ENDOGENOUS AND EXOGENOUS ATTENTION IN VIGILANCE TASKS

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INTRODUCTION

A crucial determinant of cognitive performance is the ability to maintain the focus of cognitive activity on a given stimulation source or task, in other words, sustained attention or vigilance. The study of vigilance in cognitive psychology took off with the landmark paper of Mackworth (1948). He studied a very concrete problem: in 1943, the Royal Air Force wanted to determine the optimal time on task for radar operators, to ensure maximal signal detection. Therefore it seemed necessary to describe and quantify a possible decline in attention over time.

Besides the theoretical importance of sustained attention for understanding the underlying mechanisms of human information processing, it is also relevant for applied issues in human performance and its impairment is a common problem in clinical neuropsychology (Smith, 2003). The aim of the present study is to contribute to this understanding by investigating the involvement of endogenous and exogenous attention in the decrement of vigilance over time on task.

Studies of vigilance

The traditional tasks used in studies of sustained attention are long detection tasks of scarcely occurring signals (Mackworth, 1948; Eysenck, 1982; Botella et al, 2001; Grier, 2003). In many studies a vigilance decrement is found, indexed as a decline in the detection rate over time, showing its full strength after 20 to 35 min. However, in other studies, using more complex tasks, no such decline of performance has been found (Warm & Jerrison, 1984). Several hypotheses have been described to account for the vigilance decrement. Some investigators (Stuss, 1995; Robertson et al, 1997) state that the vigilance decrement is a consequence of attentional withdrawal of the supervisory attentional system, due to underarousal caused by the insufficient workload inherent to typical vigilance tasks. Others (Temple et al, 2000; Grier et al, 2003) view the decrement as the result of a decrease of attentional capacity and thus as the impossibility to sustain the effort due to the mental workload.

According to Fisk & Schneider (1981), the data on sustained attention can be interpreted in terms of automatic and controlled processing. Their view is based on the model described by Schneider & Shiffrin (1977), describing human performance as the result of two qualitatively different forms of information processing, namely automatic and controlled processing. Controlled processing is serial in nature, requires effort, is under an individual's direct control, and requires little or no practice for asymptotic performance. Automatic processing is parallel in nature, not limited by short-term memory capacity, requires little or no effort, is not under a person's direct control and requires extensive consistent training to develop. Fisk & Schneider demonstrated that controlled processing is the locus of the vigilance decrement. The problem with this explanation is that sometimes large vigilance decrements are found in tasks where there is obviously a strong automatic component. Jacoby (1991) explained these findings by pointing out that making a distinction between automatic

and controlled processing based on task characteristics is an oversimplification, since every cognitive process requires the interplay between both modes.

Although descriptions of the vigilance decrement in terms of automatic and controlled processes intuitively seem to provide a kind of explanation, they still remain rather vague. No effort is made to understand how these attentional mechanisms work, and which of the underlying processes are assumed to deteriorate over time.

Endogenous and exogenous attention

A possible way to investigate the contribution of automatic and controlled mechanisms is to make a distinction between exogenous and endogenous attention. Exogenous attention refers to the automatic attraction of attention, due to, among others, the sudden appearance of a stimulus. This is a typical bottom-up process, controlled by external stimulus presentation, and not under subjects' control. Endogenous attention, on the other hand, refers to directing of attention under control of the individual, for example when attention is being focussed on the basis of instructions. This is a typical top-down controlled mechanism, requiring the subjects' attentional effort.

Posner (1980) demonstrated both types of attentional mechanisms by means of a cueing paradigm. Subjects had to detect a target, presented to the left or to the right of a fixation point. The target display was preceded by a cue, indicating the likely location of the target (e.g. 80%). Exogenous cueing was accomplished by presenting a brief flash to the left or to the right of fixation. Endogenous cueing was accomplished by presenting a central arrow pointing to the left or to the right. Posner found a typical cost-benefit pattern with both types of cues, that is, RTs were faster when the target appeared in the cued location, as compared to a neutral condition without cue, and RTs were slower when the wrong location was indicated. Jonides (1981) and Remington et al. (1992) demonstrated that exogenous attention involves more automatic processing than endogenous attention.

In most research on vigilance to date, mainly endogenous attention was tested. This appears clearly in Mackworth's (1948) description of the stimuli he used: "difficult to perceive because the subject had no more than a glimpse of each of these barely visible stimuli". As a first step in understanding the mechanisms of vigilance decrement, we aimed to study the evolution of endogenous and exogenous attention over time on task and the possible differences between both. Since earlier research seems to point to controlled processes as the locus of the vigilance decrement, one can expect endogenous attention to be most vulnerable to deterioration.

Air Traffic Controllers as subject population

As described in Mackworth's (1948) study, the investigation of sustained attention started because of questions related to the performance of a specific population. Therefore, we conducted our experiment with a group of Air Traffic Controllers (ATC) and a control group. Considering the task features of the work of ATC's, as described by Redding (1991, in Johnston, 1994) and Seamster (1993), it can be assumed that vigilance is of major importance. Consequently, we expect the performance of this expert group to be better than that of the control group. Investigating the evolution of endogenous and exogenous attention in vigilance for both groups will allow a better understanding of the underlying processes, and of the effect of training on both types of attentional mechanisms.

Furthermore, expertise has been described in cognition as based on knowledge organisation (Green et al, 1992, in Eysenck & Keane, 2000). Also in this respect, the results of this research can clarify whether such organization is related to the different orienting mechanisms of attention.

MATERIAL & METHODS

Subjects

Sixteen ATC's and sixteen controls participated in the experiment. All were volunteers and part of the personnel of the 1 Wing of the Belgian Air Component. The subjects from the expert group were matched with those from the control group for age, gender and socioprofessional category, for which we used the military rank. All participants had normal or corrected-to-normal vision. Subjects ranged in age from 22 to 54. All testing was done at the same time of day.

Apparatus

The experiment was generated using the E-Prime software (Schneider, 2003). All stimuli were presented on a Sony Multiscan G 400 19' monitor, at 50 cm viewing distance. Responses were collected through the keyboard of an IBM A21p PC.

Procedure

Subjects subsequently saw three types of displays: fixation, cue, and target display on each trial. The fixation consisted of a cross in the middle of the screen, between 6 square boxes: 3 right and 3 left from the cross. The six boxes and the cross were in the center of the screen, in a 11 x 97.5 mm area, measuring 11°8' horizontal and 1°17' vertical visual angle from a viewing distance of 50 cm. The boxes were grey against a white background. The stimuli appeared inside the boxes.

For endogenous attention, the cue display consisted of an arrow, replacing the central cross, indicating the likely location of the target to come. The cue could be valid, invalid, or neutral (no cue at all). For exogenous attention, either the three right boxes or the three left boxes increased in brightness to indicate where the target would likely appear (valid or invalid cue) or all boxes brightened (neutral cue).

The target displays consisted of the fixation displays with the addition of stimuli in the boxes. The stimuli could have two different shapes, a star or a circle, and two different colours, red or green.

Participants were instructed to detect the target stimulus, which was a green star. To indicate the presence or absence of the target, they had to press the keys "1" or "3" of the keyboard. The mapping of the response keys was counterbalanced accross subjects. There was an equal probability for the target to appear right or left. The time between response onset and the onset of the next stimulus, the response-stimulus interval (RSI) could be 5 s, 10 s, 15 s, 20 s, 30 s or 40 s.

Every subject participated in two sessions: one with endogenous cues and one with exogenous cues. Each session started with the instructions appearing on the screen and two examples of the stimuli. After these, a practice block of 66 trials was presented. The experimental block consisted of 186 trials. A target was present in 108 trials. 67% of the cues were valid, 22% invalid and 11% neutral.

RESULTS

The results and effects described in this section are in terms of reaction times (RT's). Indeed, the overall lack of variation of error rates across conditions made it clear that the results obtained were not due to a trade-off between speed and accuracy.

Evolution of the validity effect over time

The evolution of reaction times (RT's) for correct responses over time for endogenous and exogenous cues for both ATC's and controls is shown in Figure 1 and Figure 2. These data seem to confirm our hypotheses. There is a decrease of the endogenous cueing effect over time for the control group only, whereas there is no such effect in the exogenous cueing condition.

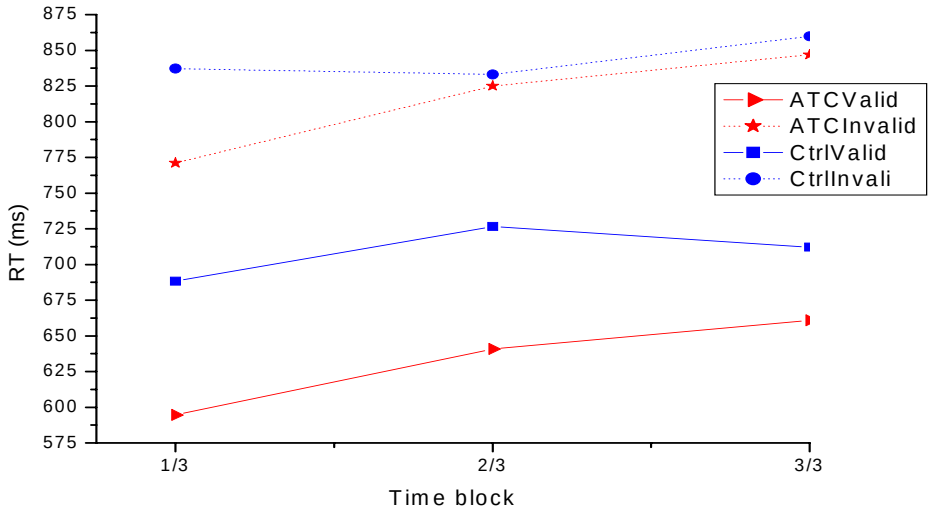

Figure 1: Endogenous cues: RT in function of time on task for valid and invalid cues in ATC's and control group (Ctrl).

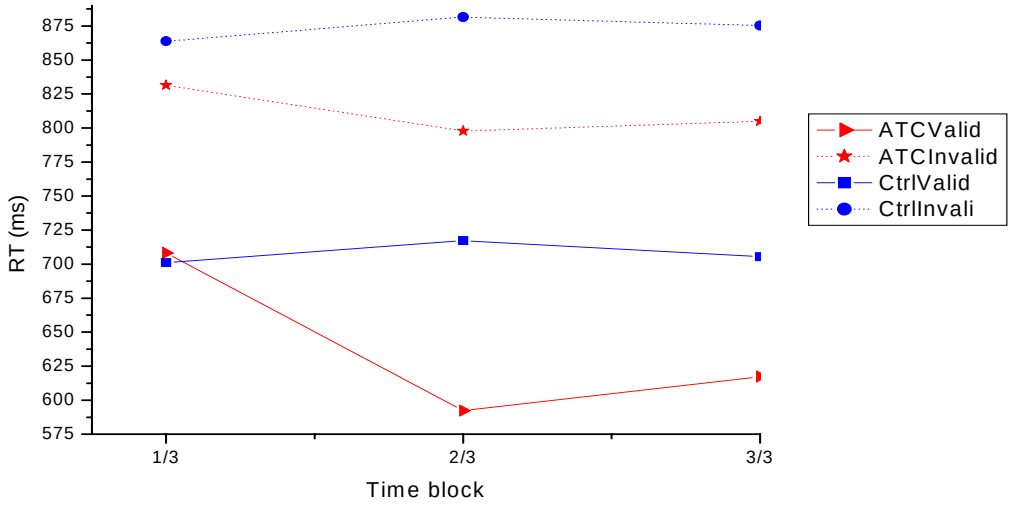

Figure 2: Exogenous cues: RT in function of time on task for valid and invalid cues in ATC's and control group (Ctrl).

The data were analysed using a 3 (time block) x 2 (cue type) x 2 (validity) x 2 (group) mixed analysis of variance (ANOVA). Greenhouse-Geisser Epsilon corrections were used when Mauchly's Test turned out to be significant. This yielded a significant main effect of validity, $F(1,30) = 61.09$, $p < .000$. As expected, subjects respond significantly faster after a valid cue as compared to an invalid cue. Over all conditions, the mean difference in RT's after valid and invalid cues is 163.6 ms. There were no other significant main effects.

In contrast to our expectations, we found no significant third order interaction between validity, cue type, time and group. This is quite puzzling, since it doesn't tally with the graphical representation of our results. Indeed, the initial decrease of the validity effect over time in the control group for the endogenous cueing corresponds to the vigilance decrement we predicted, since it is a less effective processing of the cue that affects only the control group in the endogenous condition.

The ANOVA also showed a significant interaction between cue type and time, $F(2,60) = 4.25$, $p = .035$, which points to the different evolution over time of both cueing conditions. Furthermore, we also found a significant second order interaction between cue type, time and group, $F(2,60) = 3.30$, $p = .044$. This is in favour of our hypotheses, according to the view that ATC's and control differ in their susceptibility to vigilance changes over time. However, the nature of the difference is quite surprising: while the validity effect of endogenous cues doesn't vary over time for ATC's, their RT's show a steady increase over time, while they remain faster than the controls.

These results indicate that we do not demonstrate a vigilance decrement in terms of increase in RT or error rate, but as an effect on cue-information processing. Indeed, there is no significant main effect of time, $F(2,60) = 0.29$, p = ns and the mean RT's for the first, second and third time blocks are respectively $\underline{M_1}$ = 747,30 ms, $\underline{M_2}$ = 746,04 ms, $\underline{M_3}$ = 755,14 ms. The pattern of changes in the validity effect, despite the fact that it doesn't reach statistical significance, is a demonstration of the modification in the underlying attentional processes over time.

Effect of the duration of RSI

The variation of attentional mechanisms over time can also be considered in function of the length of the RSI. The effect of this factor on RT's of correct responses was tested using a short, medium and long RSI, respectively 5, 20 and 40 s. The data are shown in Figures 3 and 4. We can see an increase of the validity effect with RSI length for endogenous cueing in the control group and for exogenous cueing for ATC's, while we see a decrease of this validity effect for exogenous cueing in the control group.

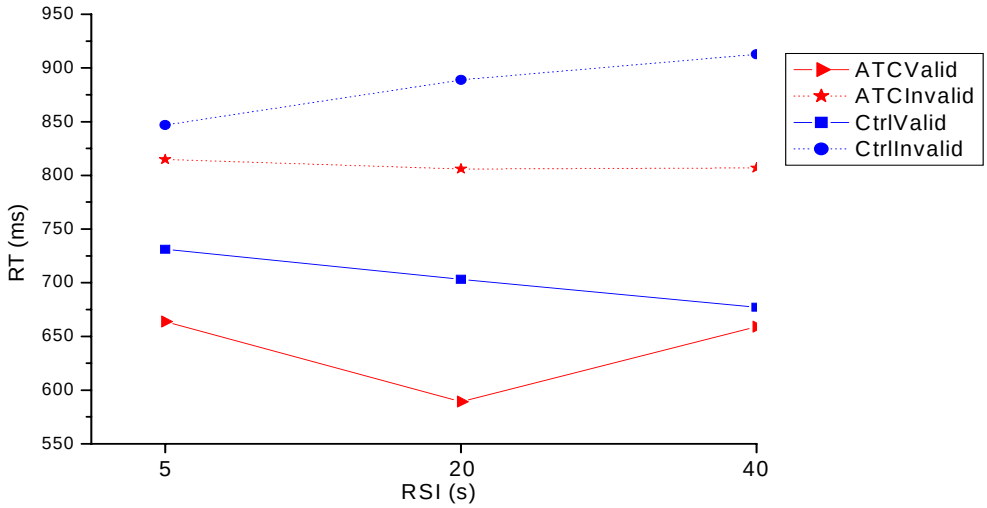

Figure3: Endogenous cues: RT in function of RSI for valid and invalid cues in ATC's and control group (Ctrl).

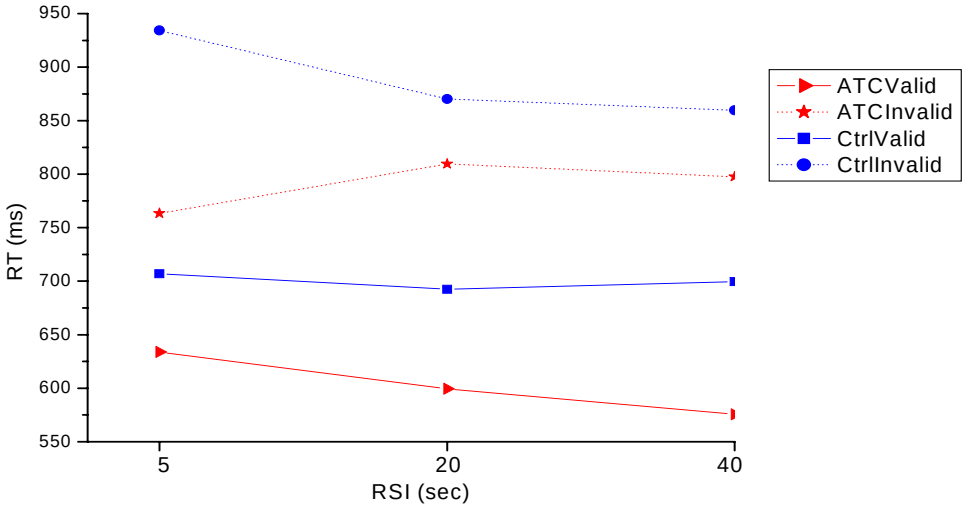

Figure4: Exogenous cues: RT in function of RSI for valid and invalid cues in ATC's and control group (Ctrl).

A 3 (RSI) x 2 (cue type) x 2 (validity) x 2 (group) mixed ANOVA revealed again a significant main effect of validity, $F(1,30) = 81.78$, $p < .000$. As suggested by the graphic representation of our data, the analysis also showed a significant third order interaction between cue type, validity, group and RSI, $F(2,60) = 3.55$, $p = .035$. However, the separate ANOVA for endogenous cues yields only a significant main effect of validity, $F(1,30) = 56.22$, $p < .000$. Despite the visible linear increase of the validity effect with RSI for the control group, this interaction didn't reach significance. A separate ANOVA for the exogenous cues showed a marginal significant interaction between validity, group and RSI, $F(2,60) = 3.28$, $p = .06$.

DISCUSSION

The overall effect of time: the expected vigilance decrement?

The decrease of the endogenous cueing effect in the control group, despite being non significant, is in favour of our hypotheses. It also fits with the theory of Fisk & Schneider (1981), who demonstrated that controlled processing is the locus of the vigilance decrement. Indeed, the decrease of the validity effect can be seen as a less effective processing. As indicated by the lack of variation in hits and false alarms, this effect cannot be reduced to a difference in perceptual sensitivity or response criterion. The lack of statistically significant interaction with this validity effect, despite the clear evolution over time, can be accounted for in several ways. To begin with, the experimental design could be improved in the choice of the endogenous cue. This could implie the use of more than two locations for the stimuli, in order to increase the strength of the cue. Further, the use of a dynamic fixation stimulus would also allow a reduction the exogenous effect of the central (endogenous) cue, which was due to its abrupt onset. Moreover, the intra-group variation of the results is very high. This may have two implications: on one hand, the theoretical assumption that there is a major interindividual variability in the capacity to sustain attention, on the other hand, that the effects we demonstrated would be more significant if tested on more homogeneous groups. Indeed, we took great care of the matching between ATC's and the control group, but there was still a great variability in the chosen parameters (age, gender, socioprofessional category) within each group. An experimental design that would take into account this problem might allow to solve the question.

The absence of an overall RT effect over time, as well as the lack of variation in hits and false alarms for the different conditions over time, challenges the classical description of the vigilance decrement. The pattern of change in the use of the cue, allows inferences about the underlying attentional mechanisms, which cannot be reduced to changes in perceptual sensitivity or response criterion. Finally, the differences between the variation of endogenous and exogenous attention over time show the need for further research to study the underlying processes of sustained attention.

The duration of the RSI: sustained attention on a different time scale?

Since the lack of reported results regarding the influence of similar time intervals in the literature, we can consider two possible influences of the RSI length. First, we can consider it to have a similar effect as the overall time on task, therefore requiring sustained attention. This doesn't seem likely, according to the different evolutions of the validity effect in the control group for both time scales. Furthermore, we can interpret the influence of the RSI in terms of preparation of the subject: the duration of the waiting period between a given response and the next stimulus will create expectations regarding the probability of the apparition of a stimulus, therefore influencing the RT of the response (Gottsdanker, 1970; Niemi & Näätänen, 1981; Van der Lubbe, 2004).

It seems puzzling that the evolution of the validity effect in function of a short time scale is different from its evolution over a longer time scale. Indeed, we see a decrease of the validity effect in the control group over time on task (1 h 30 min) and an increase of this effect with a longer RSI (40 s).

The increase of the validity effect after exogenous cueing for ATC's can be seen as a more efficient use of the cue. This more efficient use after a longer RSI in

the exogenous condition can be accounted for by a state of automatic processing. According to Hollenbeck (1995), the low frequency of stimulus presentation will induce a state of automatic processing. Considering the results of Jonides (1981), we know exogenous cues to trigger an automatic orienting of attention. We can therefore assume the effect of such cues to be enhanced by the state of the subject after a longer waiting period. The increase of the validity effect with increasing RSI after endogenous cueing for the control group can be seen in function of the expectations of the subject. As Jonides (1981) demonstrated, the effect of central cues depends on the expectations of the observer. Expectations need time to develop, so that they will be maximal for the longest RSI's.

The difference between the groups can be explained as follows: ATC's are used to routine monitoring tasks and they might therefore be faster in their transition between controlled and automatic processing and thus more susceptible to effects regarding this automatic processing. The demonstrated difference between the two groups supports our hypotheses regarding the different information processing in these groups.

Conclusion

Our results confirm that controlled processing is the locus of the vigilance decrement. However, we challenge the classical description of this decrement in several ways. First, we demonstrate that there is more to sustained attention than perceptual sensitivity or response criterion. Indeed, our results show a variability of underlying processes that cannot be explained by signal detection alone. The decrease of the validity effect in the control group for endogenous cueing shows a less effective use of the cue over time on task. This implies that the controlled processing of the endogenous cue suffers from the vigilance decrement, whereas this decrement doesn't affect the more automatic processing of the exogenous cue. Furthermore, this effect is only present in the control group. Once again, it should be stressed that this decrement isn't indexed as an increase in RT's or error rates, but as a change in the efficiency of processing the cue information.

Second, we describe the effect of an underestimated variable, the RSI. Again, the use of the validity effect instead of absolute RT's allows inferences about the underlying processes. We demonstrated this effect increases with longer RSI, due to different mechanisms in endogenous and exogenous cueing.

Third, the differences between ATC's and the control group demonstrate that expertise can involve differences in information processing abilities. A question that remains is whether these differences are due to individual capacities identified in the selection, or to training, or to the interaction of both. To conclude, we demonstrated that more refined research is needed to study the underlying processes of vigilance, in order to be able to develop adequate tests for measuring sustained attention.

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