P2465 Attention Reading Review
Reference: MacLeod, C. M. (1991). Half a Century of Research on the Stroop Effect: An Integrative Review. Psychological Bulletin, 109(2), 163-203.
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1) Goal of the paper:
   a) Organize and review past 50 years of research on Stroop Color-Word task.
   b) Survey existing theories, showing critical weaknesses in the standard explanation and dispel some myths that have arisen.

2) Before Stroop's 1935 paper:
   a) Cattell (1886) found that saying red to a patch of color was slower than saying the word 'red'. He speculated that word naming has take place so often it became automatic, but identifying color patch is a voluntary act.
   b) Brown (1915) found that practice could not explain the findings.
   c) Lund (1927) found that "children younger than reading age was faster on color naming than word reading".
   d) Ligon (1932) showed that RT improve across grades 1-9, but the task difference still there.

3) Stroop's Classic Article (1935):
   a) Wanted to study color naming vs. word reading, came up with the idea to test 'compound' stimulus: word incongruent with the ink color.
   b) Experiment one: read color words in black ink vs. read color words in incongruent ink

Table 1
Experiment 1: Mean Times (in Seconds With Standard Deviations [SD]) for Reading Color Words in the Experimental Condition (Incompatible Colored Inks) and in the Control Condition (Black Ink Only)

		Experimental: words in color		Control: words in black	
Experiment	Sample size	*M*	*SD*	*M*	*SD*
Stroop (1935b)	70	43.30	6.15	41.00	4.84
MacLeod (1986)	50	41.58	6.98	41.16	7.12

c) Experiment 2: name the color of squares or the color of color words

Table 2
Experiment 2: Mean Times (in Seconds with Standard Deviations [SD]) for Naming Ink Colors in the Experimental Condition (Incompatible Color Words) and in the Control Condition (Solid Color Squares)

		Experimental: words in color		Control: squares in color	
Experiment	Sample size	*M*	*SD*	*M*	*SD*
Stroop (1935b)	100	110.3	18.8	63.3	10.8
MacLeod (1986)	40	102.27	18.06	59.76	8.09

d) Experiment 3: explored the impact of practicing color naming of interference in word reading. Comparison of a pretest and posttest where subjects read words in incongruent colors showed that intervening 8 days of practice introduced interference into word reading, but this newly developed interference quickly disappeared after a second post-test.

e) Some other cautious note:
   i) Stroop never tested congruent color words
   ii) Stroop never tested single trial reaction time, the dependent measure here is the time the subject took to finish reading the whole list.

Eighteen Major Empirical Results That Must be Explained by Any Successful Account of the Stroop Effect

1. The Stroop effect is observed with lists of stimuli, with single stimuli, and with many variations on the response required. Similar data patterns are evident in numerous Stroop analogs, such as the picture–word task.
2. Both orthographic and particularly acoustic/articulatory relations between the irrelevant word (or part of the word) and the to-be-named ink color contribute to the interference.
3. Compared with naming the ink color alone, irrelevant verbal stimuli that are unrelated to the concept of color interfere only minimally with color naming. However, as the word's semantic association to the concept of color increases, so does its power to interfere.
4. A color-unrelated word can be made to cause greater interference (or facilitation, or both) with color naming if its meaning is activated by a related word or phrase shortly before the color-naming trial.
5. Congruence between the irrelevant word and the to-be-named ink color often produces facilitation. However, this facilitation is much less than the corresponding interference in the incongruent condition, and the choice of control condition may be crucial.
6. If the to-be-named color and the to-be-ignored word are presented in separate spatial locations, interference will be reduced (but not eliminated) relative to the standard, integrated version of the task. Locational uncertainty makes an important contribution in nonintegrated situations.
7. The presence of congruent trials among the incongruent and control trials will tend to invoke the tactic of splitting attention over the two dimensions, thereby increasing interference on incongruent trials.
8. When the irrelevant word on trial $n-1$ is the name of the target ink color on trial n, interference with color naming will be enhanced temporarily; when the ink color on trial $n-1$ matches the word on trial n, there will be some facilitation of color naming on trial n. If the word on trial $n-1$ is repeated on trial n, then the word is already suppressed and will cause less interference in naming a different ink color on trial n.
9. Advance cues conveying information about the upcoming Stroop trial can be used to establish processing strategies that improve performance if these cues are above the level of subjective awareness and if a very small set of cues is used consistently.
10. When the color (or picture) is to be named, maximal impact of a congruent or incongruent word will be observed when the two dimensions begin within 100 ms of each other. Facilitation may extend to longer SOAs than interference when the word comes first. Manipulating SOA has virtually no impact on word reading unless a very high proportion of congruent trials biases use of the color to initiate response production.
11. A reverse Stroop effect (i.e., interference with word reading caused by an incompatible, irrelevant ink color) appears to be possible, but this effect is not simply a consequence of the relative speeds of processing each dimension.
12. Degree of practice in processing each of the dimensions of a multidimensional stimulus is very influential in determining the extent of interference from one dimension on another. The greater the practice in processing a dimension, the more capable that dimension seems of influencing the processing of another dimension.
13. Although still significant, interference (but perhaps not facilitation) is reduced when response modality is switched from oral to manual. Stimulus–response compatibility matters; if the normal processing of the irrelevant dimension leads to a response in the mode designated for the relevant dimension, interference is likely to be heightened.
14. When the irrelevant dimension of a set of stimuli includes names that are eligible responses for the relevant dimension, more interference results than when the sets are nonoverlapping. Although variations in response set size might be expected to affect interference, existing results are unclear.
15. There are no sex differences in Stroop interference at any age.
16. Interference begins early in the school years, rising to its highest level around Grades 2 to 3 as reading skill develops. With continued development of reading, interference declines through the adult years until approximately age 60, at which point it begins to increase again.
17. The left hemisphere generally shows more interference than the right.
18. Interference between the two languages of a bilingual, although not as great as that within either one of the languages, is very robust: Between language interference typically is about 75% of within-language interference. Furthermore, a dominant language has more potential for interfering than does a nondominant one.

4) After Stroop's classic article (1935 - 1989):
   a) Variations on the Stroop Procedure
      i) The Stroop Color-Word Interference Test (Classic Stroop)
         (1) Subjects tested on naming colors of incompatible words and color patches

      ii) The Individual Stimulus Version of the Color-Word Task
         (1) Individual stimuli were presented and timed, allow for control of single trial SOA and measure of RT, now dominates the field

      iii) Sorting and Matching Versions of the Color-Word Task
         (1) Rather than naming/reading, subjects sort the cards into categories. Studies have shown that sorting color only cards faster than sorting incongruent color word cards.

      iv) The Picture-Word Interference Task
         (1) Compound stimuli consist of pictures with words written on them.

      v) Auditory Analogs of the Stroop Task
         (1) Compound stimuli consist of words low or high presented with a low or high pitch
   b) Conclusion: The Stroop effect is observed with lists of stimuli, with single stimuli, and with many variations on the response required Similar data patterns are evident in numerous Stroop analogs, such as the picture-word task.

   c) Manipulations of trial components
      i) Hue variation
         (1) Achromatic color patches are named faster than chromatic patches.
         (2) Very few studies, premature to offer empirical generalization.

      ii) Acoustic Variation
         (1) Both orthographic and particularly acoustic/articulatory relations between the irrelevant word (or part of the word) and the to-be-named ink color contribute to the interference.

      iii) Semantic Variation
         (1) Compared with naming the ink color alone, irrelevant verbal stimuli unrelated to the concept of color interfere only minimally with color naming. However as the word's semantic association to the concept of color increases, so does its potential to interfere.

(2) There is an increase in interference or facilitation when the irrelevant word is primed.

iv) Congruency Effects

(1) Congruence between the irrelevant word and the to-be-named ink color often produce facilitation. However this facilitation is much less than the corresponding interference in the incongruent trial, and the choice of control condition may be crucial.

v) Integrating the Two Dimensions

(1) If the to-be-named color and the to-be-ignored word are presented in separate spatial locations, interference will be reduced (but not eliminated) relative to the standard, integrated version of the task. Locationa uncertainty makes an important contribution in nonintegrated situations.

d) Manipulations of experiment components

i) Probability of various trial types

(1) The presence of congruent trials among the incongruent trials will invoke the tactic splitting attention over the two dimensions, thereby increasing interference on incongruent trials

ii) Stimulus Set Size

(1) Conflicting data, It seems unknown how it affects interference and facilitation.

iii) Trial Sequence

(1) When the irrelevant word on trial n - 1 is the name of the target ink color on trial n, interference with color naming will be enhanced temporarily; when the ink color on trial n - 1 matches the word on trial n, there will be some facilitation of color naming on trial n. If the word on trial n - I is repeated on trial n, then the word is already suppressed and will cause less interference in naming a different ink color on trial n.

iv) Pretrial Cues

(1) Advance cues conveying information about the upcoming Stroop trial can be used to establish processing strategies that improve performance if these cues are above the level of subjective awareness and if a very small set of cues is used consistently.

v) Stimulus Onset Asynchrony

(1) When the color (or picture) is to be named, maximal impact of a congruent or incongruent word will be observed when the two dimensions begin within 100ms of each other. Facilitation may extend to longer SOAs than interference when the word comes first. Manipulating SOA has virtually no impact on word reading unless a very

high proportion of congruent trials biases use of the color to initiate response production

vi) Reverse Stroop Effect
(1) When color or picture interferes with reading the word, that is a reverse stroop effect.
(2) Has been sparsely shown in the literature, but no bidirectional interference studies.

vii) Practice
(1) Degree of practice in processing each of the dimensions of a multidimensional stimulus is influential in determining the extent of the interference from one dimension on another. The greater the practice in processing a dimension the more capable that dimension is of influencing the processing of another dimension

e) Manipulations of Response
i) Order response
ii) Response modality: Oral Versus Manual
(a) Although still significant, interference (but perhaps not facilitation) is reduced when response modality is switched from oral to manual. Stimulus-response compatibility matters; if the normal processing of the irrelevant dimension leads to a response in the mode designated for the relevant dimension, interference is likely to be heightened.
iii) Responses Set Size and Composition

f) Individual Differences
i) Sex differences: non effects found
ii) Age Differences
(1) Interference begins in school years, rising to the highest level around grades 2 to 3 as reading skills develops.
(2) Interference declines through the adult years until approximately age 60. Then begins to increase again.
iii) Hemispheric Differences
(1) Left hemisphere generally shows more interference
iv) Language differences
(1) Interference between the two languages of a bilingual, although not as great as that within either one of the languages, is very robust: Between-language interference typically is about 75% of withinlanguage interference. Furthermore, a dominant language has more potential for interfering than does a nondominant one.
(2)

5) Theoretical models should be able to explain all 18 findings

- Theoretical accounts of the Stroop Effect
  - Relative Speed of Processing
    - Words are read faster than color are named
    - Two potential responses (word reading vs color naming) compete to be the actual response. The time cost of this competition is the interference.
      - Model assumes a parallel processing of word reading and color naming
      - A limited capacity of responses channel, priority is determined by processing speed. Fast processor interferes with slow processor

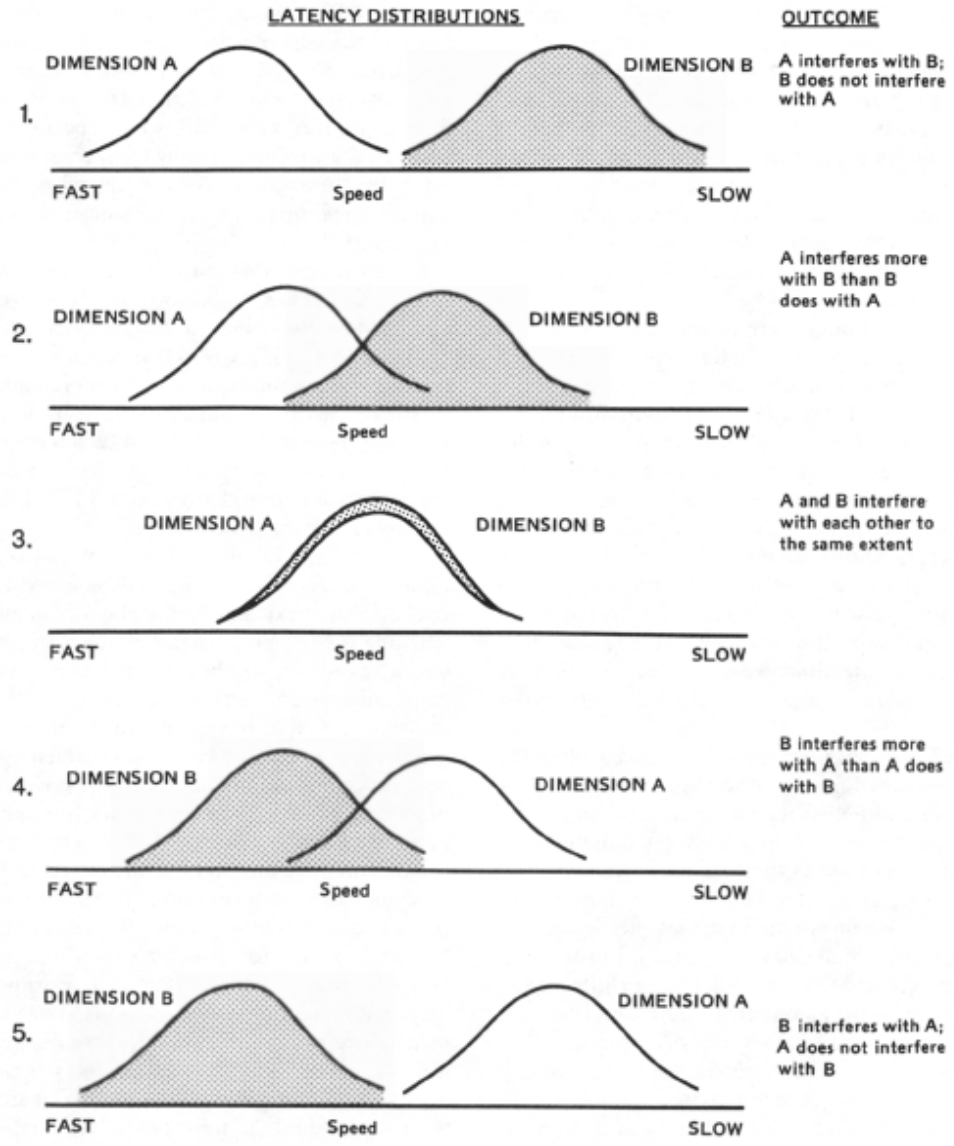

Figure 1. Relative speed of processing and interference. As the latency distributions for the processing of the two dimensions shift, so should the patterns of interference.

- Could not explain the SOA results

- Automaticity
  - Processing one dimension requires much more attention than processing of the other dimension. More automatic processing could interfere with less automatic processing (word reading interfere with color naming).
  - The authors questioned: But if word reading is automatic and requires no resource, how could it draw resources away from color naming? (According to the CAP2 model automatic processes are hard to control)

- Perceptual Encoding
  - Interference occurred at early stages of processing, perceptual stage.
  - Perceptual encoding of ink-color information is slowed by incompatible information from a color word as supposed to a neutral control.

- Parallel Models: Accumulating Evidence Toward a Decision
  - Logan (1980) cast his model of Stroop effect as decision process gathering evidence.
  - Evidence accumulates over time until a response threshold is reached.
  - Evidence from each dimension is processed at a rate governed by its weight.
  - Two weights determine each dimension contribution to the decision: a stable automatic weight and a flexible strategic attentional weight.
  - Total evidence at threshold is the sum of all evidence from all dimensions.
  - If irrelevant dimension provide evidence conflicting with the desired dimension, response speed will be slowed.
  - The extent of intrusion (interference?) will be a function of its weights; those with larger weights will have a greater impact on the composite decision process.
  - Problem: predict symmetrical facilitation and interference, yet facilitation always smaller than interference.

- Parallel Distributed Processing Model
  - Two pathways, one for color naming one for word reading. Each pathway includes number of units, input units, hidden units, and final decision unit.
  - If two pathways are active simultaneously and produce conflicting activation at their intersection, interference results. If produce coinciding activation, facilitation results.

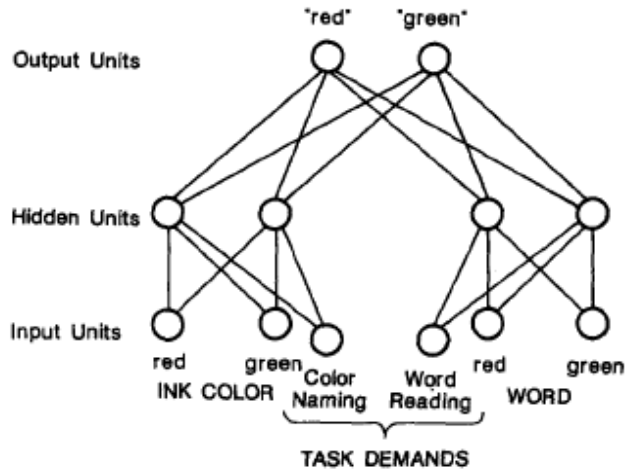

Figure 2. A parallel distributed processing model of the Stroop effect (after Cohen, Dunbar, & McClelland, 1990).