Encyclopedia of Color Science and Technology
DOI 10.1007/978-3-642-27851-8_67-1

The Stroop Effect

Colin M. MacLeod*
Department of Psychology, University of Waterloo, Waterloo, ON, Canada

Synonyms

Color-word interference; Stroop interference

Definition

The Stroop effect is one of the best known phenomena in all of cognitive science and indeed in psychology more broadly. It is also one of the most long standing, having been reported by John Ridley Stroop in the published version of his dissertation in 1935 [1]. In its basic form, the task is to name the color in which a word is printed, ignoring the word itself. When the word is a color word printed in a mismatched ink color, this is very difficult to do and results in slow, error-prone responding. To illustrate, consider **GREEN**: To say "red" to the ink color is difficult relative to a variety of comparison or control conditions such as naming the color of **XXXXX** or the word **TABLE** or even the word **RED**. The performance cost in the mismatch condition – usually referred to as the incongruent condition – relative to the controls is called the Stroop effect or Stroop interference. Figure 1 provides an illustration of the phenomenon.

Background

Since the very beginning of experimental psychology, it has been clear that words are faster to read than objects or their properties are to name. In his dissertation in 1886, Cattell [2] even went so far as to suggest that word reading is automatic due to extensive practice, introducing the concept of automaticity to cognitive science. Automatic processes can be thought of as unintentional, uncontrolled, unconscious, and fast [3]. Under the automaticity account, people cannot comply with an instruction not to read because reading cannot be "turned off"; hence it is guaranteed that incompatible words will cause interference when attempting to name their print colors.

From early on, the other prevalent explanation of Stroop interference was the relative speed of processing account, which in its simplest form argued that faster processes can affect slower processes but not vice versa [4]. Thus, because words are read faster than colors can be named, interference results when the task is to name the colors and ignore the words. This also fits nicely with Stroop's other finding – that there was no "reverse Stroop" interference when the task was to read the words and ignore the colors: Reading performance for incongruently colored words was equivalent to that for words printed in standard black ink. Stroop's results are highly replicable, as MacLeod [5] showed over a half century later.

Since Stroop's landmark study, many hundreds of studies have sought to understand this superficially simple phenomenon, and many more have used his method to explore key aspects of attention, learning, memory, reading, language, and other cognitive skills [5]. More recently, the Stroop task has also been

*Email: cmacleod@uwaterloo.ca

Encyclopedia of Color Science and Technology
DOI 10.1007/978-3-642-27851-8_67-1

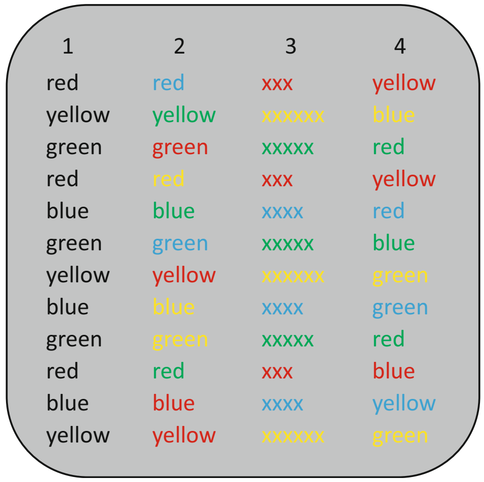

Fig. 1 An illustration of the Stroop effect. In columns 1 and 2, the task is to read each word in the column aloud, ignoring its print color, and to do so as quickly as possible. This represents Stroop's (1935) first experiment, where he found little difference in reading time between the experimental condition (column 2) and the control condition (column 1). In columns 3 and 4, the task is to name the print color of each word in the column aloud, ignoring the word itself, again doing so as quickly as possible. This represents Stroop's (1935) second experiment, where he found dramatic interference in that color naming time in the experimental condition (column 4) was much slower and more error prone than was the case in the control condition (column 3). Note that to make the conditions comparable, the same responses are required for every item in every column

extended to investigate neural mechanisms [6] and clinical disorders [7], among other issues. Interest in Stroop's method shows no signs of abating; indeed, it is one of the rare phenomena/tasks where interest seems to be growing rather than diminishing with the passage of time.

The Gradient of Interference

An intriguing feature of the Stroop literature, though, is that there was virtually no follow-up to his work for about 30 years; it is only in the 1960s that research on this phenomenon resumed and then with a vengeance. The simplest explanation of this is that the advent of computer-controlled experiments, and especially the resulting ability to time individual trial stimuli, opened up a rich new realm of investigation for which the Stroop task was ideally suited. But the study that actually relaunched research on color-word interference was reported by Klein in 1964 [8] using multiple-stimulus cards in much the same format as Stroop had used. Klein sought to understand what aspects of the words interfered with naming colors. To do so, he incorporated several new conditions. In addition to the baseline "colors-alone" card, there were six interference cards. As always, the standard incongruent condition – using words incongruent with the print colors – showed large interference. When color words that were not the names of the print colors were substituted, interference was cut in half, implicating a large role for response set in interference. Interference then declined more slowly across color-related words (e.g., *lemon, sky*); common, unassociated words (e.g., *put*, *heart*); and rare words (e.g., *sol*, *abjure*) and fell to its smallest – but still reliable – level for unpronounceable nonsense syllables (e.g., *hjh*, *gsxrq*). Clearly, despite the instruction to ignore the word, subjects cannot do so, and the greater the relevance of the word, the greater is the resulting interference with color naming. MacLeod [5] reviews the many studies that have taken up where Klein left off.

DOI 10.1007/978-3-642-27851-8_67-1

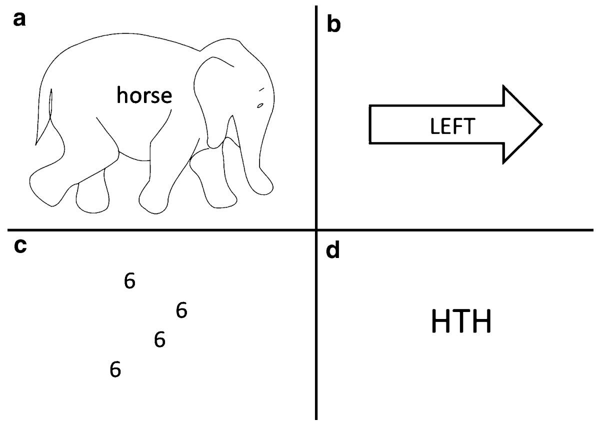

Fig. 2 Illustrations of some interference tasks derived from the Stroop "template." (**a**) The picture-word task, where naming the picture while trying to ignore the word results in interference (e.g., compared to a picture containing a row of Xs); (**b**) the "directional Stroop" task, where stating the direction in which the *arrow* is pointing suffers interference from the incompatible word (e.g., compared to no word or a row of Xs); (**c**) the "counting Stroop" task, where counting the number of digits suffers interference from the identity of the digits (e.g., compared to using letters in place of the digits); and (**d**) the flanker task, where identifying the center letter suffers interference from peripheral (flanker) letters that sometimes also appear as central targets (e.g., compared to flankers that are never central targets)

Variants of the Classic Stroop Task

In essence, Stroop's paradigm provides a template for studying interference, and investigators have often mined that template to create Stroop-like tasks suited to their particular research purposes. Figure 2 illustrates some of the many alternate versions in the literature. The best known is the picture-word interference task [9; A in Fig. 2], in which a conflicting word is embedded in a picture. As with the classic Stroop task, interference is largely unidirectional: Naming the picture shows interference from the word, but reading the word is hardly influenced by the picture. Other common variants include the directional version [10; B in Fig. 2], in which again reading the word is quite unhampered by the mismatched arrow, but there is substantial interference from the embedded word when identifying the direction of the arrow, and the digit version [11; C in Fig. 2], in which counting the number of digits is impaired when the digits themselves are incompatible with their numerosity. Further afield, but clearly related, is the flanker task [12, D in Fig. 2], wherein identification of the central letter is impaired by flankers that sometimes also serve as central targets (relative to flankers that are never targets). The list goes on, and MacLeod [5] reviews some of the more common illustrations, although more have appeared in the ensuing quarter century since that review.

Evidence Against the Speed of Processing Account

Stroop himself interpreted the interference phenomenon that now bears his name as follows: "it seems reasonable to conclude that the difference in speed in reading names of colors and in naming colors may be satisfactorily accounted for by the difference in training in the two activities." Indeed, the third experiment in his paper actually manipulated training and provided support for this explanation, and more recent studies investigating training have confirmed the importance of experience. Notably, MacLeod and Dunbar [13] trained subjects over multiple days to apply color names to initially unfamiliar white shapes. They then were able to track the growth of interference in naming the print colors of

DOI 10.1007/978-3-642-27851-8_67-1

incongruent shapes (e.g., the shape called "red" printed in blue) with extended practice on naming just the shapes in white. As shape naming became more practiced (more automatic), shapes produced more interference with naming colors, and print colors produced less interference with naming shapes.

One striking element to the MacLeod and Dunbar pattern was that there was a point in shape training where shape interference in color naming coexisted equally with color interference in shape naming. Such a result is entirely incompatible with a speed of processing account in that the shapes, although still slower to name than colors, nevertheless interfered with color naming. Two converging results were reported around the same time. First, Glaser and Glaser [14] separated the word and color, allowing one dimension to be presented at varying lags before the other. Most critically, even when the color preceded the word by a time sufficient to allow processing of the color before processing of the word, there was still no "reverse Stroop" interference: The color never interfered with the word. Second, Dunbar and MacLeod [15] transformed the words by rotating them in various ways, such as upside down and backwards. This dramatically slowed word reading time, such that it became slower than color naming time. Yet when transformed words were presented in incongruent colors, they still caused as much interference as did upright words. If relative speed of processing were all that mattered for interference, then interference should have been apparent in the Glaser and Glaser studies when color was sped up but not in the MacLeod and Dunbar studies when words were slowed down: In fact, the converse was true. Although compellingly intuitive and widely accepted [4], then, the speed of processing account does not provide a sufficient explanation of Stroop interference.

Alternative Explanations of Stroop Interference

So how *are* we to explain this apparently powerful and simple effect? In the past 25 years, three major explanations have emerged. The first of these was Cohen, Dunbar, and McClelland's parallel distributed processing, or connectionist, model, proposed in 1991 [16]. At its core, their theory is a strength theory, designed as it was to capture the training data reported by MacLeod and Dunbar [13]. Processing pathways gain strength with practice, and relative strength determines likelihood and degree of interference. Thus, given our extensive experience with reading, color-word pathways ordinarily are much more strongly connected to color name responses than are color pathways. When Cohen, Dunbar, and McClelland trained the model in various ways, they were able to reproduce many of the major empirical results in the Stroop literature identified by MacLeod [5].

In 2003, Melara and Algom [17], coming from a fundamental perception perspective, proposed that two factors underlie Stroop interference: dimensional imbalance and dimensional uncertainty. Dimensional imbalance reflects how correlated the two dimensions of a stimulus are and how surprising a stimulus is and determines the ease of recovery of a stimulus representation from memory. Dimensional uncertainty reflects how salient a stimulus is, notably how likely or unlikely it is in the context of other (recently presented) stimuli. Together, these two factors determine the success of attentional selection by focusing on salient, surprising, and/or correlated information contained within each dimension and across the two dimensions of a Stroop stimulus. Each influences excitation of targets and inhibition of distractors. Stroop interference occurs both because there is more uncertainty in the colors than in the words and because the words are more salient than the colors. Their experiments manipulating these two factors were able to produce many of the major empirical results.

Also in 2003, Roelofs [18] proposed his model of Stroop interference, a model situated in an already implemented model of word production (WEAVER ++) from the psycholinguistic literature. This also can be viewed as a two-factor model, with processing interactions occurring in the system that carries out language production, modulated by a supervisory attentional system that maintains task control. Roelofs

DOI 10.1007/978-3-642-27851-8_67-1

posited that different architectures underlie color naming and word reading, with color naming, because it is conceptually driven, requiring an extra step due to colors not being directly connected to their names, unlike words. His experiments derived from this model also reproduced many of the major results in the Stroop literature.

The Big Picture

Anyone who has tried doing the Stroop experiment themselves knows that the interference caused by an incongruent word in naming its print color is powerful. As soon as we can read, we start to show this interference. Although we think of colors as being processed with ease, the existence of Stroop interference is an indication that there is computation involved in processing color names, a computation that can be disrupted. Some of this interference in the standard Stroop paradigm is response interference (i.e., the word and the color name are different responses within the small set), which reveals little about color processing. But the fact that color words not in the response set and words simply related to colors also produce interference demonstrates the semantic contribution to the Stroop effect.

This remarkable phenomenon has been used in recent years for many purposes, including to help to identify the function of certain brain regions, notably the anterior cingulate cortex and dorsolateral prefrontal cortex, both of which are active when resolving conflict. In the context of the Stroop task, the dorsolateral prefrontal cortex appears to be involved in the relevant executive functions, particularly in maintaining response set (to name the color, not to read the word), whereas the anterior cingulate cortex plays a central role in selecting the appropriate response and evaluating its accuracy [19, 20].

One thing is clear after 80 years: This simple and robust paradigm and the interference phenomenon that it demonstrates continue to provide valuable insights into the operation of cognitive processes. It would have been hard to imagine in 1935 that merely pitting a few colors against their names could provide such an important tool.

Cross-References

► Cheers
► Colin

References

1. Stroop, J.R.: Studies of interference in serial verbal reactions. J. Exp. Psychol. **18**, 643–662 (1935)
2. Cattell, J.M.: The time it takes to see and name objects. Mind **11**, 63–65 (1886)
3. Moors, A., De Houwer, J.: Automaticity: a theoretical and conceptual analysis. Psychol. Bull. **132**, 297–326 (2006)
4. Dyer, F.N.: The Stroop phenomenon and its use in the study of perceptual, cognitive, and response processes. Mem. Cogn. **1**, 106–120 (1973)
5. MacLeod, C.M.: Half a century of research on the Stroop effect: an integrative review. Psychol. Bull. **109**, 163–203 (1991)
6. MacLeod, C.M., MacDonald, P.A.: Inter-dimensional interference in the Stroop effect: uncovering the cognitive and neural anatomy of attention. Trends Cogn. Sci. **4**, 383–391 (2000)

DOI 10.1007/978-3-642-27851-8_67-1

7. Williams, J.M.G., Mathews, A., MacLeod, C.: The emotional Stroop task and psychopathology. Psychol. Bull. **120**, 3–24 (1996)
8. Klein, G.S.: Semantic power measured through the interference of words with color-naming. Am. J. Psychol. **77**, 576–588 (1964)
9. Rosinski, R.R., Golinkoff, R.M., Kukish, K.S.: Automatic semantic processing in a picture-word interference task. Child Dev. **46**, 247–253 (1975)
10. Shor, R.E., Hatch, R.E., Hudson, L.J., Landrigan, D.T., Shaffer, H.J.: Effect of practice on a Stroop-like spatial directions task. J. Exp. Psychol. **94**, 168–172 (1972)
11. Windes, J.D.: Reaction time for numerical coding and naming of numerals. J. Exp. Psychol. **78**, 318–322 (1968)
12. Eriksen, B.A., Eriksen, C.W.: Effects of noise letters upon identification of a target letter in a non-search task. Percept. Psychophys. **16**, 143–149 (1974)
13. MacLeod, C.M., Dunbar, K.: Training and Stroop-like interference: evidence for a continuum of automaticity. J. Exp. Psychol. Learn. Mem. Cogn. **14**, 126–135 (1988)
14. Glaser, M.O., Glaser, W.R.: Time course analysis of the Stroop phenomenon. J. Exp. Psychol. Hum. Percep. Perform. **8**, 875–894 (1982)
15. Dunbar, K.N., MacLeod, C.M.: A horse race of a different color: Stroop interference patterns with transformed words. J. Exp. Psychol. Hum. Percep. Perform. **10**, 622–639 (1984)
16. Cohen, J.D., Dunbar, K., McClelland, J.L.: On the control of automatic processes: a parallel distributed processing account of the Stroop effect. Psychol. Rev. **97**, 332–361 (1990)
17. Melara, R.D., Algom, D.: Driven by information: a tectonic theory of Stroop effects. Psychol. Rev. **110**, 422–471 (2003)
18. Roelofs, A.: Goal-referenced selection of verbal action: modeling attentional control in the Stroop task. Psychol. Rev. **110**, 88–125 (2003)
19. Banich, M.T., et al.: fMRI studies of Stroop tasks reveal unique roles of anterior and posterior brain systems in attentional selection. J. Cogn. Neurosci. **12**, 988–1000 (2000)
20. Milham, M.P., Banich, M.T., Claus, E.D., Cohen, N.J.: Practice-related effects demonstrate complementary roles of anterior cingulate and prefrontal cortices in attentional control. Neuroimage **18**, 483–493 (2003)