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TIME OF DAY, SPEED-ERROR TRADE-OFF, AND THE ENCODING OF NEW INFORMATION IN CHOICE REACTION TIME TASKS

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ABSTRACT

Background: It is well established that human performance varies with the time of day. The pattern of diurnal variation depends on the type of task performed. Responses in simple reaction time tasks are usually faster later in the day. In search tasks, there is often a speed-error trade-off, with responses later in the day being faster but less accurate. This was examined here, and the study also measured the speed of encoding in the morning and afternoon. **Method:** Ninety-six university students participated in the study. They each completed the tasks in the late morning (11.00-12.00) and afternoon (15.00-16.00). Half the participants carried out the sessions in the morning and then in the afternoon, and the others in the reverse order. The two test sessions were on separate days. Participants carried out a focused attention two-choice reaction time task and categoric search tasks. The outcomes of interest were mean reaction times, errors and the speed of encoding new information (alternations-repeats). Cardiovascular measures were also taken to confirm physiological changes over the day. **Results:** Heart rate decreased over the day, and blood pressure increased. Reaction times in the focused attention task were quicker in the afternoon, and the speed of encoding new information was also quicker. The categoric search tasks showed a speed-error trade-off, with performance being faster but less accurate later in the day. Significant differences were found between the different types of categoric search tasks, but these did not interact with the time of day. **Conclusion:** The present study confirmed the changes in cardiovascular function found over the day. The search tasks also replicated the speed-error trade-off, with performance in the afternoon being faster but less accurate. The performance of the focused attention task was quicker in the afternoon, and this was associated with faster encoding of new information.

KEYWORDS: Time of day; Focused attention; Categoric search; Choice reaction time; Speed-error trade-off; Encoding; Alternations; Repeats; Heart rate; Blood pressure.

INTRODUCTION

There is an extensive literature on diurnal variation in performance.[1-3] Psychomotor tasks, such as reaction time or simple search tasks, are performed faster in the afternoon than in the morning.[1-3] This slow performance in the morning may reflect low circadian alertness and may also reflect sleep inertia.[1-3] The faster performance later in the day may be at the expense of increased errors.[4-5] This could reflect cumulative fatigue over the day. The present study compared performance in the mid to late morning with late afternoon. Cardiovascular measures were also taken to confirm that there were physiological changes over the day.

The present study examined the effects of time of day on two-choice reaction time tasks developed by Broadbent.[6,7] One of these tasks involved focused attention, with the target letter always being in the same place. In the categoric search task, the target could be in one of two possible locations. These tasks have been used to study the effects of changes in activation states induced by factors such as caffeine, exposure to noise and minor illnesses.[8,17] Broadbent et al.[7] examined the effects of time of day on selective attention measures derived from these tasks. The Eriksen effect, a measure of focused attention, was smaller in the afternoon, suggesting that attention is set at a wide angle later in the day. This result was confirmed by Smith.[16] The place repetition effect, faster responses to stimuli presented in the same location, was also greater in the afternoon.

The present study examined the speed-error trade-off in these choice reaction time tasks, and it was predicted that performance would be faster but less accurate later in the day. The speed of encoding new information was also examined and calculated by the difference in reaction time to stimuli, which differed from the previous trial (alternations) and those that were the same (repetitions).

This measure has not previously been examined at different times of day. Many studies of the effects of time of day also include physiological measures to demonstrate significant physiological states between the different times. Often, the temperature rhythm has been measured. In the present study, cardiovascular parameters were recorded. Previous research suggests that heart rate decreases over the day[18], whereas systolic and diastolic blood pressure increase.[19]

Sanders[20] has argued that by systematically changing task variables in choice reaction time tasks, one can determine whether effects are due to changes at the encoding, central or output stages of information processing. For example, by degrading the quality of visual stimuli, input-related encoding is manipulated. If the effects of time of day on choice reaction time are at this stage, then an interaction between time of day and stimulus degradation conditions should be observed. Similarly, central processing or response selection can be examined by varying the compatibility between stimulus and response, and the output side of the information processing system can be investigated by varying the time uncertainty (the inter-stimulus interval).

METHOD

The study was approved by the Psychology ethics committee and carried out with the informed consent of the participants.

Participants

A sample of volunteers were recruited from a university student population. Ninety-six (48 male, 48 female; age range: 18- 24 years) went on to complete the study successfully. Participants received a written explanation of the experiment explaining the aims of the research and that they were free to withdraw at any time. They were assured that all data collected would remain anonymous. They were paid £20 upon completion of the study.

Exclusion Criteria

Volunteers were not selected for the study if they:

- Had suffered serious physical or mental illness that would influence physical or mental performance.
- Smoked more than five cigarettes during the daytime.
- Consumed more than 20 units of alcohol during the week (Monday - Friday).

The above criteria were imposed to eliminate the possible effects of alcohol or nicotine withdrawal.

Design

On a day before the test sessions, the participants were familiarised with the performance tests. Test sessions occurred in the morning (11.00 – 12.00) or (15.00-16.00). Half of the participants carried out the sessions in the morning-afternoon order, and the others were in reverse order. The two test sessions were on separate days.

Procedure

At the start and end of each session, blood pressure and pulse rate were measured. Participants then carried out the following choice reaction time tasks

a) Focused Attention Task

Broadbent developed this selective attention task.[6,7] Target letters appeared in upper case A's and B's. On each trial, three warning crosses were presented on the screen, and the outside crosses were separated from the middle one by either 1.02 or 2.60 degrees. Participants were told to respond to the letter presented in the centre of the screen and ignore any distractors presented in the periphery. The crosses were on the screen for 500 msecs and were then replaced by the target letter. The central letter was either accompanied by 1) nothing, 2) asterisks, 3) letters which were the same as the target or 4) letters which differed. The two distractors were identical, and the targets and accompanying letters were always A or B. The correct response to A was to press a key marked A on the left-hand side of the response box, while the correct response to B was to press the key marked B on the right-hand side of the response box. Participants were given ten practice trials followed by ten blocks of 64 trials. In each block, there were equal numbers of near/far conditions, A or B responses and equal numbers of the four distractor conditions. The nature of the previous trial was controlled.

b) Categoric Search Task 1 (basic form)

Broadbent also developed this task.[6,7] to measure aspects of selective attention. Each trial started with the appearance of two crosses in the positions occupied by the non-targets in the focused attention task (i.e. 2.04 or 5.20 degrees apart). Participants did not know which of the crosses would be followed by the target. The letter A or B was presented alone on half the trials and was accompanied by a digit (1-7) on the other half. Again, the number of near/far stimuli, A versus B responses and digit/blank conditions were controlled. Half of the trials led to compatible responses (i.e. the letter A on the left side of the screen or the letter B on the right), whereas the others were incompatible. Participants were given ten practice trials followed by five blocks of 64 trials. In each block, there were equal numbers of near/far conditions, A or B responses and equal numbers of the four distractor conditions. The nature of the previous trial was controlled.

c) Categoric Search Test 2 (with delay)

This test was similar to the categoric search task described above. However, this form of the test included a variable length delay after the warning crosses disappeared and the target letter appeared on the screen. Manipulating the task in this way permits closer examination of motor preparation in organising an appropriate response to the target. Participants were given ten practice trials followed by five blocks of 64 trials. In each block, there were equal numbers of near/far conditions, A or B responses and equal numbers

of the four distractor conditions. The nature of the previous trial was controlled.

d) Categoric Search Test 3 (with delay and masked target)
This test was similar to the two categoric search tasks described above, but this form of the test included a variable length delay; after the warning crosses disappeared, the target letter appeared on the screen, and in addition, the target letter was 'masked'. The stimulus quality was degraded to examine the encoding stage of response organisation. Participants were given ten practice trials followed by five blocks of 64 trials. In each block, there were equal numbers of near/far conditions, A or B responses and equal numbers of the four distractor conditions. The nature of the previous trial was controlled.

e) Categoric Search Task (basic form)
This was a repeat of the task described above. Participants either carried out the tasks in the order shown above or in the reverse order.

RESULTS

The results were analysed with ANOVAs. The within-subject factor was the time of day and also, in the case of categoric search, the type of task. The between-subject factors were the order of testing times and the order of performance tasks.

Time of day effects

Cardiovascular measures

There was a main effect of time of day upon pre-performance pulse rate, with pulse rate being significantly higher in the morning ($F(1, 80) = 10.69$, $p < 0.01$; morning pre-performance pulse rate mean = 71.2 beats/min, afternoon pre-performance pulse rate mean = 66.7 beats per min). There was a significant main effect of time of day upon post-performance systolic blood pressure, with blood pressure being higher in the afternoon ($F(1, 80) = 40.78$, $p < 0.001$; morning post-performance systolic blood pressure = 107.5 mm/hg, afternoon post-performance systolic blood pressure = 114.8 mm/hg). There was also a significant main effect of time of day upon post-performance diastolic blood pressure, with blood pressure being greater in the afternoon ($F(1, 80) = 6,52$, $p < 0.05$; morning post-performance mean diastolic blood pressure = 68.7 mm/hg, afternoon post-performance mean diastolic blood pressure = 71.1).

Focused attention choice reaction time task

There was a significant main effect of time of day upon mean response time to targets presented alone or with asterisks, with performance being faster in the afternoon ($F(1, 80) = 8.04$, $p < 0.01$; morning mean response time = 377.1msec, afternoon response time = 369.8msec). Time of day was also significant for reaction times to targets presented with distractors, which either agreed or were different from the target, with performance being faster in the afternoon ($F(1, 80) = 5.85$, $p < 0.05$.; morning mean response time = 380.9 msec, afternoon response time = 374.6 msec.

Response to alternations and repetitions

There was a significant main effect of time of day upon mean response time taken to encode a new stimulus, with new stimuli being responded to more quickly in the afternoon (difference between alternations and repetitions: $F(1, 80) = 17.12$, $p < 0.001$; morning mean difference in response time = 16.5 msec, afternoon difference in response time = 10.9 msec).

Categoric search choice reaction time tasks

Mean reaction times and accuracy

There was a significant main effect of time of day upon mean response time to targets presented alone or with an asterisk, with reaction times being faster in the afternoon ($F(1, 80)$ 7.12, $p<0.01$; morning mean response time = 508.0 msec, afternoon mean response time = 501.1 msec). The time of day effect was significant for trials where the target was presented alone ($F(1, 80)$ 9.32, $p<0.01$; morning response time = 447.2 msec, afternoon response time = 438.5 msec). There was a significant main effect of time of day for the number of errors made, with accuracy being greater in the morning ($F(3, 240) = 27.91$, $p<0.001$; morning mean errors = 16.56 afternoon mean errors = 18.01).

Effects of type of categoric search task

The versions of the task with longer delays between the warning crosses and the target and with masked targets led to significantly slower response times but greater accuracy compared to the standard form of the task. However, there were no significant interactions between time of day and task type.

DISCUSSION

The aim of the present research was to examine the speed and accuracy of performing different types of choice reaction time tasks in the late morning and afternoon. The previous research has identified that the pattern of time-of-day effects varies with the type of task. Search tasks often show a change in the speed-error trade-off function over the day, with performance being faster but less accurate later in the day. This may reflect cumulative fatigue and a shift towards low-effort strategies. However, other types of tasks only show faster responses later in the day, and other underlying mechanisms are probably involved. It is also important in time of day effects to confirm basic changes in physiology with time of day, and this was done here using cardiovascular measures.

The results confirmed that the cardiovascular measures changed over the day, with a different profile for heart rate and blood pressure. The categoric search tasks confirmed the change in the speed-error trade-off function, with faster but less accurate performance later in the day. This effect was very robust in that it was

found with different versions of the categoric search task and at both the beginning and end of the test session. In contrast, the focused attention task was performed more quickly later in the day but did not show a significant change in error rate over the day. The speed of encoding new information, the difference between trials that involved different stimuli from the previous trials (alternations) and those that were the same (repetitions), was faster in the afternoon. These results show two plausible mechanisms for faster performance later in the day, namely a change in the speed-error trade-off and encoding of new information. Future research using electrophysiological techniques and brain imaging can identify changes in brain function associated with these psychological mechanisms. Other factors also influence these mechanisms. For example, caffeine increases the encoding of new information.[21] Research has also investigated neurotransmitters that may influence encoding, and the cholinergic system has been shown to influence response to alternations and repeats.[22] Time of day effects are important in education and work. They are also important in many activities, and errors in the laboratory may translate into reduced safety in real life.

CONCLUSION

Extensive research has shown that human performance varies over the day. The pattern of these time-of-day effects depends on the type of task performed. Responses in psychomotor tasks are usually faster later in the day. There is often a speed-error trade-off in simple tasks, with responses being quicker but less accurate later in the day. This was examined in the present study, which also measured the speed of encoding. Ninety-six university students completed the study. They each carried out tasks in the late morning (11.00-13.00) and afternoon (15.00-17.00). The two test sessions were on separate days. Half the participants did the sessions in the morning and then in the afternoon, and the others in the opposite order. They carried out a focused attention choice reaction time task and categoric search tasks. Cardiovascular measures were also taken to confirm that there were physiological changes over the day. The results showed that heart rate decreased over the day and blood pressure increased. Response times in the focused attention task were faster in the afternoon, and the speed of encoding new information was also quicker. The categoric search tasks showed a speed-error trade-off, with performance being quicker but less accurate later in the day. Significant differences were found between the different types of categoric search tasks, but these did not interact with the time of day. In conclusion, the results from the present study confirmed the changes in cardiovascular function found over the day. The search tasks also replicated the speed-error trade-off, with performance in the afternoon being faster but less accurate. The performance of the focused attention task was quicker in the afternoon, and this was associated with faster encoding of new information. Future research can identify the mechanisms underlying these effects of time of day and also consider their practical implications in work, education and other real life contexts.

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