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Transfer of skill engendered by complex task training under conditions of variable priority

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ABSTRACT

We explored the theoretical underpinnings of a commonly used training strategy by examining issues of training and transfer of skill in the context of a complex video game (Space Fortress, Donchin, 1989). Participants trained using one of two training regimens: Full Emphasis Training (FET) or Variable Priority Training (VPT). Transfer of training was assessed with a large battery of cognitive and psychomotor tasks ranging from basic laboratory paradigms measuring reasoning, memory, and attention to complex real-world simulations. Consistent with previous studies, VPT accelerated learning and maximized task mastery. However, the hypothesis that VPT would result in broader transfer of training received limited support. Rather, transfer was most evident in tasks that were most similar to the Space Fortress game itself. Results are discussed in terms of potential limitations of the VPT approach.

Although practice almost invariably improves performance, some types of practice are more effective than others (Schmidt & Bjork, 1992). For tasks that require the simultaneous performance and coordination of multiple component tasks, Variable Priority Training (VPT) accelerates learning and produces superior performance (see Gopher, 2007 for a review). VPT learners practice the whole task, but focus their attention on improving specific subcomponents of the task at different times (thus differing from traditional part-task training in which task subcomponents are practiced in isolation, Whaley & Fisk, 1993; Wightman & Lintern, 1985). In one test of VPT, participants performed a challenging dual-task in which they monitored several gauges and simultaneously solved symbolic arithmetic problems (Kramer, Larish, & Strayer, 1995; Kramer et al., 1999). The control group emphasized both aspects of the task equally while the VPT group completed different blocks of trials in which they were instructed to emphasize performance on the gauge monitoring component more than the arithmetic component, and other blocks in which this emphasis was reversed. Critically, participants in the VPT group still had to perform both task components even while shifting their emphasis. As a result, VPT participants learned the task faster and reached a higher level of mastery compared with participants who emphasized both task components equally.

Although training efficiency is critical to an effective training regimen, the ideal training method not only produces improved performance on the trained task, but on other tasks as well. VPT, compared with part-task training or training involving equal emphasis on task components, appears to engender broader transfer to untrained tasks and situations. Compared with the control group, participants who received VPT while learning the gauge monitoring and arithmetic task demonstrated greater performance gains on a novel task involving simultaneous scheduling and working memory components (Kramer et al., 1995).

Some of the best evidence for the superiority of VPT comes from studies using the complex video game Space Fortress, which was designed by cognitive psychologists as a research tool to study learning and training strategies. Space Fortress incorporates many diverse task demands including manual control, memory, visual attention, and executive control (Donchin, 1989). Players navigate a ship and fire missiles at the "Space Fortress", while dealing with friend and enemy mines that periodically appear on the screen, in addition to performing a number of other subtasks. Consistent with a VPT

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advantage, participants trained to play Space Fortress using VPT showed faster learning and higher levels of mastery compared with participants trained to emphasize the whole task (Fabiani et al., 1989; Gopher, Weil, & Siegel, 1989). VPT also resulted in superior resistance to distraction when participants were asked to perform other demanding tasks concurrently with the Space Fortress game (Fabiani et al., 1989).

Further evidence for broad transfer of training following VPT comes from a study of Israeli Air Force cadets (Gopher, Weil, & Bareket, 1994). Cadet flight performance was evaluated before and after 10 h of Space Fortress training. One group of cadets practiced the Space Fortress task under VPT and another group practiced Space Fortress under VPT and also received part-task training. Cadets who received both types of training (VPT and part-task) excelled in the Space Fortress game compared with participants who only received VPT, but both groups showed significant transfer to actual jet flight performance compared with a control group that received no Space Fortress training. Transfer of training occurred even though the visual and control dynamics of Space Fortress have little in common with piloting. In this case it was impossible to disentangle VPT effects from general video game transfer effects (e.g., Basak et al., 2008; Boot et al., 2008; Green & Bavelier, 2006, 2008; Li, Polat, Makous, & Bavelier, 2009) since no group received Space Fortress training without also receiving VPT. Thus strong conclusions regarding VPT cannot be drawn.

How does VPT accelerate skill acquisition and increase transfer of training? VPT protocols typically incorporate a number of features known to improve learning (Gopher, 2007), including increased training variability and an emphasis on the use of feedback (Schmidt & Bjork, 1992). However, the primary benefits of VPT may derive from encouraging learners to explore and evaluate different strategies, effectively pushing participants out of suboptimal strategies and towards more optimal ones. Furthermore, by encouraging participants to shift priorities, the relationships between different components of a task are made more salient. In this sense, learners build a more complete and complex representation of the task (see Ericsson, 2007; Ericsson, Krampe, & Tesch-Römer, 1993 for similar explanations for how expert performance is achieved).

While a greater understanding and exploration of the task itself can explain greater skill mastery, it does not necessarily explain transfer of acquired skills to other tasks. Broad transfer (improvement on tasks dissimilar from the trained one) could result from learning the value of strategy exploration which learners might then apply to other tasks, or broad transfer might result from improved attentional control gained from the experience of monitoring and adjusting the allocation of cognitive resources during VPT (Gopher, Weil, & Bareket, 1994; Kramer et al., 1995). In the latter case, this may suggest that complex, real-world tasks such as driving and piloting may especially benefit from VPT transfer effects since these tasks involve the simultaneous monitoring and performance of multiple task subcomponents. Consistent with the attentional control explanation, practice on tasks that exercise executive control (the planning and coordination of tasks) results in broad improvements on untrained tasks (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Persson & Reuter-Lorenz, 2008). A third possibility is that VPT improves performance of specific task subcomponents of the trained task that happen to overlap with components of the transfer task. For example, jet piloting and Space Fortress appear on the surface very different, but may actually require some similar skills. If those skills are emphasized and exercised to a greater extent under VPT, then the transfer from Space Fortress to piloting might just reflect training of those components. Cadets might have learned the importance of correcting deviations between actual and intended ship/jet trajectory with small, controlled motor movements. Since Space Fortress under VPT occasionally asks players to devote resources to monitoring motor control performance, cadets trained with VPT might have learned this sooner.

The goal of the current study was to test the limits of VPT and transfer of training to untrained tasks. Participants were trained to play Space Fortress and completed a broad battery of cognitive and psychomotor assessment tasks before and after training. This battery included tests of basic memory, visual processing, visual attention, task-switching, and reasoning ability, as well as complex simulated real-world tasks (radar monitoring and flight simulation). We tested the hypothesis that VPT would engender broader transfer of training by comparing participants trained under a VPT protocol with participants trained to emphasize all task components equally (which we call the Full Emphasis Training group, or FET). By including this control group, we can ensure that our experiment tests transfer attributable to VPT and not due to video game training per se. Our assessment battery included tasks that can distinguish between alternative accounts for a VPT transfer advantage. If attentional control is the fundamental mechanism behind broad transfer, VPT should differentially enhance performance on transfer tasks that rely heavily on executive and attentional control (e.g., task switching and dual-tasking measures). If training improves specific cognitive and psychomotor skills that are common to both Space Fortress and the transfer tasks, then transfer should be fairly narrow (i.e., limited to tasks with clear analogues to tasks within the Space Fortress game).

1. Methods

1.1. Participants

Forty-two participants were recruited from the Urbana-Champaign community. Participants were selected for the study if they reported no more than a moderate amount of video game experience (<3 h of game play per week over the past two years). Participants reported normal or corrected-to-normal vision and were right-handed. Thirty-nine participants completed the study, which included 42 h of testing and training (including brain imaging sessions, data from which are reported elsewhere; Erickson et al., 2010). Excluding three participants who did not complete the study, twenty participants were randomly assigned to the VPT group, and nineteen were assigned to the FET group (see Table 1 for participant demographics).

1.2. Stimuli and procedure

Before and after 20 h of Space Fortress training, participants completed a battery of assessment tasks over the course of 4 h (two 2-hour sessions taking place on different days). After the first administration participants were taught the rules of the Space Fortress game, which were explained in a separate session in which participants viewed a 20 min movie explaining the details of the game, a 5 min movie summarizing the most important game aspects, and then played 24 3-min long games. After this session, but before the 20 h of game training, participants completed one 2-h magnetic resonance imaging (MRI) session and one 3.5-h event-related brain potential recording (ERP) session in which they played the Space Fortress game and completed other tests. After neuroimaging and

Table 1
Participant demographics for each training group.

	FET	VPT	*p*-value
N	19	20	NA
Age	21.79 (2.37)	22.70 (3.33)	.33
% Male	21	35	.33
Baseline SF	221.79 (1878.70)	202.18 (1715.87)	.97

Note. Standard deviations are indicated within parentheses. The *p*-value column demonstrates that groups did not differ significantly in terms of basic demographics or initial game proficiency (as determined by *t*-test or χ^2 test). FET = Full Emphasis Training; VPT = Variable Priority Training; SF = Space Fortress.

assessment sessions were completed, participants began game training. Training consisted of ten 2-h training sessions that differed for each group.

FET participants engaged in a strategy in which they always attempted to obtain the highest overall score. VPT participants engaged in a strategy in which they focused their attention on a subset of skills during game play on different blocks of trials. After 20 h of training, participants again completed the assessment battery (in addition to another MRI and ERP session). The assessment battery, Space Fortress game, and training protocols are described below.

1.2.1. The Space Fortress game

The Space Fortress game was developed by cognitive psychologists as a tool to study learning and training strategies (Donchin, 1989). Detailed game descriptions, including figures, can be found elsewhere (Mané & Donchin, 1989; Shebilske et al., 2005); here we provide a brief description of game goals and dynamics. Space Fortress requires players to manage multiple demanding and overlapping component tasks and simulates the complexity of many important real-world tasks.

The main goal of the game is for players to destroy the Space Fortress (at the center of the screen) as many times as possible while avoiding damage to their own ship. Players must navigate their ship with precise control using a joystick in a frictionless environment. The ship has no braking system; to slow or stop the ship players must rotate it so it faces the opposite direction of its current motion and apply a thrust. This makes control of the ship a challenging and demanding task. To destroy the fortress, players must hit it with missiles by aiming their ship towards it and pushing the fire button on the joystick. The fortress becomes vulnerable to destruction after it is hit by ten missiles with the timing between each hit at least 250 ms. It can then be destroyed with a rapid double shot (two missile hits with the time between shots being less than 250 ms). The vulnerability of the fortress is reset to zero if it is hit with a double shot before it is vulnerable to destruction. The fortress rotates and shoots back at the player's ship, so the player's ship must be in constant motion. Each time the player's ship is hit four times it is destroyed.

At regular intervals, mines appear on the screen. Mines pursue the ship and try to damage it. Importantly, the fortress cannot be attacked as long as a mine is on the screen, thus mines must be dealt with immediately. The mine handling component of the game is based on the memory task developed by Sternberg (1966). Each mine has a letter associated with it that is displayed in the instrument panel at the bottom of the screen. This letter identifies it as friendly or not. At the beginning of each game participants are asked to memorize three letters that represent foe mines; all other mines are friends. Depending on whether the mine is a friend or a foe, the player must engage in different sequence of actions, and mine identification mistakes are costly.

Finally, there is a constant resource monitoring task embedded in the Space Fortress game. Below the fortress, a stream of symbols appears. Whenever a dollar sign symbol appears for the second time, players can use the mouse to either select bonus points or bonus missiles (which are a limited resource). If participants incorrectly identify the first dollar symbol as the second, they miss their opportunity to obtain a bonus. Participants are encouraged to monitor this information and obtain available bonuses.

Points are awarded to participants based on their game performance, and different actions add to, or subtract from, different subscores displayed in the instrument panel at the bottom of the screen. For example, participants are asked to keep their ship within a designated area on screen (in between a smaller and larger hexagon surrounding the fortress). Doing so increases the Control subscore. Flying the ship outside of the large hexagon or leaving the screen entirely subtracts from the Control subscore. The Velocity subscore rewards participants for maneuvering their ship slowly. The Speed subscore rewards/punishes participants for how quickly and accurately they deal with mines, and the Points subscore rewards participants for shooting and destroying the fortress, but subtracts points for damage and destruction of the player's ship.

1.2.2. Training and game strategies

The block and trial structure were identical for both groups, the only aspect that differed was the instructions the groups received before certain blocks of trials. Each session started with 3 test game trials in which participants were asked to maximize performance and focus on obtaining the highest total score. Next participants completed 30 practice games per session. For the FET group, participants were always asked to maximize total score during practice. For the VPT group, participants were asked to focus their resources on improving and monitoring different subscores of the game during practice. During each session, VPT 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). On odd numbered sessions, they completed the same emphasis blocks in the reverse order. At the very end of each 2-hour session, all participants (FET and VPT) completed another block of three test trials in which both groups were asked to emphasize total score. Average game scores in this block served as the primary unit of analysis, in addition to the very first block of three test-trails participants completed on the first session before training protocols diverged (referred to as baseline). Participants completed 3 to 5 sessions a week. In total, training consisted of 360 games of Space Fortress.

1.2.3. The assessment battery

Participants completed a number of tasks before and after Space Fortress training to assess differential transfer of training produced by VPT. These tasks are described below. Table 2 provides a brief summary of each task and the construct it assessed. In general, tasks fell into four categories: 1) visual and attentional tasks, 2) inhibitory and executive control tasks, 3) memory tasks, and 4) complex tasks, including two simulated real-world tasks.

1.2.3.1. Visual and attentional tasks

1.2.3.1.1. Dot comparison task. Participants were asked to quickly indicate whether two dot patterns were the same or different by pressing one of two keys on the keyboard. 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. On half the trials, the dot pattern on the right was different from the one on the left (one filled dot could be displaced by one position in the matrix). Feedback (correct or incorrect) was given during practice, and response time served as the primary measure of performance.

1.2.3.1.2. Attention blink (Raymond, Shapiro, & Arnell, 1992). Participants were asked to identify two targets in a rapid sequence of letters appearing at the center of the screen by making untimed keyboard responses. All letters were black except for one white letter. At the end of the sequence participants reported: (1) the identity of the white letter and (2) whether or not an X was presented some time after the white letter (50% of trials). Letters appeared for 12 ms, followed by an 84 ms inter-stimulus interval. Letter sequences varied in length from 16–22 letters and the white letter appeared unpredictably in the letter stream. The X could occur 2, 4, 6, or 8 letters after the white target (referred to as lag). Participants often fail to report the X when it appears soon after the white target (referred to as the "attention blink"). Participants completed one practice block of trials in which they had to detect the white letter, and another practice block in which they had to detect whether or not an X was present. Finally, participants completed test trials in which they had to report both. Of primary interest was the size of the "blink" observed. That is, the difference between when the X was the second

Table 2
Transfer task list and details.

Task name	Task order	Session assessed	Construct measured	Primary measure	# Practice trials	# Actual trails
Dot comparison	1	1	Visual processing speed	RT	10	108
Attention blink	2	1	Visual processing speed	"Attention blink": lag 8–lag 2 accuracy	40	144
Visual short-term memory	3	1	Visual memory	Accuracy	12	204
Flanker task	4	1	Selective attention/ inhibition	Cost: distractor interference (incompatible–compatible distractor RT)/ compatible distractor RT	20	100
Task switching	5	1	Executive control	Cost: switch trial–non-switch trial RT	80 single task 64 dual task	160
Stopping task	6	1	Inhibitory control	Time to successfully inhibit response	40	240
Dual-task manual tracking	7	1	Manual control	Cost: proportional increase in tracking error	4 single task trials	12 dual-task trials
N-back memory	8	2	Working memory	Cost: RT 2-back–RT 1-back	13 1-back 13 2-back	100 1-back, 100 2-back
Sternberg memory	9	2	Short-term memory	RT	32	96
Flight simulator	10	2	Complex task performance	Tracking error	1	5
Radar monitoring	11	2	Complex task performance	Identification efficiency (trial time/# items identified)	1	5
Ravens matrices	12	2	Fluid intelligence	Proportion correct	12 (pre-test only)	18

Note. RT = response time.

letter after the white target (when detection is typically worst) and when it was the 8th letter (when detection is typically good). Only trials on which the white letter was accurately identified were analyzed.

1.2.3.1.3. Visual short-term memory. Participants memorized objects and were asked to report whether a probe object matched one of the objects held in memory. Participants viewed displays containing four objects that varied in color (cyan, purple, white, yellow, black, green, red, blue) and shape (heart, circle, cross, triangle, arrow, square, star) for 250 ms. After a delay of 900 ms, one item was presented and participants were asked to indicate whether this object was one of the original four objects displayed. Accuracy was emphasized. Participants completed one block of trials in which they only had to remember the color of each object, one block in which they had to remember the shape, and one block in which they had to remember the color and the shape of each object. Overall accuracy was considered the primary measure of performance.

1.2.3.2. Inhibition and executive control

1.2.3.2.1. Flanker task. Participants completed a standard flanker task in which they responded quickly using the keyboard to the direction of a central arrow while ignoring flanking arrows that pointed in the same or opposite direction. On half of the trials, the flanking arrows were incompatible with the target (pointed in the opposite direction). Feedback regarding accuracy was provided during practice. Selective attention/inhibition was assessed by observing the proportional response time cost when flankers were incompatible compared with compatible.

1.2.3.2.2. Task switching (see Pashler, 2000). Participants completed a task that required them to quickly switch between judging whether a number (1, 2, 3, 4, 6, 7, 8, or 9) was odd or even and judging whether it was low or high (i.e., smaller or larger than 5). Numbers were presented individually for 2500 ms against a pink or blue background at the center of the screen. Background color denoted the task to be performed (blue = high/low task, pink = odd/even task). Participants pressed a key to the left if the number was low or odd. Participants pressed a key on the right if it was high or even. For practice, participants completed two single task blocks with accuracy feedback (1 block of odd/even, 1 block of high/low), then completed the same blocks without feedback. Then participants completed a practice dual-task block (with feedback) in which the two tasks were mixed together randomly. Finally, participants completed a real dual-task block (without feedback). Switch costs were of primary interest; that is, response time on trials on which the previous task was the same as the current task subtracted from trials on which the previous task was different.

1.2.3.2.3. Stopping task (Logan et al., 1997). Inhibitory control was measured using a stopping task. Participants were asked to respond to an X or an O as quickly as possible as soon as it appeared on screen. On 25% of trials, a tone occurred shortly after the appearance of the letter and participants were asked to inhibit their response when the tone occurred (stop trials). No tone occurred on the remaining trials and participants were required to respond as quickly as possible by pressing one of two keys (go trials). The tone was initially set to play 250 ms after the appearance of the letter on stop trials. If participants successfully inhibited their response when the tone occurred the task was made more difficult by increasing the delay between the letter and the tone by 50 ms. If participants were unsuccessful the task was made easier by decreasing the delay between the letter and the tone. The delay was adjusted in this manner to find the delay at which participants were just as likely to make a response as to withhold a response. A "stop reaction time" was calculated by subtracting the average delay between the letter and the tone from the average reaction time on go-trials (see Logan et al., 1997 for further explanation). This measure of inhibitory control served as the primary measure of performance. To familiarize participants with the task, participants completed practice trials in which no stop signal was present and then completed practice trials in which a stop signal was present and had a constant delay of 100 ms to make the task easy. Participants were given feedback if they did not stop in time. No feedback was provided during test trials.

1.2.3.3. Memory

1.2.3.3.1. Sternberg Memory Task (Sternberg, 1966). 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 by pressing one of two keys on the keyboard. Accuracy feedback was provided during practice trials. Response time served as the primary measure.

1.2.3.3.2. 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) in another block of trials. Each letter appeared for 500 ms with an inter-stimulus interval of 2000 ms. On 75% of trials the correct response was “no”. Speed was stressed. Accuracy feedback was provided during practice. Memory load cost was of primary interest: the difference in response time when keeping two items in memory compared to one.

1.2.3.4. Complex task performance

1.2.3.4.1. Dual-task manual tracking. Participants used a joystick to keep a cursor centered on screen as its location was influenced by random noise pushing it away from center. After four 90-s long single task trials participants completed 12 dual-task trials 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 (0, 1, or 2 gauges could go out of range per trial). Of primary interest was the cost of performing the gauge monitoring task on manual control.

1.2.3.4.2. 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. After a practice trial, participants completed 5 trials in which they had to identify each aircraft on the screen as quickly and as accurately as possible. An efficiency score was computed by dividing the time to complete each scenario by the number of items classified.

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

1.2.3.4.4. Ravens matrices (Raven, 1990). Participants were presented with a complex visual pattern with a piece cut out of it. The task of the participant was to find the missing piece that completed the pattern. The full version of Advanced Ravens was divided into two sub-tests of approximately equal difficulty, with each test containing 18 items. Before the participants were administered the pre-training form they were given 5 min to complete a practice version of the test. Participants were given 40 min to complete each 18 item test, once before and after training.

2. Results

To reduce the influence of within-participant outliers, we analyzed median rather than mean response times when applicable. Practice blocks of the transfer tasks were not included in any of the analyses. Analyses were conducted using Mathematica version 7 (Wolfram Research, Inc., 2009) and SPSS version 11.5 (*SPSS* Inc., 2002). To evaluate the treatment effect on transfer data, the effect size index eta-square (η^2) was calculated. First we confirm the effect of training on game performance, and then examine transfer of training effects.

2.1. Summary of training results

We sought to determine whether or not VPT was effective in producing accelerated learning and superior performance in the Space Fortress game. To control for gender effects (males tended to score higher than females), gender was included as a covariate in each analysis. Analyses were performed on eleven game blocks with each block composed of three games. These blocks included the initial three games participants played before the strategy manipulation was introduced (referred to as baseline) as well as the last three games played each session after training began (sessions 1–10). For each of these blocks, participants were told to emphasize total score. In cases where the sphericity assumption was violated, degrees of freedom were adjusted and reported when this correction resulted in a different pattern of significance (Hyun–Feldt adjustment). Fig. 1 depicts training gains for each group on total score and each game subscore.

2.1.1. Total score

VPT participants learned the game at an accelerated rate compared with FET participants and reached higher levels of mastery. An ANOVA was performed on Total Score data with session (baseline, sessions 1–10) as a within-participant factor and Training Strategy (FET vs. VPT) as a between-participant factor. This revealed a significant effect of Session ($F(10, 360)=97.57$, $p<.\ 001$), no effect of Strategy ($F(1, 34)=.59$, $p=.45$), and a significant Session by Strategy interaction ($F(10, 360)=2.81$, $p<.01$).

2.1.2. Control score

All participants improved as a result of practice, as indicated by a significant effect of Session ($F(10, 360)=49.97$, $p<.001$). However, there was no significant effect of Strategy ($F(1, 36)=1.92$, $p=.17$), and no significant interaction between Strategy and Session ($F(10, 310)=1.36$, $p=.20$).

2.1.3. Velocity score

As with control scores, participants made large gains in the velocity score over time, as indicated by a significant effect of Session ($F(10, 360)=28.85$, $p<.001$). There was no significant effect of Strategy ($F(1, 36)=.36$, $p=.55$), but there was a significant Strategy by Session interaction ($F(10,360)=2.31$, $p<.05$). However, this effect must be interpreted with caution as it did not survive after correction for the violation of sphericity ($F(2.15, 77.24)=2.31$, $p=.10$).

2.1.4. Points score

Point scores (reflecting damage to player's ship, fortress destructions) demonstrated an accelerated learning rate for participants in the VPT group. The overall ANOVA indicated a main effect of Session ($F(10, 360)=65.99$, $p<.001$), no effect of Strategy ($F(1, 36)=.17$, $p=.68$), and a significant interaction between Session and Strategy ($F(10, 360)=2.70$, $p<.05$).

2.1.5. Speed score

An ANOVA performed on speed scores (reflecting mine handling and identification) revealed a significant effect of Session ($F(10,360)=52.24$, $p<.001$), no effect of Strategy ($F(1, 36)=.83$, $p=.37$), and no Session by Strategy interaction ($F(10, 360)=1.32$, $p=.22$).

2.2. Discussion of training results

Training results were consistent with a VPT advantage (Fabiani et al., 1989; Gopher et al., 1989; Kramer et al., 1995, 1999). Participants who received VPT reached higher levels of performance more quickly compared with participants who practiced the game while emphasizing all subcomponents equally. While it is apparent that VPT improves learning, we next turn to the claim that VPT also engenders broader transfer of training.

2.3. Transfer of training results

Table 3 presents group means and standard deviations of all cognitive tests in the assessment battery, including their primary and

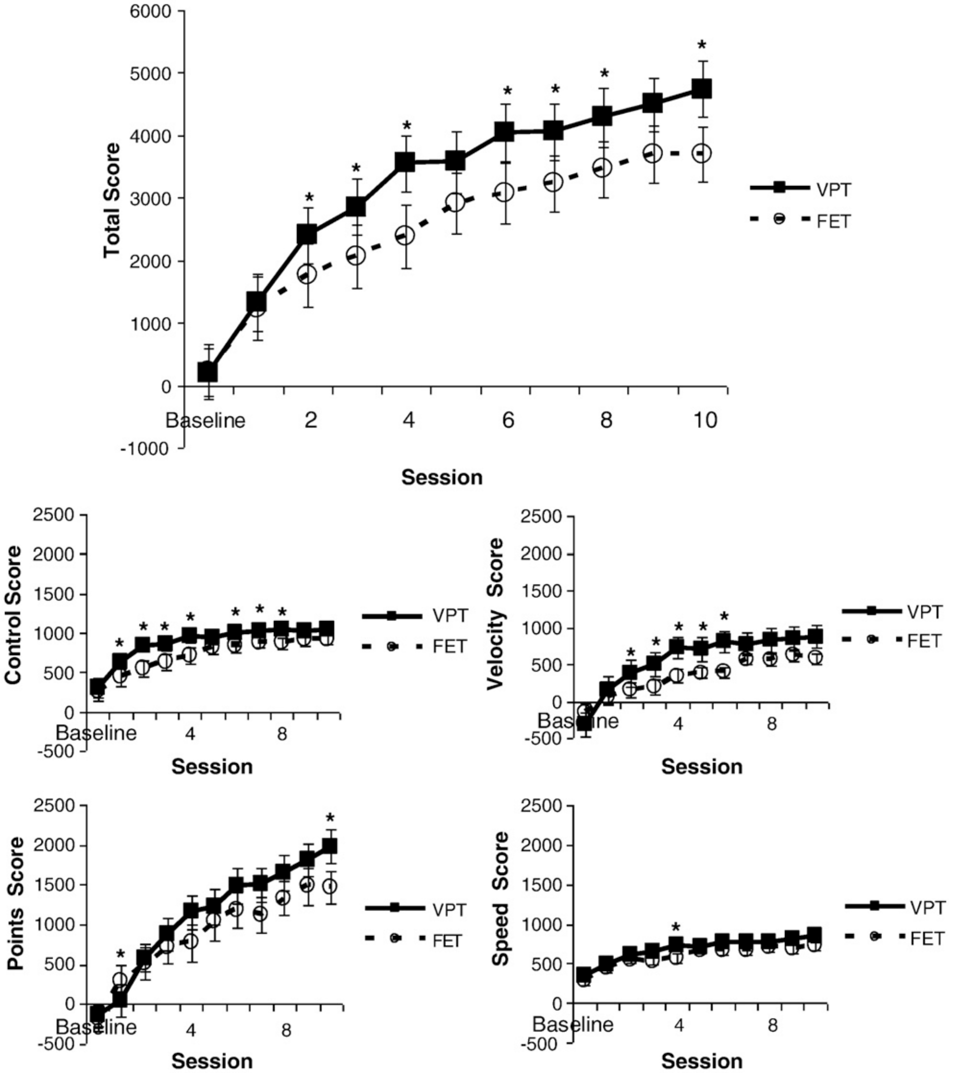

Fig. 1. Total score and subscores as a function of training and strategy group. Asterisks indicate one-tailed significant differences after controlling for gender and baseline performance ($p<.05$). Error bars represent +/− 1 SEM.

ancillary measures, across pre- and post- training cognitive testing sessions.

Post-training primary measures of transfer task performance were entered into a MANOVA. Baseline game proficiency (total score) was included as a covariate, along with gender and pre-training primary measures of transfer task performance. Strategy was entered as a between-participant factor. Because some participants failed to complete all pre or post-training tasks, this MANOVA included 19 FET and 15 VPT participants. Confirming that the nature of training received did indeed have an effect on transfer task performance, there was a significant effect of strategy, Wilks's $\Lambda = 0.14$, $F(7, 12) = 3.58$, $p<.05$, $\eta^2 = 0.86$ (large effect size). Next we examined the transfer tasks individually, starting with basic cognitive and psychomotor tasks, and then examining the performance of complex real-world task (radar monitoring, flight simulation).

2.4. Basic cognitive tasks

To better understand how the two training groups differed post-training, univariate ANCOVAs were performed on each task separately with the post-training primary measure of task performance as the dependant measure, group as a between-participant factor, and pre-training performance, baseline Space Fortress proficiency, and gender as covariates. Given the directional hypothesis of VPT performance exceeding FET performance, group comparisons were one-tailed (see Table 3 for full details). Tasks on which the group effect was significant are explored next.

2.4.1. Sternberg Memory Task

Averaged response time across set-sizes 3 and 5 served as a primary performance measure. A main effect of strategy group was significant, $F(1, 33) = 3.39$, $p<.05$ (one-tailed), $\eta^2 = 0.09$; estimated marginal means indicated that VPT participants were faster (733 ms) than FET participants (814 ms). A similar analysis of accuracy indicated no speed-accuracy tradeoff, $F(1, 33) = 1.47$, $p = .12$ (one-tailed), $\eta^2 = 0.04$ (estimated marginal means of .94 and .95 for VPT and FET groups, respectively). Interestingly, a further analysis of RT indicated transfer beyond set sizes encountered within the game. Recall that participants only had to remember 3 letters for the mine identification task within the game. An ANOVA with set size (3 vs. 5), time (pre vs. post-training) and strategy group as factors (and baseline Space Fortress performance and gender as covariates) revealed no set size by time by group interaction, $F(1, 34) = .96$, $p = .33$, $\eta^2 = 0.03$.

2.4.2. Manual tracking under dual load

The primary measure for this task was proportional dual-task tracking cost [(dual distance–single distance)/dual distance].

Table 3
Summary of transfer results comparing full emphasis and variable priority training groups.

	Pre-training		Post-training		*p*-value
	FET	VPT	FET	VPT	
Basic cognition tasks					
Stopping task ($n_{FET}=19$, $n_{VPT}=20$)					
Stop RT*	222.4 (59.82)	200.19 (68.30)	202.14 (64.33)	182.70 (60.37)	.50
Go RT	589.37 (153.25)	639.11 (215.34)	587.42 (168.88)	644.62 (189.26)	.42
Stop probability	0.51 (0.03)	0.51 (0.03)	0.53 (0.07)	0.51 (0.04)	.21
Dot comparison ($n_{FET}=19$, $n_{VPT}=20$)					
RT*	1899.21 (652.31)	1775.65 (373.39)	1636.74 (437.03)	1557.27 (327.80)	.35
Accuracy	0.92(0.05)	0.92(0.5)	0.91(0.05)	0.91(0.07)	.40
Task switching ($n_{FET}=19$, $n_{VPT}=19$)					
Switch cost *	200.02 (117.19)	242.41 (111.06)	165.93 (114.18)	176.94 (113.61)	.20
Non-switch RT	642.10 (112.56)	629.49 (97.52)	623.09 (94.60)	624.63 (85.03)	.49
N-back memory ($n_{FET}=19$, $n_{VPT}=20$)					
Memory load cost *	210.80 (149.06)	230.83 (227.95)	121.88 (131.19)	139.89 (124.20)	.36
1-back RT	612.62 (121.32)	607.34 (103.29)	602.86 (127.70)	597.57 (133.87)	.32
Flanker ($n_{FET}=19$, $n_{VPT}=20$)					
Proportion cost*	0.14 (0.13)	0.14 (0.07)	0.14 (0.12)	0.13 (0.06)	.26
Incongruent RT	512.39 (59.14)	496.38 (49.78)	475.26 (56.68)	476.90 (34.45)	.14
Congruent RT	450.63 (57.71)	433.43 (31.16)	418.11 (36.90)	422.98 (27.75)	.14
VSTM ($n_{FET}=19$, $n_{VPT}=20$)					
Accuracy	0.69 (0.08)	0.67 (0.10)	0.69 (0.09)	0.69 (0.10)	.34
Attention blink ($n_{FET}=19$, $n_{VPT}=19$)					
Size of blink	0.54 (0.27)	0.45 (0.24)	0.46 (0.34)	0.37 (0.28)	.35
Ravens matrices ($n_{FET}=19$, $n_{VPT}=19$)					
Proportion correct	0.79 (0.15)	0.82 (0.15)	0.70 (0.18)	0.71 (0.19)	.49
Sternberg memory ($n_{FET}=19$, $n_{VPT}=19$)					
RT*	815.26 (281.38)	817.28 (168.88)	810.66 (284.27)	729.26 (171.96)	.04 **
Accuracy	0.95 (0.03)	0.95 (0.09)	0.94 (0.05)	0.95 (0.05)	.12
Dual-task manual tracking ($n_{FET}=19$, $n_{VPT}=20$)					
Proportional dual-task cost *	0.39 (0.86)	0.58 (1.53)	0.95 (1.63)	0.17 (0.70)	.02 **
Single-task tracking error	54.63 (37.72)	49.76 (31.76)	25.41 (21.07)	30.45 (23.08)	.26
Applied cognition tasks					
Radar monitoring ($n_{FET}=19$, $n_{VPT}=19$)					
Identification efficiency	9.02 (2.26)	8.29 (1.50)	7.59 (1.86)	6.82 (1.19)	.15
Flight simulation task ($n_{FET}=19$, $n_{VPT}=20$)					
Total RMS error*	31.65 (9.21)	32.67 (11.89)	24.69 (7.58)	22.83 (6.85)	.08 ^^
Altitude error	13.96 (4.01)	13.95 (5.20)	10.70 (4.48)	8.39 (2.74)	.007**
Latitude error	17.69 (5.81)	18.71 (7.39)	14.00 (4.39)	14.44 (4.48)	.44

Note. Standard deviations are indicated within parentheses. Number of participants in each analysis for FET and VPT groups are denoted by n_{FET} and n_{VPT}, respectively. * indicates the primary measure of task performance. *P*-values indicate one-tailed comparisons between groups on post-training performance controlling for gender, initial Space Fortress proficiency, and pre-training task performance. ^^ denotes $p<.10$, ** denotes $p<.05$. FET = full emphasis training; VPT = variable priority training; RMS = root mean square; RT = response time.

Participants were to keep the cursor centered on the (0,0) coordinate using the joystick. A smaller average distance to the (0, 0) coordinate $[(x^2+y^2)^{1/2}]$ indicates better tracking. The main effect of strategy group was significant, $F(1,34)=6.33$, $p<.05$ (one-tailed), $\eta^2=0.12$, where estimated marginal means indicate that the dual-task tracking cost was smaller for VPT (.15) than FET (.97). Interestingly, overall tracking error in the absence of a dual-task was unaffected by strategy, $F(1, 34)=.44$, $p=.26$ (one-tailed), $\eta^2=0.01$; estimated marginal distance from (0,0), in terms of pixels, was 30 and 25 pixels for VPT and FET groups, respectively.

2.5. Applied tasks

2.5.1. Flight simulator task

Root mean square error was the primary measure of performance for the flight simulator task. The group effect was marginally significant for flight simulator performance, $F(1, 34)=2.04$, $p=.08$, $\eta^2=0.06$; the estimated marginal means suggested smaller error for VPT (24.98) than FET (22.55). Examining flight simulator data in more detail, it was discovered that there was a significant VPT transfer advantage in terms of plane altitude, $F(1, 34)=6.54$, $p<.01$, $\eta^2=0.16$, estimated marginal means of 8.4 and 10.7 for VPT and FET groups, respectively. No such advantage was found for plane latitude $F(1,34)=.026$, $p=.44$, $\eta^2=0.01$, estimated marginal means of 14.4 and 14.0 for VPT and FET groups, respectively.

Other than the previously discussed tasks, no other task trended towards a VPT advantage in either primary or ancillary measures.

2.6. Discussion of transfer results

Similar to previous reports of VPT, we found evidence that transfer to untrained tasks was greater for VPT participants. However, this evidence was not overwhelming. In terms of the basic cognitive battery, the VPT advantage seemed to be restricted to the two tasks most analogous to Space Fortress: retrieving letters from memory quickly, and manual tracking while performing other tasks. Results are also suggestive of an advantage for VPT participants on the flight simulator task. Again, manual control is a critical component of both flight simulator performance and Space Fortress. However, it is impressive that transfer was observed to both manual control tasks despite the dynamics of these tasks being completely different compared with Space Fortress. Recall that in Space Fortress, pushing forward on the joystick initiates thrusters, while left and right rotate the ship. In the manual tracking task under dual load, there was a 1-to-1 mapping of the joystick direction and how the tracking dot would move on the screen. In the flight simulator task, forward and backward joystick movements descended or ascended the plane, and left and right movements caused the plane to bank. Thus, in this sense, the transfer of manual control skill was broad.

3. Discussion

Variable Priority Training is known to accelerate learning and to produce superior mastery in a number of contexts (Gopher, 2007). Consistent with the notion that the type of training rather than solely the amount of practice may be the best facilitator of skilled performance (Ericsson, 2007; Ericsson et al., 1993), our results demonstrated that extensive VPT on Space Fortress led to 28% better performance than FET by the end of 20 h of training. Fig. 1 shows that participants in the VPT group reached the same level of performance (total score) as the FET group at the end of training in half the time. Thus, VPT effects were replicated in terms of accelerated learning and improved mastery.

Earlier work on training with Space Fortress found that VPT led to transfer from this video game to cadet flight performance in the Israeli military (Gopher et al., 1994). Consistent with the idea that VPT engenders broader transfer of training than FET, some tasks in our cognitive battery showed greater improvements following VPT than FET. Specifically, VPT led to superior performance on tasks involving manual control and on a memory task similar to a component task of Space Fortress. Unlike the earlier studies of flight performance, our transfer advantages are specific to the VPT strategy and are distinguishable from videogame training. The current study, and training studies like it, may contribute to our understanding of why in some situations VPT engenders broad transfer (e.g., Kramer, Larish, & Strayer, 1995; Kramer et al., 1999) and in some situations no transfer advantage is found (e.g., Bherer et al., 2005, 2008).

It is debatable whether these differential improvements constitute “broad” transfer. If the VPT protocol were primarily training executive and attentional control, we might have expected the task switching, flanker, and stopping tasks to have demonstrated differential transfer effects as well. If instead VPT encouraged strategy exploration in the context of novel tasks, even broader transfer might be expected. One explanation for the lack of broad transfer might be that broad transfer effects could have been swamped by processing benefits from the Space Fortress game per se, as was the case from the first person shooter games examined by Green & Bavelier (e.g., Green & Bavelier, 2006, 2008). Additional research is needed to distinguish benefits of the game itself from benefits specific to the type of training regimen. Our labs are currently in the process of a large-scale replication and extension of the reported study with a no-game control group that will distinguish between these alternatives. However, the current results are notable in that VPT alone appeared to engender some limited transfer benefits.

Video games are currently a hot topic of research in cognitive psychology. The most recent wave of interest stems from the demonstration of broad transfer of training from action games to laboratory tasks (Green & Bavelier, 2003). However, findings from the current study and the Space Fortress literature suggest that these studies may ignore important strategic factors that influence potential gains. An initial report found benefits when participants simply engaged in action video game play (Green & Bavelier, 2003). However, more recent studies come closer to “training” in that game difficulty was adjusted dynamically based on performance (e.g., Green & Bavelier, 2006; Green & Bavelier, 2007; Li et al., 2009). Differences in training strategy may explain inconsistent findings on the effects of video game play on perceptual and cognitive abilities (Boot et al., 2008). Given the current finding of a VPT advantage over and above video game effects, a fruitful future direction might be to combine VPT with modern complex action video games that seem to induce broad transfer of training on their own. This may be the best strategy in designing game interventions to sharpen perceptual and cognitive skills and obtain transfer not just to artificial laboratory tasks, but to real-world, safety-critical tasks such as driving, luggage screening, and Air Traffic Control.

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