

The Effects of Alternative Input Devices and Repeated Exposures on the Test of Basic Aviation Skills (TBAS) Performance

LT Nausheen Momen, MSC USNR

ABSTRACT The use of computer-based, psychomotor testing systems for personnel selection and classification has gained popularity in the civilian and military worlds in recent years. However, several issues need to be resolved before adopting a computerized, psychomotor test. The purpose of this study was to compare the impact of alternative input devices used for the Test Of Basic Aviation Skills (TBAS) as well as to explore the practice effects of the TBAS. In study 1, participants were administered the TBAS tracking tests once with a throttle and once with foot pedals in a classic test-retest paradigm. The results confirmed that neither of the input devices provided a significant advantage on TBAS performance. In study 2, participants were administered the TBAS twice with a 24-hour interval between testing. The results demonstrated significant practice effects for all the TBAS subtests except for the dichotic listening tests.

INTRODUCTION

Presently, the U.S. Navy is engaged in the revalidation and redevelopment of the Aviation Selection Test Battery (ASTB). The ASTB is a test of basic aviation skills and abilities administered by the Naval Operational Medicine Institute (NOMI). It is the primary basis for selection of potential candidates for Navy and Marine Corps aviator training programs. The ASTB is primarily administered using a paper-and-pencil format but an equivalent Web-based format is also available. As part of an effort to improve aviation selection tests, the U.S. Navy in collaboration with the U.S. Air Force, is evaluating other selection tools such as the performance-based Test of Basic Aviation Skills (TBAS). However, before incorporating a performance-based test, careful attention must be given to issues such as the effects of alternative input devices and multiple test exposures. The current studies were designed to examine these issues related to the TBAS.

From the early days of military pilot selection, apparatus-based, psychomotor testing has been used in the military aviation personnel selection process. Although psychomotor testing has evolved significantly with historical events and technological advances, it has remained as one of the principal categories of the military pilot selection batteries.¹ In recent years, computer-based tests have replaced the traditional apparatus tests for the measurement of psychomotor ability.

Naval Health Research Center, 140 Sylvester Road, San Diego, CA 92106.

The study protocol was approved by the Naval Aerospace Medical Research Laboratory Review Board in compliance with all applicable federal regulations governing the protection of human subjects.

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In 1981, the U.S. Air Force initiated a project to develop a computer-administered test battery for pilot selection and classification based on studies that demonstrated the reliability and validity of psychomotor testing.^{2,3} The resulting product was the Basic Attributes Test (BAT). The BAT is designed to assess psychomotor and cognitive skills and abilities, as well as risk-taking attitudes. It consists of five subtests that include two-hand coordination, complex coordination, mental rotation, item recognition, time sharing and activities interest inventory. The BAT administration requires a 386-based computer, 2 joysticks, and a number pad. Candidates who perform well on the BAT are found to be more likely to complete ground school, require fewer hours of training, have higher class rankings, and complete advanced jet training.⁴ In 1999, Air Force Training Command requested development of a new skills battery for pilot selection that uses the latest advances in psychomotor and cognitive research.⁵ As a result of this effort, the TBAS was developed as an improved version of the BAT. The TBAS has been operational since 2006. The TBAS consists of a series of individual tasks such as the directional orientation test, 3-digit listening test, 5-digit listening test, horizontal tracking test (HTT), airplane tracking test, and emergency scenario test as well as a series of multitasks that are combinations of two or more of these tests administered simultaneously. These tests are designed to measure spatial apperception, selective attention, coordination, and decision-making abilities under stress. The TBAS administration requires a specialized computer system that includes joystick, throttle or rudder pedals, headphones, and keypad.

Unlike the Air Force, the U.S. Navy relies primarily on the ASTB to select candidates for its aviation pilot and flight officer training programs. The latest version of the ASTB was developed by the NOMI in cooperation with Educational Testing Services (ETS) in Princeton, New Jersey and was implemented in 1993.⁶ The ASTB is designed to assess aviation-specific skills and abilities that are predictive of primary flight training success.⁷ It consists of 4 subtests: math and verbal

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test (MVT), mechanical comprehension test (MCT), aviation and nautical information (ANI) test, and spatial apperception test (SAT). Each of these subtests measures specific abilities (e.g., spatial apperception subtest measures spatial ability). Weighted combinations of these subtest scores are compiled to compute composite scores. Academic qualification ratings (AQR), pilot flight aptitude rating (PFAR), and flight officer flight aptitude rating (FOFAR) of the ASTB are the composite scores relevant for flight training. The AQR has been validated to predict academic performance in ground school and the PFAR/FOFAR has been validated to predict primary flight training grades.⁶

Because the ASTB primarily measures basic cognitive skills and abilities, it may not be an adequate measure of the complete set of cognitive and coordination aptitudes related to successful flight training. Valid, comprehensive computer-based tests, on the other hand, can enhance the prediction of flight-training success.⁸ Therefore, in recent years, the Navy has been involved in revalidation and modification of the current aviation selection process and has been planning to incorporate a performance-based psychomotor test such as the TBAS.

In an effort to incorporate the TBAS, the initial step was to select the particular input devices that are appropriate for naval aviators. The purpose of incorporating devices such as the foot pedals and joysticks is to measure abilities that are relevant in flying an aircraft. In an aircraft the rudder pedals are operated with the feet. The right rudder pedal is used to make the aircraft yaw (i.e., rotate about the vertical axis) to the right, and the left pedal is used to make it yaw to the left. The primary purpose of the rudder is not to change direction of the aircraft, but mainly to balance it in turns, or to compensate for winds and the effects from other controls.⁹ In a fixed-wing aircraft, although the rudder is used during takeoffs and landings, it is not typically used in flight when the aircraft is properly trimmed.

When flying a fixed-wing aircraft, a pilot primarily uses the hands to operate the control stick or yoke and the throttle. The control stick or yoke is used to control the direction and orientation of the aircraft relative to the horizon (i.e., the attitude of the aircraft), in both pitch and roll. The throttle, on the other hand, is used to control the engine speed.⁹ A pilot often needs to use both hands to have simultaneous access to the control stick or yoke and the throttle. Thus, coordination between the hands seems to be particularly important when flying a fixed-wing aircraft. Moreover, it is easier to standardize a throttle rather than foot pedals as an input device across various testing facilities. Interestingly, the original BAT actually uses two joysticks and does not involve rudder pedals but the newly developed TBAS uses both joystick and rudder pedals. The next revision of the ASTB plans to incorporate a modified version of the TBAS that replaces the foot pedals with a throttle. However, input devices can affect the rate and ease of response in a computer-based test.¹⁰ Therefore, it is imperative to evaluate the impact of alternative input devices on TBAS performance before making such substitution.

Study 1

The objective of this study was to examine the impact of substituting a throttle control for foot pedals during the TBAS horizontal tracking tests. The goal was to determine whether such substitution can affect TBAS performance.

Method

Participants

Students waiting to attend aviation preflight indoctrination (API) were recruited to take the TBAS. A total of 47 students participated in the study. However, TBAS records for 4 students were not complete and a final set of 43 TBAS scores were used for the analysis. Out of the 43 participants, 39 were male and 4 were female. The sample of participants included 38 Caucasians, 2 African Americans, 1 Asian, 1 Hispanic, and 1 Native American.

Materials

TBAS

The TBAS is a revised version of the BAT. It is a computerized test, which measures psychomotor coordination and information processing speed.¹¹ This test takes approximately 1.5 hours to administer. The TBAS system is compatible with Windows XP operating system and requires a monitor, a Thrustmaster HOTAS Cougar USB joystick and throttle, CH Products Pro pedals USB flight simulator pedals, a bidirectional headphone, and a keypad.

The TBAS consists of a series of individual tasks such as the directional orientation test, 3-digit listening test, 5-digit listening test, horizontal tracking test, airplane tracking test, and emergency scenario test as well as a series of multitasks which are combinations of two or more of these tests administered simultaneously.

The directional orientation test measures spatial orientation abilities. This test requires determining a figure analogous to an unmanned aerial vehicle's (UAV) position relative to a target. The 3- and 5-digit listening tests measure selective attention abilities. This test requires responding when any of the 3 or 5 specified numbers are presented aurally. The horizontal and the airplane tracking tests measure coordination. The horizontal tracking test requires using a throttle or rudder pedals and the airplane tracking test requires using the joystick to track a moving target. Emergency scenario test measures decision making under stress and it is administered along with the horizontal and the airplane tracking test. In this test, the participants are presented with three emergency scenarios (one at a time) that must be canceled out by typing a preinstructed three letter code while performing the horizontal and the airplane tracking tests. Table I contains a complete list of the TBAS subtests.

Procedure

Participants were first asked to read and sign an informed consent form approved by an institutional review board (IRB).

TABLE I. Construction of the TBAS Tests

Single Tasks
DOT: Directional Orientation Test
DL3: 3-Digit Dichotic Listening Test
DL5: 5-Digit Dichotic Listening Test
HTT: Horizontal Tracking Test (requires throttle or rudder pedals)
ATT: Airplane Tracking Test (requires joystick)
Multitasks
AHT: Horizontal Tracking Test + Airplane Tracking Test
AHDL3: Horizontal Tracking Test + Airplane Tracking Test + 3-Digit Listening Test
AHDL5: Horizontal Tracking Test + Airplane Tracking Test + 5-Digit Listening Test
AHSC: Horizontal Tracking Test + Airplane Tracking Test + Emergency Scenario Test

They were then administered the TBAS twice, once with the throttle and once with the rudder pedals with an interval of 2 hours in between testing. The order of the input device was counterbalanced with 21 (49%) participants taking the TBAS first with the throttle and 22 (51%) participants taking the TBAS first with the rudder pedals. The order of the input device for each subject was predetermined by using a random number generator.

The participants skipped the first subtest, the direction orientation test, since that does not require using a tracking device. The individual listening tests were included in the procedure because although they do not require any tracking device, they are included in the subsequent multitasks that require tracking. Therefore, the participants started the TBAS with the 3-digit-listening test.

The participants were allowed to adjust their joysticks, throttle, and foot pedals to feel comfortable. However, the position of the monitor remained stable. The keyboard was positioned at the center of the units, in front of the monitor; the joystick was located on the right side of the key board; the throttle was on the left side of the key board; and the foot pedals were approximately directly below the key board. The volume of the headphones was adjustable and the participants were free to adjust the volume.

RESULTS AND DISCUSSION

At the time of the analysis only the individual TBAS subtest scores were available and each of these subtests scores were analyzed for the study. Although all the subtests were analyzed, for the purpose of this study, we were mostly interested in the subtests that contain horizontal tracking test and require a throttle or foot pedals. These subtests included horizontal tracking test (HTT), airplane + horizontal tracking test (AHT), airplane + horizontal tracking + 3-digit listening test (AHDL3), airplane + horizontal tracking + 5-digit listening test (AHDL5), and airplane + horizontal tracking + emergency scenario test (AHSC). A key for abbreviations used in the analyses is presented in Table I.

Analysis of the Impact of the Input Device

Participants were categorized into two groups. Group 1 took the TBAS with the throttle first and group 2 took the TBAS with the foot pedals first. To determine the impact of the specific input device, the performance score on each of the TBAS subtests was compared between groups 1 and 2. The results demonstrated no significant input effect for any of the TBAS subtests.

Analysis of Practice Effect

All the TBAS scores from the first test and the retest were compared for each participant to measure practice effect. Significant practice effects were found for all of the subtests except for DL3 and DL5. For example, scores for HTT, ATT, AHT, AHDL3, AHDL5, and AHSC for all of the participants were significantly better when taken the second time regardless of the input device, $t(42) = -2.8, p < 0.05, t(42) = -5.4, p < 0.001, t(42) = -5.0, p < 0.001, t(42) = -5.0, p < 0.001, t(42) = -2.9, p = 0.005, \text{ and } t(42) = -3.1, p < 0.005$, respectively. However, the scores for DL3 were in fact lower when taken the second time, which was marginally significant, $t(42) = 2.0, p < 0.05$. The scores for DL5 were at the same direction as DL3, but not significant, $t(42) = 1.5, p > 0.05$.

Interestingly, just as the combined group, the practice effects for group 1 participants remained strongly significant for HTT, ATT, AHT, AHDL3, AHDL5, and AHSC except for DL3 which consequently became nonsignificant. However, the practice effects for group 2 participants were compromised for HTT, AHDL5, and AHSC, $t(21) = -1.1, p > 0.05, t(21) = -1.9, p > 0.05, \text{ and } t(21) = -1.0, p > 0.05$. Practice effects for ATT, AHT, and AHDL3 in group 2 became weaker but remained significant, $t(21) = -2.4, p < 0.05, t(21) = -2.7, p < 0.05, \text{ and } t(21) = -2.4, p < 0.05$, respectively. In other words, the practice effects evident in the combined group were mostly due to group 1 participants who took the TBAS with the throttle first. This finding implies that it is easier to transfer tracking skills learned by using a hand-controlled throttle to a similar task using foot-controlled pedals. However, when the initial tracking skills are acquired by using foot pedals it is less transferable to a similar task using a throttle.

A literature search in this area revealed no relevant study on human ability to transfer learned skills from hand to foot or foot to hand. However, previous research has demonstrated that there is unique structural and functional specialization that differentiates human upper and lower limb use.¹² Fewer neural resources are found to be devoted to leg and foot control than to arm and hand control and we usually have a uniquely restricted use of the lower limb. In addition, the status of leg and foot control differs from that of arm and hand control both early in life and during the later years of decline.¹² Therefore, it is not surprising that a hand-learned skill is easier to transfer to a task requiring foot control than a foot-learned skill is to transfer to a task requiring hand control.

The practice effect found in this study also warrants further exploration. Although in this study, the TBAS was readmin-

istered with different input devices and the interval between testing was only 2 hours, the demonstrated practice effect was consistent with the results of a previous study¹³ that examined the short-term retest reliability of the BAT. Carretta found a significant practice effect when Air Force pilot training candidates took the BAT twice in 2 consecutive days. The TBAS and the BAT are comparable since both are performance-based, computerized tests and the TBAS is the revised version of the BAT. Out of the BAT subtests, the two-hand coordination and complex coordination tests are similar to the TBAS tracking tests and require similar input devices (e.g., control stick and rudder pedals). The results demonstrated that in two-hand coordination and complex coordination tests, tracking error was reduced significantly when taken the second time. The author of that study concluded that additional research needs to be conducted to determine the test-retest interval required to avoid retest improvement due to prior experience with the test battery. Consequently, the next study was designed to further investigate the effect of repeated exposures of the TBAS.

Study 2

The purpose of study 2 was to further explore the TBAS practice effect found in study 1. This study was designed to administer the TBAS twice with the same input device with a 24-hour interval between testing.

Method

Participants

Students waiting to attend aviation preflight indoctrination (API) were recruited to take the TBAS. A total of 45 students participated in the study. However, TBAS records for several students were either incomplete or not retrievable and a complete set of 36 TBAS scores were used for the analysis. Out of the 36 participants, 33 were male and 3 were female. The sample of participants included 31 Caucasians, 3 Asians, 1 Hispanic, and 1 Native American.

Materials

The materials were the same as in the first study. However, the rudder pedals were excluded as an input device in this study.

Procedure

Similar to study 1, all participants were first asked to read and sign an informed consent form. The participants were administered the TBAS twice in 2 consecutive days with a 24-hour interval in between testing. Unlike study 1, the participants were tested on all the TBAS subsets including the direction orientation test (DOT; see Table I). All the TBAS peripherals were arranged in a similar manner as in study 1.

RESULTS AND DISCUSSION

Similar to study 1, the scores from each of the TBAS subtests were analyzed for this study. The TBAS is designed to record both correct responses and time duration for each of

the subtests. For the direction orientation test, the TBAS generates scores for correct responses, elapsed time for correct responses, number of wrong responses, and elapsed time for the wrong responses. For the tracking tests, the TBAS incorporates both correct response and reaction time into a single score. For the dichotic listening tests, it produces the number of correct responses as well as the total elapsed time. The total numbers of correct responses as well the total elapsed time were taken into account for each of the subtests to analyze the practice effect.

For the single tasks, each subtest score was analyzed for practice effect. For the multitasks (see Table I), a single score was derived by adding the multiple test scores similar to study 1. The individual test scores within that multitask were also analyzed separately for practice effect.

Analysis of Practice Effect of the Single Tasks

All the TBAS scores from the initial test and the retest were compared for each participant to measure practice effect. For the single tasks, significant practice effect was noted for DOT, HTT, and ATT, $t(35) = -4.4, p < 0.001$, $t(35) = -4.4, p < 0.001$ and $t(35) = -6.3, p < 0.001$, respectively. However, there was no practice effect for DL3 or DL5, $t(35) = -1.7, p > 0.05$ and $t(35) = 0.98, p > 0.05$, respectively.

For DOT, total elapsed time improved for correct responses as well as for the total responses, $t(35) = 3.7, p < 0.01$ and $t(35) = 5.8, p < 0.001$, respectively. For the dichotic listening tasks, higher number of correct responses seemed to be related to larger values of elapsed time. There was a significant positive correlation between DL3 score for correct responses and elapsed time as well as between DL5 scores for correct responses and elapsed time, $r = 0.91, p < 0.01$ and $r = 0.53, p < 0.01$, respectively. There was only a minimal variability among the DL3 and DL5 scores. Twenty-six participants responded correctly to all the 3-digit stimuli and 23 participants responded correctly to all of the 5-digit stimuli. The participants with perfect scores on DL3 showed no significant difference in elapsed time on the second trial, $t(25) = -1.8, p > 0.05$. However, the participants with perfect scores on DL5 had significantly higher elapsed time on the retest, $t(22) = -3.5, p < 0.05$. In other words, participants with all correct responses on the 5-digit listening test took longer to respond on the second trial.

Analysis of Practice Effect of the Multitasks

For the combined test of AHT, practice effect was significant for the combined test score as well as for the airplane and horizontal tracking score individually, $t(35) = -7.3, p < 0.001$, $t(35) = -7.5, p < 0.001$ and $t(35) = -3.4, p < 0.005$, respectively. For AHDL3, practice effect for the overall score as well as the individual test scores of ATT and HTT were significant, $t(35) = -4.8, p < 0.001$, $t(35) = -7.0, p < 0.001$ and $t(35) = -4.3, p < 0.001$, respectively. However, DL3 score within AHDL3 was not significant $t(35) = -0.07, p > 0.05$. For AHDL5, the total score as well as individual scores on ATT and HTT were

significant, $t(35) = -5.3, p < 0.001$ ($35) = -5.1, p < 0.001$ and $t(35) = -4.3, p < 0.001$, respectively, but the DL5 score was not significant, $t(35) = -1.0, p > 0.05$. Similarly, for AHSC, the total score as well as individual scores on ATT and SC (emergency scenario test) were significant, $t(35) = -3.2, p < 0.005$, $t(35) = -5.2, p < 0.001$ and $t(35) = -4.3, p < 0.001$, respectively, but HTT was not significant, $t(35) = -1.3, p > 0.05$.

Correlational Analyses of Total Flight Hours and Practice Effect

The participants had a range of 0 to 400 total hours of flight training at the time they took the TBAS ($M = 49$; $SD = 86$). The total hours of flight training were negatively correlated with practice effect on DOT and AHT, $r = -0.40, p < 0.05$ and $r = -0.35, p < 0.05$, respectively. In other words, participants with more flight experience showed less improvement in performance on the second trials of DOT and AHT. This is not unexpected with tests that are correlated with flight training performance because the participants with more flight experience may start out with higher scores on DOT and AHT and are therefore, less likely to improve significantly in the subsequent trials. However, the correlation between flight hours and performance on the first trials of DOT and AHT fell short of being significant although the trend was in the expected direction.

The results of this study demonstrated that TBAS performance in all the subtests except for the ones including dichotic listening tests improved when the participants took the test the second time. The practice effect found in this study is consistent with the results of study 1, which found significant practice effect for most of the TBAS subtests with a 2-hour interval between testing.

GENERAL DISCUSSION

These preliminary studies provided the directions needed to modify the TBAS to incorporate it into the naval aviation selection process in an effort to reduce attrition and training costs, improve pilot performance, and enhance aviation operational safety in the fleet. The current studies were specifically designed to provide insight into the appropriate input devices and the adequate test-retest interval for the performance-based measures of the redeveloped ASTB.

The results demonstrated that TBAS performance was not affected as a result of the specific input device used for the horizontal tracking tests. Thus, although the original TBAS was designed to use foot pedals for the horizontal tracking tests, the foot pedals can be substituted for throttle without having any significant impact on overall TBAS performance.

These results also established that TBAS performance does improve with repeated exposure. However, in this study the

retest was administered after only 24 hours. Therefore, follow-up studies should further investigate the relationship between practice effect and the test-retest interval. It would be useful to test the TBAS practice effect according to the ASTB retest policy. Currently, pilot candidates are allowed to take the ASTB 3 times with 30 days gap between tests 1 and 2 and 60 days gap between tests 2 and 3. Therefore, TBAS practice effect should be examined after 30 days and again after 60 days to determine whether candidates should be allowed to retake the TBAS according to the authorized ASTB retake interval.

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