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Automaticity of Word Reading: Evidence from the Semantic Stroop Paradigm

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Abstract

Various lines of research have independently reported that different interventions reduce or even eliminate Stroop interference. Because such findings have been interpreted as evidence that word reading can be prevented and/or controlled, these lines of research consequently challenge the widespread automatic view of word reading. This paper provides methodological and empirical arguments explaining why such conclusions might not be warranted. Since it also summarizes direct empirical evidence showing that interventions used in past studies have as yet not been found to prevent or impose any control over word reading in the Stroop task, the main conclusion of this paper is that the processes involved in word reading might (still) be considered as automatic.

Keywords: Automaticity; Response conflict; Semantic conflict; Stroop interference; Word reading.

Whether individuals complete the famous Stroop task (Stroop, 1935) on their Nintendo DS (e.g., *Brain Age: Train Your Brain in Minutes a Day!*) just for fun or as part of a highly controlled scientific experiment taking place in an fMRI machine (e.g., van Veen & Carter, 2005), the difficulty they experience is exactly the same. The effort individuals make to identify the font color of written words as quickly and accurately as possible is impeded by their incidental reading of these words. Indeed, because so-called color-incongruent Stroop words are displayed in a color that is different from the one they actually designate (e.g., **BLUE**, **GREEN**), it takes much longer to identify their font colors than it does to identify those of color-neutral words (e.g., **DEAL**, **TABLE**).

The theoretical importance of this difference, which is called Stroop interference (see also e.g., MacLeod, 1991 for a more complete review of Stroop findings), cannot be overstated as it has been central to the development of many prominent theories such as those of attention or executive function, to name just a few (see e.g., MacLeod, 1991 for a review; see also e.g., Miyake & Friedman, 2012 for an example). It has also helped researchers to gain insights into the key features of word reading, which encompasses all the processes that are mobilized up to the point at which a written word is correctly recognized so that its meaning is adequately retrieved. This paper critically discusses a portion of this research with the specific goal of examining whether word reading in the Stroop task can actually be prevented or controlled.

What Stroop interference has to tell us about word reading?

For decades, the great stability and robustness of the aforementioned difference in identification times between color-incongruent and color-neutral Stroop words (e.g., **BLUE** – **DEAL**) has been considered to provide compelling evidence that individuals cannot prevent themselves from word reading even when it clearly worsens their performance on the color-

naming Stroop task (e.g., Brown, Gore, & Carr, 2002²). In short, Stroop interference has made a significant contribution to the generally held view that word reading is *automatic* in skilled readers in the sense that it cannot be prevented or controlled (see also e.g., Neely & Kahan, 2001 for a more detailed discussion of the automatic view of word reading; and e.g., Moors, & De Houwer, 2006; for a discussion of automaticity in general).

More recently, however, this well-established view has come into question as studies from different fields (e.g., psycholinguistics, social cognition, clinical psychology etc.) have independently reported important reductions and even complete eliminations of Stroop interference (see e.g., Augustinova & Ferrand, 2014 for a review).

These spectacular findings were achieved using various interventions focusing either on the presentation of the Stroop words or on the participants who performed the task. For instance, Besner, Stolz and colleagues repeatedly demonstrated that coloring only a single letter in an incongruent color to be identified (e.g., *BLUE*, *GREEN*) eliminates Stroop interference (e.g., Besner, Stolz, & Boutilier, 1997). Other researchers obtained similar results by means of a post-hypnotic suggestion technique that caused highly suggestible individuals to consider the characters they see as gibberish (see e.g., Lifshitz, Aubert-Bonn, Fischer, Kashem, & Raz, 2013 for a review) or simply by making university students think about what the everyday life of a dyslexic person might be like (e.g., Goldfarb, Aisenberg, & Henik, 2011).

Because these different findings seem to indicate that word reading is controllable, they have been interpreted as evidence that the automaticity of word reading is a myth (e.g., Stolz & Besner, 1999), or more recently, that word reading (i.e., an automatic process that cannot be controlled voluntarily) can actually be controlled unconsciously (e.g., Goldfarb, et al., 2011; see also e.g., Lifshitz et al., 2013). In short, these different lines of research have challenged the widespread automatic view of word reading presented above.

Is the widespread automatic view of word reading threatened?

It would be, at least in our view, premature to reconsider the widespread automatic view of word reading.

It should be remembered at this point that the presence of Stroop interference clearly indicates that word reading has occurred. Indeed, it arises precisely because the meaning of the word-dimension of incongruent Stroop words (i.e., blue for **BLUE**) conflicts with the meaning of their color-dimension (i.e., green)³. Furthermore, the automatic view of word reading mentioned above requires this so-called *semantic conflict* to occur automatically since, within this view, skilled readers cannot prevent themselves from reading. However, even the complete absence of Stroop interference does not necessarily guarantee that word reading has not occurred, and this for at least two reasons.

First, even though our understanding of the processes involved in the Stroop task and their time course is still somewhat limited, it is now broadly accepted that the aforementioned semantic conflict does not entirely explain the Stroop interference depicted above (see e.g., De Houwer, 2003; Zhang & Kornblum, 1998 for more detailed reasoning). This is also –and to much greater extent– thought to result from the contribution of so-called *response conflict*, which arises from the simultaneous activation of both correct (say “green”/press green button) and incorrect (say “blue”/press blue button) response tendencies. Perhaps because this conflict is likely to occur later in processing (i.e., during the so-called response stage), it is not (unlike semantic conflict) initiated automatically even though these two types of conflict are not independent (see e.g., Augustinova & Ferrand, 2014 for more details). Consequently, any given reduction of Stroop interference might simply reflect the reduction or the elimination of this latter response conflict.

Second, even if it were possible to distinguish satisfactorily between the respective contributions of semantic and response conflict (which is not the case with Stroop interference), the probability of actually detecting the already small contribution of semantic conflict (see upper part of Figure 1) is relatively low when the Stroop task is administered with manual responses (e.g., press green button for **BLUE**).

Indeed, because manual responses produce much less interference than vocal responses (i.e., say “green” for **BLUE**; see e.g., MacLeod, 1991 for explanations), standard time measures might not be sensitive enough to detect the contribution of the semantic conflict even before any intervention designed to further reduce Stroop interference is applied (e.g., Sharma & McKenna, 1998). This is especially the case when manual Stroop tasks are used in small samples (see e.g., Kihlstrom, 2011 for a similar criticism of past work on the automaticity of word reading). Thus, as mentioned above, even a complete elimination of Stroop interference does not necessarily guarantee that word reading has been prevented because such a reduction might once again simply reflect the elimination of response conflict rather than the elimination of semantic conflict.

Because the conclusion drawn by past studies that word reading can be prevented and/or controlled is based precisely on the reductions and/or eliminations of Stroop interference observed with manual responses (see Manwell, Roberts, & Besner, 2004 for the only exception⁴), it remains plausible at this point to consider that such conclusions are unwarranted. To avoid such risk, it is important to demonstrate that a given intervention designed to further reduce Stroop interference specifically influences semantic conflict.

How to isolate the contribution of semantic conflict to Stroop interference?

One fairly straightforward way of observing a reliable semantic conflict is to use vocal instead of manual responses (e.g., Brown, Joneleit, Robinson, & Brown, 2002). Indeed, the

greater Stroop interference that vocal responses produce also proportionally increases the size of the contribution that is due to the semantic conflict (i.e., word reading). It can then be reliably detected using standard time measures – at least when appropriately isolated from the contribution of response conflict.

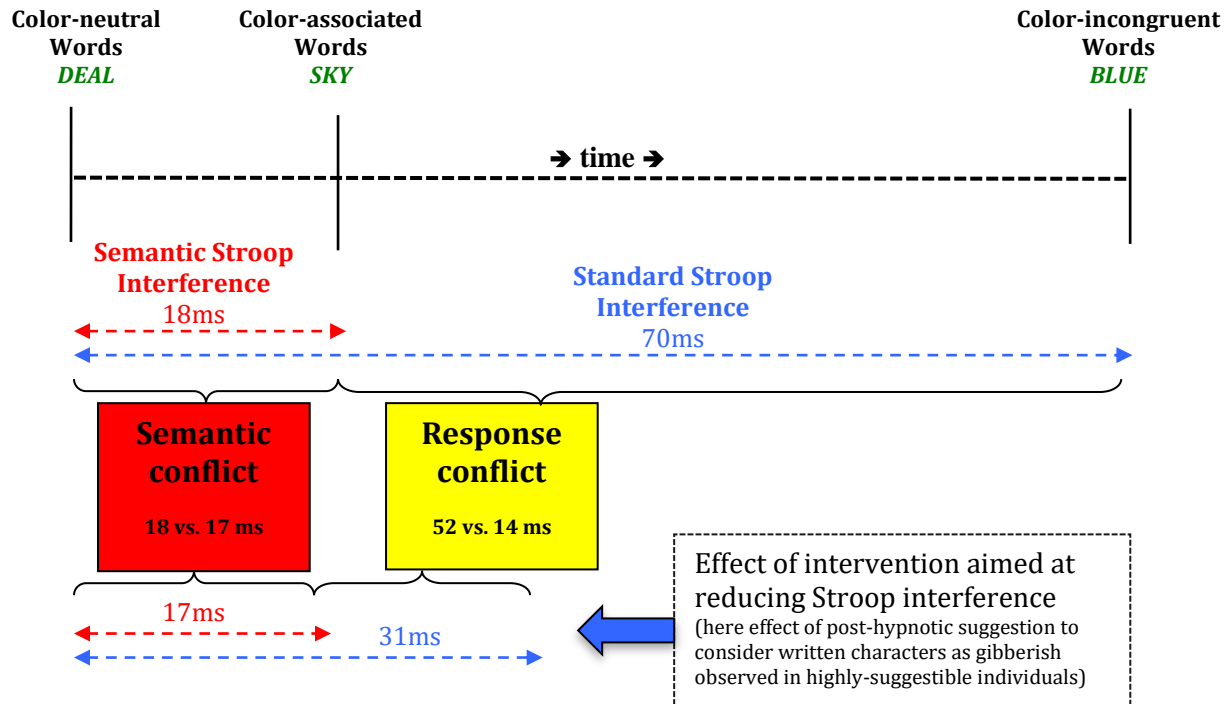


Figure 1. The semantic Stroop paradigm. Its “subtractive” logic (applied here to the data from Augustinova & Ferrand, 2012a; Experiment 1 using vocal responses) makes it possible to differentiate between the respective contributions of semantic versus response conflict to the overall Stroop interference and thus to clearly determine the type of conflict a given intervention influences.

One way to address this critical, but as yet unresolved issue is to use the so-called *semantic Stroop paradigm* (see Neely & Kahan, 2001 for the initial incentives to use this type of research). This more fine-grained variant of the Stroop task (Klein, 1964) supplements original Stroop words (e.g., **BLUE**, **GREEN**) with others that are only semantically associated with an incongruent color (e.g., **SKY**, **FROG**).

The addition of words of this type makes it possible to compute both *standard* (e.g., **BLUE** – **DEAL**) and so-called *semantic* Stroop interference (e.g., **SKY** – **DEAL**) and

consequently to isolate the semantic conflict. Because a color-associated word (e.g., **SKY**) is strongly associated with a given color (e.g., sky with blue), this semantic feature is (automatically) retrieved when the word dimension is read and “blue” subsequently conflicts with the meaning of the word's color dimension (i.e., “green” for **SKY**). This semantic conflict is, however, free of response conflict since the color-associated words do not activate (incorrect) motor responses linked to the associated color (i.e., say “blue”/press blue for **SKY**; e.g., Schmidt & Cheesman, 2005).

Also, and importantly, by simply subtracting the semantic Stroop interference from its standard counterpart, the semantic Stroop paradigm makes it possible to estimate the contribution of both semantic and response conflict to standard Stroop interference (see Figure 1, but see also e.g., De Houwer, 2003, for other possibilities).

The main advantage of this paradigm is that it does not modify the original Stroop task (i.e., it is not a new Stroop-like task) and consequently also permits comparisons with past studies, including those that have focused on word reading and its automaticity.

Past interventions have had no influence on word reading

Our own research, which has taken advantage of such comparisons, has allowed us to empirically demonstrate that our methodological reservations regarding past research (see above) are justified.

Indeed, when for instance the aforementioned post-hypnotic suggestion technique that causes highly suggestible individuals to consider the characters they see as gibberish has been applied within the semantic Stroop paradigm administered with vocal responses, it has failed to eliminate either standard or semantic Stroop interference (see lower part of Figure 1). It should be remembered that the consistent presence of both kinds of interference clearly shows that this intervention does not actually prevent these individuals from reading Stroop words.

Despite the fact that this so-called *word blindness suggestion* still considerably reduces the standard Stroop interference normally exhibited by highly suggestible participants, it has been found to have no effect on the magnitude of participants' semantic Stroop interference.

Moreover, exactly the same pattern of results has been observed with all interventions used in past research, whether they have focused on the presentation of the Stroop words (e.g., manipulation of single-letter coloring or Stroop words' position on the screen) or on the participants who performed the task (e.g., before or after they thought about the everyday life of a dyslexic person etc.). Indeed, in 13 published experiments involving more than 500 participants, semantic Stroop interference has always remained significant and of the same size irrespective of whether or not any of these interventions were applied (Augustinova & Ferrand, 2007, 2012a, 2012b, 2014, Augustinova et al., 2010; Ferrand & Augustinova, 2014).

Thanks to the subtractive logic of the semantic Stroop paradigm, this pattern of results clearly implies that past interventions (see lower part of Figure 1) have solely influenced response conflict, and sometimes to the point at which it has been completely eliminated (see e.g., Augustinova & Ferrand, 2014, Experiment 3). Thus although these interventions seem to affect the resolution and sometimes even the detection of the response conflict, they seem to have no influence on either the detection or the resolution of the semantic conflict (see e.g., Coderre, Conklin & van Heuven, 2011 for the distinction between conflict detection and resolution). However, before affirming such a conclusion, future research needs to further explore the effect of interventions known to reduce and/or eliminate Stroop interference within the semantic Stroop paradigm and do so using measures that are, unlike standard reaction times (hereafter RT), sensitive to the actual time course of this interference.

(Other) Current and future directions

Established practice in our research field holds that one effective way of avoiding potential criticisms is to use exactly the same methodology as in previously published work. Such a tradition ultimately creates consensual research practices that can sometimes turn out to be inadequate. The use of a standard Stroop task with manual responses is one example of such a practice. Of course, although there is nothing intrinsically wrong with this variant of the Stroop task, different arguments outlined in this paper clearly suggest that it is not suitable for future research aimed at the detailed examination of word reading and its contribution to overall Stroop interference.

If the question of whether word reading can be eliminated and/or brought under control is (still) precisely the issue that is addressed, future research needs to demonstrate that any elimination of Stroop interference persists with vocal responses administered to a reasonably sized sample (e.g., Cohen, 1992). In order to provide unequivocal evidence against the widespread automatic view of word reading, it is also equally important to demonstrate that any such elimination is specifically due to the elimination of the semantic conflict that was significant *before* any intervention designed to reduce it was applied.

Indeed, the reduction (as opposed to the elimination) of the semantic conflict within RT only might still not constitute sufficient evidence that the effect of word reading is itself reduced (i.e., evidence that would also run counter to the idea of its automaticity). It should be remembered that the automatic view of word reading requires only the automatic detection (as opposed to the resolution) of the semantic conflict (see e.g., Catena, Fuentes, & Tudela, 2002 for a similar idea). However, as already mentioned, a reduction of semantic Stroop interference within RT does not make it possible to determine whether the type of intervention that is being studied specifically influences the detection or the resolution of the semantic conflict⁵.

The idea that some interventions might influence the resolution of the semantic conflict actually seems to be quite plausible since the conflicting (i.e., incorrect) response tendency (e.g., say “blue”/press blue button for **BLUE**) is likely to be activated (thereby causing response conflict to occur) because the semantic conflict is not resolved when the preparation of the color-naming response is initiated. In this view, response conflict does not occur if the semantic conflict is successfully resolved beforehand. Consequently, interventions that actually reliably eliminate response conflict might produce such an effect because they influence processes involved in the resolution of semantic conflict. By contrast, interventions that reliably reduce (but do not eliminate) response conflict might influence processes involved in its resolution. Again, future research needs to further explore this still unresolved and exciting issue directly (i.e., with measures that are sensitive to the time course of Stroop interference).

Finally, if any intervention is found to indisputably prevent or control word reading, then this finding should be mirrored in complementary analyses such as those involving negative priming (i.e., an additional indicator of the fact that the word-dimension of a Stroop word has been read; but see e.g., Besner, 2001 for a different view). It should be remembered that with manual responses, the aforementioned word blindness suggestion considerably reduces and even eliminates the standard Stroop interference that highly suggestible participants otherwise exhibit. However, the complete elimination reported by Raz and Campbell (2011) was not reflected in the amount of negative priming exhibited by the participants in their study (i.e., it remained significant and of the same magnitude before and after this suggestion was administered to them). In sum, the evidence available so far from such complementary analyses of negative priming (see also e.g., Marí-Beffa, Estévez, & Danziger, 2000) strengthens our previous conclusion that past interventions do not influence word reading or its contribution to overall Stroop interference.

To summarize, the conclusions of this paper are twofold. First, the methodological and empirical arguments discussed above clearly indicate that no empirical evidence from the Stroop task currently contradicts the widespread automatic view of word reading. It can therefore be conceptualized as a process that can be neither prevented nor controlled. Second, Stroop interference can continue to serve as the “gold standard” of automaticity if, and only if, the semantic conflict is appropriately isolated and adequately separated from the response conflict, as can easily be done when the semantic Stroop paradigm is administered with vocal responses.

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Notes Page

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² In line with the idea that individuals cannot prevent themselves from reading, this research suggests that words can be read outside the focus of people's attention (see also e.g., Lachter, Ruthruff, Lien, & McCann, 2008; but see also e.g., Robidoux, Rauwerda, & Besner, 2014 for a broad discussion of the idea that the color-naming Stroop task, unlike other paradigms, does not effectively control the attention which is, according to these authors, necessary for words to be read).

³This view implies that the origin of Stroop interference is semantic (i.e., conceptual) although some authors consider that its origin is perceptual (see e.g., Hock & Egeth, 1970).

^{4,5}But see also e.g., Augustinova, Flaudias, and Ferrand (2010), for a discussion of power issues associated with elimination of semantic Stroop interference reported in this paper. Given this latter difficulty, the findings reported by Manwell et al. might indeed reflect, at best, the reduction of semantic Stroop interference which does not guarantee that word reading is itself under control.

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Recommended Reading

Augustinova, M., & Ferrand, L. (2014) (see References). This paper offers an example of empirical research using the semantic Stroop paradigm with vocal responses and also provides further details about the logic underlying its use.

Brown, T. L. (2011). The relationship between Stroop interference and facilitation effects: Statistical artifacts, baselines, and a reassessment. *Journal of Experimental Psychology: Human Perception and Performance*, 37, 85-99. This paper clearly explains why the baseline consisting of color-congruent words (e.g., **GREEN**, **BLUE** as compared to color-neutral words, e.g., **DEAL**, **TABLE**) is conceptually inappropriate, and more generally addresses the issue of different baselines (including the one consisting of letter-strings, e.g. **DDDD**, **BBBBB**) in a Stroop task.

Li, K. Z., & Bosman, E. A. (1996). Age differences in Stroop-like interference as a function of semantic relatedness. *Aging, Neuropsychology, and Cognition*, 3, 272-284. This largely overlooked work convincingly shows that only the magnitude of standard Stroop interference is larger in older adults than in young adults. This finding is consistent with the idea that word reading is indeed automatic as suggested by the lack of an age-related effect on semantic Stroop interference.

MacLeod, C. M. . <http://www.arts.uwaterloo.ca/~cmacleod/Research/Stroopbiog.htm>
This website provides interesting insights into the life and work of John Ridley Stroop.

Neely, J. H., & Kahan, T. (2001) (see References). This chapter offers a much more detailed discussion of the automaticity of word reading than the present paper.

van Veen, V., & Carter, C. S. (2005) (see References). This paper provides an insight into the distinct neural correlates of semantic and response conflict.