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The Cognitive Neuroscience of Vigilance – A Test of Temporal Decrement in the Attention Networks Test (ANT)

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***Abstract*—**The aim of this study was to test whether the Attention Networks Test (ANT) showed temporal decrements in performance. Vigilance tasks typically show such decrements, which may reflect impairments in executive control resulting from cognitive fatigue. The ANT assesses executive control, as well as alerting and orienting. Thus, it was hypothesized that ANT executive control would deteriorate over time. Manipulations including task condition (trial composition) and masking were included in the experimental design in an attempt to increase performance decrements. However, results showed that there is no temporal decrement on the ANT. The roles of task demands, cognitive fatigue and participant motivation in producing this result are discussed. The ANT may not be an effective tool for investigating temporal decrement in attention.

***Keywords*—**ANT, executive control, task engagement, vigilance decrement

I. Introduction

THE vigilance decrement has been described as a slowing in reaction times or an increase in error rates as an effect of time-on-task during monitoring tasks. Vigilance decrement in performance is common in tasks requiring signal detection.

Vigilance decrement is defined as "deterioration in the ability to remain vigilant for critical signals with time, as indicated by a decline in the rate of the correct detection of signals" [1]. Vigilance decrement is most commonly associated with monitoring to detect a weak target signal. Detection performance loss is less likely to occur in cases where the target signal exhibits a high saliency. For example, a radar operator would be unlikely to miss a rare target at the end of a watch if it were a large bright flashing signal, but might miss a small dim signal. The ability to maintain high levels of focused attention or vigilance over long periods of time underlies success on a range of tasks, from reading to airport security monitoring; but concentration often fails in such situations [2] (e.g., Mackworth, 1948). Moreover, sustained attention is deemed to be effortful and stressful when one is required to maintain high levels of performance [3], [4], [5].

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Among the major theories of vigilance, the resource model [6] proposes that the drop-off in performance over time – the vigilance decrement – is a result of the exhaustion of information processing resources that are not replenished over time. The well-known construct of attention resources is critical to the modern cognitive-psychological theory of vigilance [7], [8].

Modern cognitive-psychological theories of vigilance, based on constructs such as resources [8] and loss of mindful awareness [9] have only relatively recently been used as the conceptual framework for vigilance studies. A pivotal finding in vigilance research is that task demands control performance decrement over time. A meta-analysis of 42 studies showed that perceptual sensitivity decrement in vigilance is systematically related to the level of demands of the task; the higher the workload, the greater the performance deterioration [10]. Prolonged high workload may lead to depletion of resources, causing performance decrement. Thus, individual difference factors that relate to resource availability or utilization should predict vigilance [11].

Attentional resource theory [12], [13] is based on the idea that a metaphorical pool of energy (‘resources’) supports attention and processing of information. Resource theory holds that, as more effort is needed to fulfill the demands of a task, more resources are used and workload increases. Information processing and performance become impaired when demands exceed available resources. There are probably multiple pathways through which fatigue and stress may impact performance [14]. However, fatigue factors may impair sustained attention by reducing the quantity of available resources. Resource theory appears to be especially valuable as a means for understanding stressor and fatigue effects on tasks requiring vigilance or sustained attention [13]. In addition, temporary mental states such as fatigue and stress may be related to individual differences in attentional processes. Specifically, a state of task engagement has been found to relate positively to performance on a range of demanding attentional tasks [15]. Task engagement is associated with higher energetic arousal, greater task motivation and greater concentration [16]. Low task engagement corresponds to a state of fatigue.

A limitation of resource theory is that the underlying cognitive and neural processes that control variation in resource availability are not precisely specified. A more precise account of vigilance and cognitive fatigue may be obtained by investigating temporal change in executive control. Cognitive fatigue may disrupt the person’s ability to regulate information-processing, for example, by inhibiting processing of irrelevant stimuli. Thus, it is important to test

whether executive control in fact becomes impaired during extended task performance. Subjective task engagement is interconnected with the regulation of attention on demanding tasks [16], and so loss of engagement may be associated with impaired executive control. Recent work on the cognitive neuroscience of attention may provide a methodology for investigating temporal change in executive control. According to Posner's theory [17] attention is controlled by three neural networks: Alerting, Orienting, and Executive control. Alerting describes the function of tonically maintaining the alert state and phasically responding to a warning signal. Automatic and voluntary orienting are involved in the selection of information among multiple sensory inputs. The visual orienting function involves aspects of attention that support the selection of specific information from numerous sensory inputs arriving at different spatial locations. Executive control describes a set of operations that includes monitoring and resolving conflicts in order to control thoughts or behaviors. The executive control function of attention involves more complex mental operations in detecting and resolving conflict between computations occurring in different brain areas [18], [19]. The networks have been differentiated on the basis of both behavioral evidence from studies of attentional task performance, and cognitive neuroscience methods including functional magnetic resonance imaging (fMRI). Fan et al. (2002) [20] developed the Attentional Network Test (ANT), to provide independent indices of the efficiency of functioning of each network. The ANT is based on a combination of the cued reaction time (RT) [21] and the flanker tasks [22] paradigms. A schematic diagram of the stimuli and design of the ANT is shown in Fig. 1. Investigation of temporal change in the ANT may support a new understanding of loss of vigilance as a possible impairment in executive function. The standard version of the ANT lasts for about 15 min, which may be insufficient to observe temporal change in performance. The aim of the present study was to use a longer-duration version of the ANT to test for possible temporal decrements in the functioning of the attentional networks described by Posner and Peterson [17]. Studies of vigilance [5], [10] suggest that various workload factors influence whether or not a decrement in perceptual sensitivity is found in any given study. Two task manipulations were included in the design of the present study in order to increase the likelihood of performance decrement. First, half the subjects performed with masked stimuli to increase the mental demands of the task. Vigilance studies show that use of masked stimuli tends to amplify the decrement [11], [14]. Second, the standard ANT activates different networks from trials to trial, which may reduce fatigue of the network. Thus, several trials may intervene between the incongruent-flanker trials that activate the executive system, allowing a period in which the system may recover from fatigue. Galinsky et al. (1990) [23] suggested that alternation between different processing pathways might help to protect vigilance, via such a recovery process. To reduce the potential for recovery, we also included modified task conditions, that tested only a single network, and so should give stronger decrements.

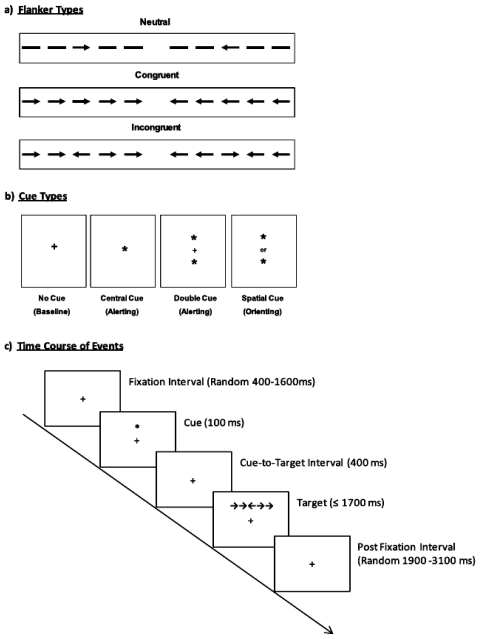

Fig. 1 A schematic diagram of the stimuli and design of Experiment [20]

Fig. 2 Examples of masked (left) and unmasked (right) target stimuli

The study also assessed subjective state and workload. These measures were used to evaluate the levels of fatigue and mental demand produced by the extended ANT.

II. Methods

A. Subjects

The participants were 160 students from Kazakh National University aged 17 to 30 years old (141 females and 19 males). Participants were required to be free of psychiatric and medical diseases at the time of the study. All were right handed, with normal or corrected-to-normal vision. Participants were all drug-free. During the experimental session, participants did not drink or eat anything containing caffeine (e.g., coffee, tea, chocolate).

B. Design

A 2 × 4 (masking × task condition) between-subjects design was used. Participants were randomly assigned to one of the eight groups defined by this design. Four groups performed using the standard ANT stimuli, with no mask. The remaining four groups performed with a masked version of the central target stimulus. The four task conditions were as follows. The first was the standard ANT, which includes trials assessing alertness (presentation of a central or double cue), orienting (presentation of a spatial cue) and executive function (incongruent flankers). The remaining three, modified conditions included only the stimuli necessary to compute a single index. The experimental design was accepted by the local ethics committee.

C. ANT Task

The ANT requires participants to determine whether a central arrow points left or right. The arrow appears above or below fixation and may or may not be accompanied by flankers. Efficiency of the three attentional networks is assessed by measuring how response times are influenced by alerting cues, spatial cues, and flankers. Task duration (c. 66 min) was extended beyond the 15 min duration of the original Fan et al. (2002) task in order to increase the likelihood of participant fatigue. The task comprised 12 blocks of trials, e each made up of 96 individual trials. In the mixed task condition, the trial types were the same as used by Fan et al. (2002), with flanker type and cue varied from trial to trial (see Fig. 1). In the modified task conditions, stimuli were reduced to those necessary to measure a single network. Calculation of the three ANT indices was modified accordingly. Stimuli in these conditions were as follows:

Alertness task. On 50% of trials, there was no cue. On the remainder, a double cue was presented. In addition, 50% of stimuli were presented with congruent flankers, and the remainder with neutral flankers. The Alertness index was then calculated as the difference in RT between cued and uncued trials.

Orienting task. All trials were cued, either by a central cue or a spatial cue (in upper or lower position). In addition, 50% of stimuli were presented with congruent flankers, and the remainder with neutral flankers. The Orienting index was calculated as the difference in RT between spatial-cue and central-cue trials.

Executive Control. All trials included a non-spatial cue: 50% of trials used a central cue, and the remainder a double trial. In addition, 50% of trials used congruent flankers, and the remainder incongruent flankers. The Executive Control index was calculated as the difference in RT between congruent and incongruent trials.

These modified indices were also used to assess network function in the standard ANT condition, to ensure comparability of indices across all conditions.

A silent, artificially illuminated room was used for testing. The display for the task was placed at a distance of 65 cm from the participant's eyes. Programming was achieved by means of E-Prime (v2.0) experiment-generation package, which provides millisecond accuracy for response timing and Microsoft Excel software. The responses were collected through the computer keyboard.

Subjective state was measured by the Kazakh version of the Dundee Stress State Questionnaire (DSSQ; Matthews et al. 1999). We also administered the "Eysenck Personality Inventory" (EPI: Eysenck & Eysenck, 1964, Form A [22]), which measures extraversion, "Amthauer's Intelligence Structure Test (IST)" and "Rational-Experiential Inventory". (Analyses of these measures are not included in this report)

Participants completed a pre-test form of the DSSQ, then performed the ANT, and then immediately completed a post-test version of the DSSQ and a standard workload measure, the NASA Task Load Index (TLX: Hart & Staveland, 1988 [24]). The ANT was adapted to a Kazakh speaking population; DSSQ was translated into Kazakh. All scales of the Kazakh DSSQ showed adequate alphas, ranging from 0.619 to 0.874.

III. Results

A. Analyses of subjective state

Differences between pre- and post-task means on the DSSQ scales were tested with *t*-tests, using Bonferroni correction. Results are shown in Fig. 3. They revealed significant ($p<0.01$) decreases during performance of the ANT in intrinsic motivation, concentration, task relevant cognitive interference, task-irrelevant cognitive interference and self-focus. There were also significant increases in success motivation and self-esteem. ANOVAs were also run to test for effects of masking and task condition on the DSSQ scales. Effects of these factors were minimal, and significant findings barely exceeded chance levels.

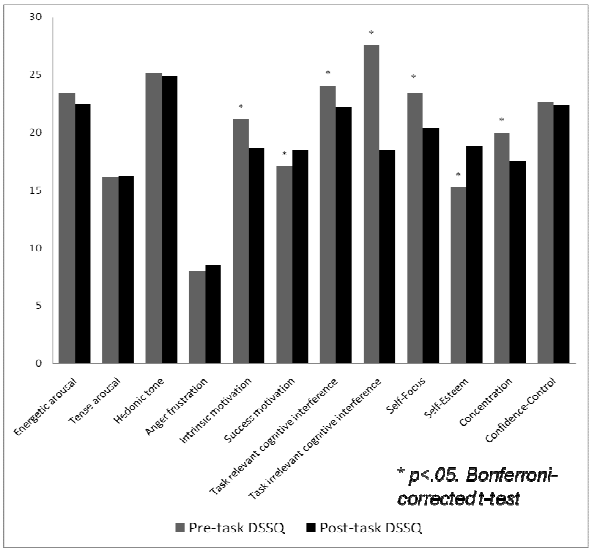

Fig. 3 Means for DSSQ scales before and after ANT

B. Analyses of workload

Workload data were analyzed using a 2 x 4 (mask x task condition) between subjects ANOVA. The only significant effect was a main effect of condition, ($F(df = 3, 152) = 4.54$, $p<0.01$. Fig. 4 shows differences in mean workload as a function of masking and task condition. The modified task versions assessing alerting (condition 2) and orienting (condition 4) produced the highest levels of workload. Workload tended to be higher in masked conditions, but the effect of the mask was non-significant.

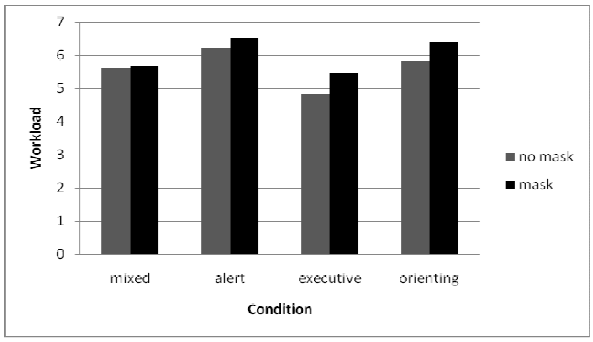

Fig. 4 Mean workload as function of masking and task condition

C.Analyses of ANT performance

The main effect of masking was significant for Executive Control (F(df =1, 75) = 87.45, p<0.01 and for Orienting (F(df=1, 75)=23.51, p<0.01. Masking reduced the EC index but increased the orienting index. The mean for the EC index was 122.8 ms in unmasked conditions, and 35.2 ms in masked conditions, averaging across task periods. Likewise, for Orienting index was 50.6 ms in unmasked conditions, and 77.2 ms in masked conditions, averaging across task periods.

The main effect of condition was significant only for Alerting (F(df=1, 76)=11.66, p<0.01. Means (averaged across periods) were 55.6 ms for the standard ANT trials and 50.4 ms for the modified conditions. The main effect of period was significant for Executive Control (F(df=11, 75)=4.96, p<0.01 and Alerting (F(df=11, 76)=3.59, p<0.01. The main effect was modified by a period x mask interaction for both EC (F(df=11, 75)=9.04, p<0.01 and for Alerting (F(df=11, 76)=19.11, p<0.01. There were no further interactions between period and the other factors for these indices. There were no main effects or interactions involving period for Orienting.

Fig. 5 shows the effects of period and masking on Executive Control. Contrary to expectation, the value of the EC index tended to decrease across task periods, suggesting improving executive control. The decrease was larger in the masked than in the unmasked condition. The figure also shows the reduced value for the index when stimuli were masked.

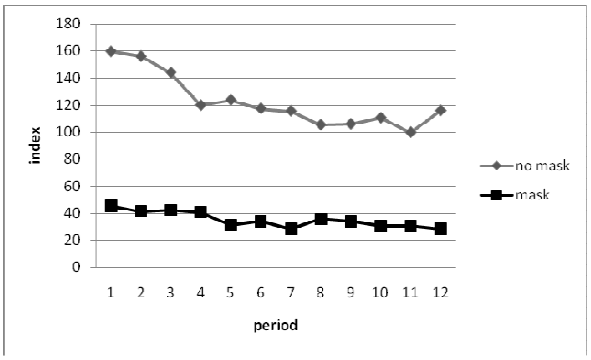

Fig. 5 Temporal change in Executive Control in mask and no mask conditions

The effects of period and masking on Alertness are shown in Fig. 6. In general, the Alertness index tended to increase across periods. The interaction with masking appears to relate to an earlier increase in the index in unmasked condition, i.e., in periods 3-5. There appeared to be no systematic effect of masking in the later periods.

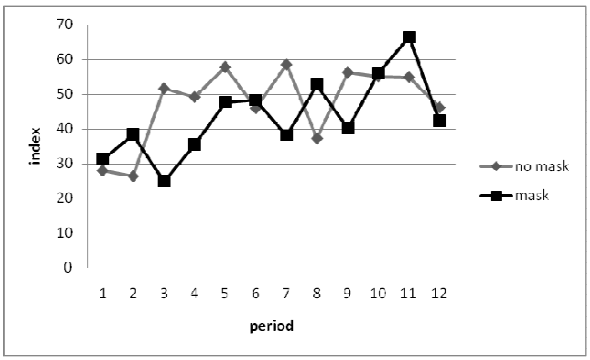

Fig. 6 Temporal change in Alerting in mask and no mask conditions

An issue for interpreting temporal change in the indices is that they are calculated as differences scores, relative to a baseline RT value. Temporal changes might then reflect changes in the baseline rather than in the efficiency of the network concerned. To address this possibility, we ran further analyses that separate baseline trials from trials on which the relevant network was believed to be activated. For space reasons, we do not present these analyses here. Instead, we will briefly provide qualitative descriptions of the data.

Fig. 7 shows the effects of task period and masking on the congruent and incongruent trials used to calculate the Executive Control index. Data from both the standard and modified conditions (total $N = 80$) are included. For this index, the trials with congruent flankers provide baseline data. The Figure shows little systematic change in RT on congruent trials across time. By contrast, RT appears to decline on incongruent trials in both unmasked and masked conditions. Thus, the temporal decline in Executive Control shown in the primary analysis does not seem to be an artifact of changing baseline.

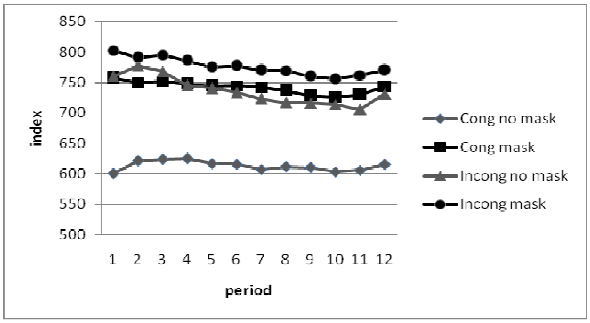

Fig. 7 Temporal change in RT for congruent and incongruent trials, in mask and no mask conditions

Fig. 8 shows comparable data for the Alertness index. In this case, baseline trials are those that include no alerting cue. The Figure suggests a small decrease in baseline RT in the masked conditions, and a small increase in no mask

conditions. RTs on cued trials decreased in both masked and unmasked conditions, with a somewhat larger decrease in masked conditions. Again, the temporal trend towards increasing Alertness cannot be attributed to a shift in baseline RT.

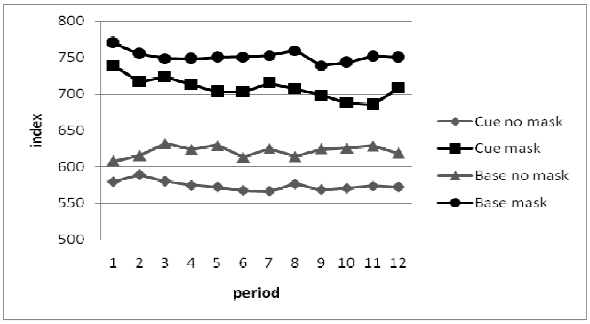

Fig. 8 Temporal change in RT for cued and baseline (no cue) trials, in mask and no mask conditions

Finally, error data were analyzed, primarily to check whether there were any temporal increases in errors. In fact, none of the relevant ANOVAs showed any significant main or interactive effects of task period on errors. Error rates were generally low; overall mean accuracy was 0.9745 on trials designed to measure alertness (averaged across periods and cue conditions) and 0.9740 on orienting trials. In the analyses of executive control, accuracy rates were higher on congruent trials (mean = 0.9814) than on incongruent trials (mean = 0.9580), but there was no temporal change observed for either trial type.

IV. Conclusions

The data show that there was no decline in executive function during a period of continuous performance on a version of the ANT exceeding 1 hour in duration. There was also no temporal decline in the alertness and orienting indices. Indeed, task period effects suggested improvements in executive functioning and alertness over time. Thus, the ANT does not appear to show any performance changes similar to vigilance decrement. Improvements in performance may suggest practice effects on the attentional indices concerned.

It was thought that the masking and task condition manipulations might increase performance decrement, but this was not the case. The manipulation of task condition had minimal effects on performance. The masking manipulation was effective in slowing overall response times (see Figs. 7 and 8). However, contrary to expectation, the executive control index indicated greater improvement over time in the masked compared to the unmasked condition. Thus, even a task version more demanding than the standard ANT failed to show a temporal decrement.

There are several possible reasons for the lack of performance decrement. First, the task may not have been sufficiently demanding for resources to become depleted over time. Against this suggestion, another recent study in our laboratory (Kamzanova et al., 2011) [25], using Kazakh students as subjects found a mean NASA-TLX value of 5.67 for a vigilance study that showed a decrement. This value is comparable to those obtained here. On the other hand, even in the modified version, there may have been sufficient time between trials for networks to recover from the cognitive fatigue induced by workload.

Second, there are multiple executive functions. Miyake et al., 2000 [26] distinguished between inhibition, set-shifting and updating working memory. The ANT assesses inhibition, but other functions may be more susceptible to cognitive fatigue. Previous work on vigilance suggests that working memory load may be important for the development of a performance decrement [14].

Third, the DSSQ data suggest that the task may not have provoked a substantial loss of task engagement. Typically, the performance of vigilance tasks influences all the DSSQ scales associated with task engagement. Energetic arousal, task motivation and concentration all decrease substantially [11] [16]. In the present study, intrinsic motivation and concentration declined, but the drop in energy was non-significant, and success motivation actually increased. Participants' ability to maintain motivation through striving for superior performance (i.e., success motivation) may have helped to preserve resources and executive control. Cross-cultural differences may have played a role in this outcome, given that Kazakh undergraduate students are typically unfamiliar with experimental psychological research. Participants may have been more motivated than the American introductory psychology students typically used as participants in vigilance studies. On the other hand, Kamzanova et al., 2011 [25] found typical declines in task engagement, including reduced energy and success motivation, during performance of a high-workload vigilance task.

In conclusion, here may be various factors contributing to participants' sustained effectiveness on the ANT, including limited cognitive demands, insensitivity of inhibition to cognitive fatigue, and participants' ability to maintain motivation. In any case, the ANT does not appear to be well-suited for investigating the cognitive processes that may contribute to vigilance decrement. Future sustained attention research might explore other information-processing tasks requiring executive control. By contrast, the present research does suggest that the ANT is a fairly robust measure for other types of inquiry, given that performance is fairly insensitive to temporal change

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