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SPECIFICITY OF ATTENTION IN THE STROOP TEST: AN EP STUDY

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General models of attention differ in the degree of specificity which they predict. The dimension of specificity was used to determine the underlying attention mechanism which modulated the amplitude of the P85 component of the VEP. The subjects attentional set was manipulated by means of the Stroop test. It was found that the selective mechanism was highly specific and an explanation for the effect was given in terms of bias in structures encoding the physical rather than semantic nature of stimulation.

1. Introduction

It is now clear that attention modulates the amplitude of evoked potentials (EPs). In the auditory modality evidence has been provided to show that the N1 measure of the auditory evoked potential (AEP) is enhanced with attention to the evoking stimulus (see Näätänen and Michie, 1979, for review). In recent years it has been shown that this phenomenon is due to the presence of a sustained negative shift which lasts some considerable time (Näätänen, Gaillard and Mäntysalo, 1978; Hansen and Hillyard, 1980).

In the visual modality various EP measures have been influenced by the deployment of attention. Harter and Previc (1978) report a sustained negative shift with attention to checkerboard stimuli. Using flashes presented to either hemifield and three types of presentation sequence, fast random, slow random and slow pseudo-random, Van Voorhis and Hillyard (1977) found that P2 recorded from Oz and N1 recorded from Cz were consistantly enhanced with

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attention. With a fast, random sequence of flashes they reported that P2 and N1 were also enhanced at both recording sites and with a slow, pseudo-random presentation which may have allowed for differential preparation (Näätänen, 1967) P1 recorded from Oz was enhanced with attention. Recently Eason (1981) has reported the enhancement of P1 with spatial attention to flash stimuli using a random stimulus presentation and a ISI which averaged around 2 sec.

Theories, couched in terms of general models of attention, have been developed in the EP attention literature about the relationship between these neurological events and underlying cognitive processing.

Models differ in the degree of specificity of attention which they predict in a given experimental situation. The dimension of specificity can therefore be used to separate various selective mechanisms. "Stimulus set" attention or filtering refers to a very general mechanism which allows all material which has a particular stimulus feature to pass through. Treisman (1969) postulated another general mechanism to deal with attention to dimensions. In her terminology this form of attention is referred to as "selection of analysers". Analysers are considered to be perceptual systems for the discrimination of sensory dimensions or attributes of a stimulus. If we select an analyser we should enhance the processing of a particular dimension of all stimuli.

However mechanisms which are dependent on interaction with permanent memory can be highly specific. Broadbent (1971) refers to "response set" attention, a mechanism which causes recognition systems to be biased for particular stimuli like one's own name or a target word in an auditory message.

Hillyard and co-workers consider that short latency indicants of attention reflect the enhanced processing of a set of stimuli possessing a particular physical characteristic. They reflect stimulus set attention. However the specificity of the N1 effect has rarely been tested. Hink, Hillyard and Benson (1978) compared the N1 evoked by targets and non-targets in a dichotic listening experiment. Subjects were presented with CV syllables (/ba/, /ga/, /da/ and /ja/). The syllables presented to one ear were in a female voice and syllables presented to the other ear were spoken in a male voice. The task was to count or respond to a target on a given ear. They found an N1 enhancement for all the probes on a given ear and no difference between targets and non-targets thus supporting the stimulus set approach while also showing that an enhancement of P300 to target stimuli was compatible with an interpretation in terms of "pigeon-holing" (Broadbent, 1971).

In previous work (Johnston, 1980) it was found that the Stroop task (Stroop, 1935) could be used to control the direction of a subjects' attention. Subjects were presented with congruent coloured colour names (e.g. RED coloured red), incongruent coloured colour names (e.g. RED coloured blue), black colour names and coloured patterns. Colours and colour names were drawn from the colour set red, green, blue and yellow. Each type of stimulus was presented equally often and the stimuli were randomised in blocks of 16 to control for differential preparation. The direction of attention was manipulated by asking subjects to respond to the colour or lexical attribute of the coloured colour names. The black colour names and the coloured patterns required no response and were used to probe the subjects attentional set.

A positive component with a latency of 85 msec (P85) evoked by black colour name stimuli embedded in the sequence of coloured colour name stimuli was enhanced when subjects had to respond to the lexical attribute of the stimuli. Similarly when subjects responded to the colour attribute of the coloured colour name stimuli the P85s evoked by the colour pattern stimuli were enhanced. This experiment was procedurely identical to the one to be described except the EEG was recorded from Pz with reference to Fz. A more standard montage was used subsequently (Oz-mastoid) in order to emphasise the P85 component.

It was considered important to test the specificity of the P85 attention effect to determine the generality of the attention mechanism which underlies it. To this end two other probes types (non-specific probes) were included in the design. These were black word probes which were not in the colour name set and colour probes which used colours not in the colour set employed in making the Stroop stimuli.

If we have a general disposition to attend to words or colours then the particular probes used will be irrelevant. We should find that any non-specific probes would produce the same results as the specific probes. However, if the attention process is highly specific only the specific probes will be influenced by attention.

2. Method

2.1. Subjects

Subjects were drawn from the general population of York and from the University. Ages ranged from 16 to 40 years. Thirty subjects were used but one subject was rejected as the P85 component could not be reliably measured.

2.2. Stimuli

Five types of stimuli were employed.

(1) Incongruously coloured colour names (e.g. "RED" coloured green). There were 256 individual stimuli of this type. The colour and colour name attributes of the Stroop stimuli were drawn from the colour set red, green, blue and yellow. Each combination was presented 20 times and the remaining 16

stimuli were taken at random with the constraint that all colours and colour names were equally represented.

(2) Specific black colour name probes (e.g. "RED" coloured black). All probe types were represented 64 times in the stimulus sequence. This stimulus type used the colour name set "RED", "GREEN", "BLUE" and "YELLOW". The form of these stimuli was identical to those described above.

(3) Non-specific black word probes (e.g. "TAX" coloured black). The stimuli were drawn from the word set "TAX". "TIMES", "HOUR" and "SOUGHT". These words were chosen to match the colour name set in terms of word lengths and frequency of occurrence in English.

(4) Specific colour probes (e.g. "RED" coloured red chopped up). Again 64 stimuli were used with equal representation of the colours red, green, blue and yellow. The stimuli were manufactured by cutting up congruent Stroop stimuli and organising the pieces into a random pattern which had no lexical content.

(5) Non-specific coloured pattern probes (e.g. "RED" coloured brown chopped up). This stimulus type was constructed by colouring the patterns used for stimulus type 4 in the colours pink, orange, brown and mauve.

Stimuli from the five sets were randomised in blocks of 16 and presented in blocks of 64. Randomisation controlled for the possibility of differential preparation (Näätänen, 1967). Thus on a given trial there was an equal probability (0.5) of a probe stimulus or a coloured colour name being presented and each of the probe types had an equal probability of occurrence (0.125).

The stimuli were back projected onto an opaque screen which had an ambient lighting of 0.3 log ft lamberts. They were surrounded by a rectangle of light 32 cm in length and 20 cm in height which had a brightness of 1.8 log ft lamberts. The duration of the stimulus presentation was 300 msecs after which the shutter on the slide projector closed and conditions returned to the situation first described. The inter-stimulus interval was 1800 msec. The colour names were 8–14 cm in length and 3 cm in height. The coloured patterns were 12–15 cm in length and 3 cm in height and the subjects' eyes were approximately 1 m from the screen. All stimuli were presented foveally.

A low level of white noise was presented to subjects by means of headphones when VEPs were being recorded. This contingency prevented subjects from hearing the relay and projection equipment in the adjacent room.

2.3. Task

The subjects had two tasks to perform, colour naming and reading. Half the subjects had to name the colour of the Stroop stimuli first and the other half read the Stroop stimuli first. They were told not to respond to the probe stimuli and indeed if a response occurred that trial was excluded from the average. The same order of stimuli was used in both tasks. The tasks were designed to direct the subjects attention to either the colour or the colour name attribute of the Stroop stimuli.

2.4. Recording

Following Van Voorhis and Hillyard (1977) the EEG was recorded from Oz with reference to linked mastoid electrodes. Silver–silver chloride cup electrodes were attached to the scalp with colodion after the scalp had been cleaned with acetone. If necessary the scalp was abraded to reduce the electrode resistance below 5 kΩ.

The EOG was recorded from above and below the eye using miniature Beckman silver–silver chloride electrodes. The amplitude of the EOG signal, when the subject blinked, was matched to the size of the eye blink artifact in the EEG by altering the gain on the pre-amplifier receiving the EOG signal. The recorded signals were amplified using a Grass a.c. pre-amplifier type 7P5 and a driver amplifier type 7DAF. The low and high frequency filters were set at 1 Hz and 500 Hz respectively. The EEG and EOG signals were recorded on FM tape by means of a Racal-Thermionic Store-4 tape recorder type D7600 for later analysis. The recorded signals were played into the input of the AD converter of a PDP-11 computer. At this stage the EOG signal was connected to one side of a differential amplifier and the EEG signal was connected to the other. By this means the eye blink artifact was subtracted from the EEG record. Having sampled the EEG the trials could be grouped and averaged, particular trials on which errors had been made could be omitted from the average at this stage. The VEP could then be displayed on a GT40 graphics terminal and the amplitude of components could be measured by setting cursors before and after the relevant component. The program then returned the peak value referred to a 50 msec pre-stimulus baseline. The cursor settings were identical for all conditions within a given task and were set within the lower and upper limits of 50 and 110 msec. There was in fact little difficulty in recognising the P85 component but two problematic records were referred to

Table 1
The amplitude of P85 (micro volts) for each combination of type of probe and response task

Specificity	Specific		Non-specific	
Response task	Reading	Colour naming	Reading	Colour naming
Probe type				
Word	2.77	2.2	2.5	2.54
Colour	2.57	2.74	2.78	2.48

the second author who was blind to the experimental conditions and who determined the cursor settings on those occasions.

2.5. Instructions

Subjects were instructed to try not to blink and to try not to tense their muscles when stimuli were being presented in order to minimise the occurrence of artifacts in the EEG. They were also asked to respond as fast as they could while minimising errors.

3. Results

The results for each condition are shown in table 1. The data were subjected to a three-way within subjects analysis of variance comparing task, probe specificity and probe type (word or colour). Only the three-way interaction was significant ($p < 0.05$). The interaction is demonstrated for one subject in fig. 1.

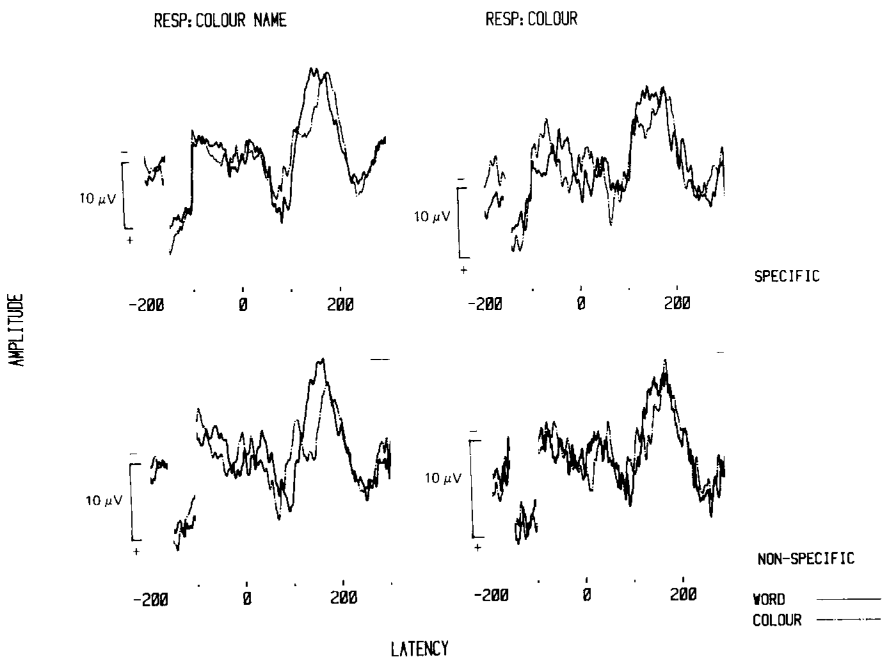

Fig. 1. Showing a 10 μV calibration pulse and VEPs to word and colour probes for specific and non-specific conditions in two response tasks; responding to colour and reading the colour names of the Stroop stimuli.

Table 2
The latency of P85 (msecs) for each combination of type of probe and response task

Specificity	Specific		Non-specific	
Response task	Reading	Colour naming	Reading	Colour naming
Probe type				
Word	84.5	86.59	83.65	85.21
Colour	84.65	84.1	84.1	83.63

We can see from table 1 that for the specific probes the P85 to word probes was larger than to colour probes when subjects were responding to the lexical attribute of the Stroop stimulus similarly, the P85 was larger to colour probes than to word probes when subjects were responding to the colour of the Stroop stimulus. To further establish that attention only affected the EP evoked by specific probes the data for specific and non-specific probes were analysed separately. There was a significant interaction ($p < 0.05$) for the specific probes but no significant effects in the analysis of the non-specific probe data.

The latency data is presented in table 2. These results were also subjected to a three-way within subjects analysis of variance by task, probe specificity and probe type. No significant effects were found.

4. Discussion

It is clear that the P85 attention effect found in this experiment is highly specific. We cannot therefore explain this result in terms of filter theory or a general mechanism like selection of analysers. We must consider that the effect derives from an interaction between stimulus material and some sophisticated internal model of the stimulus features which are relevant to the response task.

The question remains: what is the nature of the internal model? One possible explanation is that in the case of the lexical material, word recognisers or Logogens (Morton, 1970) are biased by means of the subjects' attentive control. Presumably the EP would be larger when a stimulus interacted with a biased logogen. This is the mechanism which underlies response set attention and usually thought of as a process occurring late in processing. Broadbent refers to a reduced criterion for the occurrence of a "category state", a more general statement of the above model including the possibility of a category state for colours.

These mechanisms are clearly based on ideas about semantic encoding. We would not wish to argue that the effect is due to bias in semantic encoding systems. It is quite possible that the confusion in the Stroop test arises because the colour and colour name are activating the same semantic encoders (Seymour, 1977). If this is the case semantic bias would offer no improvement in task performance.

The filter model is based on a simple sensory discrimination which influences the perceptual evidence available to a semantic encoding system and does not address itself to the effect of attention on sensory perception. It is argued that the semantic system can be biased. We can conceive of attention affecting an internal model of the physical features of a stimulus in an analogous way. This process can be thought of as setting up templates for the specific probes or in terms of an efferent process operating on a primarily afferent system. It is assumed that this highly specific selective mechanism influences processing at a later semantic stage in a similar way to filtering but the result argues against the contention that this stage of selection necessarily relies upon the discrimination of *simple* physical characteristics.

Support for this interpretation comes from an observation by Tanner and Swets (1954), that in a signal detection task where subjects had to be sure they saw a stimulus before responding "yes", the false alarm rate was correlated with the a priori probability of a stimulus being present. The false alarms were based on phenomenal seeing and thus the observation provides further evidence that bias in sensory encoding systems does occur.

The experiment shows that even at short latencies the effects of attention can be highly specific. This result using visual stimuli points to a need for a more extensive examination of the generality of the mechanism giving rise to sustained potential changes in the auditory modality before the filter model can be accepted for auditory phenomenon.

One further point can be made. It is generally assumed that the Stroop test is an example of a breakdown in selective attention as the lexical attribute interferes with naming the colour. We accept that selective attention is not absolute and that interference will occur but we argue that it is precisely in a task of this nature in which interference occurs at semantic and response levels that one would expect subjects to mobilise any faculty for enhancing sensory and perceptual processing of a relevant stimulus characteristic.

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