Fatigue Assessment in the Field: Validation of a Hand-Held Electronic Psychomotor Vigilance Task

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Introduction: In recent years, there has been an increasing need for a reliable and practical tool for assessing fatigue-related impairment in the field. This study investigated the sensitivity of one potential tool, a 5-min version of the psychomotor vigilance task (PVT) specifically designed for use on personal digital assistants (PDA), to 28 h of sustained wakefulness. ***Methods:*** There were 15 participants who slept in the laboratory overnight then remained awake from 08:00 (Day 1) to 12:00 (Day 2). During every second hour, they completed a 10-min PVT, a sustained attention task that is sensitive to the effects of sleep loss and fatigue, and a 5-min PDA-PVT. ***Results:*** While performance on both tasks significantly varied as a function of hours of wakefulness, responses on the PDA-PVT were typically slower than on the PVT. When performance scores were standardized, the negative impact of increasing hours of wakefulness on performance on the 5-min PDA-PVT and 10-min PVT did not significantly differ. ***Discussion:*** The findings suggest that the 5-min PDA-PVT may provide a reasonable substitute for the 10-min PVT, particularly in circumstances where a shorter test is required and/or the standard PVT is not as practical.

Keywords: sustained wakefulness, vigilance, performance impairment.

IN LABORATORY studies assessing the functional consequences of sleep loss and fatigue, the 10-min psychomotor vigilance task (PVT) is a widely accepted measure of neurobehavioral performance (3,5). This sustained attention task is a popular tool in large part due to its portability, size (enclosed in a plastic case, the PVT device measures 21 × 11 × 6 cm and weighs 658 g), and simplicity. It is easily performed and minimally affected by aptitude, thereby maximizing its utility. Moreover, as the PVT is reported to have a learning curve of only 1–3 trials (2), the need for extensive, time-consuming training sessions and masking effects due to skill acquisition are minimized.

Importantly, studies have consistently demonstrated that PVT performance is sensitive to the effects of fatigue, irrespective of how fatigue accumulates (e.g., total sleep deprivation, chronic partial sleep deprivation, and sleep fragmentation) (2,3,5,7). Further, repeated testing does not change the underlying psychometric properties of the test. The PVT is also favored by many researchers because it provides meaningful outcome variables that can be easily interpreted (4).

While the 10-min PVT is extremely suited for laboratory studies, a test of this length may not always be practical in time-constrained field environments. For example, assessing pilots on the flight deck during international travel is often difficult, as they have limited time available to complete an additional task. In such instances, a shorter test with similar properties to the 10-min PVT (e.g., in terms of sensitivity to the effects of sleep loss and fatigue) would be more functional. While longer tests tend to be more sensitive to the effects of fatigue (6), previous studies have also found significant fatigue-related impairment using tasks of short duration (1).

Notably, we have recently demonstrated significant fatigue-related impairment using a 5-min PVT (8), with our results indicating that this may be a viable option for assessing fatigue-related impairment in the field. Shortening the PVT would certainly make it more appropriate for time-constrained environments, particularly when repeated testing is preferable. However, the actual machine may still be considered excessively bulky (and inconvenient) if participants are required to carry it around for long periods of time (i.e., if they are traveling overseas). This may be particularly so if participants also have to carry around study-related paperwork, such as sleep/wake diaries and study instructions.

An alternative that does address this issue is a hand-held personal digital assistant (PDA). Unlike the standard PVT, PDAs are small, compact devices that are easy to carry around in a pocket. They are easy to acquire in bulk quantities, and can be used for multiple purposes. Importantly, the Walter Reed Army Institute has recently developed a version of the PVT program that is suitable for use on PDAs. In addition, any paperwork that is associated with the study can be programmed onto the PDA, for example sleep/work diaries and workload questionnaires. Thus, participants are only required to carry around one device which stores all of their data. This study aimed to validate the sensitivity of the 5-min version of PDA-PVT, which

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may prove to be a viable alternative to the 10-min PVT when multiple tests are being conducted in the field.

METHODS

There were 15 individuals (8 women, 7 men), aged 18 to 27 yr, who participated in the current study. Subjects were non-smokers who did not regularly consume large doses of caffeine or alcohol. Those recruited had no current health problems, and were not taking any medication other than an oral contraceptive (all women). All were self-reported good sleepers who did not habitually nap, and had not undertaken shift work or transmeridian travel in the past month. Before the study commenced, the protocol was approved by the University of South Australia Human Research Ethics Committee using guidelines established by the National Health and Medical Research Council of Australia. Prior to their participation, subjects were required to give written informed consent.

Subjects arrived at the laboratory at 18:00 for a short training session to familiarize them with the performance tasks. Following the training session, subjects spent 9 h in bed (23:00–08:00) to ensure they obtained adequate sleep during the night. They then remained awake for 28 h (08:00 to 12:00 the following day). During every second hour of wakefulness, subjects completed a standard 10-min PVT and a 5-min PDA-PVT. To eliminate order effects, the presentation of the tasks was randomized and counterbalanced. As each task was presented either on the hour, 15 min past the hour, 30 min past the hour, or 45 min past the hour, the interval between the presentations of the two tasks ranged from 5 to 40 min. As per standard methodology, for each device the interstimulus interval (ISI) varied from 2000 to 10,000 ms and subjects did not receive feedback at the end of the test session.

Both the PVT and PDA-PVT are hand-held devices, which required the participants to attend to a display for the duration of the test. In the current study, the Zire71™ handheld (PalmOne Inc., Milpitas, CA) was used, but other PDAs have also been successfully used. As quickly as possible after the appearance of a visual stimulus, participants pressed the appropriate response key with the thumb of their dominant hand. During testing sessions, participants were seated alone in a room in front of a blank wall. Between testing sessions, participants had free time in the sleep laboratory where they could eat, read, study, listen to music, watch television or videos, or play computer games. Throughout the study, participants were not permitted to consume caffeine, to smoke, to exercise, or to nap.

The parameters analyzed for this report were derived from response time (RT), the latency between the appearance of the stimulus and the subject's button-push response. The first metric was the mean of the inverse of response times (mean 1/RT). The second metric was mean number of lapses (mean number of RTs greater than 500 ms). The third metric was the mean of the inverse of the slowest 10% of RTs (mean slowest 10% 1/RT). As preliminary analysis of the data and anecdotal reports from subjects suggested a systematic difference in response speeds for the two devices, standardized scores for each of these variables were also analyzed.

Systematic changes in each parameter across the experimental session and differences between the two tasks were evaluated using separate repeated measures ANOVA with two within-subject factors ('hours of wakefulness' and 'task'). For all ANOVA analyses the Greenhouse-Geisser procedure was applied to produce more conservative degrees of freedom.

RESULTS

Analysis of mean RTs indicated a significant main effect for both 'hours of wakefulness' ($F_{13,182} = 7.0$, $p = 0.0001$) and 'task' ($F_{1,14} = 34.3$, $p = 0.0001$). No interaction was observed (**Fig. 1**). For percentage of lapses, a significant interaction effect ($F_{13,182} = 3.7$, $p = 0.001$) was observed, in addition to a main effect for both 'hours of wakefulness' ($F_{13,182} = 15.9$, $p = 0.0001$) and 'task' ($F_{1,14} = 29.2$, $p = 0.0001$). Similarly, analysis of responses in the lapse domain (slowest 10%) yielded a main effect for both 'hours of wakefulness' ($F_{13,182} = 24.6$, $p = 0.0001$) and 'task' ($F_{1,14} = 54.8$, $p = 0.0001$), in addition to a significant interaction effect ($F_{13,182} = 2.6$, $p = 0.026$).

Analysis of standardized score yielded somewhat different results. Specifically, a main effect for 'hours of wakefulness' was found for all of the PVT metrics: mean RT ($F_{13,182} = 33.7$, $p = 0.0001$); % lapses ($F_{13,182} = 28.3$, $p = 0.0001$); and slowest 10% responses ($F_{13,182} = 22.9$, $p = 0.0001$). In contrast, neither a main effect for 'task' nor an interaction effect were found for any of the parameters (**Fig. 2**).

DISCUSSION

With an increasing number of studies moving out of the laboratory and into the field, the need for a reliable and practical assay of fatigue has grown. The standard 10-min PVT appeared to provide us with this tool, as it is an easy to use, portable, self-contained unit which is sensitive to the effects of sleep loss and fatigue and requires minimal training. For studies conducted in time-constrained environments, the 5-min PVT is a more practical option. Indeed, the use of a shorter PVT reduces the impact of testing on an individual's day-to-day activities, or alternatively, usually increases the number of tests that can be performed within a given period. However, even the 5-min PVT lacks certain features that are important for large-scale field studies.

The PDA-PVT is a possible alternative that has these features. Specifically, it is a very small testing device that is easy to carry around in a pocket. Relative to most other devices, the PDA-PVT is inexpensive and easy to acquire. In addition, it provides researchers with the option of programming their paperwork (e.g., sleep/wake diaries) onto the device, thereby minimizing the number of items that have to be given to participants. In theory, it should also have all of the features that make the standard PVT a popular tool. For example, sensitivity to sleep loss and fatigue, and minimal training requirements. Given its potential, this study aimed to determine whether the 5-min PDA-PVT is a valid assay of fatigue.

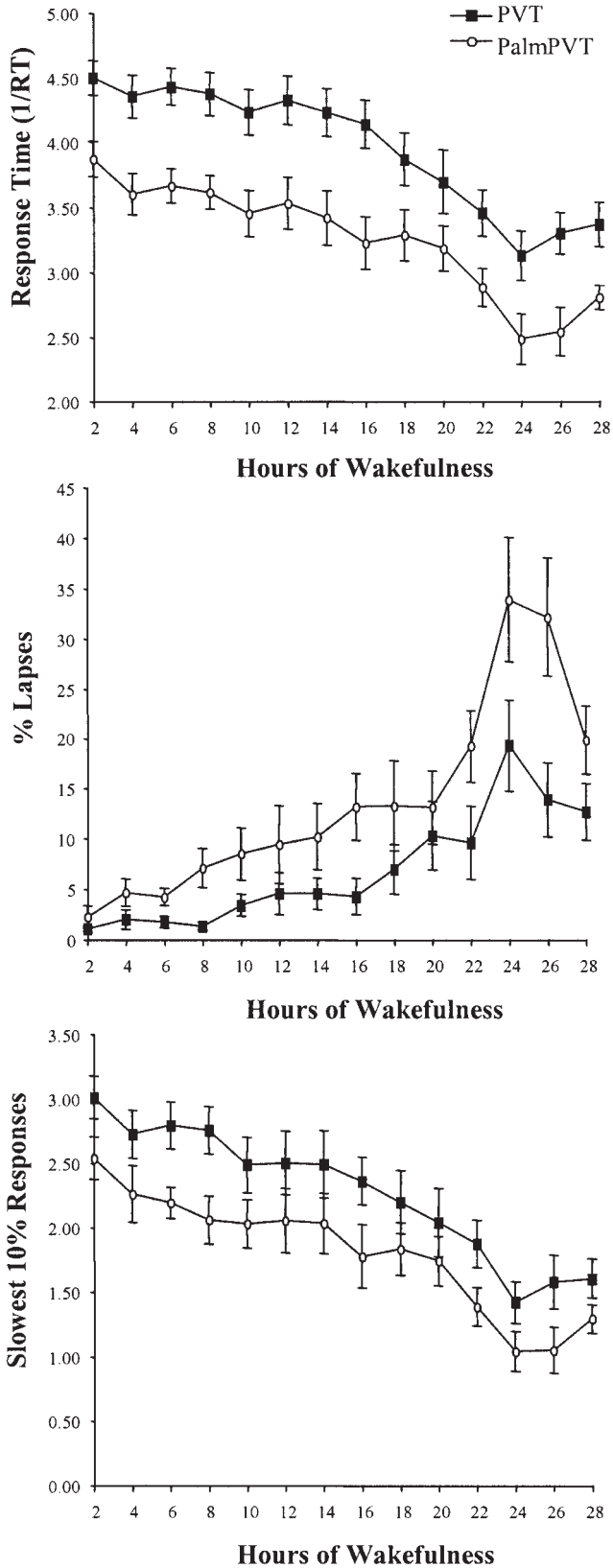

Fig. 1. Mean (± SEM) response times (1/RT), percentage of lapses, and slowest 10% of responses for the 10-min psychomotor vigilance task (PVT, closed squares) and the 5-min PalmPVT (open circles) during 28 h of sustained wakefulness.

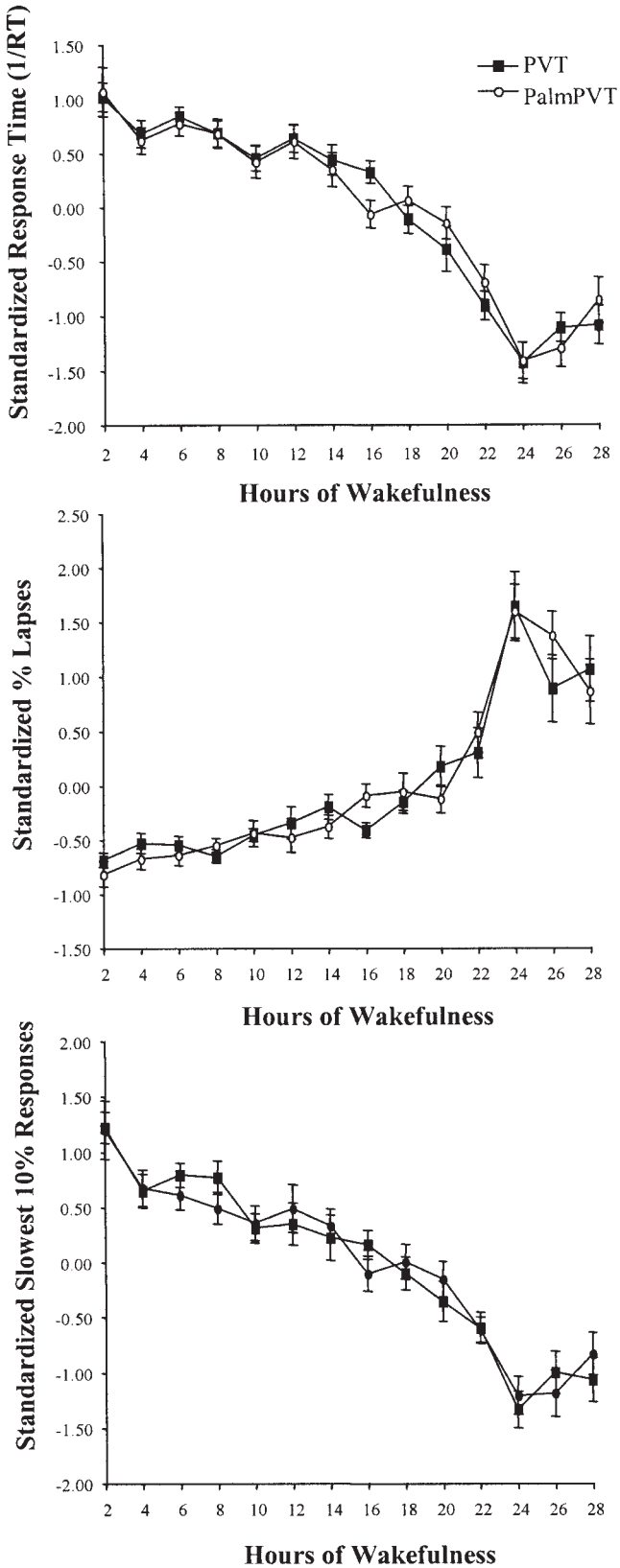

Fig. 2. Standardized scores for mean (± SEM) response times (1/RT), percentage of lapses, and slowest 10% of responses for the 10-min psychomotor vigilance task (PVT, closed squares) and the 5-min PalmPVT (open circles) during 28 h of sustained wakefulness.

It is clear from the findings that the 5-min PDA-PVT is sensitive to the effects of 28 h of extended wakefulness. Consistent with previous studies demonstrating the sensitivity of the PVT to sleep loss and fatigue (2,3,5), reaction times slowed and lapse frequency increased as hours of wakefulness increased for both the standard 10-min PVT and the 5-min PDA-PVT. Overall, poorest performance on both tasks occurred after 24 h of wakefulness, around 08:00–10:00. Similarly, for both tasks, performance slightly improved again at the end of the experiment, presumably reflecting either the well reported circadian variation in neurobehavioral performance or, as subjects were aware of at the time, an end of testing session effect. Notably however, differences between the PDA-PVT and the standard PVT were observed when the raw scores were compared. Specifically, responses on the PDA-PVT were approximately 15–70 ms slower than on the standard PVT. This is primarily attributable to mechanical differences between the testing devices. The standard PVT-192 was designed for the specific purpose of assessing response times. As a result however, the device is relatively bulky and expensive.

While PDAs were not originally intended for performance assessment, the PDA-PVT program has been designed to provide a consistent and valid assessment of response times. For example, the internal RT counter/timer is independent of the PDA's cpu clock speed (16 MHz, 33 MHz, etc.), and the program was specifically written to minimize all controllable sources of timing variance [further details are supplied by Thorne et al. (9)]. Certainly, it is clear from the findings presented here that the two devices produced comparable results when the scores were standardized to control for differences in the machinery. Indeed, it is evident from Fig. 2 that performance on the 5-min PDA-PVT closely tracked that on the standard PVT during 28 h of sustained wakefulness for all of the parameters.

Overall, this data suggests that the 5-min PDA-PVT is a valid tool for assessing fatigue, particularly in large-scale field studies. Our current study, and subsequent use of this task in several recent field studies, also demonstrated that if participants are sufficiently briefed (for example, if they are supplied with detailed, but simplified, instruction manuals), the PDA-PVT is a task that can be self-administered. As each test is time- and date-stamped, this allows for easy identification of when each test was completed. It is recommended however, that studies involving self-administration of the task also include a PDA-PVT diary for participants to record when (and where) they completed each task. It is also highly recommended that participants complete a short training session (i.e., three practice tests) prior to the collection of experimental data to minimize effects associated with learning.

Importantly, the results do not suggest that the 5-min PDA-PVT should replace the standard 10-min PVT. Rather, they indicate that the PDA-PVT is a useful substitute for the 10-min PVT in circumstances where: 1) a shorter test is required due to time restraints, or to increase the number of tests that can be performed; 2) a small, convenient device (i.e., that is easy to transport and carry around) is required; and 3) a large number of devices are needed.

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