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Feedback has a positive effect on cognitive function during total sleep deprivation if there is sufficient time for it to be effectively processed

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ABSTRACT

This study examined whether the provision of feedback and the interval between successive stimuli interact to affect performance on a serial simple reaction time test during sleep deprivation. Sixteen participants (9 female, 7 male, aged 18–27 yr) completed four versions of the 5-min psychomotor vigilance task for a handheld personal digital assistant (PalmPVT) every 2 h during 28 h of sustained wakefulness. The four versions differed in terms of whether or not they provided feedback immediately after each response, and whether the inter-stimulus intervals (ISIs) were long (2–10 s) or short (1–5 s). Cognitive function was assessed using reciprocal response time and percentage of responses that were lapses (i.e., had a response time $\geq$ 500 ms). Data were analysed using repeated measures ANOVA with three within-subjects factors: test session, feedback, and ISI. For both measures, the only significant interaction was between feedback and ISI. Cognitive function was enhanced by feedback when the ISIs were long because it provided motivation. Cognitive function was not affected by feedback when the ISIs were short because there was insufficient time to both attend to the feedback and prepare for the subsequent stimulus.

1. Introduction

In the 1970s, Wilkinson (1975) argued the need for portable devices that could be used to assess the impact of stressors, such as sleep loss and circadian disruption, on basic cognitive function. In an early version of one such device, Wilkinson and Haughton (1982) built a serial simple reaction time test with a visual stimulus into a battery-powered cassette tape recorder, and a few years later, Dinges and Powell (1985) developed software for this device to simplify the process of generating performance metrics. This reaction time test, which has become known as the psychomotor vigilance task (PVT), has been shown to be sensitive to total sleep deprivation (Doran et al., 2001; Jewett et al., 1999), partial sleep restriction (Belenky et al., 2003; Van Dongen et al., 2003), and circadian misalignment (Wyatt et al., 1999; Zhou et al., 2011).

The PVT is commonly used to assess sustained attention in laboratory studies (Lim and Dinges, 2008). However, the standard handheld version (PVT-192; Ambulatory Monitoring Inc., Ardsley, NY) has a 10-min duration, which makes it impractical for use in workplace studies in industries in which free time during shifts is scarce, such as long-haul transportation, natural resource extraction, and primary health care. In response, 3- and 5-min versions of the PVT that operate on the standard handheld hardware have been developed and validated (Basner et al., 2011; Basner and Rubinstein, 2011; Loh et al., 2004; Roach et al., 2006). In addition, a 5-min version of the PVT that operates on a handheld personal digital assistant (PalmPVT; Walter Reed Army Institute of Research, Silver Spring, MD) has also been developed and validated (Lamond et al., 2005, 2008; Thorne et al., 2005). The 5-min version of the standard PVT has been used in some workplace studies (e.g., Baulk et al., 2007, 2009), but the PalmPVT has been favoured in most cases (e.g., Ferguson et al., 2011; Gander et al., 2013; Lamond et al., 2006; Petrilli et al., 2006; Roach et al., 2012; Smith et al., 2007), probably because the hardware on which it operates is smaller, lighter and less expensive than the standard PVT's hardware.

The PalmPVT can be configured to provide feedback immediately after each stimulus presentation or not, and to have a longer or shorter interval between successive stimulus presentations (i.e., inter-stimulus interval). There is some evidence that performance on cognitive tasks is enhanced by feedback (Eckner et al., 2011; Wilkinson, 1961, 1963), and impaired if the inter-stimulus interval

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is too long or too short (Los et al., 2001), but the relationship between these two factors has not previously been considered. It is critical to determine whether or not these factors interact to influence cognitive function, because there are important implications for theory, such as an improved understanding of the nature of motivation, distraction, and preparedness; and for practice, such as the determination of a preferred configuration of the PalmPVT for use in workplace settings. Consequently, the aim of this study was to examine the interactive effects of feedback and inter-stimulus interval on cognitive function when participants are fatigued.

2. Method

2.1. Participants

Sixteen volunteers (9 female, 7 male), aged 18–27 yr, with good mental and physical health, and normal habitual sleep/wake patterns (i.e., 7–9 h in bed each night), participated in the study. With the exception of female participants who were taking birth control medication, participants were medication-free. Participants had not undertaken shiftwork or transmeridian flight in the month prior to the study. Prior to volunteering for the study, participants were informed about its nature and purpose by reading an information sheet and asking questions of the researchers. All participants signed a written consent form before beginning the study and received a nominal payment after completing the study.

2.2. Materials and measures

Cognitive function was assessed using the psychomotor vigilance task for a personal digital assistant (PalmPVT; Walter Reed Army Institute of Research, Silver Spring, MD), administered using a Zire71 Handheld (PalmOne Inc., Milpitas, CA). To complete the task, participants attend to a liquid crystal display screen for the duration of the test – set at 5 min for the current study. During the task, successive visual stimuli in the form of a bullseye are presented on the screen at variable intervals (for an image of the device and stimulus, see Thorne et al., 2005). Participants respond to each presentation of the stimulus as quickly as possible by pressing a response key with their dominant thumb. Four versions of the PalmPVT were used in the current study (see details below).

In addition to the duration of the task, there are two major aspects of the PalmPVT's configuration that can be manipulated: (i) Provision of feedback – After each response, i.e., during the foreperiod for the subsequent stimulus presentation, the PalmPVT screen can either display the response time in hundredths of a second (i.e., with feedback) or it can display nothing (i.e., without feedback). In the current study, for the two versions of the PalmPVT that provided post-response feedback, it was displayed immediately after each response for a period of 0.25 s (ii) Inter-stimulus interval – The minimum and maximum intervals between a response and the subsequent stimulus presentation can be varied in the PalmPVT. In the current study, the two most common inter-stimulus interval ranges were used (Thorne et al., 2005). Two of the versions of the PalmPVT had 'long' inter-stimulus intervals (i.e., ranging from 2 to 10 s, in 2-s increments, with a mean of 6 s), and two versions had 'short' inter-stimulus intervals (i.e., ranging from 1 to 5 s, in 1-s increments, with a mean of 3 s).

The four versions of the PalmPVT used in the current study differed in terms of whether or not they provided post-response feedback, and in the range of the inter-stimulus interval:

- version A: long inter-stimulus intervals (i.e., 2–10 s) with post-response feedback,
- version B: long inter-stimulus intervals (i.e., 2–10 s) without post-response feedback,
- version C: short inter-stimulus intervals (i.e., 1–5 s) with post-response feedback,
- version D: short inter-stimulus intervals (i.e., 1–5 s) without post-response feedback.

Post-task feedback, i.e., a summary of overall performance presented at the completion of a task, was not provided for any of the four versions of the PalmPVT.

Performance on all four versions of the PalmPVT was measured using two variables: (i) reciprocal response time – mean of the reciprocal response times for each stimulus presentation, and (ii) percentage of lapses – number of responses with a response time $\geq$ 500 ms, divided by the total number of stimulus presentations, multiplied by 100 (Lamond et al., 2005; Loh et al., 2004). A lower reciprocal response time and a higher percentage of lapses indicate poorer performance.

At least ten outcome metrics are commonly reported for the 10-min version of the standard PVT, but reciprocal response time and percentage of lapses were used in the current study because measures of response speed and frequency of lapses are the most sensitive to fatigue (Basner and Dinges, 2011). Percentage of lapses was used instead of number of lapses, even though the latter is more common (Basner and Dinges, 2011), to correct for differences in the total number of stimulus presentations. Versions of the 5-min PalmPVT with short inter-stimulus intervals (mean of 3 s) have approximately twice as many stimulus presentations, and thus twice as many opportunities to lapse, as versions of the 5-min PalmPVT with long inter-stimulus intervals (mean of 6 s).

2.3. Protocol (Fig. 1)

Participants spent two consecutive nights in a sleep laboratory; the first was a preparatory night, and the second was a night of total sleep deprivation. On the preparatory night, participants arrived at the laboratory at 19:00 h. Prior to bedtime, participants were inducted into the study, had dinner, and completed four preliminary trials of the 5-min PalmPVT (and one preliminary trial of the 10-min standard PVT). These trials were conducted to familiarise participants with the apparatus and procedures, make them aware of the four versions of the PalmPVT, and extinguish any practice effects. Participants then went to bed for 9 h from 23:00 to 08:00 h. After rising, participants ate breakfast and showered prior to beginning the first test session at 09:00 h. Subsequently, performance was assessed every 2 h until 11:00 h the following day. Ultimately, participants completed 14 test sessions during 28 h of sustained wakefulness – from waking at 08:00 h on day 2, to completing the last 1-h test session at 12:00 h on day 3.

During each 1-h test session, participants performed all four versions of the 5-min PalmPVT, and one version of the 10-min

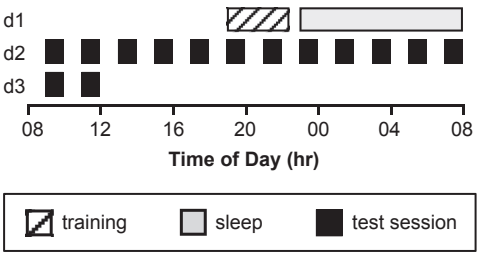

Fig. 1. Study protocol.