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Using interstimulus interval to maximise sensitivity of the Psychomotor Vigilance Test to fatigue

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ABSTRACT

There is some evidence that short interstimulus intervals (ISIs) on the Psychomotor Vigilance Test (PVT) are associated with longer and more varied reaction times (RTs). Preparation processes may impede RT following short ISIs, resulting in additional unexplained variance. The aims of this study were to investigate whether there is an effect of ISI on RT and errors within the PVT, and whether such an effect changes with three elements of fatigue: time of day, prior wake and time on task.

Twelve male participants completed 49 PVTs across 7 × 28 h periods of forced desynchrony. For analysis, RTs, reciprocal reaction times (1/RT), false starts and lapse responses within each 10 min session were assigned to a 1-s ISI group, a 2-min time of task group, a 2.5-h PW level and a 60° phase of the circadian rhythm of core body temperature (as a measure of time of day).

Responses following short ISIs (2–5 s) were significantly slower and more varied than responses following longer ISIs (5–10 s). The likelihood of a lapse was also higher for short ISIs, while the probability of a false start increased as a function of ISI. These effects were independent of the influences of time of day, prior wake and time on task. Hence, mixed model ANOVAs comprising only long ISIs (5–10 s) contained stronger effect sizes for fatigue than a model of all ISIs (2–10 s). Including an ISI variable in a model improved the model fit and explained more variance associated with fatigue.

Short ISIs resulted in long RTs both in the presence and absence of fatigue, possibly due to preparation processes or ISI conditioning. Hence, omitting short ISI trials from RT means or including an ISI variable in analysis can reduce unwanted variance in PVT data, improving the sensitivity of the PVT to fatigue.

Over the last three decades the Psychomotor Vigilance Task (PVT) has become the ubiquitous behavioural assay to measure the effects of fatigue and sleepiness (Dorrian et al., 2005). The PVT is a sustained attention, stimulus-response task developed by Dinges and Powell (1985). It was developed as an evolution of Wilkinson's earlier simple visual reaction time (VRT) task (Glenville et al., 1978; Wilkinson and Houghton, 1982), which was itself based on the previous auditory reaction time (ART) task by Lisper and Kjellberg (1972). The standard form of the PVT is a 10-min test containing approximately 90 response trials. Each trial consists of a stimulus presentation, a response, 1 s of feedback and a randomly varied 2–10 s interstimulus interval (ISI) before the next stimulus (see Fig. 1).

The PVT had been shown to be both valid and reliable (Dorrian et al., 2005) and thus has been employed extensively in the study of sleep loss (Belenky et al., 2003; Van Dongen et al., 2003) and the interaction between circadian and homeostatic sleep–wake processes on performance (Dinges et al., 1994; Matthews et al., 2010; Van Dongen et al., 2003; Zhou et al., 2010). It has been presented on different devices with various durations and ISI ranges, with and without feedback (Lamond et al., 2005, 2008; Roach et al., 2006, 2016). Recently, Basner and Dinges experimented with the sensitivity of the PVT using variable length tests (Basner and Dinges, 2011, 2012; Basner et al., 2011). Due to its wide spread use, the PVT has become the modern benchmark against which other measures of performance deficits are compared. This is due to its 'low order' nature reflecting basic frontal cortex dysfunction (Horne, 1993). As a component of more complex operations, the value of the PVT lies

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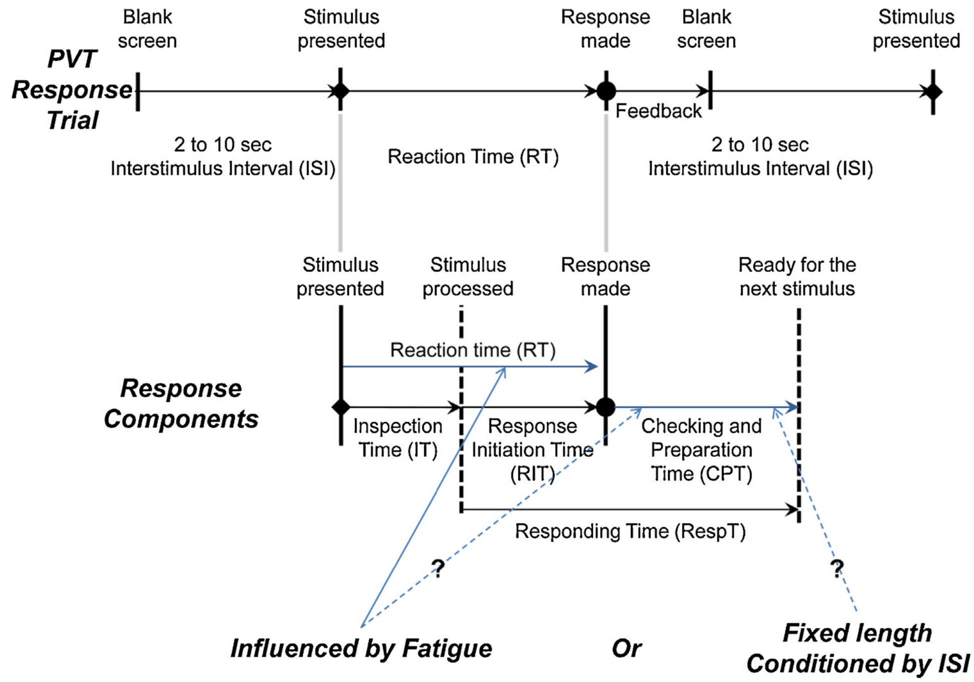

Fig. 1. Timeline of the PVT response trial shown above the theorised response components of Inspection Time (Vickers et al., 1972), Responding Time (Kirby and McConaghy, 1986), Response Initiation Time, and Checking and Preparation Time (Kirby and Nettelbeck, 1991). While research has shown that the Reaction Time component is influenced by fatigue it is unknown whether Checking and Preparation Time is also affected by fatigue or has a fixed relationship with the ISI range.

in its simple nature. This is because without the ability to sustain attention on a given task, goal directed action becomes impossible (Dorrian et al., 2005).

While a core element of the task is simple RT, the PVT is not exclusively a measure of RT like its historical counterparts. The PVT runs for a designated duration (traditionally 10 min), with the specific ISI range of 2–10 s. This allows researchers to sample across many responses from a short period of time. The relatively high stimulus rate (or signal load) is essential to avoid boredom and task fatigue effects. These distinct test characteristics are tailored towards capturing and exploring behavioural responses related to ‘vigilance’ (Basner and Dinges, 2012).

The other aspect that makes PVT more than simple RT is the test outcome metrics used to study this concentrated data. RTs are valid if they are ≥100 ms and ≤500 ms. RTs less than 100 ms are termed ‘false starts’ and represent ‘errors of commission’. These premature responses are an attempt by participants to anticipate when the stimulus will appear and represent increased compensatory effort consistent with the state instability hypothesis (Dorrian et al., 2005). Reaction times greater than 500 ms are deemed ‘lapses’. These represent transient moments of increased sleepiness (Dorrian et al., 2005) which are particularly sensitive to sleep loss and are the most common outcome metrics published in papers (Basner and Dinges, 2011). A reciprocal transformation of reaction time (1/RT) is also commonly analysed as this metric limits the influence of outliers and the skewed nature of RT distributions (Dorrian et al., 2005).

While the performance effects of many dimensions of the PVT have been studied, such as practice effects, test duration and time on task effects (Dorrian et al., 2005; Lamond et al., 2005, 2008; Roach et al., 2006), little has been published on the relationship between ISI and PVT performance. This is likely due to early research on the effect of absolute and relative durations of ISI on participants’ preparation and expectation states (Nickerson, 1967, 1968). These effects had been explored prior to Lisper and Kjellberg’s (1972) ART task, and led to the ISI range of 2–10 s being chosen for the precursor of the PVT. A fixed ISI range will condition participants’ ‘state of preparedness’, influencing what is perceived to be a relatively long or short ISI (Los et al., 2001). Hence, if research was conducted on other ISI ranges the result would be a task measuring different dimensions of vigilance and fatigue, incomparable to the standard version of the PVT.

The current authors have observed participants having apparent difficulty responding to stimuli following short ISIs in comparison to stimuli following long ISIs on the PVT. This effect has only been anecdotally reported in published papers. In one example, while investigating the RTs of lead-exposed workers it was reported that 2-s ISIs were followed by long RT’s for both lead exposed and non-exposed workers (Balbus et al., 1998). The effect of ISI on RT was so great that the influence of neurotoxic damage caused by lead exposure (the effect of interest) was only observed with ISIs longer than 2 s.

In separating the cognitive processes involved in responding to a stimulus, cognitive psychology may have provided an explanation for the effect of ISI on RT. Vickers et al. (1972) used the visual perception theory that ‘visual information is not continuous but is sampled’ to define a stage of input processing. This stage described the time required for a stimulus to be perceived and discriminated, called Inspection Time (IT) shown in Fig. 1. Elaborating on this, Kirby and McConaghy (1986) found that immediately after a response was made, input processing was inhibited. The idea of a stimulus inhibiting the perception of a second stimulus is not new (Telford, 1931), but Kirby and McConaghy (1986) definitively showed that time is needed for a participant to process the outcome of their response and ready themselves for the next stimulus. This inhibitory period was defined by Kirby and Nettelbeck (1991) as checking and preparation time but is also referred to as a psychological or response refractory period (Nickerson, 1967), or preparation state (Los et al., 2001).

It is possible that checking and preparation processes may make responding to short ISIs particularly difficult, resulting in unexplained (within-group) variance such as in the lead exposure example. If so, this would mean that responses following short ISIs on the PVT are less sensitive to the effects of fatigue. A second

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