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Effect of probe stimulus intensity on the dissociation between autonomic orienting
and secondary probe reaction time

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Abstract

Information processing accounts propose that autonomic orienting reflects the amount of resources allocated to process a stimulus. However, secondary task reaction time (RT), a supposed measure of processing resources, has shown a dissociation from autonomic orienting. The present study tested the hypothesis that secondary task RT reflects a serial processing mechanism. Participants ($N = 24$) were presented with circle and ellipse shapes and asked to count the number of longer-than-usual presentations of one shape (task-relevant) and to ignore presentations of a second shape (task-irrelevant). Concurrent with the counting task, participants performed a secondary RT task to an auditory probe presented at either a high or low intensity and at two different probe positions following shape onset (50 and 300-ms). Electrodermal orienting was larger during task-relevant shapes than during task irrelevant shapes, but secondary task RT to the high intensity probe was slower during the latter. In addition, an underadditive interaction between probe stimulus intensity and probe position was found in secondary RT. The findings are consistent with a serial processing model of secondary RT and suggest that the notion of processing stages should be incorporated into current information processing models of autonomic orienting.

An orienting response, as reflected by changes in autonomic nervous system activity, is observed following the presentation of novel or significant stimuli.

Autonomic orienting is said to reflect the allocation of processing resources from a limited resource capacity (Kahneman, 1973; Öhman, 1979, 1992). Resources are allocated for the processes of stimulus identification in the case of novel stimuli or for the selection and initiation of responses in the case of significant stimuli. To test resource models, processing resources allocated during orienting stimuli may be assessed by monitoring performance decrements on a concurrently performed reaction time (RT) task (Siddle & Spinks, 1992). Several studies have shown that autonomic orienting responses are associated with a slowing of secondary RT during both novel and significant stimuli (e.g., Siddle, Jordan, & Lipp, 1993; Siddle & Spinks, 1992) apparently confirming resource allocation models of orienting.

However, a dissociation between autonomic orienting and secondary task RT was found in an experiment reported by Dawson et al. (1989). Participants were required to count the number of longer-than-usual tones (7 s vs. 5 s) presented to one ear (task-relevant) and to ignore all tones presented to the other ear (task-irrelevant). Concurrently with the tone judgement task, participants made a speeded response to a visual RT probe stimulus. Autonomic orienting, as assessed by skin conductance activity, was larger during task-relevant tones than during task-irrelevant tones. Secondary task RT to probes presented at 150-ms following tone onset, however, was slower during task-irrelevant tones than during task-relevant tones. The latter result was surprising because it suggested that more resources were allocated early during task-irrelevant tones without a corresponding increase in autonomic orienting.

The limits and generality of the dissociation between autonomic orienting and secondary RT has been examined in research following Dawson et al. (1989). The dissociation effect is not specific to the counting task used by Dawson et al. (1989) because it has been found during a differential Pavlovian conditioning procedure (Siddle, Lipp & Dall, 1996) and when visual orienting stimuli are used (Neumann, Lipp, & Siddle, 1998). The dissociation, however, is specific to the probe positions used in an experiment in that it is limited to probe positions of 300-ms or earlier (Filion et al., 1991; Neumann et al., 1998). Probe positions 600-ms or later tend to yield slower secondary RT during task-relevant stimuli (e.g., Dawson et al., 1989; Neumann et al., 1998). The time course is important because it highlights that the dissociation effect may be related to the differing temporal resolutions of the autonomic and reaction time measures. Depending on the probe position used, secondary RT may be influenced by mental operations that precede or follow the allocation of processing resources during an orienting stimulus. The more sluggish autonomic orienting responses, by contrast, may be sensitive only to the resource allocation.

In a series of parametric studies, Neumann et al. (1998) investigated the time course of secondary task RT. If the increased slowing of secondary RT during task-irrelevant stimuli reflects a transient inhibitory process or an attentional switch process (Filion et al., 1991) during this stimulus only, it was expected that the time course would be different for the task-relevant and task-irrelevant stimuli. Instead, Neumann et al. (1998) found a downward trend in secondary RT that was *parallel* for both stimulus types. Moreover, the downward nature of the trend suggested that the slowing of secondary RT was greater the earlier the probe was presented. This

trend was interpreted as reflecting the serial processing of a specific cognitive operation (i.e., processing bottleneck). The stages of stimulus processing may be broadly divided up into stimulus encoding, decisional and response selection (including stimulus identification/perceptual decision), and response execution (McCann & Johnston, 1992). Research using the psychological refractory period paradigm suggests that the processing bottleneck lies in the decisional and response selection stage (Pashler, 1998). It may be hypothesised that the slowing of secondary RT at early probe positions rather than reflecting resource allocation during the orienting stimuli, reflects the serial processing of a decisional and response selection stage.

A serial processing model permits distinctive predictions to be made when experimental manipulations affect the duration of processing stages during the orienting and secondary probe stimuli. The most interesting follows from when the duration of the encoding stage for the RT probe stimulus is increased (e.g., if the RT probe is presented at a lower intensity; Niemi, 1979). As illustrated in Figure 1, the lengthening of the encoding of the RT probe has little effect on secondary RT at a relatively early probe position (e.g., 50-ms). The extra time for encoding the low intensity RT probe is absorbed into the slack time for which the RT probe normally waits until the decisional and response selection stage becomes available (as in the case of the high intensity probes). At relatively late probe positions (e.g., 300-ms), however, the slowing of the encoding of the RT probe will lengthen RT since encoding is more likely to be finished after the decisional and response selection bottleneck has been made available. The result will thus be an underadditive interaction between probe intensity and probe position; the difference in RT between

the earlier and later probe position will be greater for the high intensity probe than for the low intensity probes.

 Insert Figure 1 about here

The present experiment aimed to test the hypothesis that the slowing of secondary task RT at early probe positions (<300-ms) during the discrimination and counting task is due to a serial processing mechanism. A task similar to that used by Dawson et al. (1989) was employed, but slides of shapes were used as the task-relevant and task-irrelevant stimuli. Skin conductance responding was measured to confirm that task-relevant stimuli elicited larger orienting responses than task-irrelevant stimuli. The RT probe was a tone stimulus set at two intensity levels and presented at 50 and 300-ms following shape onset. It was hypothesised that the dissociation effect would be observed for both probe stimulus intensities.

Furthermore, it was predicted that there would be an underadditive interaction for both orienting stimuli as shown by a greater slowing at the 50-ms probe position than at the 300-ms probe position for the high intensity probe than for the low intensity probe. In contrast, the underadditive interaction for both stimuli is not predicted by the notion that the slowing of secondary RT reflects a transient inhibitory process or an attentional switch (Filion et al., 1991) during the processing of task-irrelevant stimuli only.

Method

Participants

Nineteen males and 8 females aged between 17 to 31 years ($M = 19.21$ years, $SD = 3.42$ years) participated. The data from three males were rejected; two because of excessive nonresponsiveness in skin conductance responding and one because unusually slow RTs resulted in excessive missing RT data.

Apparatus

Changes in skin conductance and respiration were recorded on paper (speed of 2.5 mm/s) using a Grass Model 7D Polygraph. Skin conductance was measured with a standard 0.5 V circuit through two 5 mm diameter Ag/AgCl electrodes filled with a .05 M NaCl electrolyte. The electrodes were attached to the distal phalanges of the first and second fingers of the participants' non-preferred hand. Respiration was measured using a Grass Model PRT pneumatic respiration transducer together with a Phipps and Bird Model RPBA chest pneumograph. Skin conductance and respiration signals were amplified with Grass 7P1 DC preamplifiers. The sensitivity of the skin conductance signal was set at .05 μ S/mm pen deflection. Reaction time was recorded by way of a hand held microswitch that was operated with the thumb of the participants' preferred hand. An IBM-compatible computer recorded reaction time. The computer also controlled stimulus duration and sequencing throughout the experiment.

The shapes which served as the orienting stimuli were back projected onto a projection area by a Leitz Pradovit 153 slide projector fitted with a Gerbrand Model G1166CS tachistoscopic shutter. The projection area was set into the wall of the experimental chamber at eye level, 1.5 m from the participant. The shapes were outlines of a circle and an ellipse (horizontal to vertical axis ratio of 20:24). The shapes were no more than 10 cm in width and height when projected. Tones, which

served as the RT probe stimuli, were generated by a custom-built tone generator and presented through Telephonics TDH49 stereophonic headphones. The tones were presented at a frequency of 1000 Hz and 500-ms duration at either a high intensity (83 dBA) or a low intensity (46 dBA). Tone intensity was calibrated with a Bruel and Kjaer Type 2603 audiometer.

Procedure

The experiment was conducted in two rooms, one of which housed the equipment and apparatus. The average temperature, humidity, and pressure in the adjoining participant room were 19.9 °C, 76.2%, and 1018 hPa respectively. The experiment began with a 3-min rest period during after which practice trials for the secondary RT task were presented. Participants were instructed to operate the microswitch quickly whenever a tone was heard. Thirty tones were presented (15 high intensity and 15 low intensity) in random order and separated by an intertrial interval that varied among 7, 10, and 13 s with a mean of 10 s.

After the practice trials, participants were told that a series of two shapes would be presented. They were instructed to count the number of longer-than-usual presentations of one shape (task-relevant) and to ignore presentations of the other shape (task-irrelevant). The nature of the task-relevant shape (circle/ellipse) was counterbalanced between participants. Participants were further instructed that they would initially be shown the two shapes to become familiar with them. Each shape was presented for 5 s and separated by a 20 s intertrial interval. The shape presented first was counterbalanced between participants.

Following pre-exposure, participants were instructed to perform the RT task along with the counting task. Emphasis was placed on the performance of the

counting task. The participants were told that if they correctly counted the number of longer-than-usual presentations they would receive AUS\$5, if they were wrong by one AUS\$4 and so on. The participants were presented with 48 shapes arranged into two blocks of 24. Each block consisted of 12 presentations of the circle and 12 presentations of the ellipse. Within each block, the shapes were presented in a random sequence with the restriction that the same shape was not presented more than twice in succession. The nature of the first shape was counterbalanced between participants. Seventy-five percent of the presentations of each shape (18 stimuli) lasted for 5 s whereas the remaining twenty-five percent (6 stimuli) lasted for 7 s. Longer-than-usual presentations were distributed randomly across trials with the restriction that half the 7 s presentations of each shape occurred in each block. Shape presentations were separated by intertrial intervals that varied among 25, 30, and 35 s with a mean of 30 s.

Forty-eight RT probes were presented. Of the 48 probes, 24 were presented during the intertrial intervals (12 in each block). Intertrial interval RT probes did not occur within 10 s before onset or 10 s after offset of a shape. During the intervals, there were 12 presentations of the high intensity tone and 12 presentations of the low intensity tone. The remaining 24 probes were presented during the shapes. Within each block, six probes were presented during the circle and six during the ellipse. For each shape, three high intensity and three low intensity tone presentations were made each at the probe positions of 50 and 300-ms following shape onset. Order of probe position was randomised with the restriction that the first presentation of each shape in each block contained no probe. No more than two presentations of the same probe position and tone intensity combination during the same stimulus type

were made in succession. Three different stimulus sequences that counterbalanced the sequence of probe positions between participants were used. At completion of the experiment, participants were asked to report the number of task-relevant shapes counted as longer-than-usual.

Response measurement and analysis

Skin conductance response amplitude during unprobed shape presentations was scored on paper using a latency window of 1 to 4 s after orienting stimulus onset. Amplitude was measured as the distance between trough and apex of the response. The minimum response amplitude criterion was set at 0.05 μ S. The larger response was measured if two responses occurred within the latency window. Skin conductance amplitudes were converted to microsiemens before data treatment. Skin conductance responses associated with deep breaths or sneezing, as indicated by visual inspection of the respiration trace, were scored as missing values. Skin conductance response amplitudes were subjected to a square root transformation to normalise the distributions. The distributions of RTs were positively skewed and contained outliers. Because there was little variation between each participant's RT, the outliers were eliminated and the distributions were made less skewed by the rejection of RTs faster than 100 ms and slower than 1000 ms. Overall, 3.69% of the RT data was eliminated. A two-tailed significance level of .05 was set for all analyses.

Results

Eight participants correctly reported the number of longer-than-usual task relevant stimuli (i.e., gave an answer of six). The mean number reported was 7.83 (range = 3 to 24, $SD = 4.36$) and indicated that participants tended to overestimate

the number. Skin conductance responses elicited during the orienting stimuli were divided into two blocks and analysed with a 2 x 2 (Stimulus x Block) ANOVA.

Figure 2 shows the mean skin conductance magnitude for the task-relevant and task-irrelevant stimuli across the two trial blocks. As can be seen, larger responses were elicited during task-relevant stimuli than during task-irrelevant stimuli (Main effect Stimulus $F(1,23) = 23.52$, $MSE = .01$). Responses also declined over blocks (Main effect Block $F(1,23) = 34.99$, $MSE = .01$). The Stimulus x Block interaction was not significant ($F = 0.78$).

 Insert Figure 2 about here

Secondary RTs during the intertrial intervals were divided up into two blocks of 6 trials each for the high and low intensity probes. The data was analysed with a 2 x 2 (Probe intensity x Block) ANOVA. Secondary RT to the low intensity probe in Block 1 ($M = 522.21$ ms; $SD = 91.26$) and Block 2 ($M = 539.02$ ms; $SD = 102.55$) was slower than to the high intensity probe in Block 1 ($M = 430.95$ ms; $SD = 59.3$) and Block 2 ($M = 437.31$ ms; $SD = 79.98$), as confirmed by a Main effect for Probe intensity ($F(1,23) = 44.39$, $MSE = 5032$). The difference between the intensity conditions was as large as 102 ms (Block 2). No other main effects or interactions were found (all $F_s < 1.56$).

 Insert Figure 3 about here

Secondary RT to probes presented during the orienting stimuli were analysed with a 2 x 2 x 2 (Stimulus x Probe position x Probe intensity) ANCOVA. The participants' RT during the intertrial intervals was entered in as the covariate for each probe intensity level to account for individual differences in mean RT. Figure 3 shows the mean secondary RT at each probe position and stimulus type for the high and low intensity probes. The pattern of results was the same for task-relevant and task-irrelevant stimuli: a downward trend in secondary RT across the probe positions was found when the probe intensity was high. The slowing of secondary RT across probe positions persisted, however, when the probe intensity was low. The underadditive interaction predicted by a serial processing model was confirmed by a Probe position x Probe intensity interaction ($F(1,23) = 5.57$, $MSE = 10008$). Multiple comparisons between pairs of variables were examined by *t*-tests employing critical *t*-values based on Sidak's multiplicative inequality (Rohlf & Sokal, 1981). Comparisons showed that there was more slowing at the 50-ms probe positions than at the 300-ms probe position when the probe intensity was high ($t(23) = 2.94$), but not when the probe intensity was low ($t < 1$). Secondary RT during the different stimuli differed as a function of probe intensity (Stimulus x Probe intensity interaction $F(1,23) = 4.48$, $MSE = 7261$). Comparisons showed that secondary RT was slower during task-irrelevant stimuli than during task-relevant stimuli when the probe intensity was high ($t(23) = 2.64$), but not when the probe intensity was low ($t < 1$). Thus, the dissociation effect was found only with the high probe intensity. No other main effects of interactions were found (all $F_s < 2.69$).

Discussion

The results of the present experiment showed that autonomic orienting was larger during task-relevant stimuli than during task-irrelevant stimuli. The dissociation effect (i.e., greater slowing of secondary task RT during task-irrelevant stimuli than during task-relevant stimuli) was also found, although this was limited to RT probes presented at the higher intensity. Additional findings with secondary RT were consistent with the notion that there is serial processing of a decisional and response selection stage during the processing of the orienting and RT probe stimuli. Consistent with this hypothesis, the differences between the early (50-ms) and the late (300-ms) probe positions were larger for the high intensity probe than for the low intensity probe. Moreover, this interaction was observed during both the task-relevant and task-irrelevant stimuli, suggesting that a similar processes underlies the slowing of secondary RT in both stimuli. The underadditive interaction found in this experiment and the parallel time course observed in parametric studies (Neumann et al., 1998) are inconsistent with the notion that different processes underlie the slowing of secondary RT in task-relevant and task-irrelevant stimuli (e.g., an attentional switch during task-irrelevant stimuli; Fillion et al., 1991).

The dissociation effect was found only when the high probe intensity was used. At the low probe intensity, there was no difference in secondary RT between the task-relevant and task-irrelevant stimuli. The failure to observe slower secondary RT during task-irrelevant stimuli may be due to the extensive amount of RT slowing caused by the low intensity probe. The reduction in the probe intensity may have lengthened the encoding/perceptual identification stage to such a degree that it extended beyond the time at which the serial processing mechanism occupied by at least one of the orienting stimulus types was available. This occurred at both

the 50 and 300-ms probe positions and resulted in no difference in secondary RT between the stimulus types. The high intensity probe had a shorter encoding/perceptual identification stage than the low intensity probe (Niemi, 1979). This stage was more likely to be finished before the serial processing stage during both the orienting stimuli had completed. The serial processing stage could thus modulate the slowing of secondary RT during the task-relevant and task-irrelevant stimuli and yield the dissociation effect.

The serial processing model confirmed in the present experiment offers an explanation of the dissociation effect. The increased slowing of secondary RT during task-irrelevant stimuli may reflect a difference in the duration of a processing stage between the task-relevant and task-irrelevant stimuli. Specifically, there may be a difference in the duration of a processing stage up to and/or including the response selection stage. The difference may be related to the process of stimulus identification. The task requirements may prime participants to identify the orienting stimuli on the basis of a decision on whether it is the same as or different from the task-relevant stimulus (Filion et al., 1991). Individuals tend to be faster in identifying simple categorical shapes that are the same as a target rather than different (the fast “same” effect; Farell, 1985). Thus, the encoding/perceptual identification stage is longer during task-irrelevant stimuli than during task-relevant stimuli. The delay caused by the unavailability of the bottleneck stage for processing the RT probe stimulus will be greater for task-irrelevant stimuli. Consequently, secondary RT is slower during task-irrelevant stimuli than during task-relevant stimuli, and the dissociation effect is observed.

The present findings suggest that secondary RT to probes presented early during a stimulus does not reflect the resources associated with a task (see also Damos, 1991; Navon & Gopher, 1979; Pashler & Johnston, 1998). Secondary RT presented very soon following the onset of a stimulus (<300-ms) appears more sensitive to structural interference (i.e., processing bottlenecks), whereas secondary RT presented later following the onset of a stimulus (>2000-ms) may be more sensitive to strategic interference (i.e., processing resources). Future research on orienting may benefit from using at least two secondary tasks chosen in such a way that they are unlikely to result in the same type of structural interference. For instance, secondary RT causes conflict between immediately successive responses, but imposes no load on memory. A perceptual subsidiary task has reduced overt responses, but will usually have an increased load on memory (Kahneman, 1973). These two combinations of secondary tasks may thus avoid the same types of structural interference that may be present in some punctuate orienting tasks.

Sokolov (1963) asserted that the orienting response reflects the enhancement of information processing in humans. The notion that this enhancement occurs through the allocation of processing resources is not undermined by the dissociation effect. The present explanation of the dissociation effect, however, has highlighted the role of processing stages in the flow of information processing that lead to the orienting response. Kahneman's (1973) model of the orienting response does not include the notion of processing stages. Öhman (1979, 1992) explicitly addressed instances when several stimuli are encountered and the possibility that priority rules (e.g., task instructions) may determine the order in which stimuli are processed. The present findings extend this notion by suggesting that the selection of voluntary

responses occurs in a strict serial manner, in order of priority. Following the serial processing stage, resources are allocated to initiate and execute the appropriate response to the stimulus and an orienting response is elicited. Under the present conceptualisation, autonomic orienting is closely associated with resource allocation during the initiation and execution of responses to significant stimuli.

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Figure Captions

Figure 1. The effect that lengthening the encoding stage in processing the reaction time (RT) probe stimulus has on total secondary RT at early (e.g., 50-ms) and late (e.g., 300-ms) probe positions. The difference in RT between the early and late probe positions (as indicated by the length of the arrow) will be larger when the encoding stage is short than when it is long. A = encoding/perceptual identification; B = decisional and response selection; C = response initiation and execution.

Figure 2. Mean skin conductance magnitude in each trial block for the task-relevant stimuli and task-irrelevant stimuli. Vertical lines depict standard errors of the means.

Figure 3. Mean secondary task reaction time to the high and low intensity probes as a function of probe position for the task-relevant stimuli and task-irrelevant stimuli. Vertical lines depict standard errors of the means.