

Does Time Pressure Induce Tunnel Vision? An Examination with the Eriksen Flanker Task.

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Abstract

Stress is often assumed to induce tunnel vision. An effective way to induce stress in experimental settings is by imposing strict response deadlines. In this research the Eriksen flanker task was used to examine if time pressure induces tunnel vision. The effect of peripheral flanker stimuli on both response speed and accuracy was compared between low and high time pressure conditions. We fitted the parameters of the Wiener diffusion model to the data in order to gain insight into the properties of the underlying decision process. The results of our experiments showed an increased effect of peripheral flanker stimuli under high time pressure, a pattern opposite of what is to be expected if tunnel vision is induced.

Keywords: time pressure, attention, information processing, tunnel vision, Eriksen flanker task, Wiener diffusion model

Does Time Pressure Induce Tunnel Vision? An examination with the Eriksen Flanker Task.

Imagine you are driving your car in the city when suddenly the car in front of you hits the breaks. You have to react to this unexpected event and better do it quickly. Your heart rate increases, you clench the steering wheel and your eyes widen while your foot releases the gas pedal and hits the brake pedal. The only thing you see is the car in front of you and its brake lights. Thanks to the physical reactions of your body to the sudden danger and your focused attention a crash is averted and the stream of cars begins to pick up speed again. Then suddenly another car crashes into the right side of your car. As you calm down and realize what just happened, you wonder how you could have ever missed that red traffic light.

In a stressful situation such as described in the example above, a phenomenon called tunnel vision seems to occur. Information from the attended part of the visual field is still fully processed, but visual clues from other parts of the visual field that would otherwise be noticed remain completely unnoticed. This exclusive type of visual attention as a result of stress is often taken as a fact in applied settings, but the evidence from research is not that conclusive. The aim of the current research is to answer the question whether or not time pressure induces tunnel vision.

Behavioral studies have reported some support for tunnel vision as a result of different stressors. For example, Bursill (1958) found reduced performance on a secondary, peripheral signal detection task in hot and humid conditions. The results of an experiment using an evaluative observer to induce stress, only partially confirmed hypotheses that time pressure induces tunnel vision (Dirkin, 1983). In Dirkin's experiment, subjects had to identify the number of illuminated lights on any of three display panels, with one panel placed centrally before the participant and the other two panels placed at an angle of 70° to the left and right of the subject's median, in the periphery of the visual field. The identification of the lights on the

peripheral panels constituted the primary task, and identification of the lights on the central panel was the secondary task. Under stress, the performance on the primary task improved, however, the hypothesized decrease in performance on the secondary task was not found.

Results from more fundamentally based studies, using time pressure as stressor, do not match well with the hypothesis of tunnel vision as a result of stress. Osman et al. (2000) used event-related EEG potentials (ERPs) to examine the mechanisms underlying speed-accuracy trade-offs (SATs). Participants in their study performed a choice-RT task known as the Eriksen flanker task (Eriksen and Eriksen, 1974). In this task, participants respond to the identity of a target stimulus as fast and as accurately as possible. The target is accompanied by irrelevant flanker stimuli. In the congruent condition, these flankers correspond to the same response as the target. In incongruent trials, the flankers correspond to the opposite response. Participants are typically faster and more accurate on congruent trials than on incongruent trials, indicating an inability to completely ignore the flankers. In the study of Osman et al. task instructions varied between blocks, emphasizing either speed or accuracy. Instructions emphasizing speed resulted in an earlier onset of the response-locked lateralized readiness potential (r-LRP), but did not affect the onset latency of the stimulus-locked version of this potential (s-LRP), indicating that speed-accuracy instructions only affected the portion of reaction time (RT) following the start of motor preparation. Osman et al. also measured the P300 ERP component, assumed to be primarily affected by early stages such as stimulus evaluation. The peak latency of the P300 potential was affected by target-flanker congruency, with an earlier peak on congruent than incongruent trials. The speed-accuracy instructions did not affect the latency of this peak, adding support to the conclusion that only late processes are affected by speed-accuracy instructions.

Van der Lubbe, Jaśkowski, Wauschkuhn and Verleger (2001) examined the influence

of time pressure in a simple response task, a choice-by-location task and the Simon task by varying response deadlines. In both the choice-by-location task and the Simon task, they found similar effects of time pressure as Osman et al (2000). did with the Eriksen task. The level of time pressure did not have a significant effect on s-LRP but did affect the r-LRP. Another lateralized EEG potential called the PCN was used to provide more information about the influence of time pressure on earlier nonmotor processes. The onset of this PCN is used as an index for the start of discriminative processing of the relevant aspect of the stimuli. A change in onset or peak latency of this potential caused by different levels of time pressure would indicate that attentional orienting was affected. No such effect of time pressure on PCN latency was found in either the choice-by-location task or the Simon task. This finding contributes more evidence to the position that time pressure does not affect early attentional processes, but only later motor processes. Unlike the Eriksen flanker task, the choice-by-location task and the Simon task are not suited for studying a phenomenon like tunnel vision, because the successful execution of the task does not depend on the focussing of attention to the targets location and ignoring information from other locations.

There appears to be a discrepancy between the results of these EEG studies and the long held assumption based on earlier behavior studies that stress causes tunnel vision. In an attempt to bridge the gap between studies using behavioral measures and studies using physiological measures, we chose to measure overt behavioral measures (speed and accuracy), and relate them to properties of a model of underlying neurological processes. More specifically, we used both speed and accuracy information to investigate the properties of the response selection process. In our study, participants perform the Eriksen flanker task under low and high time pressure. Response time and accuracy information from both time pressure conditions are used to estimate properties of the response selection process using a

hierarchical version of the Wiener Diffusion Model (WDM).

Eriksen Flanker Task

In the current study we used an arrowhead version of the Eriksen flanker task. The overlap in direction between stimuli and response results in a strong stimulus-response mapping, which increases the response conflict (Kornblum, Hasbroucq, and Osman, 1990). In this task, participants are instructed to respond as fast and as accurately as possible by pushing a button with their left index finger if the centrally presented target arrowhead points to the left, and with their right index finger if the target points to the right. The target arrowhead is flanked by two distractor arrowheads on both sides that can either point in the same direction as the target (congruent condition), or in the opposite direction (incongruent condition). In the neutral condition, the flanker stimuli are not arrowheads, but two parallel horizontal lines. Incongruent flankers are found to reduce the speed and accuracy of the responses, despite clear instructions informing the participant to attend only to the identity of the central target stimuli. Eriksen and Eriksen (1974) interpreted this as an inability to completely ignore the irrelevant flankers. This congruency effect makes the task specifically well suited to test for the occurrence of tunnel vision. Tunnel vision should diminish the processing of the flanker stimuli and reduce the congruency effect.

The congruency effect can be manifested in both speed and accuracy. This poses a challenge in interpreting RT and proportion correct (PC) because of the speed-accuracy trade-off. Participants can choose to respond faster in a certain condition, at the expense of accuracy (Pachella & Pew, 1968; Wickelgren, 1977). This makes it difficult to compare the performance between conditions resulting in a different speed-accuracy criterion if speed and accuracy change in opposite directions. If a manipulation results in a great increase in speed,

but simultaneously in a small decrease in accuracy, the question may be raised whether the manipulation made the task more or less difficult, as speed and accuracy cannot be translated into each other. This makes it problematic to determine if the increase in speed can be completely accounted for by the decrease in accuracy, or that an increase in speed remains after accounting for SAT, which would indicate a decrease in task difficulty.

In order to be able to compare performance between two conditions when a SAT is present, we need a single measure of performance. Here the Wiener diffusion model was chosen to estimate the effects of time pressure on different properties of the underlying decision process.

Wiener Diffusion Model

The Wiener Diffusion Model is a sequential sampling model. It assumes that evidence towards a response is accumulated over time from a noisy input signal (Ratcliff, 1978). When enough evidence for a specific response is accumulated, that response is executed. Figure 1 shows a graphical representation of the process and its parameters. Evidence is accumulated with an average rate δ , called drift rate. The amount of evidence needed for a response is indicated by the boundary separation α . The initial starting point of the process is determined by β as a proportion of α . In the current study, it is set at 0.5 (no bias), as the top boundary always represents the correct response, and the bottom boundary the incorrect response. Before the start of a trial, there is no possibility to bias towards a correct or incorrect response. Such a bias can be possible if, for example, one response is correct more frequently than the other. The parameter τ represents the non-decision time, that is, all time used for everything except the decision process, such as physically executing the response.

Our main interest is in the boundary separation and drift rate. A larger boundary

separation will result in slower but more accurate responses. This means that a change in α only can explain the SAT phenomenon. We expect that in the high time pressure condition, the size of the boundary separation is reduced, enabling the participant to respond more quickly, but at the expense of accuracy. The value of the drift rate parameter δ represents the average rate of evidence accumulation. Here evidence is information about which response must be made. It is closely related to the difficulty of response selection in a particular condition. In congruent trials all stimuli can contribute evidence towards the correct response. In neutral trials, evidence can be sampled from the target, while the flanker stimuli only provide noise. In incongruent trials, sampling information from the flanker stimuli deducts the amount of accumulated evidence. Therefore, we expect the drift rate to be largest in congruent trials, medium in neutral trials, and smallest in incongruent trials. If flanker stimuli are completely ignored, evidence will accumulate at the same rate in each congruency condition, as the target always conveys the same amount of information about the correct response. If flankers are partially processed, this should increase the rate of evidence accumulation in congruent trials, but decrease the rate in incongruent trials. The difference in drift rate between congruent and incongruent trials thus represents a congruency effect that informs us about the influence of flanker stimuli in a similar way as the congruency effects found in reaction time and accuracy, but in a single measure. To investigate the phenomenon of tunnel vision under time pressure, we manipulated time pressure in a series of three experiments to see how this affected the influence of the flanker stimuli on performance.

General Method

Overview and Apparatus

Three experiments were performed using the same general method. In all three experiments, participants were seated in front of a 17" color CRT monitor at approximately 0.8 meter viewing distance. Responses were given by pressing the left or right control (ctrl) key on a standard qwerty keyboard with the corresponding index finger. The Presentation software package was used for the presentation of instructions, stimuli and feedback and for response recording.

Stimuli and Procedure

Trial structure.

A red rectangle ($10^\circ \times 1^\circ$) containing a white fixation cross ($0.7^\circ \times 0.7^\circ$) was presented on a black background in the center of the screen at trial onset. After 750ms the fixation cross was replaced by the target arrowhead pointing to the left or to the right. Four flankers were presented simultaneously, two on each side. The four flankers were identical within each trial and were either arrowheads pointing in the same direction as the target (congruent condition), arrowheads pointing in the opposite direction (incongruent condition), or equal signs (neutral condition).

Stimuli and flankers were all 0.7° wide. Immediately following stimulus presentation the color of the rectangle started to gradually fade from red to black, indicating the available time to respond. Feedback was provided immediately after a response or missed deadline. The feedback consisted of a short text, „Correct”, „Incorrect” or „Too late” (in Dutch). See Figure

2 for an overview of the screens in a single trial. For incorrect and late responses, the text was accompanied by a loud 'buzzer' sound. The duration of feedback presentation was dependent on the duration of stimulus presentation, so that the duration of the complete trial was kept constant at 2500ms.

Time pressure manipulation.

In the low time pressure condition, the response deadline was set at 800ms after stimulus onset, at which point the red background rectangle had completely turned black. In the high time pressure condition the deadline, and thus the speed at which the rectangle turned black, varied based on previous results in order to keep pressure on a relatively high level. At the start of a high time pressure block, the deadline was set at 450ms. After two consecutive correct and fast-enough trials, the available time was reduced. After every incorrect or too slow response, the available time was increased. The initial step size for adjusting the deadline was 60ms. After the first change in adjustment direction, the step size was reduced to 15ms.

Procedure.

A session began with a short oral introduction by the experimenter, followed by written instructions presented on the monitor. One very slow practice trial (2000ms deadline) was then presented. Next, a short instruction announced a practice block of ten trials, indicating that responses must be made faster compared to the first trial as evident in the faster color fading of the rectangle. After the practice block, the participant was asked, both on screen and verbal, if the task was clear. When the participant was ready, the experimenter left, and the participant began with the first experimental block.

The session consisted of eight blocks, with a mandatory five minute break between the fourth and fifth block. Low and high time pressure blocks alternated, starting with a low time

pressure block. Before each block, a short instruction was presented on the screen. The instructions preceding a low time pressure block stated that the response deadline was constant throughout the block. The instructions preceding a high time pressure block stated that the response deadline varied per trial.

A block consisted of 44 congruent trials, 44 incongruent trials and 22 neutral trials, with an equal number of left and right targets in each condition, resulting in a total of 110 trials per block. The trials within a block were presented in random order, with the restriction that the same stimulus array was not repeated in more than three consecutive trials.

Data Analysis

The first ten trials of each block were regarded as practice trials, to enable the subject to adjust to the time pressure level of the block. Responses with the incorrect hand, premature responses ($RT < 150$) and too slow responses ($RT > 800$) were defined as errors. Note that responses made with the correct hand after the deadline but before 800ms in the high time pressure condition resulted in negative feedback („too slow”) but are not included in this definition of errors.

Reaction times and Proportion of correct responses.

The mean RT of correct responses was calculated for each participant in each of the experimental conditions. Mean RTs were submitted to an analysis of variance (ANOVA) for repeated measures with Greenhouse-Geisser ϵ correction for the degrees of freedom. Significant effects were further examined using t-tests.

The mean PC was calculated for each participant in each of the experimental conditions and analyses using an ANOVA for repeated measures with Greenhouse-Geisser ϵ correction for the degrees of freedom and t-tests.

Hierarchical Diffusion Model

We used a hierarchical version of the diffusion model developed by Vandekerckhove, Tuerlinckx and Lee (2011) called the Hierarchical Diffusion Model (HDM). The HDM allowed us to include all observed data (responses and reaction times) from all conditions and all participants in one analysis. In the HDM, effects are allowed to vary over participants and conditions, enabling the analysis of multiple effects in one simulation. Using the same notation as Vandekerckhove et al. (2011) we used indices to indicate the levels of differentiation and defined the Wiener distribution as follows:

$$Y_{(phij)} \sim \text{Wiener}(\alpha_{(ph)}, \beta, \tau_{(phij)}, \delta_{(phij)})$$

The index p represents a participant, h represents pressure condition, i represents a congruency condition, and j represents a trial. The indices serve to indicate that the value of the boundary α can vary across persons and across time pressure conditions, the value of β is invariant, and τ and δ can differ across participants, time pressure conditions and trials. At the second level, for each time pressure condition, the boundary separation parameters $\alpha_{(ph)}$ are assumed to be normally distributed with an interparticipant mean and variance. The non-decision time parameter $\tau_{(phij)}$ is assumed to be normally distributed with a participant specific mean ($\theta_{(p)}$) and standard deviation ($\chi_{(p)}$) as seen in $\tau_{(phij)} \sim N(\theta_{(p)}, \chi_{(p)})$. This mean and standard deviation are in turn sampled from two population distributions: $\theta_{(p)} \sim N(\mu_{\theta}, \sigma_{\theta})$ and $\chi_{(p)} \sim N(\mu_{\chi}, \sigma_{\chi})$. We allow the drift rate parameter δ to differ for each trial, and assume it is normally distributed with an intertrial mean $\delta_{(phij)} \sim N(v_{(phi)}, \eta_{(p)})$. We further assume that this participant-specific mean v is distributed according to interparticipant normal distributions that differ across time pressure condition and experimental condition according to $v_{(phi)} \sim N(\mu_{v(hi)}, \sigma_{v(hi)})$. The standard deviation of δ differs across participants, and is also distributed according to a population distribution, as seen in $\eta_{(p)} \sim N(\mu, \sigma_{\eta})$. A graphical representation of this model and

the assumptions of the modal are depicted in Figure 3.

In this model the indices of α are p and h , meaning a value of α was estimated for both time pressure conditions for each individual participant. The indices of drift rate include not only p and h , but also i and j , indicating a value for δ is estimated for every individual trial. Since we do not focus on individual trials, but on the general effects of time pressure and congruency, we use its intertrial mean $v_{(phi)}$ in our analysis of drift rate.

Response data from the experiment were transformed in preparation of model parameter fitting. Most notably, RTs for both correct and incorrect responses were included, with RTs for incorrect responses negated to differentiate them from correct responses.

The model definition and prepared data are used as input for a model parameter fitting process using software developed by Vandekerckhove et al.(2011). This software uses Bayesian statistical methods to estimate parameter values. Two separate simulations, called chains, using the same model and the same data, but different starting values for all parameters, were run for 10,000 iterations. After this initial part of the simulation, convergence of both chains is checked using visual inspection and the Gelman Rubin statistic for all parameters of interest. Convergence is reached if the original starting values of the estimated parameters have no influence on the current estimates. This was evaluated by comparing the values of the chains with different starting values. When we were satisfied that convergence has been met, another 30,000 iterations were run to create the posterior distribution. The result of the analysis are the posterior probability distributions of the parameters, which describes the estimated value and confidence interval after having observed the data.

The estimated mean parameter values for boundary separation α , and information evidence accumulation rate v (the across-trial mean of δ) for each participant and each

experimental condition were further analyzed using an ANOVA for repeated measures.

Experiment 1

Method

Participants.

Eighteen students (mean age 21 years, 12 females, 1 left-handed) with reported normal or corrected-to-normal visual acuity participated in this experiment. All participants signed an informed consent form and received course credits for their participation. The experiment was approved by the ethics committee of the Faculty of Behavioral Sciences at the University of Twente.

Stimuli and Procedure

The stimuli and procedure used are described in the General Method. Specific to this experiment was only the interstimulus distance. The distance between the stimulus and flankers as well as the distance between flankers was 1.4° .

Data Analysis

The model as was defined in the introduction $Y_{(phij)} \sim \text{Wiener}(\alpha_{(ph)}, \beta, \tau_{(phij)}, \delta_{(phij)})$ was used with indices p for participants ($p=1, \dots, P$), h for time pressure ($h=1, 2$), i for congruency condition ($i=1, 2, 3$), and j for trial ($j=1, \dots, J$). Where P = the number of participants (18) and J = the total number of included trials (14 352). We assume no bias: $\beta=0.5$.

After the first 10,000 iterations all parameters of interest had a Gelman Rubin statistic under 1.1, and visual inspection of the two chains showed no signs of convergence problems.

Results

After dismissing the first ten trials of each block as training trials, a total of 14,400 trials remained for analysis. Of those trials three had premature responses ($RT < 150\text{ms}$), 45 had too late responses ($RT > 800\text{ms}$) or no response, and 1,320 had wrong responses. The mean reaction times and proportions of correct responses for each time pressure * congruency condition are shown in the top panel of Table 1.

Reaction times.

Mean RT for each condition was calculated for each participant and submitted to an ANOVA for repeated measures with Greenhouse-Geisser ϵ correction. In the high time pressure condition, participants responded faster $F(1, 17) = 141.24, p < .001, \epsilon = 1, \eta^2_{\text{partial}} = .89$ compared to the low time pressure condition, indicating the effectiveness of our time pressure manipulation. The standard effect of flanker congruency was also found $F(1.08, 18.34) = 48.92, p < .001, \epsilon = 0.54, \eta^2_{\text{partial}} = .74$.

Our main interest concerned the interaction between time pressure and congruency. Tunnel vision should result in a decreased congruency effect in the high time pressure condition. An interaction effect between time pressure and congruency was indeed found, $F(1.47, 25.07) = 13.48, p < .001, \epsilon = 0.74, \eta^2_{\text{partial}} = .44$. The congruency effect was significantly smaller in the high time pressure condition ($M=25, SD=17.48$) compared to the low time pressure condition ($M=37, SD=18.70$) $t(17) = 4.66, p < .001$. This reduced effect of target-flanker congruency under high time pressure might indicate the presence of tunnel vision.

Proportion of correct responses.

Mean PC for each condition was calculated for each participant and submitted to an

ANOVA for repeated measures with Greenhouse-Geisser ϵ correction. Participants were less accurate in the high time pressure condition compared to the low time pressure condition $F(1, 17) = 162.10, p < .001, \epsilon = 1, \eta^2_{\text{partial}} = .91$. The standard congruency effect was also found, with the greatest accuracy in the congruent condition, and the lowest accuracy in the incongruent condition, $F(1.11, 18.79) = 29.74, p < .001, \epsilon = 0.55, \eta^2_{\text{partial}} = .64$.

As with RT, a significant interaction between time pressure and congruency was found, $F(1.25, 21.27) = 25.94, p < .001, \epsilon = 0.63, \eta^2_{\text{partial}} = .60$. However, now the congruency effect was larger in the high time pressure condition ($M=16.80, SD=9.76$) as compared to the low time pressure condition ($M=6.35, SD=9.56$), $t(17) = 5.96, p < .001$. In contrast to the RT findings, the PC data suggests an increased influence of flanker identity under high time pressure.

Together the PC and RT data cannot answer the question whether or not tunnel vision has been induced. An increase in time pressure resulted in a decreased influence of flankers on RT, but an increased influence on PC. In order to be able to answer this question, we estimate the values of the parameters of the diffusion model based on the observed data. In this model, the estimated rate of evidence accumulation can be used to compare the influence of flankers in low and high time pressure condition.

Diffusion model.

After the first 10,000 iterations, convergence was checked and these iterations were discarded. The results of the remaining iterations were used to calculate mean estimated values of the variables of interest here. Table 2 shows the estimated means for the two parameters relevant to our question, α (boundary separation) and v (rate of information processing).

Boundary separation.

The value of α is an estimate of the boundary separation, that is, the amount of evidence that must be collected before a decision is made. It represents the response criteria, where a higher value of α indicates that more evidence is needed to make a decision (i.e., a more conservative strategy).

Our time pressure manipulations clearly resulted in a change of the speed-accuracy criterion, with a 48% reduction of the boundary separation. A paired samples t-test confirmed the significance of the effect, $t(17) = 11.03, p < 0.001$.

Rate of evidence accumulation.

The value of v represents the rate of evidence accumulation, and might inform us about the influence of the flanker stimuli. The mean values of v depicted in Table 2 show three effects. First, the standard congruency effect is present; evidence is accumulated fastest in the congruent condition, and slowest in the incongruent condition $F(1.09, 18.46) = 118.51, p < .001, \varepsilon = .54, \eta^2_{\text{partial}} = .88$. Second, the mean v is smaller in the high time pressure condition compared to the low time pressure condition, indicating a decrease in evidence accumulation rate under high time pressure $F(1, 17) = 37.48, p < .001, \varepsilon = 1, \eta^2_{\text{partial}} = .69$. Third, the difference between congruent and incongruent conditions is larger in the high time pressure condition ($0.596 - 0.268 = 0.328$) than in the low time pressure condition ($0.614 - 0.376 = 0.238$) $F(1.31, 22.22) = 13.36, p = .001, \varepsilon = .65, \eta^2_{\text{partial}} = .44$. This suggests a larger influence of the flankers in the high time pressure condition.

Discussion

Time pressure resulted in faster but less accurate responses, indicating some speed-

accuracy trade-off was made. Congruent trials were faster and more accurate than neutral trials and incongruent trials were slower and less accurate than neutral trials. This shows the flanker stimuli influenced performance despite their irrelevance to the task. In the high time pressure condition, the congruency effect in RT was smaller compared to the low time pressure condition. The congruency effect found in PC, however, was larger in the high time pressure condition compared to the low time pressure condition. The RT data thus suggest a decreased flanker influence under high time pressure, while the PC data suggest an increase in flanker influence. Based on these results, it is not possible to conclude a general increase or decrease in flanker influence caused by increased time pressure.

Values for the diffusion model parameters boundary separation α and drift rate v were estimated to provide insight in the properties of the underlying decision process. In the high time pressure condition, the value of α was smaller compared to the low time pressure condition, indicating the use of a more liberal strategy that required less evidence to be accumulated before a decision is made. The value of drift rate v was influenced by target-flanker congruency. As expected, evidence is accumulated faster in congruent trials compared to incongruent trials, indicating some influence of the task-irrelevant flankers. The difference in drift rate between congruent and incongruent trials was larger in the high time pressure condition compared to the low time pressure condition, indicating a greater influence of the flanker stimuli in the high time pressure condition. It seems that increased time pressure not only results in a change in strategy, but also in a change in the way stimuli are processed. However, the change in stimuli processing is opposite to the predicted effect in the case of tunnel vision. We hypothesized that if tunnel vision was induced, it should result in less processing of the flanker stimuli, and therefore in a smaller congruency effect. The results suggest the opposite: increased time pressure resulted in a larger congruency effect, indicating

increased processing of the flankers. We conclude that in this experiment with the Eriksen flanker task, we found no evidence for tunnel vision induced by time pressure.

In this first experiment, the distance between the target stimuli and the nearest flanker stimuli was 1.4 degree of visual angle, resulting in a strong congruency effect. This relatively small interstimulus distance may explain the absence of evidence for tunnel vision. It may be possible that attention was more focussed, but not enough to exclude the flanker stimuli. To investigate this possibility, we increased the interstimulus distance to 3.5° in the second experiment.

Experiment 2

Method

Participants.

Twenty students (mean age 19.5 years, 15 females, 2 left-handed) with reported normal or corrected-to-normal visual acuity participated in this experiment. All participants signed an informed consent form and received course credits for their participation. The experiment was approved by the ethics committee of the Faculty of Behavioral Sciences at the University of Twente.

Stimuli, Procedure and Data Analysis

The stimuli and procedure used are described in the General Method. Specific to this experiment was only the interstimulus distance. The distance between the stimulus and flankers as well as the distance between flankers was 3.5°. The width of the background rectangle was increased to fit the complete stimulus array. Data analysis procedures were the

same as in first experiment.

Results

A total of 16,000 trials remained for analysis after dismissing the first ten trials of each block as practice trials. Premature responses ($RT < 150\text{ms}$) made up 23 of these trials, 63 had to late responses ($RT > 800\text{ms}$) or no response and 1,627 had wrong responses.

Reaction times and proportions of correct responses.

Table 1 shows the mean RT and PC for each condition. These means were also calculated per participant and analyzed using ANOVAs for repeated measures. Time pressure resulted in faster $F(1, 19) = 119.62, p < .001, \epsilon = 1, \eta^2_{\text{partial}} = .86$, but less accurate responses $F(1, 19) = 91.70, p < .001, \epsilon = 1, \eta^2_{\text{partial}} = .83$, as it did in our first experiment. A small but significant congruency effect was also found, with slower $F(2, 38) = 10.40, p < .001, \epsilon = .97, \eta^2_{\text{partial}} = .35$ and less accurate $F(2, 38) = 6.63, p = .003, \epsilon = .96, \eta^2_{\text{partial}} = .26$ responses in the incongruent condition. There was no significant interaction found between time pressure and congruency for either reaction time $F(2, 38) = 1.57, p = .22, \epsilon = .698, \eta^2_{\text{partial}} = .08$ or proportion correct $F(2, 38) = .88, p = .43, \epsilon = .89, \eta^2_{\text{partial}} = .04$. Pairwise comparisons revealed responses in incongruent trials were significantly slower $t(19) > 3.55, p < .002$, and less accurate $t(19) > 2.25, p < .037$ as compared to responses in congruent trials, in both high and low time pressure conditions. Responses for neutral trials ($M=367, SD=29,00$) were slower compared to responses for congruent trials ($M=360, SD=29,75$) in the high time pressure condition only $t(19) = 3.30, p = .004$, and neutral trials ($M=84.01, SD=5.85$) only differed significantly $t(19) = 2.28, p = .034$, on PC with the incongruent ($M=81,48 SD=7.41$) condition in the high time pressure condition. All other differences between the neutral condition and the congruent or incongruent condition did not reach significance at the $p < .05$ level in either

time pressure condition. Differences in reaction time $t(19) > 8.68, p < .001$ and proportion correct $t(19) > 8.38, p < .001$ between low and high time pressure conditions were significant for all congruency conditions.

Diffusion model.

After the first 10,000 iterations, convergence was checked and these iterations were discarded as burn-in. Table 2 shows the mean estimated parameter values for α and v calculated from the remaining posterior distribution.

Boundary separation.

The values for α show a similar pattern as in the first experiment, with a 49% reduction of α in the high time pressure condition, $t(19) = 11.16, p < .001$.

Rate of evidence accumulation.

The estimated means of v were submitted to an ANOVA for repeated measures to examine the effect of flanker congruency and time pressure on performance. As in the first experiment, the expected effect of flanker congruency is observed, $F(2, 38) = 33.91, p < .001, \epsilon = .96, \eta^2_{\text{partial}} = .64$. The effect of time pressure on v was also repeated, $F(1, 19) = 31.10, p < 0.001, \epsilon = 1, \eta^2_{\text{partial}} = .62$. No interaction effect between time pressure and congruency was found, $F(2, 38) = 0.40, p = 0.67, \epsilon = .91, \eta^2_{\text{partial}} = .02$.

With the increased interstimulus distance, incongruent flankers still decrease the rate of evidence accumulation, as does time pressure, but time pressure no longer amplifies the congruency effect.

Discussion

Increased time pressure resulted in faster and less accurate responses, showing a speed-accuracy trade-off comparable to the one found in the first experiment. The influence of the flanker stimuli on both speed and accuracy was smaller, but still significant in this experiment. In this experiment, time pressure did not affect the influence of flanker stimuli on RT and PC as it did in the first experiment. The RT and PC data suggest only a general SAT effect of time pressure.

The effect of time pressure on the evidence criteria as represented by α is again clearly present. The flanker congruency effect was found in the estimated value of drift rate v , as in the first experiment, but the size of the effect was very small. In contrast with the first experiment, there was no significant interaction between time pressure and congruency. A main effect of time pressure on v was present, as in the first experiment, with a smaller rate of evidence accumulation in the high time pressure condition compared to the low time pressure condition.

These findings only show an overall decrease in evidence accumulation rate under time pressure, while the results of the first experiment also showed an increased influence of flankers in the high time pressure condition. The findings of the first experiments suggest a less focussed distribution of attention. At first sight, the results of this second experiment do not seem to fit the same explanation. The general decrease in evidence accumulation rate under time pressure seems to suggest a reduction in the amount of attentional resources used instead of a different distribution of attention. However, a more diffuse distribution of attention can also account for the results of the second experiment, as it is likely that a change in distribution would have a larger effect near its center than near its extremities. To

understand how the redistribution of a constant amount of attentional resources can result in a large change near the center, but only small changes near the edges, it is important to realize that attention may not be uniformly distributed within the attended area of the visual field. Although the exact properties of the distribution of attention around a point of focus are still an area of debate, there is some consensus that there is a kind of attentional gradient, with a gradually decreasing attentional facilitation as the distance to the focus of attention increases (LaBerge and Brown, 1989). If we assume for a moment that the distribution of attention around the point of focus follows the shape of a normal distribution, Figure 4 illustrates how a change in spread can have a much larger effect near the center of the distributions than near the edges. The area under the curves represents the total amount of attentional resources, and is equal under both curves. Only the spread of the distributions differ. Such a change in the distribution of a fixed amount of attentional resources fits the results of both our experiments. In both cases, the more diffused distribution of attention under high time pressure results in a decrease of attention at the location of the target stimuli. In the first experiment, where the flankers are close enough to receive a substantial amount of attention, the increase in attention directed at their location is also considerably increased. In the second experiment however, the flankers are positioned at more eccentric positions of the attended area, and only receive a very small amount of attention, which is only slightly enhanced by the diffusion of attention. Note that this explanation does not depend on attention being normally distributed. Another distribution of attention, for example a linear one, will have similar results. As long as there is a decline in attention with increasing distance from the center of attentional focus, the impact of a change in the distributions spread will be larger near the center compared to the edges.

Our first two experiments show a somewhat different effect of time pressure on the influence of flanker stimuli identity. However, both can be explained by less focused

distribution of attention in the case of high time pressure. An alternative possibility is that the experiments show the influence of different top-down strategies. In the third experiment, we will combine both interstimulus distances within one experiment. Trials with a small interstimulus distance and trials with a large interstimulus distance will be randomly distributed within each block, to discourage the employment of different strategies. If the patterns of results found in the first two experiments were the result of the same change in the decision process, they should be replicated in the third experiment. If the observed differences were the result of different strategies, the third experiment should give different results as the use of different strategies is unlikely as interstimulus distance varies within each block of trials.

Experiment 3

Method

Participants.

Seventeen students (mean age 22 years, 11 females, 1 left-handed) with reported normal or corrected-to-normal visual acuity participated in this experiment. All participants signed an informed consent form and received course credits for their participation. The experiment was approved by the ethics committee of the Faculty of Behavioral Sciences at the University of Twente.

Stimuli and Procedure

The third experiment combines the first two experiments: the general method is the same, but interstimulus distance is added as a within-subject parameter.

In this experiment, a block contains 110 trials with small interstimulus distance and 110 with large interstimulus distance, randomly distributed within the block.

Data Analysis

The same HDM is used as in the first two experiments; no extra hierarchical level is added for interstimulus distance. Instead the combination of congruency and interstimulus distance is defined as the `stimulus condition`. Thus, the structure of the HDM remains the same, but the meaning of the index i changes from congruency condition to stimulus condition and now has six instead of three possible values. After parameter fitting, mean parameter values for congruency and interstimulus distance are derived from the estimated parameters values for each stimulus condition. Interstimulus distance was included as independent variable in the ANOVAs of α and v .

Results

As in the first two experiments, the first ten trials of each block were dismissed as practice trials. Of the remaining 28,560 trials, 291 had premature responses ($RT < 150\text{ms}$), 277 had too late responses ($RT > 800\text{ms}$) or no response and 3,309 had wrong responses.

Reaction times and proportions of correct responses.

The bottom panel of Table 1 shows the mean RT and PC for each condition. These means were calculated per participant and analyzed using ANOVAs for repeated measures.

As in the first two experiments, time pressure resulted in faster $F(1, 16) = 164.26, p < .001, \epsilon = 1, \eta^2_{\text{partial}} = .91$ but less accurate $F(1, 16) = 133.89, p < .001, \epsilon = 1, \eta^2_{\text{partial}} = .89$ responses. The standard effect of target-flanker congruency was also present in both reaction times $F(1.47, 23.47) = 45.08, p < .001, \epsilon = .73, \eta^2_{\text{partial}} = .74$ and proportions of correct responses $F(2, 32) = 22.82, p < .001, \epsilon = .79, \eta^2_{\text{partial}} = .59$. Time pressure interacted with the

congruency effect in RT $F(2, 32) = 8.97, p = .001, \epsilon = .88, \eta^2_{\text{partial}} = .36$ and in PC $F(1.44, 22.97) = 18.29, p < .001, \epsilon = .72, \eta^2_{\text{partial}} = .53$. Interstimulus distance had a main effect on RT $F(1, 16) = 10.86, p = .005, \epsilon = 1, \eta^2_{\text{partial}} = .40$ but not on PC $F(1, 16) = 0.42, p = .526, \epsilon = 1, \eta^2_{\text{partial}} = .03$. The interstimulus distance interacted with congruency $F(2, 32) = 17.01, p < .001, \epsilon = .91, \eta^2_{\text{partial}} = .52$ in RT, but not in PC $F(2, 32) = 3.21, p = .054, \epsilon = .95, \eta^2_{\text{partial}} = .17$. There was no interaction found between interstimulus distance and time pressure in either RT $F(1, 16) = 3.67, p = .073, \epsilon = 1, \eta^2_{\text{partial}} = .19$ or PC $F(1, 16) = 1.32, p = .267, \epsilon = 1, \eta^2_{\text{partial}} = .08$. The interaction between interstimulus distance, time pressure and congruency was significant for PC $F(2, 32) = 15.00, p < .001, \epsilon = .80, \eta^2_{\text{partial}} = .48$ but not for RT $F(2, 32) = 1.14, p = .332, \epsilon = .92, \eta^2_{\text{partial}} = .07$.

Separate analyses for both interstimulus distances were performed to enable a direct comparison with the results of the first two experiments. As in the first experiment time pressure reduced both RT $F(1, 16) = 153.21, p < .001, \epsilon = 1, \eta^2_{\text{partial}} = .91$ and PC $F(1, 16) = 120.10, p < .001, \epsilon = 1, \eta^2_{\text{partial}} = .88$ for trials with a small interstimulus distance. The congruency effect was also found in both RT $F(1.47, 23.58) = 43.26, p < .001, \epsilon = .73, \eta^2_{\text{partial}} = .73$ and PC $F(2, 32) = 7.48, p = .002, \epsilon = .86, \eta^2_{\text{partial}} = .32$ as in the first experiment. The reduction of the congruency effect on RT under high time pressure was also replicated $F(2, 32) = 5.45, p = .009, \epsilon = .97, \eta^2_{\text{partial}} = .25$. The increase of the congruency effect on PC under high time pressure failed to reach significance $F(2, 32) = 1.36, p = .270, \epsilon = .88, \eta^2_{\text{partial}} = .08$ in contrast to the first experiment. For trials with a large interstimulus distance, time pressure again resulted in faster $F(1, 16) = 166.86, p < .001, \epsilon = 1, \eta^2_{\text{partial}} = .91$ and less accurate $F(1, 16) = 121.80, p < .001, \epsilon = 1, \eta^2_{\text{partial}} = .88$ responses, as in the second experiment. The congruency effect was also replicated in both RT $F(2, 32) = 18.88, p < .001, \epsilon = .89, \eta^2_{\text{partial}} = .54$ and PC $F(2, 32) = 23.77, p < .001, \epsilon = .83, \eta^2_{\text{partial}} = .60$. Here, time pressure reduced the

congruency effect on RT $F(2, 32) = 5.17, p = .011, \varepsilon = .97, \eta^2_{\text{partial}} = .24$ and increased the congruency effect on PC $F(2, 24.05) = 27.85, p < .001, \varepsilon = .75, \eta^2_{\text{partial}} = .64$, where such interactions were not observed in the second experiment.

Diffusion model.

Table 2 shows the mean estimated parameter values for α and v calculated from the posterior distribution after discarding the first 10,000 iterations to ensure convergence has been met.

Boundary separation.

The values for α show a similar pattern as in the first two experiments, with a reduction 55% of α in the high time pressure condition, $t(16) = 10.05, p < .001$.

Rate of evidence accumulation.

The estimated means of v were submitted to an ANOVA for repeated measures to examine the effect of interstimulus distance, flanker congruency and time pressure on evidence accumulation. The typical congruency effect was again found $F(1.23, 19.71) = 74.01, p < .001, \varepsilon = .62, \eta^2_{\text{partial}} = .82$, as was the effect of time pressure $F(1, 16) = 9.81, p = .006, \varepsilon = 1, \eta^2_{\text{partial}} = .38$. An interaction between time pressure and congruency was found, as in the first experiment $F(2, 32) = 9.45, p = .001, \varepsilon = .97, \eta^2_{\text{partial}} = .37$. Interstimulus distance had a main effect $F(1, 16) = 6.01, p = .026, \varepsilon = 1, \eta^2_{\text{partial}} = .27$ on v . Interstimulus distance also affected the interaction between time pressure and congruency $F(2, 32) = 5.02, p = .013, \varepsilon = .92, \eta^2_{\text{partial}} = .24$. Separate analyses for both distances showed the time pressure * congruency effect was significant at small interstimulus distance $F(2, 32) = 12.86, p < .001, \varepsilon = .92, \eta^2_{\text{partial}} = .45$, but not at large interstimulus distance $F(2, 32) = 1.16, p = .326, \varepsilon = .99, \eta^2_{\text{partial}} = .07$.

Discussion

The main effects of time pressure and congruency have been repeated. When trials with a small interstimulus distance are compared to the first experiment, consisting of only trials with a small interstimulus, the same patterns are observed. In this experiment however, the interaction between time pressure and congruency on PC did not reach significance. Results from trials with a large interstimulus distance were compared with the results from the second experiment, which consisted solely of trials with large interstimulus distance. Here we found a significant interaction of time pressure on the congruency effect on both RT and PC that was not found in the second experiment. The general patterns found in RT and PC in both first experiments are replicated in this third experiment, but the differences between the first two experiments are not completely reproduced.

Separate analysis of the estimated drift rate for both interstimulus distances did show similar effects of time pressure and congruency compared to the first and second experiment. Time pressure and congruency both affected drift rate in both small and large interstimulus distance trials. Time pressure increased the congruency effect on drift rate in trials with small interstimulus distance and did not influence the congruency effect on drift rate in trials with a large interstimulus distance.

General Discussion

We examined the question if time pressure causes tunnel vision using an arrowhead version of the Eriksen flanker task. The standard target-flanker congruency effect was found, both in reaction times and proportions of correct responses. Increased time pressure resulted

in faster, but less accurate responses, a phenomenon known as the speed-accuracy trade-off. To assess the occurrence of tunnel vision, we compared the congruency effect in low and high time pressure conditions. We hypothesized that if tunnel vision was induced, it should reduce the processing of peripheral flanker stimuli, decreasing their effect on performance.

In our first experiment, using a small (1.4°) distance between stimuli, RTs exhibited this reduction of congruency effect under time pressure, but PC showed the opposite pattern, with a larger congruency effect in the high time pressure condition compared to the low time pressure condition. Because of these opposite effects of time pressure on the congruency effect in RT and PC, it is difficult to draw a conclusion on the occurrence of tunnel vision when looking at these two measures of performance separately. We used a hierarchical version of the Wiener diffusion model to model the underlying decision process, and estimated the values of its parameters in the various conditions.

Time pressure had a large effect on the estimated value of boundary separation, the amount of evidence required to make a decision. Target-flanker congruency affected the estimated drift rate, the rate of evidence accumulation. In congruent trials, evidence was accumulated faster compared to incongruent trials. The drift rate thus informs us about the level of influence of the flanker stimuli, and is based on both speed and accuracy information.

Time pressure was found to have a main effect on drift rate, with a lower value in the high time pressure compared to the low time pressure condition. This result, a reduction in evidence accumulation rate when time pressure is higher, may be somewhat counter-intuitive as responses are given faster, but these faster responses appear to be the result of a reduction in the amount of evidence necessary to give a response (the boundary separation), not an increase in evidence accumulation speed (the drift rate).

To assess the occurrence of tunnel vision, we compared the influence of flanker stimuli on drift rate between low and high time pressure conditions. In the high time pressure condition, the found congruency effect was larger than in the low time pressure condition. Thus, a high level of time pressure increased the effect of peripheral flanker stimuli. We conclude that no evidence for the occurrence of tunnel vision under time pressure is found in this experiment. Instead, it seems spatial attention was *less* focused in the high time pressure condition.

The absence of evidence for tunnel vision in our first experiment could be the result of the relatively small distance between the target stimuli and flanker stimuli. We can not exclude the possibility that spatial visual attention was indeed more focused under high time pressure, while still resulting in an attended area of the visual field that includes some flanker stimuli. To investigate this possibility, we repeated the experiment with an interstimulus distance of 3.5 degrees of visual angle. At this distance, the congruency effect was much smaller than in the first experiment, but still significant. Time pressure resulted in faster but less accurate responses as the first experiment. In this experiment however, time pressure did not effect the size of the congruency effect found in RT or PC. The estimated values for boundary separation (the amount of evidence needed to make a response) again showed a large effect of time pressure. As in the first experiment, the drift rate was smaller in the high time pressure condition. The effect of target-flanker congruency was also repeated, with a smaller drift rate in incongruent trials compared to congruent trials. An interaction effect on drift rate between time pressure and congruency was not found in this experiment. As in the first experiment, no evidence for the occurrence of tunnel vision was found. In the first experiment, a pattern was found that is the opposite of what we expected to find if tunnel vision was induced: an increased influence of peripheral flanker stimuli. This pattern was no

longer present in the second experiment where the influence of the targets was much smaller. We argued, however, that the results of the second experiment can fit well with the explanation of less focussed attention under high time pressure.

In the third experiment, we combined both interstimulus distances. Trials with small and large interstimulus distances were randomly varied within blocks. The results of the third experiment showed somewhat different patterns in the behavioral measures than the first two experiments. This indicates that the differences observed between the first and the second experiment may be, at least in part, the result of a difference in strategy. The estimated values of the drift rate in the third experiment do replicate the patterns found in the first experiment. The estimated values for drift rate consistently show a decrease in evidence accumulation speed under time pressure, and a lower rate for incongruent trials compared to congruent trials. When the interstimulus distance is 1.4 degrees of visual angle, the effect of congruency on drift rate is increased under time pressure. With the interstimulus distance set at 3.5 degrees, time pressure no longer influences the size of the congruency effect seen in drift rate.

The differences seen when comparing RT and PC from small interstimulus distance trials with the first experiment, and when comparing RT and PC from large interstimulus distance trials with the second experiment indicate a different strategy may have been used in the first two experiments. The similarities between the small interstimulus distance trials of the third experiment and the first experiment and between the large interstimulus distance trials of the third experiment seen in the estimated drift rate indicate that the differences between the first two experiments and the third experiment can be explained without a structural difference in evidence accumulation rate.

Based on the estimated diffusion model parameters we conclude that time pressure

does not reduce the influence of task-irrelevant peripheral stimuli. The validity of this conclusion depends on the validity of the estimated model parameter values. We used the estimated parameter values of the third experiment to generate response data, in order to evaluate the fit of the model parameters to the observed data. Figure 5 shows the observed and predicted RT distributions for each condition for the first three participants, with incorrect responses flipped left. The gray bars represent the observed data, and the open bars represent data generated by the diffusion model based on the estimated parameter values. The predicted data matches the observed data well. Although the correspondence is not perfect, the observed differences in RT distributions between conditions and between participants are clearly replicated in the distributions of predicted data. The histograms of observed and predicted RTs for all participants in the third experiment are available in the Supplemental Materials.

In applied settings, the occurrence of tunnel vision as the result of stress is often assumed. But evidence for such an effect is scarce. For example, the experiment of Dirkin (1983) that is often cited as evidence for this effect only shows an effect of time pressure on a primary task on which attention was focussed, but no decrease in performance on the secondary, unfocussed task. The results of the current research suggest the absence of tunnel vision as the result of time pressure, and possibly even an opposite effect; a more diffused distribution of visual spatial attention in high time pressure conditions compared to low time pressure conditions. These results may seem surprising given the long held assumption of tunnel vision as the result of stress. However, they resemble results of other more fundamental research such as that of Osman et al (2000). and van der Lubbe et al (2001). The use of the Wiener diffusion model has enabled us to replicate findings from EEG studies using only behavioral measures. Our question could not be answered by interpreting the speed and accuracy information alone, as RTs on PC showed different patterns. By estimating properties

of the underlying decision process, based on that same speed and accuracy information, we were able to answer the question.

Although the Eriksen flanker task used in this study seems well suited to test the occurrence of tunnel vision, its properties do limit the range of situations into which our results can be generalized. First, the stimuli that are to be ignored are always present in each trial. In a real live situation, such as in the car accident example in our introduction, stimuli outside the focus of attention will be far less predictable. Second, on the base of the flanker task is the notion of task relevance. The target is the only stimulus that informs the participant about the correct response and is thus task-relevant. The flankers contain no information about which response is correct and are deemed task-irrelevant. This categorization of stimuli as either task-relevant or task-irrelevant may not generalize well from the lab to real-world settings. In the real world, every stimuli is potentially important, even more so when they are very similar to the attended stimuli, as is the case in the flanker task. Buetti, Lleras and Moore (2014) recently showed that unexpected distractor stimuli are noticed more, and influence task performance more if the distractors are target-like in their appearance. They conclude the congruency effect typically found in the flanker task should be interpreted not as the failing of attention to select only the target, but as the successful selection of target-like stimuli. This alternative interpretation of the congruency effect found in the flanker task would not lead to a different conclusion about the occurrence of tunnel vision in our experiment, however. The absence of a reduced effect of peripheral flankers under high time pressure indicates tunnel vision did not occur. The interpretation of the congruency effect does matter in regard to the way the results can be generalized to real-world situations. In the classic interpretation, the manifestation of the congruency effect indicates the inability to ignore irrelevant stimuli. Based on this interpretation, a change in a task that reduces the congruency effect would be

considered desirable. In the interpretation of Buetti et al. (2014) the congruency effect in the flanker task represents the successful selection of target-like (and thus relevant) stimuli. In this interpretation, a manipulation that reduces the congruency effect would be considered undesirable.

The results of the current research indicate no increase in attentional selectivity based on location in high time pressure conditions. It is possible, though, that time pressure does influence the ability to select relevant stimuli based on other physical properties such as color. This could be examined using an adapted version of the flanker task. Imagine for example a target arrow placed in the center of a two-dimensional array of flanker arrows. A random selection of 50 percent of the flankers are congruent with the target, and the other 50 percent are incongruent. If the congruent flankers consistently share a visual characteristic with the target, for example the same color, this may facilitate the performance of the participant, as feature based selection can be used to select only target-like stimuli from the display. The extent of this facilitation may be influenced by time pressure, which would indicate an interesting effect of time pressure that is different than tunnel vision.

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Table 1

Mean Reaction Time and Percentage of Correct Responses in Low and High Time Pressure Conditions.

Distance	Time pressure	RT			PC		
		Congruent	Neutral	Incongruent	Congruent	Neutral	Incongruent
Experiment 1							
1.4°	Low	398	404	436	97.92	97.82	91.58
	High	361	366	386	92.73	90.36	75.96
Experiment 2							
3.5°	Low	404	407	411	96.10	95.83	94.62
	High	362	368	368	84.37	84.02	81.46
Experiment 3							
1.4°	Low	396	402	419	96.38	94.38	94.12
	High	344	348	357	85.16	81.86	79.94
3.5°	Low	395	400	406	97.57	91.11	96.55
	High	346	347	351	86.58	84.10	74.07

Table 2

Estimated Values for Boundary Separation α and Drift Rate ν , in Low and High Time Pressure Conditions.

Distance	Time pressure	α	ν		
			Congruent	Neutral	Incongruent
Experiment 1					
1.4°	Low	0.0856	0.6138	0.5786	0.3763
	High	0.0443	0.5966	0.5313	0.2680
Experiment 2					
3.5°	Low	0.0787	0.5143	0.4899	0.4551
	High	0.0398	0.4561	0.4223	0.3935
Experiment 3					
1.4°	Low	0.0866	0.5067	0.4789	0.3640
	High	0.0394	0.4981	0.4274	0.2733
3.5°	Low	0.0866	0.5038	0.4640	0.4313
	High	0.0394	0.4611	0.4045	0.3684

Note. Estimated values of two diffusion model parameters. The boundary separation α (alpha) represents the amount of evidence required to make a response. The intertrial drift rate ν (nu) represents the rate of evidence accumulation.

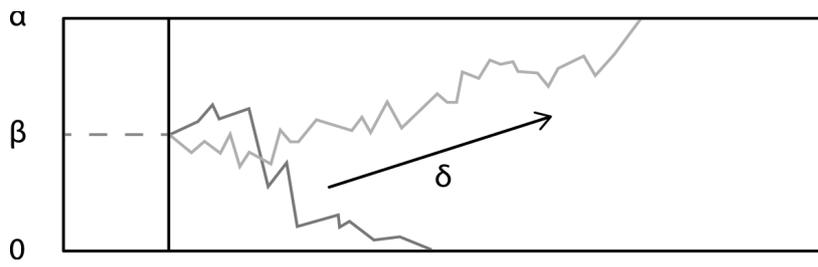


Figure 1. Graphical representation of the diffusion model. α = Boundary separation; δ = Drift rate; β = Starting point. Two possible processes are shown, one reaching the top boundary (correct response) and one reaching the bottom boundary (incorrect response). Two processes with the same average drift rate can have different outcomes as the result of random variation in the evidence accumulation.

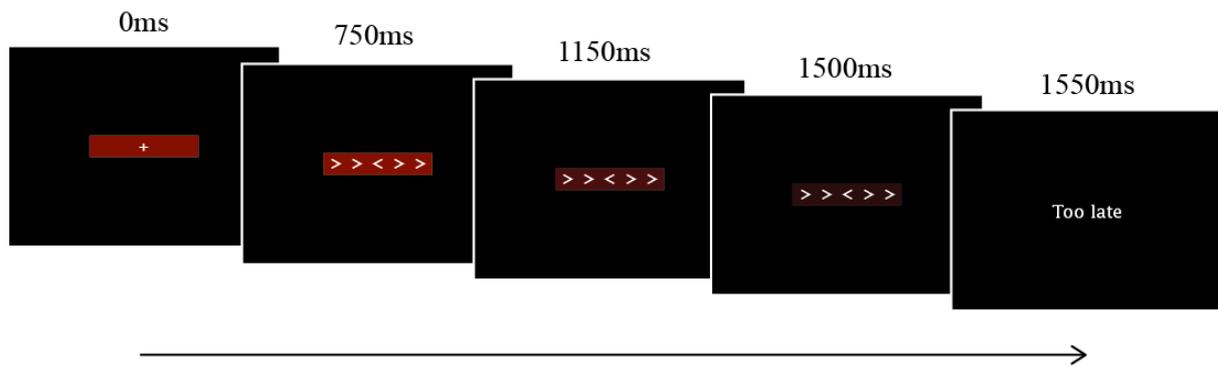


Figure 2. Trial structure. An example of the screens in a trial with a small interstimulus distance, incongruent flankers, low time pressure, and no response given before the deadline. Note that the color of the rectangle changes gradually from the onset of the stimuli at 750ms till the deadline at 1550ms.

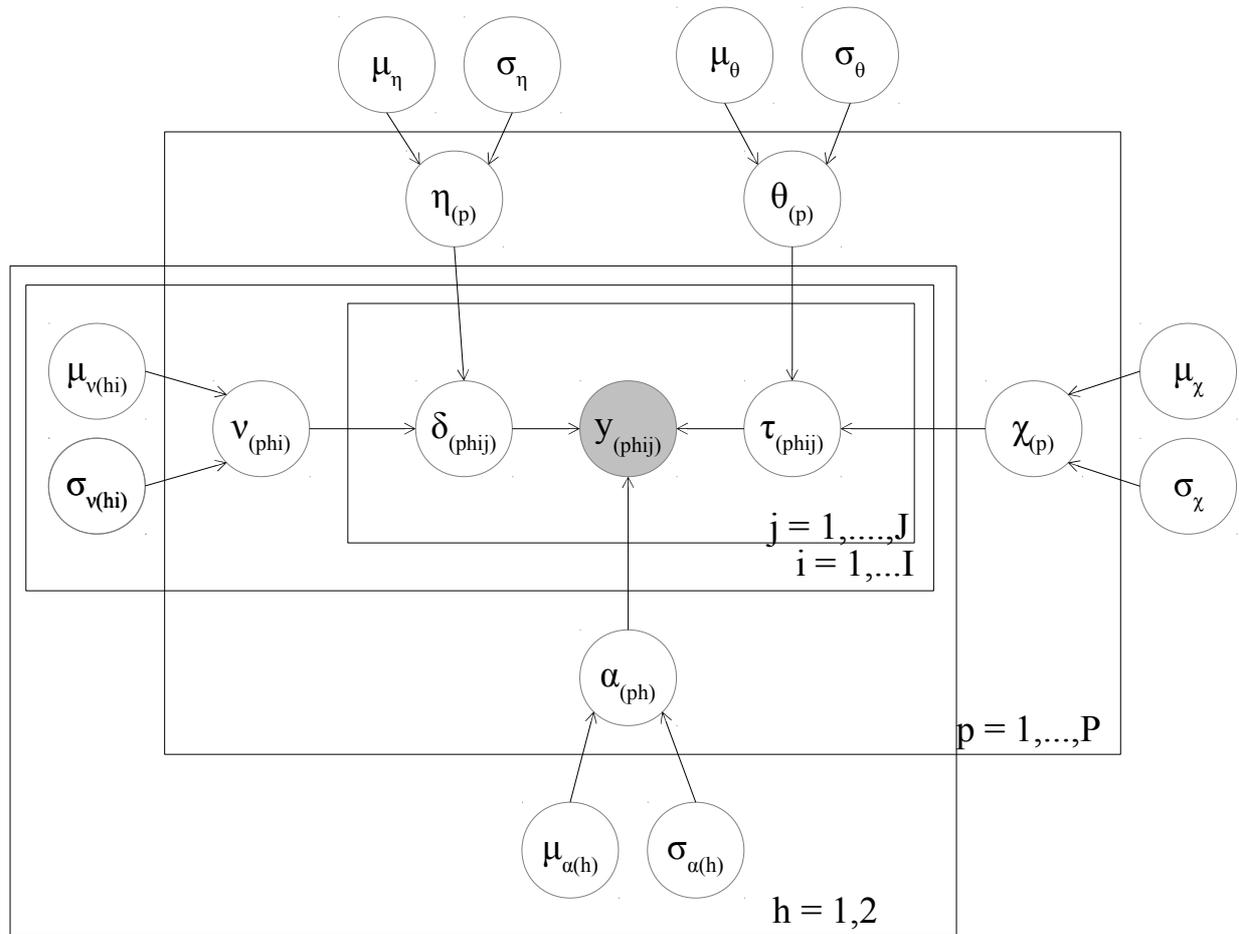


Figure 3. The graphical representation of the hierarchical model used in all three experiments. The shaded node $y_{(phij)}$ represents the observed data (reaction times of correct and incorrect trials). The nodes $\alpha_{(ph)}$, $\delta_{(phij)}$, and $\tau_{(phij)}$ represent the main parameters of the model. The index h indicates the time pressure condition, and has two possible values. The index i represents the experimental condition. It has three possible values in the first two experiments (representing the three target-flanker congruency levels), and six in the third experiment, where congruency and interstimulus distance are combined. The index p represents a participant, and the index j represents a trial. The boundary separation $\alpha_{(ph)}$ is allowed to vary between participants and time pressure condition, and is assumed to be normally distributed with a interparticipant mean ($\mu_{\alpha(h)}$) and variance ($\sigma_{\alpha(h)}$). The drift rate $\delta_{(phij)}$ can vary between individual trials, but is assumed to be normally distributed with an intertrial mean ($v_{(phi)}$) and variance ($\eta_{(p)}$). The intertrial mean drift rate ($v_{(phi)}$) is assumed to be normally distributed with mean $\mu_{v(hi)}$ and variance $\sigma_{v(hi)}$. The non-decision time $\tau_{(phij)}$ can vary between trials, but is assumed to be normally distributed with a participant specific mean ($\theta_{(p)}$) and variance ($\chi_{(p)}$). Vague priors were specified for the prior parameters $\eta_{(p)}$, $\theta_{(p)}$, and $\chi_{(p)}$.

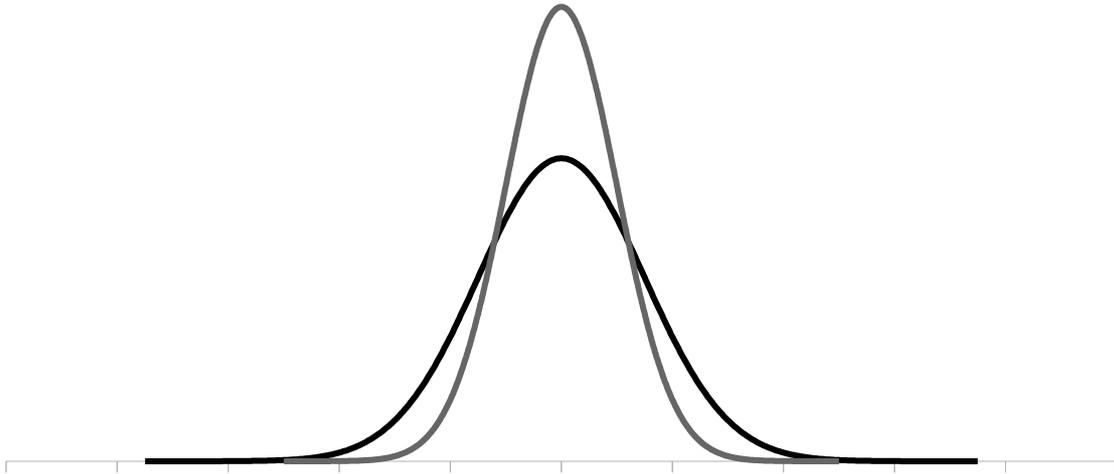


Figure 4. Two normal distributions with the same area under the curve, but with a different spread. A change in spread has a large effect on the height of the curve near its center, but much smaller effects at its extremities.

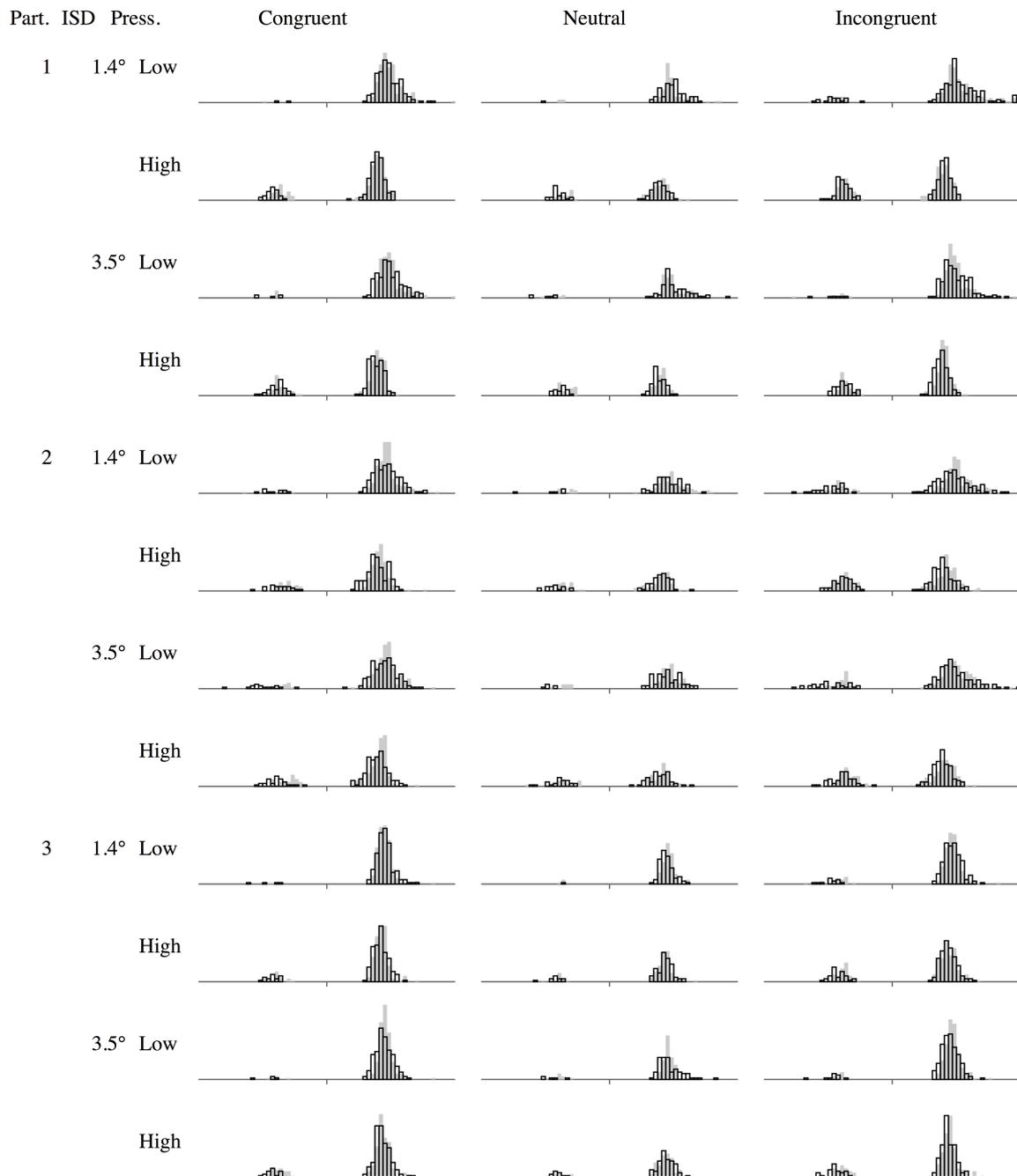


Figure 5. Frequency histograms of observed and predicted data for the first three participants in the third experiment. Part. = participant, ISD = interstimulus distance, Press. = time pressure. The filled gray bars represent actual measured reaction times, divided into 50ms bins. The open bars represent the reaction times predicted by the diffusion model using the estimated parameter values. The left half of each cell is a flipped histogram of the incorrect responses. The open bars show the same general patterns as the filled bars, indicating the model with its estimated parameters fits the observed data well.