PERFORMANCE FLUCTUATIONS OF LOW AND HIGH DEMANDING TASKS: DIURNAL VARIATIONS IN RESOURCES

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INTRODUCTION

Performance fluctuates systematically during the day, which fluctuation is referred to as ‘diurnal variation’. Performance is maximal at midday and minimal in the morning and at night \(^1\). However, a continuous decline over the waking day is sometimes found \(^2\). If multiple testing sessions are conducted during mid-afternoon, a post-lunch dip is sometimes found \(^1\). In order to clarify the task differences in peak performance, investigators have proposed that performance peaks may be explained in terms of resources. The lower the vigilance level, the less resources might be available \(^3\). Tasks that require a high amount of resources will consequently be the first tasks to yield worse overall performance. Only when resources have declined to a large extent will task performance get worse on simple, less demanding tasks. Moreover, demanding tasks should therefore also show diurnal variation to a greater extent. Task performance is considered to reflect vigilance level \(^4\), but vigilance can be determined with other measures, as well. Diurnal trends have been reported for EEG parameters \(^5\). Subjective alertness follows a comparable pattern and has been shown to correlate with task performance \(^1\). Furthermore, subjective alertness has been reported as a marker for resource availability \(^6\). Therefore, vigilance level and resources appear to be closely related. The level of vigilance is determined by task performance and subjective alertness and thus used in a descriptive manner.

We investigated diurnal variation in vigilance and tested the hypothesis that it is the availability of resources that determines the timing of the peak in performance. We used the relatively simple SART, which is considered to measure vigilance \(^7\), and a revised version of the SART. The adapted version of the SART places a great demand on memory and thus on resources. We predicted that both subjective alertness and task performance would show the inverted u-shaped pattern of diurnal variation. Performance on the demanding ‘memory’ SART is expected to show an earlier peak and to display more variation during the day than the simple SART.

METHODS

Sixteen students, receiving 18 Euros, were tested once during four different sessions that took place at four different times: 8.30h, 13.30h, 16.00h, and 20.00h. Each session was followed by the next a day later. Order of testing times was counterbalanced across participants. Participants were presented with the SART, the memory-SART, the Thayer alertness scale, and two VAS (Visual Analogue Scale) alertness scales. The SART consisted of 225 single digits which were presented visually on a computer screen over a 4.3-min
period. Each digit was presented for 250 ms, followed by a fixation cross that had 900-ms duration. Subjects were requested to respond to each digit, except in those cases that the digit 3 appeared. Then they had to withhold a response. Identical stimuli were presented in the memory version of the SART. The instruction, however, was different. Participants were asked to respond on each occasion a digit appeared that was the same digit as the preceding, minus 1. Thus, the digit 7 was considered to be a target if it was preceded by the digit 8. There were 26 targets, distributed randomly over the 225 trials. A paper-and-pencil version of Thayer’s subjective alertness scale was used. This scale entails the factors: energy, tiredness, tension and calmness. Together, the factors are assumed to reflect the subjective state of alertness. Two paper-and-pencil versions of a visual analogue scale (VAS) were used. The scale was a 10-cm stripe, ranging from ‘completely awake’ to ‘extremely tired’ for the alertness VAS and from ‘extremely sleepy – not sleepy at all’ for the sleepiness VAS.

RESULTS AND DISCUSSION

As we expected the inverted u-shape pattern of alertness and performance over the day, we performed curve estimations to fit the plots of daily variations in performance and alertness. For the SART, the variation in the amount of targets that were missed followed a quadratic function; \( p < 0.001 \) (Figure 1). Misses tended to decrease during the day, but increased again at 20.00h. Performance increased up until 16.00h. There were no significant curve fits for false alarms and reaction times (RTs) on the SART. For the memory SART, the pattern in the amount of misses did not follow a quadratic function, \( p = 0.80 \). However, Figure 1 clearly shows that there is a more pronounced variation in misses for the memory-SART than for the simple SART. Performance peaks during the second session and already worsens during the third session. The RTs for the memory-SART followed a quadratic function, \( p = 0.010 \), but could also be described by a linear function, \( p = 0.011 \). The diurnal variation in false alarms did not fit a quadratic function.

For the Thayer scale, variations in scores on general activation tended to follow a quadratic function \( (F = 63.66; p = 0.088) \): activation scores tended to be higher during the day than in the morning, but tended to be lower in the evening. For the other factors there were similar trends, but these were not significant. Variations in both the alertness VAS and the sleepiness VAS fitted quadratic functions \( (F = 2642.62; p = 0.014 \) for alertness; \( F = 362.95; p = 0.037 \) for sleepiness). Sleepiness was high in the morning, decreased during the day and increased at 20.00h. The opposite pattern was present for alertness: alertness was low in the morning, increased during the day, but decreased again at 20.00h. Diurnal variations were visible for most vigilance measures.

Both the subjective and performance vigilance measures showed diurnal variation. Task performance and subjective alertness tend to increase during the day and decrease towards the evening. In line with our hypothesis, the performance plots (for misses) clearly revealed an earlier performance peak for the resource-demanding memory-SART, than for the simple SART. The ANOVA demonstrated the difference between the tasks: performance on the memory SART peaked at 13.30h, whereas performance on the SART remained high until 16.00h. Besides the exact timing of the performance peak, the pattern in diurnal performance variation is similar for the two tasks. The earlier peak of the more demanding memory-SART corroborates the view that vigilance is lowered when resources are depleted: the more resources are required to perform a task, the earlier a decrease in resources can be detected by means of a drop in performance. In addition, two factors of the Thayer scale showed similar early peaks, which indicates that subjective scores are sensitive to vigilance and
resource measures as well. Therefore, it does not seem necessary to assume separate performance rhythms, which have been suggested \(^1\). The assumption of resource availability determining the timing of all peaks is more parsimonious.

The second hypothesis was that the memory-SART should yield greater amplitude in diurnal variation. Performance plots showed that the amplitude in variation was greater for the memory-SART. However, a quadratic function fitted the amount of misses on the SART, but failed to fit the misses of the memory-SART. This seemed due to the fact that the peak in performance on the memory-SART was almost immediate. The results are also in line with a resource view on vigilance. The most demanding task, which requires the highest amount of resources, tended to be the most sensitive in revealing daily fluctuations. The memory-SART yielded a massive decline during task performance, whereas the SART failed to produce a significant decrement. The finding that a demanding task provides a larger performance decrement is consistent with other studies and corroborates a resource view on performance \(^3\). The data strongly suggest that the amount of required resources determines whether a decrement is observed. Therefore, demanding tasks appear particularly appropriate as vigilance tasks. Moreover, the results show that vigilance tasks need not be of long duration, since the duration of the memory-SART is less than 5 minutes.

![Figure 1](image)

**Figure 1.** The diurnal variation in the targets that were missed in the simple SART and the memory-SART is presented. Testing time is the actual time of day (1=8.30h; 2=13.30h; 3=16.00h; 4=20.00h).

Performance and subjective scores were correlated. The amount of misses for the tasks followed a pattern opposite to that of subjective alertness, which suggests that the lower the alertness scores are, the more misses are made. This pattern of results is consistent with results of others \(^1, 2\) and has been found for the SART before \(^8\). In contrast to the general pattern found for vigilance measures, RTs of the memory-SART declined steadily over the day. This result is particularly interesting, as in the present study participants were presented with only one task per day. Practice effects are therefore less likely, and still faster responses are made at later testing times.
The present data indicate that diurnal vigilance effects reported in other studies\(^1,2\) can also be found if corrected for order and practice effects. Although the effects were not robust, correlational analyses showed that all vigilance measures were reliable. The lack of vigor in the effects may have been a consequence of our different methodology in collecting the data. Correspondingly, less robust diurnal findings have also been reported in a narcolepsy study in which motivational and order effects were ruled out\(^9\). Therefore, practice and motivational aspects may enhance the effects of diurnal variation in vigilance. Motivation may drop after several tasks and practice effects might predominantly affect the first testing sessions. The outcome of this combination of effects is an enhanced diurnal performance effect.

**CONCLUSIONS**

Diurnal variation in vigilance is present if controlled for practice effects and motivation, but the effects are less strong than expected. In line with our hypotheses, performance on the resource-demanding memory-SART tended to show both an earlier performance peak and greater amplitude in diurnal variation. Additionally, the demanding task yielded a steep performance decrement, indicating that it is particularly suitable as a vigilance task. The availability of resources varies systematically with the level of vigilance: the higher the vigilance level, the greater the availability of resources. Stated even more resolutely, the availability of resources and the level of vigilance might be conceptually indistinguishable: the level of vigilance may be defined as the availability of processing resources, which can be determined by both performance and subjective measures.

**REFERENCES**