive battery sessions.

letter appeared for 500 ms with an inter-stimulus interval of 2000 ms. On 75% of trials the correct response was “no” and on 25% of trials the location was “yes”. Speed was stressed. Participants first completed the 1-back task (1 practice block of 13 trials with feedback, then 5 blocks of 20 trials without feedback). Participants then completed the 2-back task (1 practice block of 13 trials with feedback, then 5 blocks of 20 trials without feedback). Of primary interest was the memory load cost; the difference in response time when keeping two items in memory compared to one.

2.6. Complex Task Performance

2.6.1. Dual-Task Manual Control

Participants used a joystick to keep a cursor centered on screen as its location was influenced by random noise pushing it away from center. Participants completed four 90-second long single task trials. Participants then completed a dual task version in which they also had to monitor 3 gauges while keeping the cursor centered. Each time a gauge went out of range participants were required to reset it using one of three buttons on the keyboard. Participants completed 12 dual-task trials in which 0, 1, or 2 gauges could go out of range on each trial. Of primary interest was the cost of performing the gauge monitoring task on manual control (i.e., dual-task costs).

2.6.2. Radar Monitoring Task

Participants completed a simplified radar monitoring task in which they viewed a screen with 12 aircraft, and used the mouse to obtain information from each aircraft (speed, altitude) to classify it as a friend or foe. Participants completed 6 trials in which they had to identify each aircraft on the screen as quickly and as accurately as possible. Of primary interest was the number of correctly classified items. The first trial was considered practice.

2.6.3. Flight Simulation Task

Participants completed 6 computer-based flight simulation trials, the first of which was considered practice. Each 4-minute trial had participants use a joystick controller to maintain a path in the center of a yellow “tunnel-in-the-sky”. The tunnel participants navigated differed from trial to trial. Speed of the aircraft was held constant and of primary interest was deviation from the center of the tunnel during flight.

2.6.4. Probability Learning

Participants were presented with two pairs of colored doors sequentially, and were asked to select one door by pressing the mouse button corresponding to the door's location. In the first selection, one of the colored doors was more likely to lead to the room with a higher probability of leading to an exit. In the second selection, one of the colored doors was also more likely to lead to the exit, and the probability was determined by the first selection. Two pairs of colors were chosen from a set of eight colors (red, green, blue, yellow, green, brown, magenta, and orange) to be used in two choice sets in the task. Participants were required to select colored door pairs (first door and then second door) leading to the more likely exit. In the dual task condition, participants were required to perform a concurrent auditory 2-back memory task as a secondary task. In each single and dual condition, participants performed 10 blocks, and each block had 10 trials each. The pairings of colors and door probabilities were the same throughout all 100 trials and learning rate was measured by subtracting the probability of getting to the exits in the first block from the last block.

2.6.5. Raven's Matrices

Participants completed a version of the Raven's Advanced Matrices task. Participants were presented with a complex visual pattern with a piece cut out of it. The participant's task was to find the missing piece that completed the pattern. The full version of the Raven's was divided into two sub-tests of approximately equal difficulty, with each test containing 18 items. Before participants were administered the pre-training form they were given 5 min to complete a practice version of the test. Participants were given 30 min to complete each 18-item test, once before and after training.

2.6.6. Game training

After the initial assessment sessions were completed, participants began the Space Fortress game training. This training consisted of fifteen, 2-hour training sessions that differed for each of the training strategy groups (FET and HVT). Each session started and ended with 3 test-game trials (which will be referred to as a test block) in which participants were asked to maximize performance and focus on obtaining the highest total score by emphasizing each task component equally. For the FET group, throughout the 15 sessions, participants were always asked to maximize total score during practice, and were reminded that total score was the sum of the Control, Velocity, Speed, and Points sub-scores. Participants completed 30 practice games between the first and last test blocks per session.

For the HVT group, the first 5 sessions were a combination of 1 h and 10 min of part-task training and 50 min of VPT. Part-task training was used to train the components of the game independently, starting from the simple sub-task of firing missiles and destroying the space fortress, and increasing the complexity of training to the full game. The details of part-task training are described in Table 4 (see also Frederiken & White, 1989). After the part-task training, participants received 50 min of VPT emphasizing a particular aspect of the Space Fortress game. After the first 5 sessions, participants completed 10 sessions of VPT. For VPT, participants were asked to focus on improving and monitoring different sub-scores of the game during practice. That is, participants completed five practice blocks of six trials each in which they were asked to emphasize a particular aspect of the Space Fortress game, (control, velocity, speed, points and total score).

The control group played the Space Fortress game for only 3 sessions, one at the beginning of the training, one at the average time-point after which training groups had completed 10 h of training and one at the end of the training in order to compare their performance and transfer effect with other training groups (FET and HVT).

For all game trials, feedback was given about total score and all sub-scores. Participants generally completed 3 to 5 sessions a week. In general, the entire training took about 8–10 weeks.

Table 4
Details of part training for sessions 1–5 for HVT.

Part-training	
1. Destroy Fortress by shooting	(only for session 1–2)
2. Slow down a ship	
3. Aiming	(only for session 1–2)
4. Aiming and Firing	
5. Navigating a ship in trajectory 1	
6. Navigating a ship in trajectory 2	
7. Navigating a ship in trajectory 3	
8. Navigating a ship in big hexagon	
9. Navigating a ship in small hexagon	
10. Navigating a ship in hexagon and aiming	
11. Navigating a ship in hexagon, aiming and firing	
12. Navigating a ship in hexagon, aiming and firing on the shooting fortress	
13. Ship control only	
14. Full game without bonus and mine	
15. Mine control only	
16. Bonus control only	
17. Mine and Bonus control	
18. Mine and Ship control	
19. Bonus and Ship control	
20. Full game without bonus control	
21. Full game without mine control	

2.6.7. Retention session

Participants played 36 games in the retention session. In the retention session, participants were instructed to obtain the highest total score by emphasizing all task components equally (Full Emphasis).

3. Results

3.1. Space Fortress game score

As a first step, we examined whether game experience (FET) and directed training (HVT) influenced performance on the game itself, and later whether game experience or directed training resulted in transfer of acquired skill.

3.1.1. Training groups vs. control group

Dependent variables were the average game scores of the last test block of each of the three sessions (sessions 1, 6 and 15), which were entered into Analysis of Variances (ANOVAs) with session as a within-subject factor and group (FET, HVT and control) as a between-subject factor. The outcomes of these analyses are shown in Table 5. As can be seen in the Table there was a significant interaction between group and session for all measures. This was a result of larger training benefits for the FET and HVT groups compared to the control group, which was expected given the limited game experience the control group received. We now focus on whether there were differential training benefits on measures of Space Fortress performance for the HVT group compared to the FET group, and if so, which components of the game benefited most.

3.1.2. HVT vs. FET

We divided the 15 training sessions into three phases (early, middle and late) and examined training strategy effects between phases in order to determine if the effect of training strategies differed over the course of training. For each game measure, we conducted ANOVAs with phase (early, middle and late) and session (5 sessions for each phase) as within-subject factors and training strategy group (FET, HVT) as a between-subject factor. Gender and baseline game performance (average score of initial test block at session 1) were included as covariates in each analysis.

3.1.2.1. Total score. HVT participants reached higher levels of mastery on the game (Fig. 2A). As expected, there was a main effect of phase and session, indicating performance improved over time for both groups ($F(2,92)=7.76$, $p<.01$, $\eta^2=.144$, $F(4,184)=5.44$, $p<.01$, $\eta^2=.106$, respectively). However, there was a marginally significant effect of training strategy group ($F(1,46)=3.78$, $p=.058$, $\eta^2=.076$), and a trend for training strategy to interact with phase and session ($F(8,368)=1.72$, $p=.093$, $\eta^2=.036$). We explored this trend further by performing separate ANOVAs on data from each phase of learning (early, middle, and late). Results indicated a marginally significant session by training strategy interaction favoring the HVT group, but only during the initial early phase of training ($F(4,184)=2.27$, $p=.064$, $\eta^2=.081$).

3.1.2.2. Velocity score. Velocity scores (i.e., the ability to maneuver the ship slowly and in a controlled manner) are depicted in Fig. 2B. Fig. 2B suggests that an HVT advantage can be seen almost immediately after the start of training. Consistent with this impression, training strategy had a significant effect on Velocity scores ($F(1,46)=5.70$, $p<.05$, $\eta^2=.110$), favoring HVT over FET. The effects of phase and session were not significant, likely due to little or no difference in scores across sessions starting from about Session 7 ($F(2,92)=.631$, $p>.1$, $\eta^2=.014$, $F(4,184)=1.057$, $p>.1$, $\eta^2=.022$, respectively). The interaction between phase, session and group was not significant ($F(8,368)=1.13$, $p=$n.s.).

3.1.2.3. Control score. Control scores (i.e., the skill to keep the ship within the two hexagons on the screen) indicated no difference between two training strategy groups (Fig. 2C, $F(1,46)=1.23$, $p>.1$, $\eta^2=.026$). Indicative of both groups improving, there were significant main effects of both of phase and session ($F(2,92)=8.47$, $p<.01$, $\eta^2=.155$, $F(4,184)=7.91$, $p<.01$, $\eta^2=.147$, respectively). The interaction between phase, session and group was not significant ($F(8,368)=1.03$, $p=$n.s.).

3.1.2.4. Points score. Point scores (i.e., the sub-score rewarded to participants for shooting and destroying the fortress, but subtracted from for damage and destruction of the player's ship) are depicted in Fig. 2D. The effect of training strategy group was not significant ($F(1,46)=.001$, $p>.1$, $\eta^2=.001$). As expected, there was a significant main effect of phase and session indicating general improvement ($F(2,92)=11.43$, $p<.01$, $\eta^2=.199$, $F(4,184)=4.50$, $p<.01$, $\eta^2=.089$, respectively). The interaction between phase, session and group was not significant ($F(8,368)=.742$, $p=$n.s.).

3.1.2.5. Speed score. Speed scores (i.e., sub-score rewarded/punished participants for how quickly they dealt with mines) are depicted in Fig. 2E. The main effect of training strategy group was not significant ($F(1,46)=1.31$, $p>.1$, $\eta^2=.028$), however there was a significant main effect of phase indicative of better scores as learning progressed ($F(2,92)=6.69$, $p<.01$, $\eta^2=.127$). There was no main effect of session ($F(4,184)=1.71$, $p>.1$, $\eta^2=.036$) and no significant interaction between phase, session and group ($F(8,368)=.236$, $p=$n.s.).

3.1.3. Interaction between initial proficiency and training strategy

Although significant training effects were largely found only within the domain of Velocity scores, previous studies have found that

Table 5

Results of ANOVA on total score and each sub-score with block as a within-subject factor and group as a between-subject factor (FET, HVT and control).

	Group	Session 1	Session 6	Session 15	ANOVA
Total	FET	248.24	2424.8	4054.9	Main effect of session, $F(2,140)=10.14$, $p<.01$
	HVT	373.14	2754.4	4644.4	Main effect of group, $F(2,70)=12.43$, $p<.01$
	Control	422.29	1314.8	1617.6	Interaction, $F(4,140)=24.59$, $p<.01$.
Control	FET	226.09	759.94	1041.0	Main effect of session, $F(2,140)=2.88$, $p=.059$
	HVT	151.14	725.32	1073.9	Main effect of group, $F(2,70)=4.39$, $p<.05$
	Control	222.29	633.44	492.61	Interaction, $F(4,140)=13.67$, $p<.01$
Velocity	FET	201.04	627.20	805.84	Main effect of session, $F(2,140)=.273$, $p=.761$
	HVT	412.72	910.28	1061.7	Main effect of group, $F(2,70)=2.36$, $p=.102$
	Control	762.16	762.16	774.85	Interaction, $F(4,140)=3.74$, $p<.01$
Points	FET	−499.91	426.28	1371.4	Main effect of session, $F(2,140)=12.84$, $p<.01$
	HVT	−518.7	522.70	1652.8	Main effect of group, $F(2,70)=21.89$, $p<.01$
	Control	−772.5	−301.4	−53.78	Interaction, $F(4,140)=15.86$, $p<.01$
Speed	FET	320.26	611.46	774.93	Main effect of session, $F(2,140)=6.46$, $p<.01$
	HVT	317.60	591.13	833.86	Main effect of group, $F(2,70)=20.04$, $p<.01$
	Control	320.00	437.86	446.66	Interaction, $F(4,140)=17.65$, $p<.01$

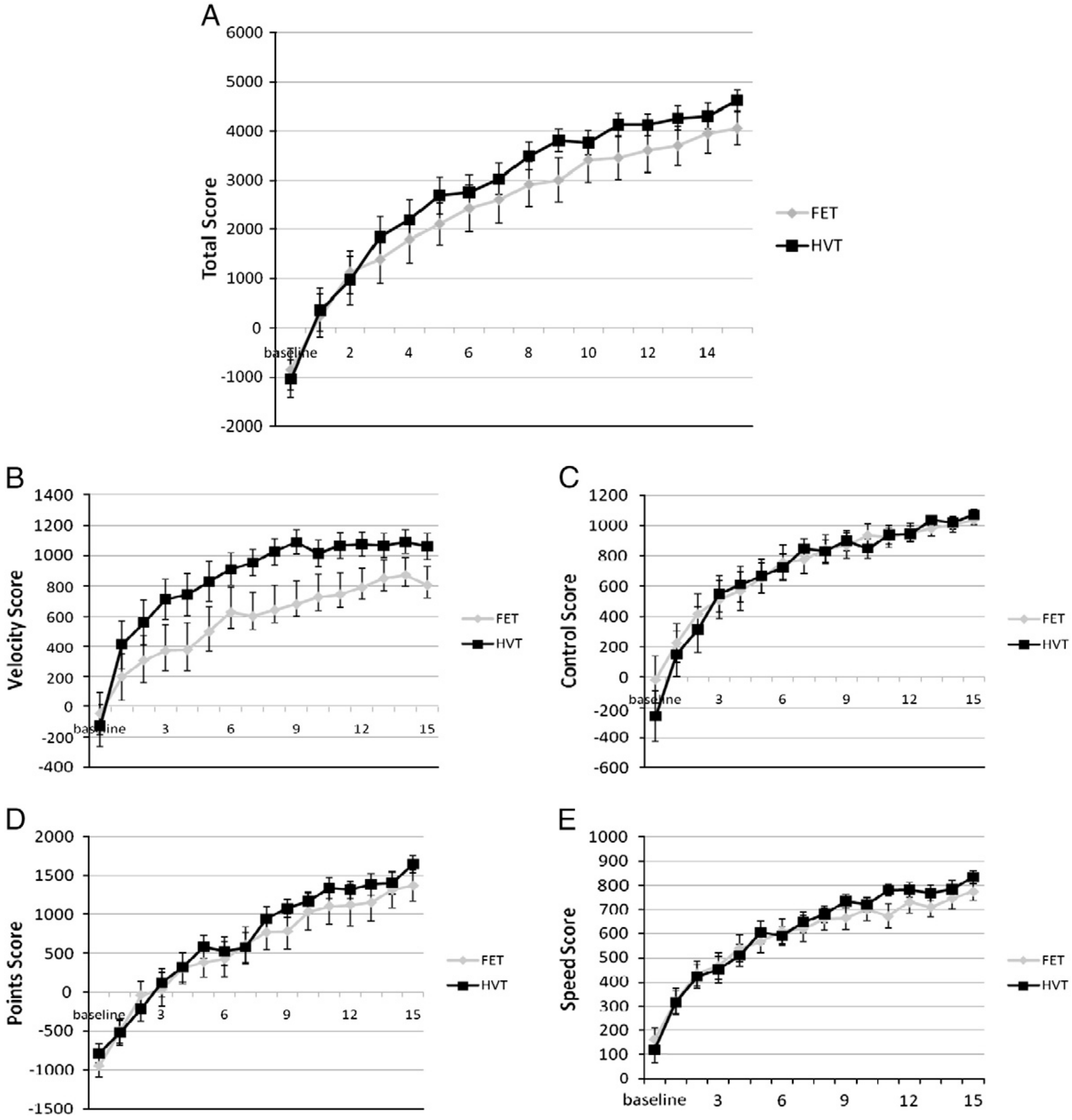

Fig. 2. A) Total score, B) Velocity score, C) Control score, D) Points score, and E) Speed score as a function of training strategy group. Error bars represent ±1 SEM.

participants who benefited most from VPT were those who were initially less proficient performers (Gopher et al., 1989). As shown in Fig. 3, the current study found a similar pattern of results. An ANOVA was performed on each sub-score with session (baseline and 15 sessions; since initial game proficiency was determined by the median split of baseline score, we included the baseline score as a dependent measure and not as a covariate) as a within-subject factor and training strategy (FET vs. HVT), and initial game proficiency (high vs. low) as between-subject factors. Gender was included as a covariate.

In all sub-scores, the main effect of initial game proficiency was significant ($F(1,45)=19.86$, $p<.001$, $\eta^2=.306$, $F(1,45)=9.71$, $p<.01$, $\eta^2=.178$, $F(1,45)=12.25$, $p<.001$, $\eta^2=.214$, $F(1,45)=14.74$, $p<.001$, $\eta^2=.247$, $F(1,45)=23.44$, $p<.001$, $\eta^2=.342$, for total, velocity, control, points and speed respectively). Also the interaction between session and initial game proficiency was significant ($F(15, 675)=3.10$, $p<.001$, $\eta^2=.065$, $F(15, 675)=4.23$, $p<.001$, $\eta^2=.086$, $F(15, 675)=11.65$, $p<.001$, $\eta^2=.206$, $F(15, 675)=1.71$, $p<.05$, $\eta^2=.037$, for total, velocity, control and speed, except in points sub-score ($F(15, 675)=1.42$, $p>.1$, $\eta^2=.031$), suggesting the performance difference between the initially high and low performing groups decreased with practice. Next we examined whether strategy had a differential effect on performance depending upon initial proficiency by reporting this interaction term for total score and each sub-score.

3.1.3.1. Total score.

Total scores are depicted in Fig. 3A. The interaction between training strategy group and initial game proficiency was significant, $F(1,45)=4.70$, $p<.05$, $\eta^2=.095$. High performers showed equivalent game performance regardless of the training strategy. However, for low performers, HVT training demonstrated an advantage.

3.1.3.2. Velocity score.

The interaction between training strategy group and initial game proficiency was marginally significant, $F(1,45)=3.94$, $p=.053$, $\eta^2=.081$. High performers showed equivalent game performance regardless of the training strategy. However, for low performers, HVT produced higher velocity scores than FET (Fig. 3B).

3.1.3.3. Control score.

The interaction between training strategy group and initial game proficiency was not significant, $F(1,45)=.939$, $p>.1$, $\eta^2=.020$ (Fig. 3C).

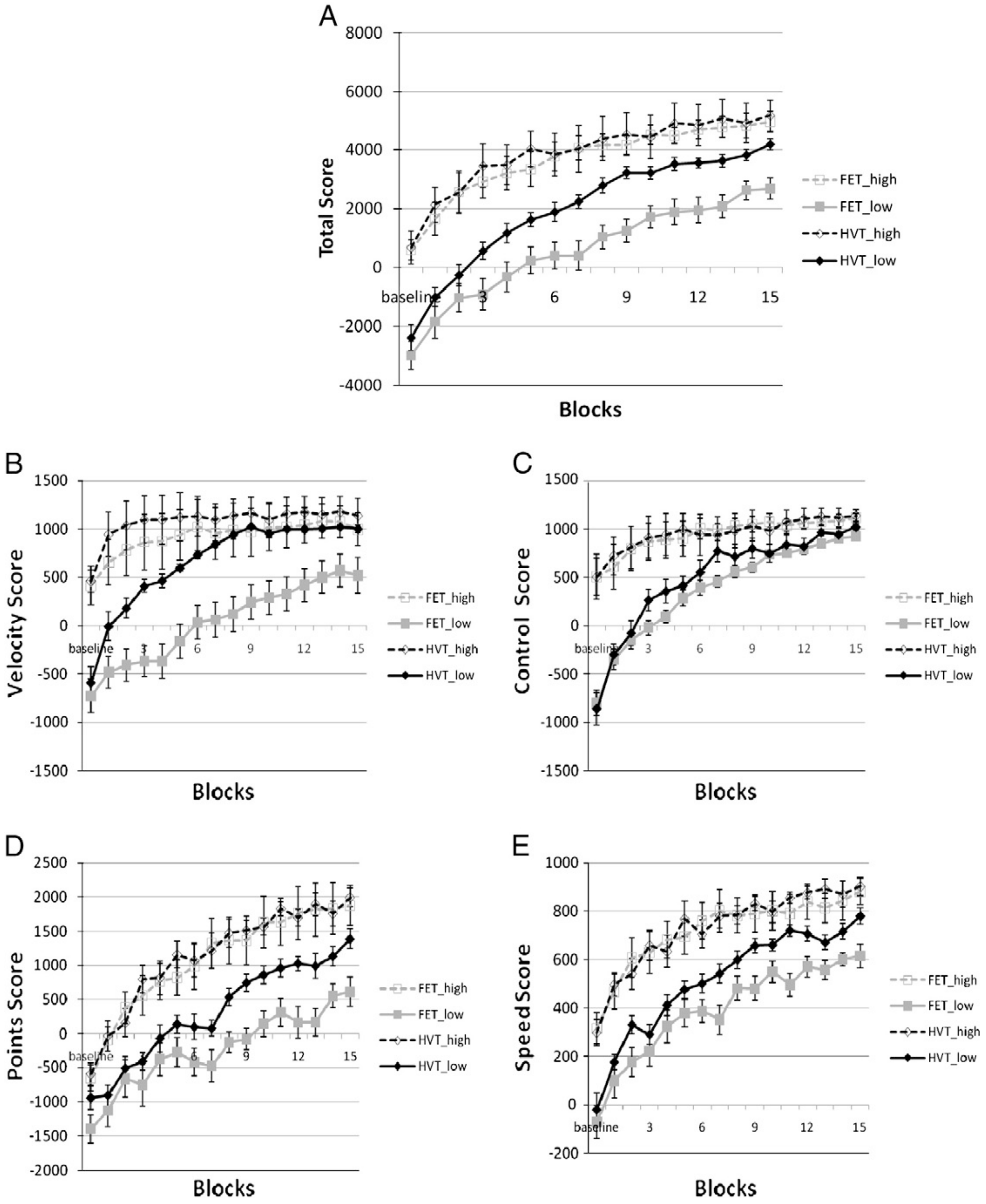

Fig. 3. A) Total score, B) Velocity score, C) Control score, D) Points score, and E) Speed score as a function of training strategy group and initial proficiency. Note the more pronounced effect of strategy for low performers. Error bars represent ± 1 SEM.

3.1.3.4. Points score. The interaction between training strategy group and initial game proficiency was significant, $F(1,45) = 4.04$, $p = .05$, $\eta^2 = .082$. HVT produced a significantly higher point score compared to FET only for initially poor performers (Fig. 3D).

3.1.3.5. Speed score. The interaction between training strategy group and initial game proficiency was marginally significant, $F(1,45) = 3.89$, $p = .055$, $\eta^2 = .080$. As in the other sub-scores, there was a HVT advantage only for the low performers (Fig. 3E).

3.1.4. Summary of retention results

In order to compare the retention of acquired skill 7 months after the cessation of training, an ANOVA was performed on total score and each sub-score of the retention session with group (FET, HVT, and control group) as a between-subject factor. Baseline game performance and gender were included as covariates.

In all sub-scores, the main effect of group was significant ($F(2, 38) = 11.47$, $p < .01$, $\eta^2 = .376$, $F(2, 38) = 4.30$, $p < .05$, $\eta^2 = .185$, $F(2, 38) = 8.14$, $p < .01$, $\eta^2 = .300$, $F(2, 38) = 8.02$, $p < .01$, $\eta^2 = .297$, $F(2, 38) = 13.56$, $p < .01$, $\eta^2 = .417$, for total, velocity, control, points and speed respectively). Not surprisingly, this appears to be attributable to the two groups with extended Space Fortress experience (FET, HVT) outperforming the control group. The effect of extended game experience and the effect of HVT specifically are explored next (Fig. 4).

3.1.4.1. Total score. The two groups with extended Space Fortress experience (FET and HVT) showed higher scores in the retention session compared to the control group (2064 pts), $p = .001$. However, HVT

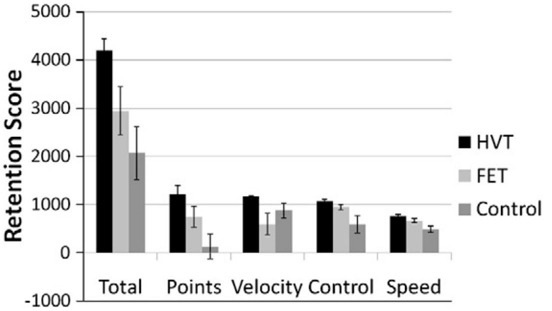

Fig. 4. Retention session scores as a function of training strategy group. Error bars represent ±1 SEM.

participants (4195 pts) retained more game skill after 7 months compared to FET participants (2946 pts), $p = .014$.

3.1.4.2. Velocity score. The difference between the two groups with extended Space Fortress experience (FET and HVT) and the control group (870 pts) was not significant, $p = .77$. This null effect was mainly driven by the low Velocity score of the FET group. HVT participants (1150 pts) retained more game skill with respect to the velocity sub-score after 7 months compared to FET participants (590 pts), $p = .006$.

3.1.4.3. Control score. The two groups with extended Space Fortress experience (FET and HVT) showed higher scores in the retention session compared to the control group (585 pts), $p = .001$. The difference between HVT (1063 pts) and FET (946 pts) was not significant, $p = .25$.

3.1.4.4. Points score. The two groups with extended Space Fortress experience (FET and HVT) demonstrated higher scores in the retention session compared to the control group (126 pts), $p = .001$. The difference between HVT (1216 pts) and FET (745 pts) was not significant, $p = .18$.

3.1.4.5. Speed score. The two groups with extended Space Fortress experience (FET and HVT) showed higher scores in the retention session compared to the control group (482 pts), $p = .001$. The difference between HVT (754 pts) and FET (664 pts) was not significant, $p = .169$.

3.2. Summary of transfer of training results

Table 6 presents group means and standard deviations of all cognitive tests in the assessment battery, including their primary and ancillary measures, across pre-, during- (after 10 h of training) and post- (after 30 h of training) assessment sessions for the HVT, FET and control participants. Multivariate analysis of covariance (MANCOVA) was conducted to determine the effects of Space Fortress training and differential training strategies on the *primary measures* of cognitive tests.

3.2.1. During training (after 10 h of training)

We first examined the effect of transfer from the first 10 h of training. The dependant variables were the primary measures of the cognitive tasks. For those tasks measuring both RT and accuracy, we used composite scores by averaging z-transformed RT and Accuracy. Initial game proficiency (total score) was included as a covariate in the MANCOVA, along with gender and pre-training primary measures of the assessment tasks. Group (HVT, FET and the control group) was considered as a between-subject factor. Results showed that the effect of group was not significant, $F(22,98) = .849$, $p = .659$, $\eta^2 = .160$.

When we conducted the multiple contrasts between the two groups with extended Space Fortress experience (HVT and FET) and the control group there was no significant difference in all tasks. The contrast between HVT and FET was not significant in all tasks except the Sternberg Memory task, favoring HVT over FET, $p = .014$.

3.2.2. Post-training (after 30 h of training)

Next we examined the transfer effect after 30 h of training. Other than including primary measures obtained after 30 h of training, analyses were identical to those previously described. The results showed that the effect of group was not significant, $F(24,94) = .879$, $p = .629$, $\eta^2 = .183$.

When we conducted the multiple contrasts between the two groups with extended Space Fortress experience (HVT and FET) and the control group, there was no significant difference in all tasks except Raven's matrices and N-back cost favoring the groups with extended game experience over the control group, $p = .02$, $p = .045$. The contrast between HVT and FET was not significant in all tasks.

Overall, we found no evidence that transfer to untrained tasks was greater for HVT participants. Furthermore, there was no significant transfer benefit from video game experience as evidenced by the lack of differences at transfer between the two groups receiving extended Space Fortress experience and the control group.

4. Discussion

In the present study, we disentangle the effect of practice and training strategy on training and transfer of training by comparing a directed training strategy involving part-task and variable priority training (HVT) to non-directed training (FET) and a no-contact control group. Overall, prolonged hours of game experience (HVT and FET) led to improved performance compared to the control group, but HVT led to higher levels of game mastery compared with FET, particularly with respect to the velocity sub-score. The benefits of HVT extended to the retention session 7 months after the cessation of training. Another study has documented persistent benefits of game training for perceptual sensitivity over months (Li et al., 2009), but our study is the first to identify a training strategy (rather than game practice) that leads to persistently better performance of a complex video game over seven months after the completion of training.

Beyond examining the effect of strategy on game performance, we also considered individual differences in the ability to learn Space Fortress. Consistent with other training studies (Day, Espejo, Kowollik, Boatman, & McEntire, 2007; Espejo, Day, & Scott, 2005; Gopher et al., 1989), training strategy mattered less for participants who started training with high game proficiency. HVT most benefited those participants who started training with lower performance. This benefit of HVT for low-performing participants was observed in all sub-scores (see Fig. 3B–E), but was driven mostly by the velocity score. The velocity score is closely related to learning how to slow or stop the ship, which is one of the most difficult components of the Space Fortress game. Explicit lessons on slowing and stopping in the part-task training of HVT may have driven increased mastery of the low proficiency group.

Another important contribution of our study is to provide a missing link between studies of transfer of training from trained tasks to other, unrelated cognitive tasks. Although some studies have found that Space Fortress training involving VPT can result in transfer to seemingly different tasks like jet piloting (Gopher et al., 1994), others found little benefit of VPT for transfer to tasks other than those specifically trained (Boot et al., 2010). Gopher et al. (1994) examined the effect of two directed training conditions involving differing degrees of VPT, and compared these two training groups to an untrained control group. Therefore, it was unclear whether broad transfer was attributable to VPT or simply experience playing the Space Fortress game. Furthermore, Gopher et al. (1994) used only one transfer task engaging many overlapping processing components with the Space

Table 6

Summary of transfer of training results comparing participants who received HVT to those receiving FET training and control group. Standard deviations are within parentheses.

	Pre-testing			During-training			Post-training			p-values	
	FET	HVT	No-contact	FET	HVT	No-contact	FET	HVT	No-contact	During	Post
Dot Comparison ($N_{FET}=25$, $N_{HVT}=25$, $N_C=25$)											
RT	1932.08 (490.82)	1861.16 (423.26)	2023.62 (501.29)	1876.79 (396.36)	1804.84 (397.33)	1884.08 (505.21)	1713.10 (378.90)	1688.65 (394.41)	1830.33 (558.26)		
Accuracy	90.40 (5.50)	89.32 (6.30)	90.44 (5.00)	91.84 (3.67)	89.92 (5.51)	90.48 (5.95)	91.12 (5.10)	89.52 (5.03)	89.56 (6.50)		
Composite[a]	.076 (1.04)	.033 (1.16)	−.11 (.95)	.16 (.75)	−.04 (1.03)	−.11 (1.16)	.25 (.89)	.02 (1.01)	−.28 (.13)	.683	.221
Sternberg Memory ($N_{FET}=25$, $N_{HVT}=25$, $N_C=25$)											
RT	912.34 (211.11)	1061.48 (330.82)	1026.09 (286.48)	1004.17 (310.82)	1020.05 (308.97)	1065.54 (268.50)	955.71 (319.83)	1069.15 (269.99)	1094.35 (266.73)		
Accuracy	94.60 (4.22)	94.24 (3.81)	93.62 (3.79)	91.92 (7.96)	94.16 (4.82)	91.34 (8.22)	91.98 (8.86)	93.84 (4.15)	89.36 (8.76)		
Composite[a]	.38 (1.37)	−.16 (1.70)	−.21 (1.46)	.01 (1.78)	.25 (1.25)	−.27 (1.64)	.33 (1.76)	.18 (1.10)	−.52 (.13)	.075	.115
Flanker ($N_{FET}=25$, $N_{HVT}=25$, $N_C=25$)											
Congruent RT	448.49 (61.48)	447.36 (44.26)	464.46 (73.54)	429.84 (48.19)	424.98 (30.29)	432.54 (70.34)	403.89 (42.71)	416.71 (25.34)	417.74 (46.03)		
Incongruent RT	497.31 (53.89)	503.01 (39.14)	522.41 (63.96)	483.31 (47.39)	488.37 (37.77)	489.45 (71.68)	456.79 (36.71)	470.73 (28.82)	465.78 (21.43)		
Congruent accuracy	99.36 (1.11)	99.20 (1.82)	99.68 (.74)	98.80 (1.41)	99.20 (1.63)	98.48 (2.10)	99.04 (1.54)	98.72 (2.93)	98.64 (2.13)		
Incongruent accuracy	96.00 (4.50)	92.88 (1.52)	96.08 (4.91)	94.00 (5.68)	93.36 (6.39)	88.08 (2.03)	91.2 (6.08)	91.6 (5.85)	90.96 (8.02)		
Cost composite[a]	−.255 (1.09)	.07 (1.07)	.18 (.83)	−.26 (.98)	.19 (.85)	.07 (1.17)	.14 (1.33)	−.02 (1.40)	−.12 (1.42)	.304	.722
N-back ($N_{FET}=25$, $N_{HVT}=25$, $N_C=25$)											
1-back accuracy	97.48 (1.91)	96.32 (3.4)	95.28 (7.01)	96.20 (3.10)	95.60 (4.78)	93.44 (7.20)	96.48 (2.85)	94.56 (4.36)	93.36 (6.81)		
2-back accuracy	93.12 (5.94)	90.60 (9.87)	90.16 (5.96)	92.72 (6.10)	93.44 (5.52)	89.16 (12.56)	93.52 (6.39)	92.04 (6.03)	86.48 (14.8)		
Dual cost[a]	4.36 (5.40)	5.72 (9.12)	5.12 (7.04)	3.48 (4.56)	2.16 (6.48)	4.28 (8.29)	2.96 (5.20)	2.52 (5.18)	7.20 (12.67)	.454	.095
Change detection ($N_{FET}=25$, $N_{HVT}=25$, $N_C=25$)											
Accuracy change	84.60 (8.41)	84.42 (11.70)	77.91 (18.61)	87.81 (6.39)	85.04 (20.28)	81.91 (10.09)	86.43 (9.90)	86.43 (9.50)	85.91 (8.89)		
Accuracy no-change	72.00 (38.4)	63.54 (38.85)	82.00 (31.88)	86.66 (26.35)	86.00 (33.91)	96.00 (20.00)	82.00 (31.89)	82.00 (31.39)	82.00 (37.86)		
Accuracy composite[a]	.152 (.98)	−.09 (.71)	−.06 (1.25)	.10 (.74)	−.12 (1.60)	.014 (.82)	.01 (1.22)	.01 (1.16)	.03 (.91)	.843	.957
Attentional Blink ($N_{FET}=25$, $N_{HVT}=25$, $N_C=25$)											
T2 dual cost (lag8–lag2)[a]	33.28 (10.12)	43.96 (31.74)	33.92 (29.92)	23.24 (31.1)	27.16 (38.05)	17.40 (36.43)	25.20 (39.45)	31.20 (40.05)	16.56 (25.92)	.759	.489
Manual Sequence ($N_{FET}=25$, $N_{HVT}=25$, $N_C=25$)											
RT_decrease	134.14 (90.20)	87.23 (72.53)	140.57 (73.06)	124.60 (94.58)	81.31 (90.58)	106.95 (94.33)	140.06 (119.83)	122.532 (99.62)	66.58 (89.25)		
Accuracy	97.8 (.016)	97.4 (.021)	96.3 (.067)	96.8 (.035)	96.9 (.024)	96.2 (.037)	96.0 (.032)	96.7 (.025)	96.4 (.036)		
Composite[a]	.317 (1.22)	−.35 (.90)	.03 (2.14)	.26 (1.39)	−.15 (1.19)	−.10 (1.78)	.16 (.122)	.23 (1.15)	−.40 (1.52)	.820	.194
Raven's Matrices ($N_{FET}=25$, $N_{HVT}=25$, $N_C=25$)											
Accuracy[a]	78.66 (14.28)	77.47 (17.26)	71.47 (18.40)	N/A	N/A	N/A	83.60 (12.18)	79.51 (14.30)	69.46 (21.42)		.021
Probability Learning ($N_{FET}=25$, $N_{HVT}=25$, $N_C=25$)											
Single learning	3.75 (30.52)	9.20 (24.3)	0.00 (26.4)	2.8 (26.06)	8.8 (27.73)	9.6 (23.53)	13.2 (27.4)	5.2 (26.31)	7.6 (20.26)		
Dual learning	−3.33 (22.48)	1.60 (23.03	7.2 (19.04)	8.4 (21.54)	4.0 (27.98)	−4.8 (24.51)	3.6 (25.63)	−.4 (24.4)	0.00 (23.6)		
General learning[a]	−.25 (1.46)	.17 (1.44)	.08 (1.59)	.06 (1.52)	.12 (1.45)	−.19 (1.15)	.28 (1.33)	−.20 (1.6)	−.08 (1.41)	.701	.431
Dual-Task Manual Tracking ($N_{FET}=25$, $N_{HVT}=25$, $N_C=25$)											
Single distance from (0,0)	43.09 (27.64)	48.21 (37.03)	70.65 (52.05)	22.93 (16.52)	24.42 (15.63)	37.21 (30.29)	16.43 (13.96)	24.86 (17.99)	27.78 (17.85)	.224	.388
Dual distance from (0,0)	48.94 (37.74)	46.75 (33.26)	74.89 (67.70)	21.42 (14.55)	39.24 (26.32)	40.03 (41.86)	26.89 (18.05)	29.60 (23.07)	36.24 (28.16)		
Dual cost[a]	.09 (1.12)	−.18 (1.05)	.09 (1.67)	−.32 (1.13)	.59 (1.97)	−.27 (1.95)	.20 (1.43)	−.02 (2.13)	−.18 (1.9)	.153	.823
Radar Monitoring ($N_{FET}=25$, $N_{HVT}=25$, $N_C=25$)											
Accuracy[a]	94.55 (6.35)	95.59 (6.86)	96.6 (4.86)	95.61 (6.29)	97.01 (4.41)	93.95 (14.16)	95.30 (6.54)	96.40 (5.39)	97.00 (5.72)	.409	.896
Flight Simulation ($N_{FET}=25$, $N_{HVT}=25$, $N_C=25$)											
X-plane score[a]	.496 (1.72)	.05 (1.99)	−.55 (2.16)	.58 (1.61)	.26 (1.89)	−.84 (2.18)	.55 (1.69)	.32 (1.8)	−.87 (2.1)	.264	.194

Note: Number of participants in any task for FET, HVT, and control group are denoted by N_{FET}, N_{HVT} , and N_C respectively. The signs for the 'Manual Tracking Dual cost' and 'X-plane score' are reversed in order to be consistent with other scores. Positive score indicates better performance, except for cost scores (positive means higher cost).

[a] Indicates primary measure.

Fortress game such as manual control and visual and spatial attention. Therefore, the breadth of transfer effects was uncertain.

On the other hand, Boot et al. (2010) compared a directed training strategy (VPT) to non-directed training (FET) using a transfer battery much larger than the assessment used by Gopher et al. (1994). Boot et al. (2010) found very little advantage of VPT over FET. However, this study did not include a no-game control group, therefore it was unclear whether the general lack of transfer observed was due to limited ability of the training strategy to produce effects or due to practice (regardless of strategy) improving performance generally.

The current study was designed to disentangle the effect of training strategy and practice on transfer to various cognitive tasks by comparing a directed training strategy group (HVT), non-directed training strategy group (FET) and a pure control group. Contrary to recent claims of potentially broad transfer of training involving Space Fortress (e.g., Gopher et al., 1994), our results demonstrated neither game practice nor directed strategy improved transfer, although both affected Space Fortress game performance to varying degrees.

On the surface, our results appear inconsistent with evidence that video game training transfers to measures of basic perceptual and cognitive abilities (Green & Bavelier, 2003, 2006a, 2006b, 2007). In these studies, non-gamers were trained to play a fast-paced action games and improvements were observed on a variety of tasks tapping attentional and visual processing, sometimes with as little as 10 h of training. One possible explanation for this discrepancy is the specific overlap of processing components between criterion and transfer tasks (Dahlin, Neely, Larsson, Backman, & Nyberg, 2008). Green and Bavelier used commercially available first-person shooter games that provide a rich virtual environment with many objects that demand attention and visual resources (Medal of Honor, for Green & Bavelier, 2003, 2006b; Unreal Tournament 2004, for Green & Bavelier, 2006b, 2007). Similarly, task complexity (but not visual complexity) of the Space Fortress task and certain game components overlap with the task of jet piloting, consistent with previous training findings (Gopher et al., 1994). However, we found that Space Fortress training produced no transfer to laboratory tasks spanning a range of complexity and processing demands, some with clear connections to the Space Fortress task itself (e.g., manual control). Future studies will need to resolve the connection between different elements of training and transfer to aid in our understanding of how visual complexity, general task complexity, and specific overlapping task components all contribute to producing transfer to not just laboratory tasks of ability, but to the complex tasks we perform every day outside of the laboratory.

The lack of transfer found in the current study is consistent with recent studies demonstrating little or no transfer benefit from game training (Ackerman et al., 2010; Boot et al., 2008; Owen et al., 2010), suggesting that often training gains might be restricted to the trained task or tasks requiring common cognitive processes with the trained task. Therefore, large gains on trained tasks resulting from practice or directed training do not necessarily lead to greater transfer of training.

4.1. Summary

Video games have become increasingly popular as a way to acquire new skills and to train cognitive abilities. Consequently, the efficacy of video game training and transfer of training have become important topics of study in cognitive psychology. The present study demonstrated that a hybrid training technique (HVT) produced accelerated learning and better performance compared to FET, with the advantages persisting seven months after the training. Also, the gains from video game training depend, in part, on individual differences. The advantage from HVT was greatest for those participants who were initially among the lowest performers. Performance gains from HVT, however, did not necessarily lead to better transfer to untrained tasks. Additionally, there was no general advantage of game experience when compared to the control group, suggesting that training and practice can produce task-specific improvements, but improvements do not necessarily transfer from trained to untrained tasks.

Given that the training strategy and individual differences contributed to learning, future studies could explore other sorts of individual or group differences in the effectiveness of training (e.g., age differences in training effectiveness). Given the greater effectiveness of HVT for less proficient participants, HVT might be ideal for older adults, particularly those with cognitive decline (but see Blumen, Gopher, Steinerman, & Stern, 2010).

Acknowledgment

We thank Shanna DeSouza, Douglas Finney, James Ricci, Zach Richardson, Emily Havansek, and Gerard Wong for their help in data collection. This study is funded by Office of Naval Research (N00014-07-1-1913).

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