1. Introduction

The current study investigated factors influencing strategy use in a complex real-time task. We focused on a circumstance in which individuals who already have a well-learned strategy face a novel environment in which the learned strategy becomes difficult to implement successfully. This circumstance is common in everyday settings. For instance, learning how to drive involves learning to execute a set of procedures in the correct sequences and fine-tuning the associated parameters (e.g., how much acceleration is needed to achieve 50 mph). After some practice, the combination of the procedures and the associated parameters allows one to achieve a reasonable level of performance. However, the driving strategy acquired under normal road conditions may not work successfully when one drives on icy roads. Faced with the change, one can still maintain the learned strategy by adjusting the parameters (e.g., decreasing the vehicle speed and applying smoother acceleration). Alternatively, one can deviate from the learned strategy and adopt a novel strategy geared to the constraints of the new environment. Instead of trying to control the car on icy roads according to the learned strategy, one can let momentum carry the car over the slippery patch and the driver can then steer into the skid.

Studies of human problem solving have shown that people often adopt a new, more efficient strategy or select between available strategies to adapt to various task requirements (Lovett & Anderson, 1996; Lovett & Schunn, 1999; Reder, 1987; Siegler, 1988; Walsh & Anderson, 2009). People strategically chose between mental computation and calculator use depending on problem difficulty and calculator responsiveness (Walsh & Anderson, 2009). People show adaptive strategy use not only in static problem solving tasks but also in dynamic tasks (Best, Schunn, & Reder, 1998; John & Lallement, 1997; Reder & Schunn, 1999). For example, participants learned to use a more efficient strategy that saved the number of key presses in the Kanfer–Ackerman Air Traffic Controller task (Lee, Anderson, & Matessa, 1995). However, people do not always adopt a better strategy (Fu & Gray, 2004; Schunn & Reder, 1998). This seems particularly likely when they have to change a well-practiced strategy to adapt to a new environment (as in driving on an icy road). If only some people discard the well-practiced strategy and adopt an alternative strategy, the question is what factors explain those who do and those who do not. We investigated two factors: Workload and individual differences in strategy use.

Workload is defined as the cost or demands that one experiences in achieving a specific level of performance. Workload can be detrimental to performance as more investment of resources on a task makes fewer resources available for performing other activities (Mane & Wickens, 1986). Negative effects of workload have been observed in various tasks ranging from dynamic decision making (Gonzalez, 2005), perceptual–motor skill (Morris & Leung, 2006), and mathematical problem solving (Sweller, 1988). The cognitive load theory (Sweller, 1988; Sweller, van Merrienboer, & Paas, 1998) claims that successful learning depends on minimizing unnecessary working-memory load. The effects
of workload can be especially critical in non-normal situations in which people need to deal with unexpected changes in the environment. For example, severe turbulence encountered during flight will impose increased workload on a pilot. In addition to flying the aircraft, the pilot may need to check a radar system to find a safer route to fly and communicate with air traffic control system.

Several studies investigated the relationship between cognitive capacity and strategy selection in reasoning and problem solving tasks. In MacLeod, Hunt, and Mathews (1978), individuals with higher spatial ability chose to use a spatial strategy rather than a verbal strategy in a sentence-picture verification task. The authors claimed that individuals chose strategies based on their rational estimate of capabilities. Reichele, Carpenter, and Just (2000) found significantly negative relations between strategy-related cortical activation (e.g., language-related regions) and psychometric performance (e.g., reading span). Based on capacity-constrained view of working memory (Just & Carpenter, 1992), the authors predicted that people should prefer strategies that minimize cognitive workload. In Beilock and DeCaro (2007), individuals with higher working-memory capacity were more likely to use computationally demanding processes than individuals with lower working-memory capacity did in solving complex math problems. Roberts, Gilmore, and Wood (1997) found that in a reasoning task in which a spatial strategy was less efficient than a cancellation strategy, individuals with high spatial ability adopted the cancellation strategy instead of the spatial strategy. They claimed that individuals with high spatial ability were able to construct a more accurate, stable representation of the task, which further allowed them to develop a more efficient strategy.

A limited-capacity view (Brooks, 1968; Kahneman, 1973; Navon & Gopher, 1979) predicts that high workload would negatively affect the ability to adopt an alternative strategy in skill performance. Trying to improve one’s strategy creates a dual-task situation. While one performs a task using the strategy (primary task), one may also monitor and evaluate how successful the strategy is (secondary task). When the strategy becomes less successful, one may attempt to develop an alternative strategy and evaluate its outcome. As workload from the primary task consumes more mental resources, fewer resources will be available for the secondary task interfering with the ability to adopt an alternative strategy. One can further question whether the type of workload would affect strategy use. In contrast to a single-resource view (Kahneman, 1973) that assumes a capacity-limited pool of undifferentiated resources that can be allocated to multiple activities, a multiple-resource view (Brooks, 1968; Navon & Gopher, 1979; Wickens, 2002) assumes that multiple capacity-limited pools of resources exist for different processes (e.g., perceptual, motor). The multiple-resource view predicts that two tasks that share the same resource structures will cause greater interference than two tasks that use different resource structures. Based on the multiple-resource view, we investigated the role of workload in strategy adoption by manipulating type of workload imposed on individuals performing a dynamic task. The significant relationship between working-memory capacity and strategy use (e.g., Beilock & DeCaro, 2007; Schunn & Reder, 1998) suggested manipulation of working-memory load. However, one can question whether it is the most relevant manipulation of workload in a complex dynamic task that requires a high level of perceptual-motor coordination. Therefore, in another condition we used a perceptual-motor load manipulation.

Substantial individual differences in reasoning and problem solving have challenged the development of a unified theory of strategy use (Roberts & Newton, 2001). The cognitive style account claims that different individuals have qualitatively distinct, consistent approaches to organizing and processing information. Cognitive styles reflect relatively fixed, stable cognitive structures that emerge as a function of genetic disposition, maturation, and experience (Kogan, 1980) and predispose individuals to particular preferences in instructional methods in learning situations (Riding & Sadler-Smith, 2002). Evidences suggest that matching the cognitive style with learning activity can optimize learning performance (Hayes & Allinson, 1993; Hayes & Allinson, 1996).

Individual differences in strategy use have been observed not only in academic learning situations (e.g., learning course materials, mathematical problem solving) but also in complex tasks performed in dynamic environments (Best et al., 1998; John & Lallement, 1997; Reder & Schunn, 1999). However, the cognitive style account has mostly focused on the former. One might question whether the cognitive style account can provide insights to understanding individual difference in the latter. In typical training situations in which an ideal strategy for normal situations is instructed to all trainees (e.g., pilots trained to use an exemplary navigation strategy), individuals may exhibit distinct patterns in precisely how they execute the instructed strategy. We questioned whether those patterns would predispose individuals to different strategies when they encounter non-normal situations. We suspected that those who adopt an alternative strategy in a non-normal situation would exhibit certain behavioral characteristics that distinguished them from those who continue with the instructed strategy.

To summarize, the current study aimed to investigate two factors that can affect strategy use in a dynamic task: 1) Workload imposed during the adaptation to a new environment, and 2) individual differences in the pattern of prior strategy execution. We trained participants to practice one strategy in a standard environment and then introduced changes that made executing the practiced strategy much more challenging. We imposed different types of workload on participants adapting to the changed environment. We identified two groups of individuals, those who continued with the learned strategy and those who adopted an alternative strategy. We further investigated the behavioral precursors of future strategy adoption. We used the Space Fortress game, a real-time dynamic task that simulates multitasking activities such as piloting an aircraft.

2. Navigation strategy in the Space Fortress task

2.1. The Space Fortress task

The Space Fortress game (Donchin, 1989) is a computer-based video game that requires flexible coordination of perceptual, cognitive, and motor components in a dynamic environment. The game was developed for the learning strategy program initiated by DARPA and has been used in skill acquisition studies to explore the effects of various training or instructional strategies on learning outcomes (Boot et al., 2010; Erickson et al., 2010; Fabiani, Buckley, Grattan, Coles, & Donchin, 1989; Frederiksen & White, 1989; Gopher, Weil, & Bareket, 1994; Joerger, Sims, Volz, Workman, & Shebliske, 2003; Lee et al., 2012; Mane, Adams, & Donchin, 1989; Newell, Carlton, Fisher, & Rutter, 1989; Whetzel, Arthur, & Volz, 2008).

The game (Fig. 1) mainly consists of four tasks: navigation, a fortress task, a mine task, and a bonus collection task. The participant navigates the ship in a frictionless environment by rotating it left or right (using the A and D keys, respectively) or thrusting (using the W key) to accelerate it. The participant has to control the ship to fly within an area enclosed by two hexagons.

A fortress stationed in the smaller hexagon rotates like a turret, tracking the ship’s trajectory and firing shells at the ship if it stays within one of the fortress sectors (fixed-size areas, each 10° surrounding the fortress) longer than 1 s. The participant has to shoot the fortress with a missile (using the space bar) at least ten times and then make a rapid double-shot to destroy it. Once it is destroyed, a new fortress becomes available after 1 s. To earn the most points, the participant has to check a radar system to find a safer route to fly and communicate with air traffic control system. The participants to practice one strategy in a standard environment and then introduce changes that made executing the practiced strategy much more challenging. We imposed different types of workload on participants adapting to the changed environment. We identified two groups of individuals, those who continued with the learned strategy and those who adopted an alternative strategy. We further investigated the behavioral precursors of future strategy adoption. We used the Space Fortress game, a real-time dynamic task that simulates multitasking activities such as piloting an aircraft.

Mines appear at random locations. A mine can be either a ‘friend’ or a ‘foe’. At the beginning of each game, the participant is shown three
letters and asked to remember them during the game. Whenever a mine appears, a letter associated with the mine appears in the IFF (Identify Friend or Foe) box at the bottom of the screen. If the letter matches one of the letters shown at the beginning, the mine is a foe and the participant has to press the J key twice with a 250–400 ms interval between the two key presses and then shoot a missile to destroy it. If the letter does not match, the mine is a friend and the participant has to shoot a missile to destroy it. If the participant fails to execute the required actions in time, the mine (regardless of whether it is a friend or a foe) eventually collides with the ship and points are lost. The mine identification task embeds a working-memory capacity task (Sternberg, 1966) into the game.

The participant also has to monitor a stream of symbols regularly flashing underneath the fortress. When the “$” symbol appears twice in a row, the participant can collect bonus missiles or bonus points (using the K and L keys, respectively). If the participant attempts to collect bonuses when the “$” symbol appears for the first time, the bonus collection chance is lost. The bonus collection task is similar to the 1-back task that requires judging whether an item matches the item one back in a sequentially presented list of items (McElree, 2001). The difference is that the target is always the “$” symbol in the bonus collection task whereas it can be any item in the 1-back task. The bonus collection task is also similar to another working-memory paradigm called AX-CPT task (Lorsbach & Reimer, 2010) that requires one to respond to target probe (“X”) only when the probe follows a specific valid cue (“A”).

The goal of the game is to maximize the total score, which consists of four subscores: CNTRL, PNTS, VLCTY, and SPEED. The CNTRL score is accumulated as the ship flies within the larger hexagon area. Hitting the smaller hexagon or wrapping the space (flying the ship off the edge of the screen) lowers the CNTRL score. The PNTS score is earned by destroying the fortress, destroying the mines, and collecting bonus points. These points are lost when the ship is damaged by a fortress shell or a mine. The VLCTY score accumulates when flying at an intermediate speed and decrements when flying very fast or very slow. The SPEED score is earned based on how quickly and accurately one destroys the mines.

2.2. Navigation changes

Navigating the ship is one of the most challenging tasks in the Space Fortress game. The ship flies in a frictionless environment and its movement is very sensitive to the keyboard inputs. The thrust force applied to the ship produces an acceleration that increments the ship’s velocity according to the vector rule. The optimal strategy (referred to as the circle strategy) is to fly in a circle around the fortress while aiming at the fortress (to be able to constantly shoot at it), turning and accelerating the ship as needed to maintain the circular trajectory. It is a considerable challenge to learn how to maintain the proper orientation and when to apply thrust in this task (Frederiksen & White, 1989). The mean CNTRL score of our participants was below 460 (the highest possible score was 1080) in their first game, reflecting the initial challenge of the navigation task.

We trained participants on the circle strategy in the standard environment and transferred them to a new environment where they would have to adjust their navigation strategy. We introduced two changes to the navigation environment. First, we added a “wind” that constantly blew in one direction, from the top to the bottom of the screen, continuously dragging the ship down toward the bottom. Rather than a constant pattern of turning and accelerating the ship, the participant had to adjust what they did as the ship flew in different directions—for instance, applying more acceleration flying into the wind than against the wind. Second, we increased the ship acceleration from 3 to 1.2 pixels per game tick. The same amount of thrust force applied to the ship produced greater velocity than before. Thus, the increased sensitivity of the acceleration key made the cost of errors much more severe. The combination of these two factors made it very difficult to maintain the circular orbit with the desired ship velocity. We have observed no participant who was able to achieve the previous levels of CNTRL and VLCTY scores while continuing to fly in circles in the new environment.

2.3. The pendulum strategy

While experimenting with this new environment we discovered that there was an alternative strategy which seemed easier than circling the fortress. Rather than applying acceleration going down, one only applies acceleration upwards (when flying into the wind) and then allows the wind to overcome the acceleration and blow the ship down. Because one is applying the force when aiming at the fortress, this results in a pendulum motion where the ship swings up one side of the fortress, is blown back, and then swings up the other side, and so forth. The density maps1 in Fig. 2 illustrate the major differences between the two strategies: Instead of making

---

1 The circular strategy maximizes the CNTRL score that is steadily increased by staying within the larger hexagon. According to Frederiksen and White (1989), maneuvering the ship about the fortress while remaining close enough to the fortress is an optimal strategy because it enables one to hit the fortress without being hit by the fortress. Their optimal strategy involved infrequently changing trajectories, which made the trajectory more like angular rather than circular. On the other hand, Destefano (2010) found that expert Space Fortress game players made circular, frequently changing trajectories and suggested that the change from joystick to keyboard (which made it easier to execute fine-grained movements) for ship control in Pygame Space Fortress was a likely cause for the change to the circular strategy.

2 To create the density maps, we obtained an image of ship paths from each of the 8 baseline games for each participant, and then averaged the images over games and participants.
The pendulum strategy has three signature characteristics that differentiate it from the circle strategy. First, it results in the ship flying mostly in the lower half of the screen. Second, the ship makes fewer orbits around the fortress. Third, the pendulum strategy makes it easier to navigate with a slower ship velocity. This is because it involves less use of the thrust key compared to the circle strategy that also requires constantly alternating between thrusting and rotating to the right.

While the pendulum strategy is easier to execute, it is not without a cost. The ship slows down as the wind overcomes its upward acceleration. When the ship is slower it is easier for the fortress to take aim at it and hit it with a shell. A perfectly executed circle strategy would still accrue more points, but it is extremely challenging to perfectly execute such a strategy in the presence of the wind.

3. Method

3.1. Participants

62 participants with normal or corrected-to-normal vision (aged between 18 and 34 years, mean age: 23 years; 52 males and 10 females) from the Carnegie Mellon University community participated in the study for monetary compensation ($10 per session). In order to motivate participants to complete all sessions, bonus money based on their total scores was paid. The average bonus money participants earned was $3.1 (S.D. = $1.3). Informed consent approved by the Carnegie Mellon University Institutional Review Board (IRB) was obtained from each participant.

All participants had finished previous training sessions with the Space Fortress task, achieved an average of at least 2500 points in their last 8 games, and agreed to participate in two further transfer sessions. The participants all came from other ongoing experiments in our laboratories. Thirty-eight participants came from a previous 4-session study and 24 from a previous 10-session study. Only about half of the participants from the 4-session study had achieved performance good enough to be selected for this study. Note that we recruited participants with a fair amount of experience with the task because our focus was to understand how people who already had a well-learned strategy would adapt to a changed environment.

3.2. Apparatus

Two Macintosh computers were used for the experiment. Participants played the Space Fortress game using a computer keyboard to make inputs while the Space Fortress game was displayed on a 17-inch monitor. We used the Pygame Space Fortress (Destefano, 2010) based on the Python programming language.

3.3. Procedure

The experiment consisted of training (either 4 or 10 sessions) followed by two transfer sessions conducted in a quiet room in the presence of an experimenter. At the beginning of the training sessions, written game instructions were provided to participants. The game instructions explained the basic game rules of the Space Fortress game and were available to participants throughout the experiment. Participants were instructed to use the circle strategy and reached a high level of mastery of this strategy as reflected in their CNTRL and VLCTY scores.4 Participants in the 4-session study played 52 games and participants in the 10-session study played 160 games. All participants played the original version of the Space Fortress game in the last 8 games of the training sessions.

At the beginning of the transfer sessions, participants were assigned to different workload conditions and read written instructions (Appendix A) about the presence of wind and the increased sensitivity of the acceleration key. However, they were not informed about the possibility of the alternative pendulum strategy. In order to allow comparisons across workload conditions, we interspersed 8 ‘baseline games’ throughout the 2 transfer sessions. The baseline games were identical for all conditions and involved playing the original version of the Space Fortress game but with wind and increased acceleration. Each transfer session had 13 games in total: 4 baseline games (1, 5, 9, and 13th games) and 9 non-baseline games in which workload was manipulated (2–4, 6–8, and 10–12th games). The duration of each game was 3 min regardless of sessions and conditions.

3.4. Workload conditions

We designed three workload conditions that differ in the type of workload imposed during the transfer sessions. Participants were randomly assigned to one of the workload conditions: 19 to the control, 23 to the mine (perceptual-motor workload), and 20 to the N-back (working memory). The workload conditions differed in the nature of the non-baseline games:

1. The control condition had games in which the only thing participants had to do was to destroy the fortress while navigating the ship. The games had neither the mine task nor the bonus collection task (i.e., neither mines nor bonus symbols were available in the screen). This condition imposed a relatively minimal workload compared to the other two conditions.

2. The mine condition had games in which participants handled foe mines in addition to destroying the fortress while navigating. In contrast to the original version of the game, in which foe and friend mines appear with roughly equal frequencies, these games had foe mines only. Foe mines pose a higher perceptual-motor demand than friend mines because they require pressing a key twice to produce a 250–400 ms interval before aiming and firing a missile. By removing the need to discriminate foe and friend mines, we eliminated working-memory demand of remembering three letters for mine identification. We also eliminated the bonus collection task to further reduce working-memory load.

3. In the N-back condition, participants performed a version of the bonus collection task in addition to destroying the fortress while navigating. In the original version of the bonus collection task, they had to press a key only when a dollar ($) symbol from the set ($ # & * % @) flashed twice in a row. In the N-back condition, they had to press a key when any symbol from the set (♥ ♦ ♣ ♠) matched the one presented two steps earlier. The two changes: 1) 1-back to 2-back, 2) from a dollar symbol to any symbol, were intended to increase working-memory demand and to make the bonus collection task similar to the standard n-back task. To prevent participants from ignoring this task, the ship was locked out from shooting.

3 The direction of the wind naturally increases the amount of time the ship spends in the lower screen. The circle strategy minimizes the increase by forcing the ship to fly in the upper screen. This difference is illustrated in the density maps in Fig. 2. In each image, the vertical bar left to the fortress indicates ship paths made when the ship initially started moving at the beginning of the game. The bar in the left image (circle strategy) lies mostly in the upper part of the screen showing that participants accelerated the ship upward in order to orbit around the fortress. In contrast, the bar in the right image (pendulum strategy) spans across both upper and lower parts of the screen showing that participants occasionally let the wind blow the ship downward.

4 Their mean CNTRL and VLCTY scores in the last 8 games of the training sessions were 1005 and 1051, respectively. The scores earned in those measures were fairly close to the highest possible scores (1080 for the CNTRL and 1260 for the VLCTY) suggesting that participants became proficient at the instructed circle strategy for the navigation task.
missiles if they missed a correct response or made a false alarm. The lockout lasted until they succeeded in the next bonus collection chance. The mine task was eliminated to minimize perceptual-motor demand.

4. Results and discussion

We will present results on a number of measures associated with performance in the games. On each measure outliers were identified in the following procedure: 1) A mean (e.g., mean total scores in the 8 baseline games) was computed for each participant, 2) among 62 mean values (from 62 participants), any value more than 3 times of the interquartile range above the third quartile or below the first quartile was classified as an outlier. In total, 12 outliers were excluded across 33 measures we will discuss. Fig. 3 shows the total scores for the different workload conditions, displaying the average over the last 8 games before the introduction of wind (pre-wind games) and the individual scores for the 8 baseline games (B1 through B8). The scores dropped from about 4500 points in the pre-wind games to just over 1000 points in the first baseline game. They quickly recovered to about 2500 points in the subsequent baseline games. Although this was substantially below participants’ pre-wind performance, they were transferring some skill because they were well above their beginning level in the standard environment. For instance, they averaged about −1000 points in their first game in the standard environment. However, reflecting the greater difficulty of the wind environment, no participant ever regained his or her pre-wind performance. There were large decrements in the CNTRL score (from 1005 to 720) and the VLT score (from 1051 to 138), the measures that directly reflect navigation performance. To return to the driving analogy, no driver is ever as good on ice as they are on a dry road.

As is apparent in Fig. 3, there was no effect of the workload conditions on the total scores in the pre-wind games ($F(2,59) = .66, p = .518$) as well as the baseline games ($F(2,58) = .40, p = .669$). There was also no effect on any of the subscores in the baseline games. There was a strong effect of the prior level they had reached in the pre-wind games. Fig. 4 shows the relationship between pre-wind game performance and baseline game performance for the individuals in different workload conditions. There is a strong correlation ($r = .73$) and this relationship does not interact with condition. The best fitting regression line (baseline-total-score = .935 + pre-wind-total-score − 1820) suggests that the baseline game performance is the pre-wind game performance minus about 2000 points.

While the workload manipulation did not affect the performance in the baseline games, it affected the navigation performance in the non-baseline games. The workload effect was significant in the CNTRL score ($F(2,57) = 6.60, p < .01$, one outlier excluded) in the non-baseline games due to the significantly worse performance in the mine condition (Meanmine = 773; Meancontrol = 884; MeanN-back = 900). The effect was not significant in the VLT score ($F(2,58) = 1.68, p = .195$). The PNTS and SPEED scores were not available for comparison due to the differences of the workload tasks. Because the nature of the non-baseline games does not allow further comparisons across conditions, we will focus on the results from the baseline games in the remainder of this paper.

4.1. Strategy difference in the wind

When the wind was introduced, participants started diverging in their strategy use. While some participants maintained the circle strategy, other participants adopted the pendulum strategy. To identify participants who adopted the pendulum strategy, we computed the measure called $P$ (pendulum), the proportion of time the ship flew in the lower half of the screen out of the total game time for each game. $P$ of .8 means that the ship stayed in the lower half of the screen for 80% of the total game time (i.e., approximately 144 out of the 180 s for a game). We classified the participants with mean $P$ in the last four baseline games (B5 through B8) greater than or equal to .6 as pendulum participants and the rest as circle participants who focus on the challenging navigation task in the wind environment.

---

5 The lockout makes the n-back task more equivalent to the mine task where there is a large immediate cost of ignoring the mine. Failing the mine task costs immediate loss of points (50 points if the mine damages the ship, and 100 points if the mine destroys the ship) whereas failing the n-back task does not unless the ship is out of missiles and then only 3 points per missile. Unless there was an extra penalty (lockout) for failing the n-back task, it seemed likely that participants would ignore the n-back task while they focus on the challenging navigation task in the wind environment.

6 For the total scores, an analysis of covariance was performed with the mean total scores in the baseline games as the dependent variable, workload as the between-subject variable, and the mean total scores in the pre-wind games as the covariate. The same analysis was performed for each subscore except that the corresponding mean subscores was used as the covariate.

7 An analysis of covariance was performed with the mean subscores (e.g., CNTRL) in the non-baseline games as the dependent variable, workload as the between-subject variable, and the corresponding mean subscores (e.g., CNTRL) in the pre-wind games as the covariate.
participants. The cut-off value .6 was set higher than .5 in order to best differentiate those who adopted the pendulum strategy from those who maintained the circle strategy but spent slightly longer time in the lower half of the screen due to the wind direction. Among 62 participants, 34 were classified as pendulum participants.

Part way through the experiment we began collecting strategy reports and obtained reports from 37 participants. Participants were provided with a written questionnaire with two questions at the end of the experiment. They were first asked to describe any navigation strategy they used during the transfer sessions. Then the pendulum strategy was explicitly described and they were asked if they had adopted it. We asked three individuals from our research group to classify strategies based on these reports, blind to the conditions of the participants. There was complete consensus on the strategies described by 27 of the participants. The P measure agreed with the consensus in 24 of these 27 cases. The remaining 10 consisted of 9 cases where at least one rater indicated uncertainty and just 1 case where there was an outright disagreement. The P measure agreed with the majority opinion in 7 of these 10 cases. This suggests that strategy adoption was usually accompanied by explicit awareness, consistent with Schunn, Lovett, and Reder (2001).

Fig. 5 shows the P measure for the circle and pendulum participants in the pre-wind games and its change over the baseline games. There was little difference between the two groups in the pre-wind games ($t(60) = .32, p = .749$) and P was close to .5. There was an immediate increase in P in the first baseline game (B1) in both groups, reflecting the tendency of the wind to push participants to the lower half of the screen. The difference between the groups was already significant in that game ($t(58.51) = 3.16, p < .01, \text{equal variances not assumed}$) suggesting that the discovery of the pendulum strategy occurred relatively early. A repeated measures analysis of variance with P as the dependent variable, strategy (circle versus pendulum) as the between-subject variable, and the 8 baseline games as the within-subject variable showed a significant interaction between baseline games and strategy ($F(7,420) = 14.60, p < .001$) due to the increasing divergence between the two groups over the baseline games.

Two additional measures support the validity of our strategy classification: 1) Number of orbits, and 2) ship's movement direction. With the pendulum strategy, the ship stays in the lower screen instead of orbiting around the fortress. As expected, we found that the

![Fig. 3. The total scores by workload condition (control, mine, and N-back) in the pre-wind and the baseline (B1–B8) games. Error bars represent standard errors of the means.](image)

![Fig. 4. Scatter plot of the total scores in the baseline games (y-axis) versus the pre-wind games (x-axis) by workload condition (control, mine, and N-back).](image)
pendulum group made significantly fewer orbits (Mean: 4.1, SD: 2.5) than the circle group did (Mean: 12.2, SD: 3.5) in the baseline games ($t(60) = 10.67$, $p < .001$). Fig. 6 shows that the P and the orbit measures agree on the separation between the pendulum participants and the circle participants. The negative correlation between P and the number of orbits was strong ($r = -.88$, $p < .001$).

In addition to making fewer orbits, the pendulum strategy involves flying the ship in the clockwise and counter-clockwise directions for an approximately equal amount of time. The circle strategy involves flying the ship mainly in the clockwise direction. We calculated the proportion of time the ship was flying in the clockwise direction out of the total time the ship was flying in either clockwise or counter-clockwise direction in the baseline games. As expected, the circle participants spent a significantly higher proportion of time flying the ship in the clockwise direction than the pendulum participants did (Mean$_{circle} = .68$, Mean$_{pendulum} = .52$, $t(46.92) = 7.10$, $p < .001$, equal variance not assumed). The mean of the circle participants was significantly higher than .5 ($t(27) = 9.35$, $p < .001$) confirming that the clockwise movement was dominant in the circle strategy. The mean of the pendulum participants was not significantly different from .5 ($t(32) = 1.46$, $p = .154$, one participant was excluded$^9$). The correlation between the P measure and the proportion of the clockwise movement was significantly negative ($r = -.74$, $p < .001$).

4.2. The effect of workload

Table 1 shows the number of circle and pendulum participants in each workload condition. Only 35% of the N-back participants (7 out of 20) were classified as adopting the pendulum strategy, compared to 65% of the mine participants (15 out of 23) and 63% of the control participants (12 out of 19). A chi-square test indicated a marginally significant effect of the workload condition ($\chi^2(2) = 4.71$, $p < .10$). When the control and mine participants were collapsed into a single group, the result was significant ($\chi^2(1) = 4.69$, $p < .05$). We conclude that working-memory load interfered with the adoption of the pendulum strategy.

We further tested whether individuals with better performance in the pre-wind games would be more likely to adopt the pendulum strategy or be more committed to the circle strategy. We divided the participants into high versus low performance groups based on the median (4594) of the total scores in the pre-wind games. There

---

$^8$ For each baseline game, we computed the amount of time the ship was moving in the clockwise direction and counter-clockwise direction, separately, in each quadrant of the screen determined by the x and y-coordinates of the fortress. For example, in the top left quadrant, positive velocity vector in the x-axis (the ship moving from left to right) is consistent with the clockwise movement, and negative (from right to left) with the counter-clockwise movement. In the bottom right quadrant, negative velocity vector is consistent with the clockwise movement and positive with the counter-clockwise movement.

$^9$ The participant did not apply thrust at all in three of the baseline games and thus the ship did not fly in either the clockwise or the counter-clockwise direction (i.e., the ship drifted in the wind flying only vertically, not horizontally). In the rest of the baseline games, the participant navigated the ship using the pendulum strategy.
was no difference between the two groups: 17 out of 31 participants in each group adopted the pendulum strategy. The two groups did not significantly differ in the mean P value in the baseline games either (Mean\textsubscript{low} = .64, Mean\textsubscript{high} = .66, t(60) = .69, p = .489). We also tested whether the amount of practice affected strategy adoption. Although the proportion of pendulum participants was slightly higher among the participants from the 10-session study (62.5%) than the participants from the 4-session study (50%), the contrast was not significant (χ²(1) = 92, p = .335). The difference in the mean P value was not significant either (Mean\textsubscript{10-session} = .68, Mean\textsubscript{4-session} = .63, t(60) = 1.23, p = .222). We did not find evidence that the overall performance or the amount of practice significantly influenced the adoption of the pendulum strategy.

4.3. Individual differences in strategy use

While working-memory load significantly affected the number of participants adopting the pendulum strategy, we failed to find any difference in performance among conditions within each strategy. Therefore, we will focus on the differences between the two strategies. Table 2 presents a comparison of the two strategy groups on a number of critical measures in the baseline games. Despite the dramatic strategy difference between the two groups, there is no significant difference in the total scores. However, they achieved the equivalent total scores rather differently:

1. Pendulum participants were marginally worse on the CNTRL subscore, which reflects how well they managed to keep their ship within the larger hexagon. They tended to let the ship drift further to the edge of that hexagon causing a loss in their CNTRL score. This excess drifting is also reflected in their average distance from the fortress (higher on the ‘distance’ measure in Table 2).

2. Pendulum participants were significantly worse on the PNTS subscore. This reflects the fact that the ship is relatively motionless at the point where they let the wind overcome its upward velocity and blow it back. At this point, the fortress can take aim at the ship and fire a shell—as reflected in the large differences in the number of times the fortress fired a shell (‘fortress-fired’) and how often the shell hit the ship (‘shell-hit-ship’) causing loss of the PNTS score.

3. The pendulum participants made up for their poorer performance on the other subscores by showing a quite significant advantage on the VLCTY subscore, which measures how well they maintained the intermediate level of ship velocity. This is reflected in the fact that their average velocity (‘ship-velocity’) is below the upper bound for the maximum VLCTY score (4 pixels per game tick) while the circle participants are just on the edge of that boundary. As noted earlier, with the wind and the increased sensitivity of the thrust key, it is hard to control the ship’s velocity while executing the circle strategy.

While working-memory load significantly affected the number of participants adopting the pendulum strategy, we failed to find any difference in performance among conditions within each strategy. Therefore, we will focus on the differences between the two strategies. Table 2 presents a comparison of the two strategy groups on a number of critical measures in the baseline games. Despite the dramatic strategy difference between the two groups, there is no significant difference in the total scores. However, they achieved the equivalent total scores rather differently:

1. Pendulum participants were marginally worse on the CNTRL subscore, which reflects how well they managed to keep their ship within the larger hexagon. They tended to let the ship drift further to the edge of that hexagon causing a loss in their CNTRL score. This excess drifting is also reflected in their average distance from the fortress (higher on the ‘distance’ measure in Table 2).

2. Pendulum participants were significantly worse on the PNTS subscore. This reflects the fact that the ship is relatively motionless at the point where they let the wind overcome its upward velocity and blow it back. At this point, the fortress can take aim at the ship and fire a shell—as reflected in the large differences in the number of times the fortress fired a shell (‘fortress-fired’) and how often the shell hit the ship (‘shell-hit-ship’) causing loss of the PNTS score.

3. The pendulum participants made up for their poorer performance on the other subscores by showing a quite significant advantage on the VLCTY subscore, which measures how well they maintained the intermediate level of ship velocity. This is reflected in the fact that their average velocity (‘ship-velocity’) is below the upper bound for the maximum VLCTY score (4 pixels per game tick) while the circle participants are just on the edge of that boundary. As noted earlier, with the wind and the increased sensitivity of the thrust key, it is hard to control the ship’s velocity while executing the circle strategy.

Table 2 also shows differences in the average number of navigation key presses (‘hold-thrust’, ‘turn-right’, and ‘turn-left’). The differences are predictable from the differences in strategy. For the circle participants, turning right dominates turning left as they circle the fortress in a clockwise direction. Pendulum participants are changing directions and so have a more equal balance of turning right and turning left.

### Table 1

The number of circle and pendulum participants in each workload condition.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Workload</th>
<th>Control</th>
<th>Mine</th>
<th>N-back</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circle</td>
<td></td>
<td>7</td>
<td>8</td>
<td>13</td>
<td>28</td>
</tr>
<tr>
<td>Pendulum</td>
<td></td>
<td>12</td>
<td>15</td>
<td>7</td>
<td>34</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>19</td>
<td>23</td>
<td>20</td>
<td>62</td>
</tr>
</tbody>
</table>

### Table 2

The comparisons between the strategy groups in the baseline games.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean</th>
<th>SD</th>
<th>t</th>
<th>df</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Circle</td>
<td>Pendulum</td>
<td>Circle</td>
<td>Pendulum</td>
</tr>
<tr>
<td>TOTAL</td>
<td>2513</td>
<td>2367</td>
<td>961</td>
<td>1101</td>
</tr>
<tr>
<td>CNTRL</td>
<td>778</td>
<td>671</td>
<td>230</td>
<td>241</td>
</tr>
<tr>
<td>PNTS</td>
<td>386</td>
<td>173</td>
<td>341</td>
<td>455</td>
</tr>
<tr>
<td>SPEED</td>
<td>1359</td>
<td>1292</td>
<td>206</td>
<td>242</td>
</tr>
<tr>
<td>VLCTY</td>
<td>−10</td>
<td>259</td>
<td>355</td>
<td>303</td>
</tr>
<tr>
<td>Orbit</td>
<td>12.2</td>
<td>4.1</td>
<td>3.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Ship-velocity</td>
<td>4.0</td>
<td>3.4</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Distance</td>
<td>164.3</td>
<td>189.9</td>
<td>26.5</td>
<td>29.8</td>
</tr>
<tr>
<td>Hold-thrust</td>
<td>117</td>
<td>96</td>
<td>24</td>
<td>17</td>
</tr>
<tr>
<td>Turn-right</td>
<td>123</td>
<td>87</td>
<td>34</td>
<td>18</td>
</tr>
<tr>
<td>Turn-left</td>
<td>49</td>
<td>74</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>Total-navigation-key-press</td>
<td>289</td>
<td>258</td>
<td>52</td>
<td>39</td>
</tr>
<tr>
<td>Fortress-fired</td>
<td>15.0</td>
<td>31.2</td>
<td>4.9</td>
<td>7.5</td>
</tr>
<tr>
<td>Shell-hit-ship</td>
<td>4.6</td>
<td>7.1</td>
<td>2.4</td>
<td>2.8</td>
</tr>
</tbody>
</table>

Description of performance measures:

- Orbit: The number of complete orbits the ship made around the fortress.
- Ship-velocity: The average distance in pixels the ship traveled per game tick.
- Distance: The distance in pixels between the ship and the fortress.
- Hold-thrust: The number of times the thrust (‘W’) key was held down.
- Turn-right: The number of times the turn-right (‘P’) key was held down.
- Turn-left: The number of times the turn-left (‘A’) key was held down.
- Total-navigation-key-press: The sum of Hold-thrust, Turn-right, and Turn-left.
- Fortress-fired: The number of times the fortress fired a shell at the ship.
- Shell-hit-ship: The number of times the shell fired by the fortress hit the ship.

* p < .1
* * p < .05
* ** p < .01
* * * Levene’s test for equality of variances was significant for CNTRL, hold-thrust, turn-right, and fortress-fired measures. Their t-value and df were adjusted for inequality of variances.
turning left. Those results are consistent with the results of the ship movement direction (i.e., the circle participants spent a significantly higher proportion of time flying in the clockwise direction) discussed earlier. The circle participants also used the thrust key more often as they do not take advantage of the opportunity to drift with the wind.

We investigated whether patterns of behavior in pre-wind games would predict the adoption of the pendulum strategy in the baseline games. Table 3 displays the comparison between the two strategy groups in the pre-wind games for the same measures as in Table 2 for the baseline games. There was again no difference in the total scores although there is a significant difference in the SPEED subscore. As this is not consistent with performance in the baseline games, we are suspicious that it may be a spurious effect. There were highly significant differences in navigation behaviors that are consistent with the effects in the baseline games. Participants who would become pendulum participants were making fewer orbits, flying slower, and thrusting less often. As a consequence of the slower ship velocity, the fortress fired shells at the ship more often, although the ship was maintaining sufficient velocity not to suffer more hits by the shells.

4.4. Combination of the two factors

We conclude that workload and individual differences in predisposition affect whether one would adopt the alternative strategy. We found an association between working-memory load and the adoption of the pendulum strategy. Having a working-memory load would prevent participants from noticing the opportunity for a new strategy when the ship is being blown backwards by the wind, and appreciating the efficiency of the new strategy. We also found an association between the ship velocity in the pre-wind games and adoption of the pendulum strategy. If one applies less thrust (i.e., flies slower) in the baseline games as one did in the pre-wind games, one is more likely to be blown back down by the wind, setting up an opportunity to realize that this can be turned into an alternative strategy. In addition, it is more difficult to fly slowly with the circle strategy, which might have prompted those participants to shift to an alternative strategy that allows slow navigation.

Fig. 7 shows how these two factors combine in determining strategy adoption. It displays the proportion of participants who adopted the pendulum strategy as a function of whether they were slow in pre-wind games (determined by a median split) and whether they had an N-back load to tax their working memory. Over 75% of those who flew slow and did not have working-memory load adopted the pendulum strategy. These would be the ones who were predisposed to slow navigation and have working-memory capacity to understand the potential of an alternative strategy. In contrast, less than 30% of those who flew fast and had working-memory load adopted the pendulum strategy. These would be the participants who were predisposed to fast navigation and have little capacity to understand the alternative strategy. The contrast between these two conditions was significant ($\chi^2(1) = 7.62, p < .01$).

4.5. Benefits of the pendulum strategy

The remaining question is why some participants deviated from the instructed strategy and adopted the pendulum strategy. The pendulum strategy is more efficient in terms of saving key presses. In addition to making fewer thrust key presses (Tables 2 and 3), the pendulum participants also spent less time holding down the thrust key. We computed the total time duration during which the thrust key was held down in each game. Because the thrust key press accelerates the ship as a function of the key press duration, this measure serves as a proxy of the efforts made to control the ship in the wind. The pendulum participants were significantly lower on this measure in both the pre-wind and the baseline games (Meanpre-wind = 17.7 s, Meanpendulum = 12.9 s, $F(1,56) = 28.72, p < .001$, 4 outliers excluded). There was no significant effect of the presence of wind ($F(1,56) = 1.02, p = .317$, Meanpre-wind = 14.9 s, Meanbaseline = 15.7 s) nor a significant interaction ($F(1,56) = .07, p = .786$).

Within each strategy group, the total thrust duration was remarkably similar across the pre-wind and the baseline wind games (Circlepre-wind = 17.4 s, Circlescore = 18.0 s, Pendulumpre-wind = 12.4 s, Pendulumbaseline = 13.4 s), suggesting that each group maintained their prior level of navigational efforts despite the environmental change. Pendulum participants navigated with consistently lower efforts, but to do so required adopting new strategy in the wind.

The strategy reports from the pendulum participants reinforce our view that the pendulum strategy was easier. Instead of having to carefully measure the application of thrust when going with the wind to avoid building up too much velocity, one can just apply thrust when going into the wind where there is room for error:

- “I found estimating the needed thrust vectors much easier when I was using the pendulum strategy.”
- “It seemed easier to let the ship’s momentum carry it down the sides of the hexagon after accelerating up the sides as I could focus more on shooting the fortress than controlling the ship. This

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean</th>
<th>SD</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Circle</td>
<td>Pendulum</td>
<td>Circle</td>
<td>Pendulum</td>
</tr>
<tr>
<td>TOTAL</td>
<td>4535</td>
<td>4577</td>
<td>850</td>
<td>789</td>
</tr>
<tr>
<td>CNTBL</td>
<td>1009</td>
<td>1003</td>
<td>48</td>
<td>47</td>
</tr>
<tr>
<td>PNTS</td>
<td>1060</td>
<td>1037</td>
<td>594</td>
<td>529</td>
</tr>
<tr>
<td>SPEED</td>
<td>1419</td>
<td>1509</td>
<td>176</td>
<td>161</td>
</tr>
<tr>
<td>VLCTY</td>
<td>1061</td>
<td>1043</td>
<td>102</td>
<td>149</td>
</tr>
<tr>
<td>Orbit</td>
<td>9.7</td>
<td>7.7</td>
<td>2.5</td>
<td>2.4</td>
</tr>
<tr>
<td>Ship-velocity</td>
<td>1.9</td>
<td>1.7</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Distance</td>
<td>132.9</td>
<td>147.7</td>
<td>31.2</td>
<td>25.0</td>
</tr>
<tr>
<td>Hold-thrust</td>
<td>111</td>
<td>81</td>
<td>35</td>
<td>22</td>
</tr>
<tr>
<td>Turn-right</td>
<td>154</td>
<td>136</td>
<td>34</td>
<td>28</td>
</tr>
<tr>
<td>Turn-left</td>
<td>21</td>
<td>21</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Total-navigation-key-press</td>
<td>286</td>
<td>239</td>
<td>62</td>
<td>45</td>
</tr>
<tr>
<td>Fortress-fired</td>
<td>11.3</td>
<td>22.7</td>
<td>10.6</td>
<td>20.5</td>
</tr>
<tr>
<td>Shell-hit-ship</td>
<td>2.2</td>
<td>2.4</td>
<td>1.6</td>
<td>1.6</td>
</tr>
</tbody>
</table>

See Table 2 for description of performance measures.

* $p < .05$.

** $p < .01$.

Levene’s test for equality of variances were significant for ship-velocity, hold-thrust, and fortress-fired measures. Their $t$-value and $df$ were adjusted for inequality of variances.
allowed me to use the frustrating increased acceleration more to my advantage rather than railing against it.”

• “By forcing my ship into the wind, it was much easier to use thrust to stay within the inner hexagon. Also, facing the ship into the wind made it easier to keep my missiles on target. By moving the ship in a manner similar to the arc of a pendulum, I managed to more easily avoid the enemy projectiles fired by the fortress.”

The strategy reports also suggest that participants had evaluated costs and benefits associated with the strategies. Not only did the pendulum participants appreciate the efficiency of the pendulum strategy, they performed better with the pendulum strategy. Using the P measure, we classified each baseline game as ‘consistent’ if the pendulum strategy was used in that game, or as ‘inconsistent’ if the circle strategy was used. Twenty-two out of 34 pendulum participants had at least one inconsistent game. Comparison between the two types of games showed that pendulum participants performed better in the consistent games than in the inconsistent games in total score (Mean_con = 2331, Mean_incon = 1333, \( t(21) = 4.34, p < .001 \)) as well as CNTRL (Mean_con = 657, Mean_incon = 500, \( t(21) = 2.29, p < .05 \)), PNTS (Mean_con = 147, Mean_incon = −107, \( t(21) = 2.13, p < .05 \)), SPEED (Mean_con = 1289, Mean_incon = 1020, \( t(21) = 4.30, p < .001 \)), and VLCTY (Mean_con = 237, Mean_incon = −80, \( t(21) = 4.23, p < .001 \)).

The number of inconsistent games did not differ significantly between the first four baseline games and the last four baseline games (20 vs. 16 games, \( t(21) = .81, p = .427 \)) suggesting that the better performance in the consistent games was not confounded with practice effect.

5. General discussion

Consistent with the findings supporting adaptive strategy use (Best et al., 1998; Gunzelmann & Anderson, 2001; John & Lallement, 1997; Lovett & Schunn, 1999; Reder & Schunn, 1999), participants made changes in their strategy as the learned strategy became difficult to implement. Some participants maintained the learned strategy but adapted to the new environment by adjusting the associated parameters. Other participants deviated from the learned strategy and adopted a novel strategy by internalizing an external task feature.

We found that individual differences in predispositions can be a significant determinant of strategy adoption when the new situation places one predisposition in an unfavorable position in relation to the other (i.e., the wind makes it harder to fly slowly). The distinction between cognitive styles and strategies seems applicable to our results. Cognitive styles are relatively fixed, stable, and consistent across situations (Kirton, 2003; Kogan, 1980). Strategies represent the kinds of conscious decisions individuals make in coping with tasks and are much more situation-specific and malleable (Kogan, 1980). Similar to the cognitive styles, our participants exhibited distinct patterns in performing the complex, dynamic task, and those patterns persisted despite the change of the environment. The change of the environment, however, posed a greater challenge to the individuals predisposed to slow navigation pattern. This challenge may have prompted those individuals to adopt an alternative strategy that would allow them to maintain their navigation pattern. This resembles the findings that individuals with different cognitive styles often use different strategies to make the best use of the strengths and compensate for the limitations of their cognitive styles to deal with learning situations (Liu & Reed, 1994; Riding & Sadler-Smith, 2002; Sadler-Smith & Smith, 2004). We suggest that the cognitive styles approach can potentially provide useful insights to understanding individual differences in strategy use in dynamic skill performance.

Our results on workload effects on strategy can be interpreted within the framework of the multiple-resource view (Navon & Gopher, 1979; Wickens, 2002). Even though the wind exposed participants to the possibility of the alternative pattern of navigation, those under working-memory load were less likely to turn this possibility into an alternative strategy. This result suggests that the adoption of
an alternative strategy shared the common resources with the working-memory task, not with the perceptual-motor task. Our interpretation is that working-memory load influenced the ability to understand the relationship among the features (e.g., the amount of thrust force combined with the wind and the resulting vector) and construct a new task representation for the wind environment. Studies suggest that a positive correlation exists between working-memory and inductive reasoning (Carpenter, Just, & Shell, 1990; Schunn et al., 2001) and that working-memory capacity facilitates reasoning processes (Fry & Hale, 1996; Kail, 2007). Based on this view, one can hypothesize that working-memory load might have affected reasoning processes involved in strategy adoption, such as constructing and evaluating hypotheses (strategies) based on the feedback.

In various real-world settings, one often has to adapt to the changing status of the environment by adopting a new strategy, selecting one among an existing set of strategies, or simply adjusting an instructed strategy. Our results suggest that individual differences in predisposition can inform whether one would adopt a new strategy or maintain the instructed strategy in those circumstances. Identifying the precursor of future strategy adoption from prior strategy execution would be important for designing training and instructional systems to accommodate individual differences in learning complex dynamic skills. Cognitive workload is another important determinant of strategy adoption in non-normal situations in which people are often under increased task demands.

Acknowledgments

This work was supported by the ONR grant N00014-09-1-0402 to Wayne Gray & John Anderson.

Appendix A. Workload instructions

(a) Control condition

From now on, you will play games with a couple of major changes from the game you played in the previous sessions.

Changes in ship navigation:

1) The ship speed will be faster. The same duration of thrust key press will produce a greater amount of acceleration.
2) There is wind blowing in the space. This will make the ship constantly move in a certain direction even without your input.

Since the ship navigation can be more challenging due to these changes, you may need to adjust your navigation. However, try your best to orbit the ship and point at the fortress.

You will also find that some of the games do not have mines and bonus collection task. Some other games still have mines and bonus collection task. Pay attention to the screen with IFF letters and make sure you remember the IFF letters. If you see that screen in the beginning of the game, you will have to deal with mines and bonus in that game.

(b) Mine condition

From now on, you will play games with a couple of major changes from the game you played in the previous sessions.

Changes in ship navigation:

1) The ship speed will be faster. The same duration of thrust key press will produce a greater amount of acceleration.
2) There is wind blowing in the space. This will make the ship constantly move in a certain direction even without your input.

Since the ship navigation can be more challenging due to these changes, you may need to adjust your navigation. However, try your best to orbit the ship and point at the fortress.

If you do not see the IFF letter screen in the beginning of the game, you will not have friend mines in that game. In other words, all mines are foe mines in that game. In those games, make sure to make the correct response for the foe mines (press the J key twice with .25–.40 s interval and shoot with a missile). The only difference from the normal foe mine response is that you do not need to check the IFF letter since you know that every mine is a foe mine.

If you see the IFF letter screen, make sure you remember the letters since you will have both friend and foe mines in that game. In those games, you will need to check the IFF letter when a new mine appears in the screen and make appropriate responses depending on its identity.

Changes in bonus task:

Some of the games do not have the bonus collection task while some other games still have it. Try to collect bonus whenever it is available.

(c) N-back condition

From now on, you will play games with a couple of changes from the game you played in the previous sessions.

Changes in ship navigation:

1) The ship speed will be faster. The same duration of thrust key press will produce a greater amount of acceleration.
2) There is wind blowing in the space. This will make the ship constantly move in a certain direction even without your input.

Since the ship navigation can be more challenging due to these changes, you may need to adjust your navigation strategy. However, try your best to orbit the ship and destroy the fortress. You will have those ship navigation changes in all games.

Changes in mine task and bonus collection task:

Note that the following changes are applied to all games except the ‘standard’ games (games 1, 5, 9, and 13). In the standard games, the mine task and bonus collection task are the same as what you did in the previous 4 sessions (Make an appropriate response depending on the mine’s identity and collect bonus when S symbol appears twice in a row).

1) Bonus task:

1. You should respond to any symbol that matches the one presented 2 steps earlier.

(example1) ♦♥♠♥: You need to respond to the second ♦
(example2) ♥♠♣♣: You should not respond

2. If you fail to respond or commit false-alarm (respond when you shouldn’t), your ship will be locked out from shooting until you succeed in the next bonus collection chance. Therefore, it is important to pay attention to the bonus collection chance and make successful response.

To respond, you can use the K (more missiles) or L (more points) key.

2) Mine task:

There will be no screen with the IFF letters in the beginning of the game and there will be no mines in the game.

References


