and underdeveloped medial nasal processes (*14*). This was observed with scanning electron microscopy in 10- and 11-day-old embryos from ethanol-treated mothers. The inferior portions of the medial nasal processes were particularly diminished in size.

A remarkable finding of this study is that short-term ethanol exposure affects neural plate development at such an early gestational stage. At the time of ethanol exposure on day 7, the mouse embryos were undergoing gastrulation, or formation of the mesoderm. The mesoderm is responsible for induction and maintenance of the neuroepithelium. Although pronounced histological changes were noted only in the neuroepithelium, it is possible that disruption of the mesoderm was at least partially responsible for the neural deficiencies.

The striking teratogenic effect of ethanol at very early developmental stages provides excellent opportunities for studying the cellular and molecular mechanisms of ethanol teratogenesis, since very few cell types are present. Also, since mouse embryos can be grown in vitro at these stages, analysis of cellular activity and determination of direct effects of ethanol or its metabolites are possible.

In conclusion, ethanol, one of the most prevalent human teratogens, has a major effect in the mouse at a time corresponding to the third week of human gestation. Many women are not aware of their pregnancy at this stage. Those who are aware may not realize that social or binge drinking so early in pregnancy may be as deleterious to the embryo as constant heavy drinking. Results of a study by Hanson *et al.* (*15*) indicate a significant relation between alcohol consumption in the month preceding pregnancy recognition and FAS-type abnormalities. Further epidemiological studies in humans are needed to confirm or deny the existence of a critical period during which major features of FAS are determined.

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The Stroop Effect:
Brain Potentials Localize the Source of Interference

Abstract. *The P300 component of the event-related brain potential was used in conjunction with reaction time to identify the locus of interference on the Stroop color-word test. Whereas response time varied with the congruence between the stimulus word and the color in which it was printed, the duration of stimulus processing, as indexed by P300 latency, remained constant. The results indicate that response competition is the primary source of Stroop interference.*

When a stimulus provides irrelevant as well as relevant cues, research latency is often affected by the degree of congruence between the cues. A classic example of interference from stimuli that provide conflicting cues is demonstrated by the Stroop color-word test (*1*). In the standard Stroop test, the time required to name the ink color in which a word is printed is increased if the word spells a conflicting color name (for example, the word *blue* printed in red ink). Explanations for the Stroop effect differ according to whether the source of interference from the irrelevant cue is attributed to stages of stimulus encoding (*2*) or reponse production (*3, 4*).

Numerous studies have been conducted with the aim of disentangling stimulus and response effects on Stroop performance. A confounding of possible effects of the conflicting cue on stimulus and response processes has made it difficult to distinguish between perceptual and response conflict models of Stroop interference through the use of behavioral measures alone. This difficulty could be surmounted, however, if a procedure were available for directly measuring the duration of a subset of the component processes that contribute to the total duration of the reaction time (RT) (*5*). There is convincing evidence that the latency of the P300 component of the human event-related brain potential (ERP) provides such a measure (*6*): P300 latency seems to index the duration of stimulus-evaluation processes and to be independent of the time involved in response production (*7, 8*). In this study, concurrent measures of RT and P300 latency identified response competition as the primary source of the Stroop interference effect.

Twelve male subjects (*9*) performed a discrete-trials version of the Stroop task, in which each stimulus was the word *red*, *blue*, or *town* printed in either red or blue ink. There were thus three categories of stimuli: incongruent (for example, the word *red* in blue ink), congruent (for example, the word *red* in red ink), and neutral (for example, the word *town* in red ink) (*10*). The six stimuli were presented with equal probabilities in a random sequence in blocks of 80 trials. Slides containing the stimuli were presented for 200 msec at the rate of one every 2 to 4 seconds. The experimental room was dimly lit, and external sounds were masked with continuous low-level white noise delivered through earphones.

In one condition, subjects were instructed to name the color of ink (*11*), and in a second condition, to read the word. The word-relevant condition was included to maintain the association between the printed word and its name and thereby prevent possible attentuation of interference with practice (*1, 12*). This condition also served to assess the extent to which the faster responses consistently observed in the word-naming task (*1, 13, 14*) are attributable to a reduction in stimulus-processing time.

Subjects responded vocally in both conditions (*15*). After practice, the two conditions were presented four times each in an alternating sequence, with the order of presentation balanced across subjects. To make response selection maximally contingent on stimulus evaluation, accuracy of performance was rewarded (*8*).

The electroencephalogram (EEG) was recorded with nonpolarizable electrodes from frontal (Fz), central (Cz), and parietal (Pz) locations, all referred to linked earlobes and amplified with a time constant of 8 seconds and an upper half-amplitude frequency of 35 Hz. The sampling rate was 200 Hz. Eye movements were monitored by electrodes placed on the inferior and superior orbital ridges of the right eye. Trials in which there were eye-movement artifacts or erroneous responses (*16*) were excluded from analysis.

We predicted that if Stroop interference is due to a delay in stimulus identification, the latency of P300 elicited by incongruent stimuli in the color-relevant condition would be delayed relative to that elicited by congruent or neutral stimuli. Under these circumstances, P300 latency would track variations in RT. Conversely, if the interference occurs subsequent to stimulus evaluation, then P300 latency would be relatively stable across the different categories of stimuli. Responses to incongruent stimuli would, however, be delayed relative to P300. Thus, a dissociation of RT and P300 latency would point to response production as the locus of interference.

When ink color was the relevant cue, responses to incongruent stimuli were slower than those to neutral stimuli (Fig. 1) (*17*). Moreover, there is evidence of facilitation in RT to congruent stimuli relative to neutral stimuli (*4*). As expected, no differences in RT among stimulus categories were found when the word was the relevant cue (*13, 14*).

A large P300 component was elicited by all stimuli in both conditions (Fig. 2A) (*18*). In contrast to the RT data, P300 latency remained stable across the three categories of stimuli (Fig. 1) (*19*). The sole factor influencing P300 latency was the task assigned to the subject (*20*). Specifically, the duration of processing involved in stimulus evaluation, as indexed by the latency of P300, was reduced by an average of 21 msec when the subject was simply required to read the word.

Subjects are unable to ignore the word while attending to the color (*21*). Examination of the covariation of RT and P300 latency enabled us to assess the separate contributions of stimulus and reponse processing to the difference in RT between conditions. The 21-msec increase in P300 latency accounted for only a small portion of the overall increase in RT in the color-relevant condition. This increase in the duration of stimulus processing may reflect an additional operation of transforming the color of the stimulus into a form that allows response processing to begin (*13, 22*). The bulk of the increase in response time from the word-relevant to the color-relevant condition thus appears to be due to prolonged response processing. A more cautious response strategy may account for this increase in RT.

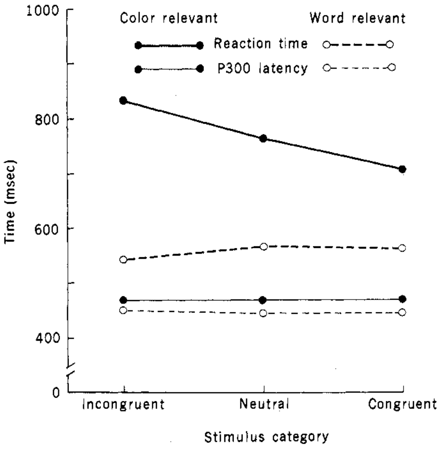

Fig. 1. Mean reaction times and P300 latencies in the color-relevant and word-relevant conditions of the Stroop color-word test as a function of stimulus category.

By using P300 latency in conjunction with RT, we have shown that the Stroop effect occurs subsequent to stimulus evaluation. Congruent stimuli were found to facilitate performance, not only in comparison to incongruent stimuli but also in comparison to neutral stimuli. If the classic Stroop effect were due to interference with the ability to encode the ink color, the pattern of P300 latency exhibited by the three categories of stimuli would have paralleled that observed for RT. The latency of P300 did not, however, vary as a function of stimulus category. This latency invariance is what would be expected if the color and word were processed in parallel, with interference arising from competition among conflicting responses.

An alternative interpretation of the data is that P300 in both conditions is elicited as a consequence of evaluation of the letter information only. If this

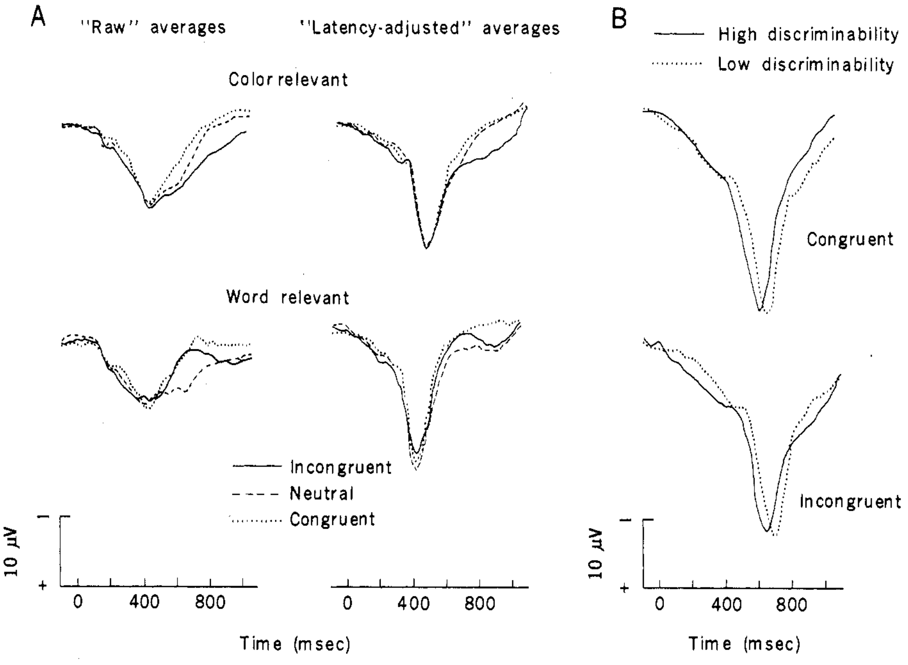

Fig. 2. (A) Event-related brain potentials, recorded from Pz and averaged over subjects, elicited during the Stroop test. "Raw" averages were time-locked to stimulus onset (at 0); "latency-adjusted" averages were obtained through the use of an adaptive-filter technique (*30, 31*). To attenuate activity outside the bandwidth of P300, each single-trial EEG record at Pz was first smoothed by a zero-phase-shift, low-pass filter (−3 db at 6.77 Hz). The parietal lead was selected because P300 was largest in amplitude at that site. To restrict latency measures to P300, a subepoch of the 1700-msec record was selected that bounded the P300 latecy range. For these analyses, the epoch ranged from 325 to 600 msec after stimulus onset. This procedure provides an estimate of the ERP waveform, adjusted for the between-trial variability of the P300. After latency adjustment, the amplitude of the P300 elicited by each of the stimuli was enhanced, although there seems to be no systematic relation between P300 amplitude and the category of the eliciting stimulus. (B) Latency-adjusted ERP's recorded from Pz and averaged over subjects, elicited in the color-relevant condition of the modified Stroop test. The P300's were larger and later in the modified Stroop task. These differences may be due to the decrease in event probability (*6, 31*) as well as the increase in task demands (*7, 8, 32*) in the modified task.

were the case, encoding of the color information would not affect P300 latency; and no difference in P300 latency would be expected among stimulus categories.

This explanation was ruled out by the results of two additional experiments in which P300 latency was shown to vary with the degree of hue discriminability of the stimuli. In the first, a choice RT experiment, P300 latency as well as RT increased significantly as the discriminability of the stimulus hues decreased (*23*). The effect of hue discriminability averaged 80 msec on P300 latency and 150 msec on RT.

In the second experiment, a modified version of the Stroop task, the latency of P300 also varied with hue discriminability. The procedures were identical to those of the primary experiment in all respects except that, in addition to the standard hues of red and blue, the words *red* and *blue* were also printed in hues of reddish purple and bluish purple—hues that were difficult to discriminate from one another (*24*). The eight stimuli were presented with equal probabilities. Ten male subjects (*25*) were asked to name the predominant hue (red or blue) of each stimulus (*26*). Catch trials were included to keep the relevance of the word information equivalent across experiments (*27*). Whereas P300 latency was again unaffected by stimulus congruence, it was increased significantly (43 msec) when the hues of the stimuli were more difficult to discriminate (Fig. 2B) (*18, 28*).

The fact that variations in P300 latency accompany variations in the discriminability of the stimulus hues argues that, in the color-relevant condition of the Stroop task, P300 is elicited after evaluation of the color information. Therefore, the invariance of P300 latency observed in the color-relevant condition suggests that the processing of color information is unaffected by the congruence of the printed word, thus pointing to response production as the locus of Stroop interference.

One current model of processing that can account for a response-competition hypothesis of Stroop interference has been provided by Morton (*29*). According to his "logogen" model, each stimulus activates relevant information stored in memory (for example, its name, its meaning, and an appropriate response). The Stroop effect can be explained by assuming that two or more inputs can activate different logogens simultaneously and without interference. When the same logogen is activated by two or more sources of information (for example, the color and word content of congruent stimuli), the logogen builds up information faster, leading to a faster response. When the irrelevant information (for example, the word content of incongruent stimuli) activates a conflicting logogen in the set leading to the relevant responses, the criterion of activation is adjusted, leading to a slower response. That is, even though more than one logogen may reach its criterion level at the same time, apparently only one response can be initiated. Thus, our data support the hypothesis that the Stroop effect is primarily an output, rather than an input, phenomenon.

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9. Subjects were students at Stanford University, ranging in age from 19 to 29 years, with normal color vision and visual acuity.
10. A neutral, noncolor word was included to assess inhibitory effects of incongruent stimuli separately from facilitatory effects of congruent stimuli on RT, P300 latency, or both. The three stimulus words were matched for frequency of occurrence in the English language [J. B. Carroll, P. Davies, B. Richman, *Word Frequency Book* (Houghton Mifflin, Boston, 1971)]. At a viewing distance of 127 cm, the words *red*, *blue*, and *town* subtended visual angles of 2.43° by 1.15°, 3.01° by 1.15°, and 3.72° by 1.15°, respectively. The brightness of the slides was equated during a pilot experiment, through the use of both subjective ratings and choice RT.
11. To ensure that subjects perceived the word as well as the color in the color-relevant condition, subjects were told that on a small number of trials (three to six per series), the stimulus would be a word other than *red*, *blue*, or *town*. The stimuli in these "catch" trials were three- and four-letter words printed in red or blue ink and matched for frequency of occurrence. A bonus of \$0.50 was paid for each of the catch trials on which the subject's initial response was not the ink color but the word. Every subject was 100 percent on the catch trials.
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15. The voice response triggered a relay.
16. Error rate ± standard error: color-relevant condition, 1.2 percent (± 0.3); word-relevant condition, 0.1 percent (± 0.1).
17. A repeated-measures analysis of variance: condition, $F(1,11) = 196.08$, $P < .0001$; stimulus category, $F(2,22) = 15.58$, $P < .001$; and interaction, $F(2,22) = 52.26$, $P < .0001$. As assessed by Tukey's honestly significant difference test, responses were slower to incongruent than to congruent stimuli ($P < .05$).
18. Because the ERP's elicited by a given stimulus printed in red or blue ink were essentially identical and a repeated-measures analysis of variance of P300 latency yielded no significant effects or interactions related to this factor, the data were averaged over ink color.
19. There was no tendency for subjects who showed the largest Stroop effect in terms of RT to show any trend toward similar differences in P300 latency: the effect of stimulus congruence on RT was uncorrelated with the corresponding effect on P300 latency ($r = .28$, not significant).
20. $F(1,11) = 7.38$, $P < .025$.
21. It has been suggested that because words can be read faster than colors can be named, there is stronger interference from the word with color naming than from the color with word reading [D. J. Murray, J. Mastronardi, S. Duncan, *Psychonom. Sci.* **26**, 305 (1972)].
22. An equally plausible alternative explanation, offered by an anonymous referee, is that the 21-msec difference could reflect the difference in task structure between conditions: "Say the word" versus "Read the word; check whether it is a catch trial; say the color."
23. P300 latency, $F(1,9) = 33.23$, $P < .001$; RT, $F(1,9) = 27.25$, $P < .001$.
24. The hues of the stimuli were obtained by placing strips of Kodak Wratten color filters (Nos. 92, 47, 34A, and 30) over the word image before mounting as a slide. This method was chosen to give even color without fading. Neutral density filters were used to equate the brightness of the slides.
25. Subjects, including three from experiment 1, were students at Stanford University, ranging in age from 18 to 28 years, with normal color vision and visual acuity.
26. The error rate was 5.6 percent (± 1.5).
27. The stimuli of the catch trials were printed in the four hues with equal probabilities. Performance on the catch trials was 100 percent accurate for every subject.
28. $F(1,9) = 6.71$, $P < .03$. Reaction time was significantly affected by hue discriminability [$F(1,9) = 53.29$, $P < .0001$] as well as stimulus category [$F(1,9) = 7.00$, $P < .03$]. The effect of stimulus category on RT was restricted to the highly discriminable hues, yielding a significant interaction [$F(1,9) = 40.15$, $P < .0001$]. Mean RT's to the highly discriminable stimuli were 828 msec (congruent) and 929 msec (incongruent). For stimuli of low discriminability, mean RT's were 1106 msec (congruent) and 1082 msec (incongruent). That is, stimulus category did not affect the RT to stimuli printed in hues of low discriminability. This may have resulted from decay of the word trace over time or from low salience of stimulus congruence relative to hue discriminability in this task.
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