Development of a Field-Deployable Psychomotor Vigilance Test to Monitor Helicopter Pilot Performance

Terry W. McMahon; David G. Newman

INTRODUCTION: Flying a helicopter is a complex psychomotor skill. Fatigue is a serious threat to operational safety, particularly for sustained helicopter operations involving high levels of cognitive information processing and sustained time on task. As part of ongoing research into this issue, the object of this study was to develop a field-deployable helicopter-specific psychomotor vigilance test (PVT) for the purpose of daily performance monitoring of pilots.

METHODS: The PVT consists of a laptop computer, a hand-operated joystick, and a set of rudder pedals. Screen-based compensatory tracking task software includes a tracking ball (operated by the joystick) which moves randomly in all directions, and a second tracking ball which moves horizontally (operated by the rudder pedals). The 5-min test requires the pilot to keep both tracking balls centered.

RESULTS: This helicopter-specific PVT's portability and integrated data acquisition and storage system enables daily field monitoring of the performance of individual helicopter pilots. The inclusion of a simultaneous foot-operated tracking task ensures divided attention for helicopter pilots as the movement of both tracking balls requires simultaneous inputs.

DISCUSSION: This PVT is quick, economical, easy to use, and specific to the operational flying task. It can be used for performance monitoring purposes, and as a general research tool for investigating the psychomotor demands of helicopter operations. While reliability and validity testing is warranted, data acquired from this test could help further our understanding of the effect of various factors (such as fatigue) on helicopter pilot performance, with the potential of contributing to helicopter operational safety.

KEYWORDS: rotary, PVT, human factors, fatigue, flight safety.

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Helicopters are aerodynamically unstable platforms and, without the use of automation, the pilot is required to continually make control inputs with both hands and feet to maintain controlled flight. Some maneuvers, such as hovering, require fine motor inputs on a repetitive basis. A control input to one flight control may require the adjustment of other flight controls in order to maintain stable flight. These adjustments of control inputs involve pilot judgement and with experience become an increasingly automatic response. Flying a helicopter is thus a complex psychomotor skill.[15,19] The nature of helicopter operations can place additional demands on the pilot. Helicopters frequently operate from unprepared landing areas and mission requirements may necessitate extended periods of precision flight such as hovering. Deployments to hostile or austere environments, sustained operations, degraded visual environments, high workloads, noise, vibration, thermal stress, dehydration, and around the clock operations may produce a decrease in psychomotor performance over time.[6,17] Any deterioration in a helicopter pilot's psychomotor performance represents a significant threat to operational flight safety.

The use of tests to determine and measure psychological performance, including psychomotor response, has long been established.[4,10] Psychomotor vigilance tests (PVT) have been used within the military for pilot selection and assessment for

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many years. More recently these tests have been used for predicting pilot performance in both rotary and fixed wing operations.[1,7] PVT tests have also been used as research tools to examine various psychomotor performance variables and factors that affect them, such as reaction time, divided attention, alertness, vigilance, and fatigue.[2,8,9] Advances in electronic technology have seen a wide range of computer-based performance tests being developed, some of which may be used to test specific operational tasks. More recently the development of small hand-held personal data assistants (PDA) have enabled field portable reaction-time tests to be used to measure the effects of sleep deprivation, shift work, and fatigue.[9,13,20] Additionally, PDAs with embedded software programs designed to generate fatigue scores based on flight and duty times have been developed and are in use with some helicopter and fixed-wing companies.[12]

None of these various available tests, however, are specific to the psychomotor tasks involved in flying a helicopter. Since we are interested in the psychomotor issues involved in helicopter flying, we sought to develop a field-deployable helicopter-specific PVT for the purpose of daily psychomotor performance monitoring of helicopter pilots conducting flight operations.

METHODS

Procedure

The initial step in this PVT development task was to define a number of general design requirements for the test in order to ensure that it was specific for helicopter operations and also field-deployable. These requirements were as follows:

1. The PVT must be easily portable for use in the non-laboratory setting.
2. It must be capable of operating on a laptop computer and be compatible with common operating software systems.
3. The test must require simultaneous inputs from both hands and feet.
4. It should make use of commercially available off the shelf (COTS) input controllers in the form of a joystick for hand inputs and a set of rudder pedals for foot inputs.
5. The test should run for a sufficient period of time to ensure sufficient data is collected in an operational setting.
6. The test should collect data that is reliable and robust, and not subjected to any signal interference.
7. The PVT should be rigorous and sensitive enough to detect psychomotor performance changes in the test period.
8. It should include a practice mode for subject familiarization
9. The task should be essentially familiar to helicopter pilots, in order to ensure a ready transfer of skill with only a small learning requirement.
10. The test should incorporate an integrated data management system, such that individual test data can be easily recorded, stored, identified, and recalled, with the ability to export the data into a spreadsheet format compatible with existing commonly used commercial software.

A total of 55 readily available computer-based psychological tests and PVTs were reviewed. These consisted of a broad range of tests, including tracking ball tests, reaction time tests, attention tests, and vigilance tests. This review confirmed that there was no readily available, helicopter-specific PVT that could be easily deployed in the field. Helicopter specificity and field deployable were the two most important aspects of our basic design requirements. None of the existing tests could satisfy both of these key requirements. None of the tests reviewed allowed simultaneous input from the feet and hands, although some tests did monitor hand performance only. While some were easily field deployable, they were not designed for use in the psychomotor performance monitoring of helicopter pilots conducting daily flight operations.

Of the large number of PVT tests reviewed, COMPTRACK was deemed to be the most readily modifiable. This test was then used as the initial starting platform for our helicopter-specific PVT, since it was possible to modify the software and integrate the required hardware to create a PVT that satisfied the design objectives outlined earlier.

COMPTRACK was developed for the U.S. Naval Medical Research and Development Command as a vigilance task in 1995.[14] The program was originally coded in the C programming language. The source code was designed to be useable and modifiable by other researchers with access to C programming skills.

The original COMPTRACK task required the subject to keep a randomly moving ball within a circular ring displayed on a computer screen. The moving ball was controlled by a hand-operated trackball. The ball movement program loops at a frequency of 22 Hz, with performance data recorded at a sampling rate of 11 Hz. The movement of the ball is determined by a random movement algorithm, which takes into account three separate forces.

The first force is a buffeting force, the magnitude and direction of which is subjected to continuous change. Two buffeting force equations are used to derive the movement pattern, one in the x-axis and the other in the y-axis (the lateral buffeting force). These equations, from the original COMPTRACK paper,[14] are as follows:

$$F_{B_x} = \sum_{n=0}^{5} c_x^{-n} \cos\left(c_x^n t + \phi_n\right), \quad c_x = \left(\frac{1+\sqrt{5}}{2}\right)$$

$$F_{B_y} = \sum_{n=0}^{5} c_y^{-n} \sin\left(c_y^n t + \phi_n\right), \quad c_y = \pi/2$$

The second force is a surface force and simulates the action of gravity by causing the ball to slip on an unseen slippery surface. This surface force is directed radially (i.e., away from the center of the bullseye). The unseen slippery surface is a circular mound shape, with the center of the bullseye being flat, but outside the ring the mound slopes progressively away from the center. The magnitude of the surface force is given by the following equations:

$$\vec{F}_S = \frac{1}{2} r^2, \qquad r \le 6$$

$$\vec{F}_S = \frac{3}{2}\left(r - 20\,diskRadius\right), \quad r > 6$$

where the magnitude of the force varies with distance from the center of the bullseye [measured by multiples of disk (ball) radius].

The third force is the user input force, based on the last movement of the trackball by the user. The resultant of these forces means that the user has to keep the ball centered in the bullseye against a random tendency of the ball to escape. If it does escape, the ball accelerates away from the bullseye center, requiring a dedicated movement by the user to attempt to return it to the bullseye. The buffeting, surface, and user input forces act as a weighted sum on the ball essentially via a spring-mass-damper mechanical system. The degree of damping is relatively slight and simulates the presence of viscous drag on the ball.

In order to develop a helicopter-specific test, the following modifications were carried out to the COMPTRACK test:

1. The hand-operated trackball was replaced by a commercial off-the-shelf computer joystick, and foot input was achieved through the incorporation of commercial off-the-shelf rudder pedals.
2. The software program was redesigned to be compatible with Microsoft® operating systems and was recoded to update it to the C++ programming language. SDL (SimpleDirect-Media Layer) software was added as a supporting platform for display of the output graphics.
3. The data sampling rate was set at 1-s intervals and the screen operating diameter of 40-360 pixels was constructed; the center circle ring of 20 pixels was retained.
4. Two fixed posts and a moving ball were added to the program to generate a foot-input from the user via integrated rudder pedals. The posts appear at the bottom of the screen, under the bullseye ring, and are separated by a distance equal to the diameter of the bullseye ring. The ball moves horizontally between the posts, with the ball moving at 22 Hz horizontally along the bottom of the screen. The movement algorithm for the ball was created by using a combination of the lateral buffeting force equation and the surface force equations for the movement of the ball within the bullseye ring. This results in the foot-controlled ball also following an unseen slippery surface in the form of a mound, which is linear in this case rather than circular. The tendency of the ball to thus accelerate away from the center position once it has escaped the confines of the two-fixed posts is the same as that of the ball in the bullseye ring. Both balls thus independently move according to a similar motion paradigm, with the exception that the lower ball is restricted to linear, lateral excursions only.
5. The original black screen was retained. The balls, ring, and bottom posts were changed to a white color (from the original light gray) for better contrast in field locations.
6. The display size of the test was increased to a resolution of 768 × 1024 pixels, in order to optimize it for laptop screen viewing.
7. A practice mode was added, which runs for 5 min but without any data recording.
8. The test mode runs for 5 min, with hand and foot input data automatically recorded. The recorded data for both balls is automatically analyzed and presented at the completion of test as both percentage and time of balls outside the target area.
9. A comprehensive integrated data management system was added which analyses the data recorded and places it in a user-specific, time and date-stamped spreadsheet file (Microsoft® Excel). The acquired data from the input of both foot pedals and the joystick show the position of both balls relative to the posts and bullseye ring, respectively, on a per-second basis.

RESULTS

The final result of this work is a helicopter-specific field deployable psychomotor vigilance test. In addition to the software modifications discussed above, the test combines simple, readily-available input controllers (joystick and rudder pedals) with a standard laptop computer. The test itself is a modified screen-based compensatory tracking test, with an enhanced sampling rate. The addition of the second ball controlled by rudder pedal inputs results in the user facing a divided attention scenario between the right hand (cyclic control) and the feet (rudder pedals). The objective is to keep the hand-controlled ball within the bullseye ring while simultaneously keeping the lower feet-controlled ball between the two fixed posts. A screen shot of the test in progress is shown in **Fig. 1**.

The integrated data management system not only records the data generated by the test, but also analyses it in terms of the percentage time that each ball spent outside its target area (the bullseye ring and between the two posts) during the test

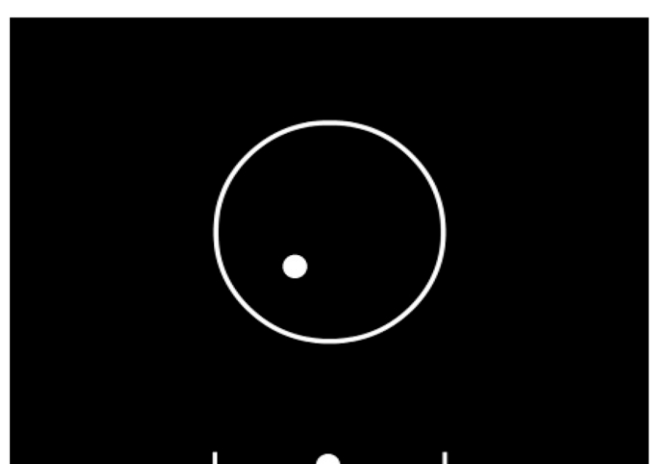


Fig. 1. Screenshot of PVT during 5-min test.

sequence. Such an output is shown in **Fig. 2**. The acquired data points are stored in a spreadsheet (.csv file) format, and can thus be pictorially represented and exported for further statistical analysis in various other analytical software programs. A typical graphical output is shown in **Fig. 3**.

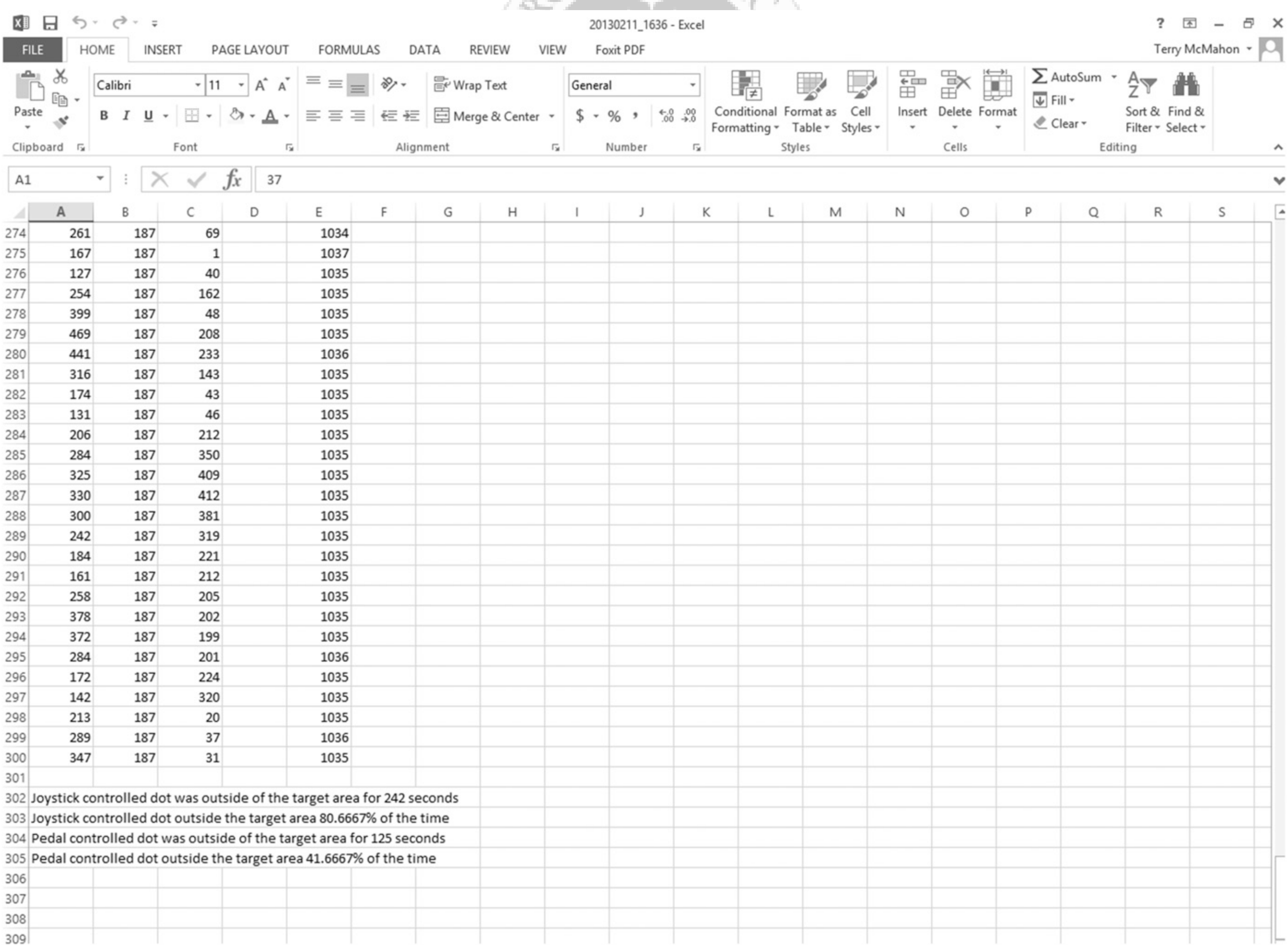
DISCUSSION

This paper describes the development of a psychomotor vigilance test which can be used to assess and monitor the psychomotor performance of helicopter pilots. The main advantages of this PVT are that it is field-deployable, simple to operate, specific to the helicopter flight task, and requires only a short period of time to complete.

The deployable nature of this PVT is important. The vast majority of human performance research and psychomotor testing is done in the laboratory. While this typically allows researchers to conduct their testing under strictly controlled experimental conditions, the results of laboratory-based testing do not always automatically concur with real-world conditions. Laboratory testing (including flight simulation) may not be able to either test specific tasks or to replicate all the conditions (environmental or otherwise) that might be at work during a particular operational flight task. There is clearly a need for some field-based testing to complement laboratory-based work.

Conducting field research is not without significant challenge, however. It may be expensive and difficult to manage due to operational complexities, time limitations, access restrictions, etc.[10] Furthermore, the safety of the flight operation cannot be jeopardized by any concurrent research. These issues make field research sometimes problematic. However, the advantage of field research is that task-specific research may be carried out in actual environmental conditions with normal operational pressures and subjects of appropriate skill level. The portable nature of the PVT described in this paper makes it easy to use for the purposes of collecting real-world psychomotor performance data in the operational field environment.

The aim of this research was to develop a PVT that was specific to the task of flying a helicopter. Helicopter pilots use both hands and feet when controlling a helicopter.[15] The inclusion of a simultaneous foot-operated tracking task ensures convergent validity for helicopter pilots as the movement of both tracking balls requires the pilot to make control inputs similar to those required during actual helicopter flight. This PVT is thus far



	A	B	C	D	E
274	261	187	69		1034
275	167	187	1		1037
276	127	187	40		1035
277	254	187	162		1035
278	399	187	48		1035
279	469	187	208		1035
280	441	187	233		1036
281	316	187	143		1035
282	174	187	43		1035
283	131	187	46		1035
284	206	187	212		1035
285	284	187	350		1035
286	325	187	409		1035
287	330	187	412		1035
288	300	187	381		1035
289	242	187	319		1035
290	184	187	221		1035
291	161	187	212		1035
292	258	187	205		1035
293	378	187	202		1035
294	372	187	199		1035
295	284	187	201		1036
296	172	187	224		1035
297	142	187	320		1035
298	213	187	20		1035
299	289	187	37		1036
300	347	187	31		1035
301					
302	Joystick controlled dot was outside of the target area for 242 seconds				
303	Joystick controlled dot outside the target area 80.6667% of the time				
304	Pedal controlled dot was outside of the target area for 125 seconds				
305	Pedal controlled dot outside the target area 41.6667% of the time				

Fig. 2. Instant read-out of performance from PVT 5-min test.

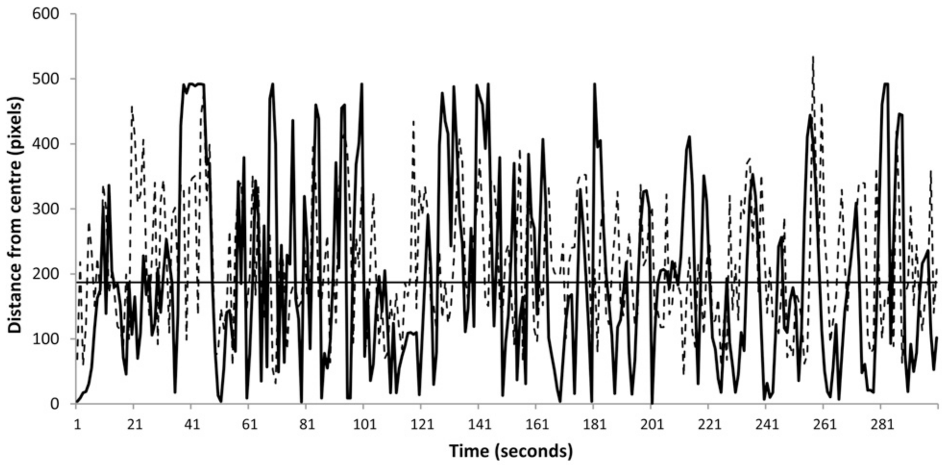


Fig. 3. Excel data capture at 1-s intervals (hands and feet) over the 5-min PVT test presented as a graph. The horizontal line represents the edge of the target circle. The dotted line represents hand inputs.

more specific to the helicopter flight domain than other tests. It should be noted that this PVT does not contain a collective (left-hand) input. This was a deliberate decision when this test was developed, since the collective control is not used as frequently as the cyclic or pedals during routine helicopter flight. The collective is fitted with a friction lock, so that during climb and cruise (for example) the lever can be positioned for the desired power setting and then left hands-off until a change is necessary.

This PVT requires the ability to process multiple sources of information and the ability to concentrate on a task without loss of concentration. These conditions are in line with the first generation taxonomy of human performance attributes for performance test batteries.[10] The skill of deliberately focusing and shifting attention is known as attentional control and refers to a subject's ability to rapidly switch attention from one item to another. Such attentional control is required with the inclusion of the simultaneous foot-operated tracking task in this PVT.[8]

PVTs have been used to test a multitude of abilities and skills, such as reaction time, arm-hand steadiness, manual dexterity, finger dexterity, motor coordination, wrist-finger speed, or speed-of-limb movement that also may be required in tracking tasks.[9,13,18] It is unlikely that a psychomotor ability test will predict performance unless it measures the particular and specific facets of psychomotor ability required by the actual task.[5] Morgan and Pitts[16] state that tests designed to assess specifically defined performance abilities should be selected on the basis of a taxonomy of the behavioral dimensions involved in operational performance. Psychomotor performance is fundamental to the control of helicopters, and this PVT mirrors helicopter control inputs and is similar to the operational task.[15]

The duration of a PVT is also important. Typically, most PVTs have adopted a standard duration of 10 min, which has been shown to be methodologically reliable.[12] This may not be practical within the field environment due to operational pressures or a large volume of test subjects.[9] In some recent studies, reducing the PVT duration to 5 min has been shown to not affect the validity of the PVT results.[9,12] In a recent fatigue-related comparative study, a 5-min PVT using a PDA with touch screen produced valid and comparable results with a 10-min computer-based PVT.[9] Thus, the adoption of a 5-min duration for this helicopter-specific PVT is a valid choice and limits the quite likely potential for the test itself to create fatigue if it ran for 10 min.

This helicopter-specific PVT has many potential applications. The field-deployable nature of the PVT may allow data gathering from helicopter pilots while conducting operations for operational planning and safety management purposes. The PVT could be used for performance monitoring over time. Such PVT-acquired psychomotor performance data for an individual over a period of operational flying time (particularly during sustained operations) may provide a predictable method to ensure maximum performance and continued safe levels of operation. It would allow any deterioration of psychomotor performance (due to fatigue, for example) to be detected early, such that the pilot might be temporarily grounded in the interests of safety. However, the metrics supporting such decisions remain to be developed, but the application of this PVT tool in this setting could help in this regard. This PVT may further be used to identify individuals with exceptional motor skills for mission-specific operations, or be used as a general tool in human factors research to gather helicopter pilot performance data to further understand the psychomotor demands of helicopter operations.[15]

Clearly, one of the major factors likely to adversely affect helicopter pilots (particularly during sustained operations) is fatigue. The countermeasures to fatigue in the aviation environment are numerous. These include various regulatory and prescriptive controls (such as flight and duty time limitations), the use of fatigue modeling software (often used as part of a wider fatigue risk management system), and even pharmacological interventions.[3] Such countermeasures may not necessarily allow for an individual's tolerance to fatigue, the effects of cumulative fatigue, differences in missions and tasking, variations in cognitive workload, or environmental considerations.[6]

The level of psychomotor performance could be used as a more accurate indicator of the level of fatigue an individual (or group) may have during operational deployments. This is particularly true of this helicopter-specific PVT, since the results of each test can be compared with previous ones and a deteriorating trend can be readily identified. While more research is clearly needed in the use of PVTs in this area, there does seem to be an opportunity to apply PVTs as part of a general decision-making support package in the management of fatigue. Development of a fatigue score based on output data from this helicopter-specific PVT represents an interesting future research opportunity. This PVT can give data, such as response times for corrective input, maximum control deflections, root mean square of deviations, etc., which could be used to help construct a fatigue score. Such data could be acquired and modeled for predictive validity using sleep restriction studies, for example. PVT-based performance data could be used to assist with the use of other countermeasures employed to prevent fatigue adversely affecting the safety of flight operations.

To obtain the maximum benefits from this helicopter-specific PVT, we would make the following recommendations. Firstly, initial baseline testing for each individual pilot should be carried out with pilots in a nonfatigued state. Secondly, field testing should be carried out at the completion of daily flying activities and ideally no sooner than 30 min following the last flight to allow for any level of arousal associated with flight activity to decrease. Thirdly, pilots should be asked about subjective levels of fatigue at the commencement of each daily test, as this will allow their subjective assessments and PVT performance to be monitored and compared over time. It is important to remember that subjective reporting of fatigue by pilots has been shown to be a useful determinant of fatigue.[11] Fourthly, this PVT needs to be further examined in a laboratory setting to determine its reliability and validity, particularly before being used for fatigue studies. Such tests could make use of sleep restriction studies and also comparative evaluations with existing PVTs.

This helicopter-specific PVT's portability and integrated data management system enables daily field monitoring of the performance of individual helicopter pilots. This 5-min PVT is quick, economical, easy to use, and specific to the operational flying task. This PVT can be used for a multitude of performance monitoring purposes and could be integrated into a helicopter operator's safety management system once it has been fully evaluated for validity and reliability. While more research is needed to explore the range of uses of this PVT and how its acquired data can best be used, this test could help further our understanding of the effect of various factors (such as fatigue) on helicopter pilot performance, with the potential to contribute in a broad sense to helicopter operational safety.

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