Title:
Suggestion Alters Stroop Automaticity: Hypnotic Alexia Through a Proactive Lens

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Contributions
A.R. designed the experiment. A.R. collected the data and published the original results. M.L. analyzed the data in-depth and wrote a draft of the manuscript. M.L., J.D-C., D.M. and A.R wrote the final version of the manuscript. A.R and M.L. secured funding for this research project.

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Abstract

Variations of hypnotic suggestion can exert substantial effects on cognitive control. For example, in the classic Stroop paradigm, posthypnotic suggestion can produce temporary alexia (i.e., word-blindness) in individuals highly susceptible to hypnotic suggestion. While the mechanisms underpinning this form of reversible (though functional) alexia remain largely speculative, some tentative explanations point to the important role of anticipatory preparedness in hypnosis. In line with the dual framework for cognitive control, the present paper—drawing on a unified dataset comprising several published studies on hypnotically-induced alexia (N=67)—examines whether posthypnotic suggestion follows a proactive process of executive control. Our approach relies on delta plots, a form of time-course analysis focusing on the frequency of change to capture differences in response time distributions across quantiles. We hypothesized that in the Stroop task, proactive control would manifest in early word-blindness within conflict. Our results support this hypothesis: suggestion practically eliminates processing related to conflict within the first quantile estimate Moreover, we fitted a linear model to account for patterns of change in the delta function and found that the suggestion reduces the slope of the delta plots. However, this effect hardly changed as a function of hypnotic susceptibility, which cast doubt on its contribution to word-blindness. These findings highlight the centrality of anticipation and response expectancy in hypnotic suggestion. This proactive view opens new research prospects for a more scientific understanding of how hypnotic suggestion molds cognitive control.

Introduction

Automaticity represents a ubiquitous feature that conveys important benefits in well-adapted behaviors (Bargh, 1989; Moors & De Houwer, 2006). Automatic processing offers an efficiency advantage, but also distinguishes between ballistic habits and higher-order cognition that relies on overarching strategies for the pursuit of a goal (Evans, 2008; Evans & Stanovich, 2013). The dual-process or dual-system theory of cognition construes the human mind as switching between controlled and automatic processes to affect judgments, decisions, and behaviors.

Despite its inherent benefits, in certain contexts automaticity may result in maladaptive responses (Wasserman & Wasserman, 2016). For example, difficulty in exerting control over apparently automatic thought patterns or images often characterizes anxiety disorders (Teachman, Joormann, Steinman, & Gotlib, 2012). Moreover, multiple scholars argue that once triggered, control processes appear limited in their capacity to override an automatic, ballistic process (Bargh, 1994; Kihlstrom, 2008). In other words, once the bell has rung, we cannot unring it.

Clinical strategies for counteracting ill-adapted automatic patterns often aim to increase cognitive control. Cognitive behavioral therapy, for example, attempts to enhance self-monitoring abilities to catch, and subsequently suppress, negative automatic thought patterns (e.g., Cohen, Mor, & Henik, 2015). And yet, deeply ingrained processes appear resistant to these sorts of tactics. For example, recalling a traumatic experience in the context of therapy may trigger strong affective reactions, which may ultimately derail the therapeutic process (e.g., Eftekhari, Zoellner, & Vigil, 2009). In recent years, hypnosis has emerged as a viable clinical approach for empowering control processes and overriding deeply ingrained responses (Alladin, 2008). Collectively, these accounts support the idea that hypnotic suggestion can assist cognitive control and illuminate the complex dynamics between controlled and automatic processes.

Experimental data from our research group and other labs establish the capability for hypnotic suggestion to modulate various ballistic processes across different conflict paradigms, especially Stroop (for review, see Lifshitz, Aubert Bonn, Fischer, Kashem, & Raz, 2013). Instead of framing automatic processes as juggernauts, this line of research paves the way to a nuanced outlook highlighting the malleability of automaticity (cf. Melara & Algom, 2003)

One putative explanation for how hypnosis regains control over automatic processes assumes the efficient deployment of top-down regulation and executive functions. Adaptive strategies aiming to achieve a specific goal facilitate selecting goal-relevant information, maintaining it, and inhibiting irrelevant distractors and maladaptive responses (Diamond, 2013). This phenomenon is perhaps best exemplified in highly hypnotic susceptible individuals who markedly reduce the Stroop Interference Effect, following a (post)hypnotic suggestion for alexia (Raz, Shapiro, Fan, & Posner, 2002). In the classic Stroop experiment, participants see the names of colors (the word “RED”) in different colored fonts, wherein the word stimulus and the color font may be congruent (e.g., the word “RED” shown in a red font) or incongruent (e.g., the word “RED” shown in blue; Stroop, 1935). In literate individuals, the difference between congruent and incongruent Stroop trials highlights the automaticity of reading (MacLeod, 1991). In other words, irrelevant semantic (but also orthographic and phonetic) information hinders the discrimination of the font color. Here, incongruent trials worsen performance (i.e., longer reaction times and fewer correct responses), whereas compatible trials improve it compared to neutral stimuli. While this phenomenon emphasizes the automatic nature of word reading, a specific hypnotic suggestion reliably de-automatizes this effect, both at the behavioral and neural levels (Raz, Fan, & Posner, 2005).

The mechanisms that enable word-blindness remain largely elusive. To gain better insight into this process, we turn to the dual framework of cognitive control and submit that word-blindness leverages anticipatory processes of early selection (Braver, 2012). This overarching view of cognitive control posits that mechanisms of executive control vary as a function of their temporal dynamics. In this fashion, proactive control corresponds to anticipatory activity upholding goal-relevant information, with respect to forthcoming stimulus (e.g., maintaining the goal "I need to attend to the color of the ink" during a Stroop task). In contrast, reactive control reflects transient stimulus-driven responses of executive processes for resolving conflict, which would interfere with achieving the goal (e.g., seeing an incongruent stimulus in the Stroop task reactivates your goal of responding to the ink color, not the semantic value; Braver, 2012). Control mechanisms separate accordingly into systems that optimize both preparation and reaction with respect to conflict resolution; moreover, multiple experimental approaches support this overarching view (Chiew & Braver, 2017). Accordingly, drawing on several lines of research proposing that hypnosis relies on some form of response preparation, we hypothesize that hypnotic responding entails proactive control (Kirsch, 1985; Kirsch, Wickless, & Moffitt, 1999; Zahedi, Abdel Rahman, Stürmer, & Sommer, 2019). Notably, previous work highlights how response expectancy – the anticipation of specific subjective and behavioral responses to situational cues – shapes forthcoming hypnotic responses (for review, see Kirsch, 1997). This theoretical framework therefore underlies our hypothesis that word blindness entails heightened response preparation through increased proactive control. This hypothesis is likewise consistent with previous work showing that word-blindness occurs at both shorter and longer inter-trial intervals—providing participants with more time to prepare their response, benefits the outcome (Parris, Dienes, & Hodgson, 2013). Furthermore, we hypothesize that anticipation will emerge as a key component for complying with a hypnotic suggestion.

Delta Plots

The current work shows the utility of delta-plot analyses and distribution-analytical techniques to explore individual differences using behavioral data from a prototypical conflict task. Related to quantile plots and Vincentile plots (i.e., an alternative to quantiles, computed by sorting the data and then splitting them in equi-populated bins), delta plots show the difference between congruency experimental conditions along the y-axis, as a function of the mean across conditions for each estimate along the x-axis (De Jong, Liang, & Lauber, 1994). In other words, they provide a visualization method based on the quantiles of reaction time (RT) distribution (Speckman, Rouder, Morey, & Pratte, 2008). Thus, delta plots uncover key information concerning the underlying mechanisms of cognitive control and inhibition (Pratte, Rouder, Morey, & Feng, 2010).

RT data tend to skew positively (i.e., right side, “tail,” of histogram is longer than its left side) with this distribution providing a meaningful source of information to inform or constrain cognitive theories and computational models (Luce, 1986; Van Zandt, 2000). However, most published papers often shy away from systematic explorations of the rich information contained within a distribution, by opting to flatten the data and summarize the variation using a single value, such as the mean. However, by illustrating the distribution or by resorting to explicit mathematical models and fitting functions to simulate the shape of the distributions, we can gain considerable knowledge and theoretical insights into the underlying cognitive process (Balota & Yap, 2011).

To this end, the current study relied on delta plots to assess the temporal dynamics of the Stroop Interference Effect during hypnotic alexia and therefore capture the time course of the word-blindness phenomenon. In the Stroop paradigm, delta plots capture the temporal component of the congruency effect (i.e., incongruent minus congruent trials) across RT percentiles through a positive slope of the delta function (Pratte et al., 2010). This upward slope indicates that conflict processing on incongruent Stroop trials grows as time elapses from target onset. Previous evidence shows that the congruency effect likely encompasses both proactive and reactive control (Gonthier, Braver, & Bugg, 2016). The rationale for assessing these cognitive systems through delta plots follows from the idea that processes involved in the mitigation of conflicting information need to ramp-up and therefore take time to unfold (Ridderinkhof, 2002a). Hence, mounting reactive control entails a steeper slope of the delta function as mitigation occurs much later in the process, as revealed through high levels of interference for late response times. A smaller slope therefore implies less conflict at later stages of the process (Ridderinkhof, 2002b) . Several reports highlight the usefulness of this analytic approach to uncover inter-individual differences regarding reactive and proactive control (e.g., Wylie, Ridderinkhof, Bashore, & van den Wildenberg, 2010) .

The current research aims to determine whether hypnotic responding impacts early quantile estimates on this basis. Given the potential for delta plots to unravel the temporal dynamics of congruency effects, we reasoned that the involvement of proactive control would manifest early during conflict-related processing. Note that this hypothesis does not preclude the possibility that the alexia suggestion also benefits from reactive control processes, especially given that the Stroop effect entails several loci of control. Proactive and reactive means of control are not mutually exclusive. Nevertheless, a reduction of the congruency effect for early quantile estimates would constitute strong evidence for the involvement of proactive processes during word-blindness. We additionally fitted a linear model across quantile estimates to capture the overall trend of congruency effect through RT distribution, and then examined whether the slope component of this model varied as a function of hypnotic susceptibility and suggestion. Drawing from previous work that adopted a similar approach (e.g., Pratte et al., 2010), our analysis allowed us to verify the gradual emergence of executive control to deal with conflict-related processing.

Methods

Participants. Our present dataset comprises an aggregate of participant data from studies, conducted by our research group, on word-blindness, hypnotic suggestion, and Stroop interference (Raz et al., 2005; Raz et al., 2003; Raz, Moreno-Íniguez, Martin, & Zhu, 2007; Raz et al., 2002). The current sample included individuals screened on the The Harvard Group Scale of Hypnotic Susceptibility Form A (HGSHS-A; Shor & Orne, 1962) and the Stanford Hypnotic Susceptibility Scale Form C, without the ammonia challenge for anosmia (SHSS-C; Weitzenhoffer & Hilgard, 1962). All participants from this previous work were included. We included individuals less susceptible to hypnotic suggestion (LHSIs; i.e., bottom 5% on the HGSHS-A and scoring 0 or 1 on the SHSS-C, N =34) and HHSIs (i.e., top 5% on the HGSHS-A and scoring 10 or 11 on the SHSS-C, N=33). All participants were proficient readers of English between 20 and 41 years of age. Note that all data were anonymized, and Ethics committee from McGill University and Columbia does permit us to share information regarding gender and age for each participant. Below, we describe in detail the procedures of the previous studies from which the current dataset is composed of.

Stimuli. Stimuli consisted of a single word written in red, blue, green, or yellow presented against a white background. Following the classic Stroop procedure, word stimuli either designated colors in the following manner: “RED”, “BLUE”, “GREEN”, and “YELLOW”; or designated neutral elements with respect to the Stroop effect: “LOT”, “SHIP”, “KNIFE” and “FLOWER.” We matched neutral words for length and lexical frequency with respect to color words. Participants received feedback throughout the experiment: the words “CORRECT” or “INCORRECT” would appear following a response. All word stimuli were upper-case characters of 0.5° vertically and 1.3° to 1.9° horizontally. Before word onset stimuli, a black fixation cross flashed in the center of the screen.

Design and procedure. Participants were sitting approximately 67 centimeters from a computer monitor and were instructed to maintain their attention on the center of the screen throughout the experiment. Each trial would start with a crosshair, replaced by the word stimulus which remained on the screen for 2 seconds or until the participant responded. Finally, participants were given feedback on the accuracy of their response. The inter-trial interval was set to 4 seconds.

The word stimuli were either congruent with the color of the text (e.g., the word “BLUE” presented in blue) or incongruent (e.g., the word “BLUE " presented in red), while neutral words provided a reliable baseline condition. For each trial, participants were asked to indicate, as quickly and as accurately as possible, the ink-color of word stimulus using one of the following four keys on a keyboard: “V”, “B”, “N”, “M” for red, blue, green, and yellow respectively.

Prior to the experiments, we informed all participants that the study would include a hypnotic suggestion. The senior author (A.R.) administered all hypnotic procedures from the Stanford Hypnotic Susceptibility Scale as well as the following post-hypnotic suggestion:

“*Very soon you will be playing the computer game. When I clap my hands, meaningless symbols will appear in the middle of the screen. They will feel like characters of a foreign language that you do not know, and you will not attempt to attribute any meaning to them. This gibberish will be printed in one of four ink colors: red, blue, green, or yellow. Although* *you will be able to attend to the symbols' ink color only, you will look straight at the scrambled signs and crisply see all of them. Your job is to quickly and accurately depress the key that corresponds to the ink color shown. You will find that you can play this game easily and effortlessly*."

Upon terminating the induction, a hand clap would serve as the cue to trigger the post-hypnotic response, therefore preceding the post-hypnotic suggestion experimental condition. A double hand clap indicated to participants to disregard the suggestion. All participants completed the task twice, once without the post-hypnotic suggestion and once with it. This experimental manipulation was counterbalanced across participants. They also completed 32 practice trials prior to the first experimental session. Each experimental condition (i.e., Stroop task with and without post-hypnotic suggestion) comprised 144 trials (i.e., congruent, incongruent, and neutral conditions) presented in random fashion.

Analysis. First, we computed quantiles (i.e., .1, .3, .5., .7, .9 percentiles) from accurate RT distributions of each participant for congruent and incongruent trials separately across suggestion conditions (i.e., with and without). We then evaluated differences across estimates using hierarchical linear regression models, whereby we included quantile estimates (i.e., first, second, third, fourth, versus fifth estimates), hypnotic susceptibility (i.e., LHSIs versus HHSIs), post-hypnotic suggestion (i.e., with versus without), and their interaction as fixed factors, and participants nested within each of the different experiments as random factors. While the delta plot approach might violate certain assumptions concerning ordinary least square methods, previous research confirms the validity of this strategy in the context of delta plots for Stroop task RT (De Jong et al., 1994; Pratte et al., 2010). Here, investigation of delta plots show that averaging across percentile is valid even for slightly different shapes of distributions (Rouder & Speckman, 2004). We included fixed factors in the model in stepwise fashion and selected the best fitting model using Chi-square goodness-of-fit test and the Bayesian Information Criterion (BIC). We further computed Bayes factor to assess the evidence for both the null and alternative hypotheses relative to our regression models using their BIC (Wagenmakers, 2007):

$$BF_{01} = e^{\Delta BIC_{10}/2}$$

Post-hoc assessments were performed using random permutations one sample t-Test with 10,000 permutations, where we additionally applied Jeffrey-Zellner-Siow Bayes factor using a default Cauchy r scaling prior of .707 (Rouder, Speckman, Sun, Morey, & Iverson, 2009).

In addition to the analyses outlined above, we further evaluated the temporal profile of conflict-related processing by fitting linear models across quantile estimates for each participant, and then evaluated the slope and the predicted value for the first quantile. The slope marks variations in the deployment of processes involved in the mitigation of conflicting information. This parameter therefore determines how quickly the system reconciles incongruent and irrelevant information. In lieu of the intercept, we looked at the predicted value on the y-axis for the first quantile estimate across each participant. We opted for this approach instead of examining the intercept because predicted delta values are meaningless at 0ms on the x-axis. No such meaningful RT exists. As such, we aimed to determine whether the model confirms that the suggestion mitigates the congruency effect at the earliest estimate of the delta function. A reduction of the congruency effect at the earliest estimate of the model would indeed corroborate the involvement of anticipation and expectancy. This secondary set of analyses therefore aims to further corroborate the findings pertaining to the overall trend of the delta function with respect to proactive control. We therefore evaluated the change in slope and predicted value at the quantile estimate of the delta function for each participant across hypnotic susceptibility and suggestion (De Jong et al., 1994). Previous work demonstrates how the analysis of the slope represents a reasonable approach to examine the trend of delta plots (Pratte et al., 2010). We again relied on linear regression models where we included participants nested within experiments as a random factor, and then included hypnotic susceptibility (i.e., low versus high hypnotic susceptibility), suggestion (i.e., with and without suggestion) and their interaction in a stepwise fashion. Again, we used Chi-square and the BIC to perform model selection.

Results. With respect to our primary analyses where we evaluated delta values as a function of quantile (.1, .3, .5, .7, & 9.), hypnotic susceptibility (low versus high), and suggestion (no suggestion versus suggestion), the best fitting model (see Table 1 and 2) included main effects of quantile estimates ($\beta = 39.77$, $SE = 13.19$, 95% CI [4.83, 56.65]), as well as quantile estimates by post-hypnotic suggestion conditions ($\beta = -20.96$ $SE = 4.43$, 95% CI [-29.66, -12.26]) and hypnotic susceptibility by post-hypnotic suggestion conditions ($\beta = -58.43$ $SE = 12.53$, 95% CI [-83.03, -33.82]) two-way interactions (see Figure 1) as reliable predictors. In this fashion, evidence shows that conflict-related processing increases as a function of quantile estimates, which replicates previous work on the Stroop task (Pratte et al., 2010). Furthermore, these results corroborate the word-blindness effect in HHSIs across all quantiles, including early estimates. Converging evidence supports this assertion. First, the hypnotic susceptibility by post-hypnotic suggestion two-way interaction was reliable and hardly varied across quantile estimates. Further support for this observation comes from the fact that the three-way interaction involving quantile estimates, hypnotic susceptibility, and post-hypnotic suggestion was not reliable and scantily improved the fit of our model (χ^2 (1) = .3, p = 0.6). Second, we evaluated evidence for the null versus the alternative hypothesis using Bayes factors and compared the best fitting model with and without the three-way interaction. This approach confirmed that evidence favored the null hypothesis for the three-way interaction, BF_{01} = 22.48, therefore indicating that word-blindness hardly varies across quantile estimates. Moreover, post-hoc evaluations using a one sample permutation t-test confirmed our assessment. For HHSIs, we observed that without the suggestion delta values reflecting conflict-related processing were greater than zero for the first (t(33) = 5.17 p < .001, JSZ BF = 1850.89) and second (t(33) = 5.96 p < .001, JSZ BF = 16214.97) quantile estimates. Conversely, with the suggestion, our results reveal that delta values for the first (t(33) = .29, p = .77, JSZ BF = 5.23) and second (t(33) = .7, p = .5, JSZ BF = 4.33) quantiles estimates were no different than zero. Early responses for word-blindness, therefore, reveal limited conflict-related processing. On the other hand, post-hoc assessments for LHSIs demonstrate that delta values of the first (t(32) = 4.17, p < .001, JSZ BF = 125.69) and second (t(32) = 5.33, p < .001, JSZ BF = 2669.28) quantile estimate show a non-zero congruency effect without suggestion, as well as with suggestion (first quantile t(32) =

3.04, $p < .01$, JSZ BF = 8.45; second quantile ($t(32) = 4.21$, $p < .001$, JSZ BF = 139.29). Taken together, these findings highlight that word-blindness occurs for early conflict-related processing.

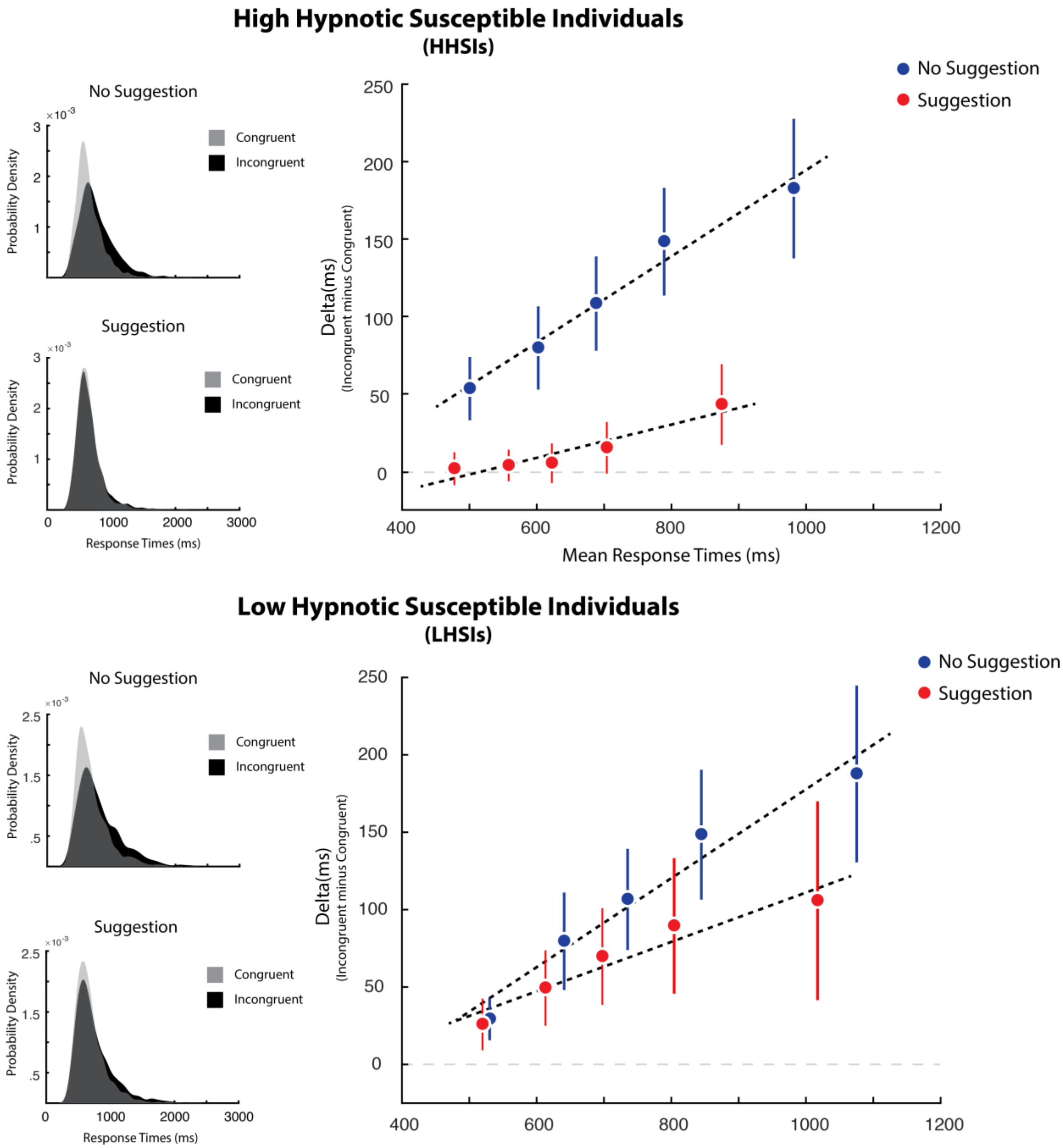

Figure 1. On the left, response time distributions across Stroop congruent (black) and Stroop incongruent (pale grey) trials, with and without suggestion for alexia, for HHSIs (top) and LHSIs (bottom). On the right, delta plots (i.e., averaged RT of Stroop incongruent minus Stroop congruent across quantile estimates) as a function of suggestion (red) and without suggestion(blue) in HHSIs (top) and LHSIs (bottom). The shaded

area represents bootstrapped 95% Confidence Interval (C.I.). Suggestion suppresses the Stroop Interference Effect, in early quantile estimates, for HHSIs under suggestion. This result is consistent with and attributable to a proactive cognitive control mechanism to manifest word-blindness.

Models	X_2	p-value	BIC
RT ~ β0 + S0 [Experiment|Subject] + ε			8167.3
RT ~ β0 + S0[Experiment|Subject] + *β1[Quantile Estimates]* + ε	90.79	p < .001	8082
RT ~ β0 + S0[Experiment|Subject] + *β1[Quantile Estimates]* + *β2[Hypnotic Susceptibility]* + ε	3.29	p = .07	8085.3
RT ~ β0 + S0[Experiment|Subject] + *β1[Quantile Estimates]* + *β2[Hypnotic Susceptibility]* + *β3[Post-Hypnotic Suggestion]* + ε	111.22	p < .001	7980.6
RT ~ β0 + S0[Experiment|Subject] + *β1[Quantile Estimates]* + *β2[Hypnotic Susceptibility]* + *β3[Post-Hypnotic Suggestion]* + *β4[Quantile Estimates* ***X*** *Hypnotic Susceptibility]* + ε	3.19	p = .07	7983.9
RT ~ β0 + S0[Experiment|Subject] + *β1[Quantile Estimates]* + *β2[Hypnotic Susceptibility]* + *β3[Post-Hypnotic Suggestion]* + *β4[Quantile Estimates X Hypnotic Susceptibility]* + *β5[Quantile Estimates X Post-Hypnotic Suggestion]* + ε	21.24	p < .001	7969.1
***RT* ~ β0 + S0[Experiment|Subject] + *β1[Quantile Estimates]* + *β2[Hypnotic Susceptibility]* + *β3[Post-Hypnotic Suggestion]* + *β4[Quantile Estimates X Hypnotic Susceptibility]* + *β5[Quantile Estimates X Post-Hypnotic Suggestion]* + *β6[Hypnotic Susceptibility X Post-Hypnotic Suggestion]* + ε**	**21.36**	**p < .001**	**7954.3**
RT ~ β0 + S0[Experiment|Subject] + *β1[Quantile Estimates]* + *β2[Hypnotic Susceptibility]* + *β3[Post-hypnotic Suggestion]* + *β4[Quantile Estimates* ***X*** *Hypnotic Susceptibility]* + *β5[Quantile Estimates* ***X*** *Post-Hypnotic Suggestion]* + *β6[Hypnotic Susceptibility* ***X*** *Post-Hypnotic Suggestion]* + *β7[Quantile Estimates* ***X*** *Hypnotic Susceptibility* ***X*** *Post-Hypnotic Suggestion]* + ε	0.28	p = .6	7960.5

Table 1. Stepwise Chi-square goodness-of-fit values, corresponding p-values and Bayesian Criterion Information (BIC) of hierarchical linear regression models for predicting average RT values across RT distribution quantile estimates (i.e., .1, .3, .5, .7, .9), hypnotic susceptibility (i.e., low versus high), and post-hypnotic suggestion (i.e., with and without), and their interactions as fixed factors, with participants nested within experiment as random factors. The best fitting model is in bold.

Variables	Coefficient	Std. Error	95% C.I.
Intercept	30.74	13.19	[4.83 56.65]
Quantile Estimates	39.77	3.85	[32.2 47.34]
Hypnotic Susceptibility	20.56	17.45	[-13.7 54.82]
Post-Hypnotic Suggestion	-.34	12.58	[-25.03 24.36]
Quantile Estimates ***X*** Hypnotic Susceptibility	-8.21	4.43	[-16.91 .49]
Quantile Estimates ***X*** Post-Hypnotic Suggestion	-20.96	4.43	[-29.66 -12.27]
Hypnotic Susceptibility ***X*** Post-Hypnotic Suggestion	-58.43	12.53	[-83.03 33.82]

Table 2. Parameter estimates, corresponding standard error, and 95% C.I. of best fitting hierarchical linear regression model.

Next, we fitted a linear model through quantile estimates for each participant as a function of suggestion conditions and tested whether the slope and the model's prediction for the first quantile estimate varied as a function of hypnotic susceptibility and suggestion (see Figure 2). Relying on hierarchical regression models where we included hypnotic susceptibility (i.e., low versus high) and suggestion (i.e, without versus with suggestion) as fixed factor and participants nested within experiments as a random factor for predicting the slope value, the best fitting model revealed that suggestion was the sole statistically reliable predictor (β = -.17 SE = .04, 95% CI [-.25, -.08]; see Tables 3 and 4). Bayes factors analysis provided further evidence against the model comprising the hypnotic susceptibility by suggestion, BF_{01} = 10.97. Hence, the alexia suggestion reduced the slope of the delta function, yet our results intimate that this effect hardly varied across hypnotic susceptibility. Conversely, the best fitting model for estimating the model's prediction at the first quantile estimate shows a statistically reliable hypnotic susceptibility by suggestion interaction (β = -52.17 SE = 17.3, 95% CI [-86.4, -17.95]; see Tables 5 and 6), thereby corroborating that the linear model predicted a lower delta value for the first quantile. This outcome is consistent with our previous analyses where we observed that the first quantile values were no different than zero. The linear model therefore indicates that word-blindness, which entails a hypnotic susceptibility by suggestion interaction, proceeds from this early mitigation of the congruency effect.

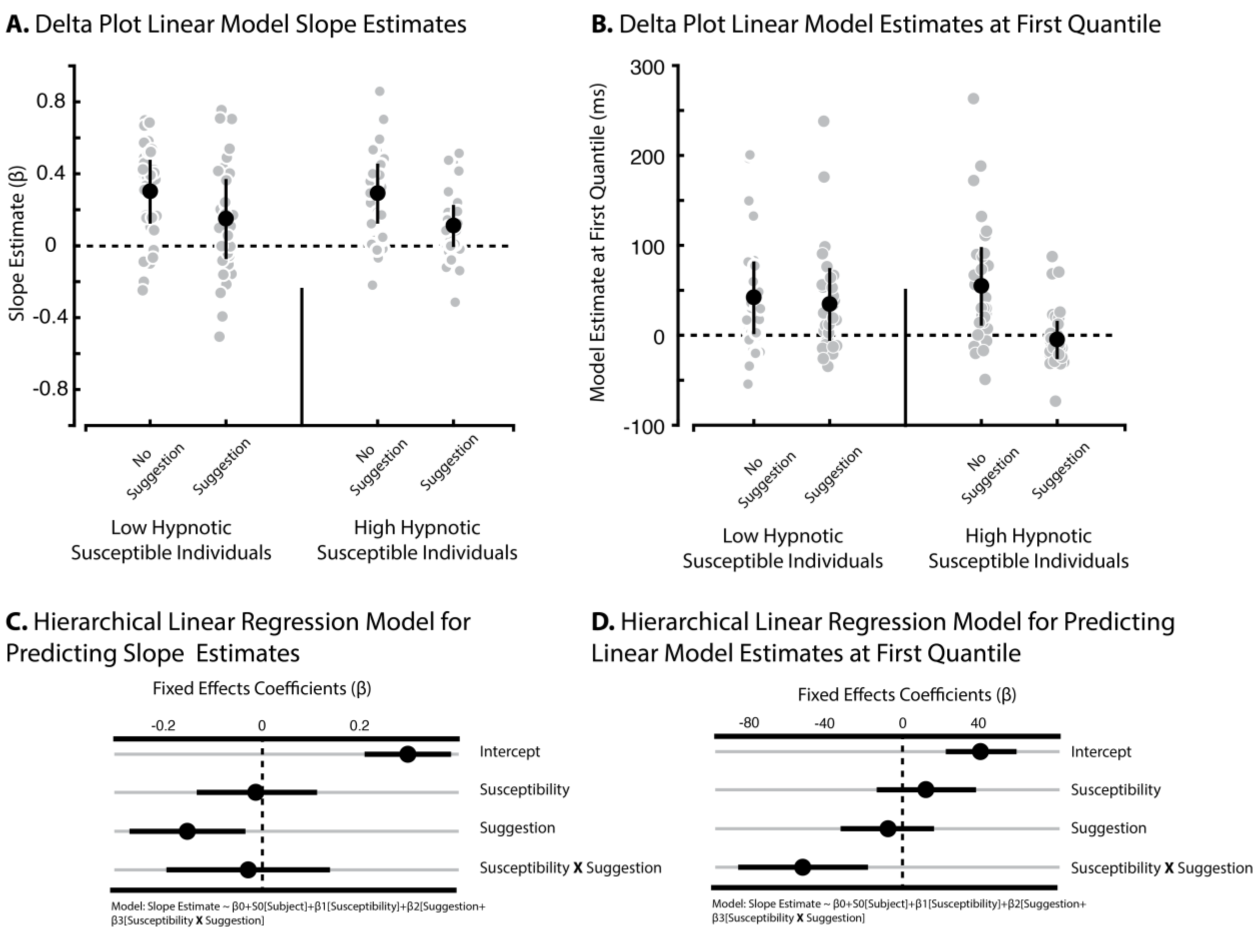

Figure 2. A. Delta plot linear model slope estimates as a function of hypnotic susceptibility and suggestion. Grey dots represent estimates for each individual participant. Black dots represent average slope values. Error bars represent 95% bootstrapped C.I. **B.** Delta plot predicted values of the linear model for the 1st

quantile estimate as a function of hypnotic susceptibility and suggestion. Grey dots represent estimates for each individual participant. Black dots represent average slope values. Error bars represent 95% bootstrapped C.I. **C.** Hierarchical linear regression coefficients and corresponding confidence intervals for predicting delta plot linear model slope estimates as a function of hypnotic susceptibility, suggestion, and their interaction. Here we observe that the sole statistically reliable predictor is the suggestion. **D.** Hierarchical linear regression coefficients and corresponding confidence intervals for predicting the linear model prediction at the 1st quantile estimate as a function of hypnotic susceptibility, suggestion, and their interaction. We observe that the interaction involving hypnotic susceptibility and suggestion was reliable.

Models	X_2	p-value	BIC
Slope ~ β0 + S0 [Experiment|Subject] + ε			43.21
Slope ~ β0 + S0[Experiment|Subject] + *β1[Hypnotic Susceptibility]* + ε	.27	p = .6	47.83
***Slope* ~ β0 + S0[Experiment|Subject] + *β1[Hypnotic Susceptibility] + β2[Post-Hypnotic Suggestion]* + ε**	**13.94**	**p < .001**	**38.79**
Slope ~ β0 + S0[Experiment|Subject] + *β1[Hypnotic Susceptibility] + β2[Post-Hypnotic Suggestion] + β6[Hypnotic Susceptibility **X** Post-Hypnotic Suggestion]* + ε	.11	p = .74	43.58

Table 3. Stepwise Chi-square goodness-of-fit values, corresponding p-values and Bayesian Criterion Information (BIC) of hierarchical linear regression models for predicting average Slope values across hypnotic susceptibility (i.e., low versus high), and post-hypnotic suggestion (i.e., with and without), and their interactions as fixed factors, with participants nested within experiments as random factors. The best fitting model is in bold.

Variables	Coefficient	Std. Error	95% C.I.
Intercept	.31	.04	[.23 .38]
Hypnotic Susceptibility	-.02	.05	[-.12 .06]
Post-Hypnotic Suggestion	-.16	.04	[-.25 -.08]

Table 4. Parameter estimates, corresponding standard error, and 95% C.I. of best fitting hierarchical linear regression model.

Models	X_2	p-value	BIC
Prediction 1st Q. ~ β0 + S0 [Experiment|Subject] + ε			1486.1
Prediction 1st Q. ~ β0 + S0[Experiment|Subject] + *β1[Hypnotic Susceptibility]* + ε	1.74	p = .19	1483.3
Prediction 1st Q. ~ β0 + S0[Experiment|Subject] + *β1[Hypnotic Susceptibility] + β2[Post-Hypnotic Suggestion]* + ε	12.35	p < .001	1481.8

***Prediction 1st Q.* ~ β0 + S0[Experiment|Subject] + *β1[Hypnotic Susceptibility] + β2[Post-Hypnotic Suggestion] + β6[Hypnotic Susceptibility X Post-Hypnotic Suggestion]* + ε**	**8.53**	**p < .01**	**1478.2**

Table 5. Stepwise Chi-square goodness-of-fit values, corresponding p-values and Bayesian Criterion Information (BIC) of hierarchical linear regression models for predicting the model's prediction for the 1st quantile estimate across hypnotic susceptibility (i.e., low versus high), and post-hypnotic suggestion (i.e., with and without), and their interactions as fixed factors, with participants nested within experiments as random factors. The best fitting model is in bold.

Variables	Coefficient	Std. Error	95% C.I.
Intercept	41.72	9.43	[23.05 60.38]
Hypnotic Susceptibility	12.74	13.24	[-13.46 38.94]
Post-Hypnotic Suggestion	-7.47	12.32	[-31.85 16.92]
Hypnotic Susceptibility X Post-Hypnotic Suggestion	-52.17	17.3	[-86.4 -17.95]

Table 6. Parameter estimates, corresponding standard error, and 95% C.I. of best fitting hierarchical linear regression model.

Discussion

The current research effort aims to test the proactive view of hypnosis and evaluate the centrality of mental preparation in producing a reliable response to a post-hypnotic suggestion for alexia—i.e., suggestion for word-blindness. This research proceeds from theories that emphasize the involvement of anticipation and expectancy in hypnosis {Kirsch, 1997 #746;Ploghaus, 2003 #178, while evidence for this view remains limited with respect to word-blindness. Hence, we aimed to investigate this prediction and verify whether hypnotic suggestion for alexia benefits from proactive control. To test this idea, we examined the word-blindness effect in the Stroop task through delta plots – an approach designed to explore the time course of conflict-related processing through quantile estimate of RT distributions.

The contribution of proactive control to word-blindness entails that individuals should exhibit rapid management of cognitive conflict. This effect would effectively translate to early benefits of the suggestion for HHSIs during the Stroop task. Our results support this prediction. Specifically, we found evidence for early mitigation of the congruency effects, thereby indicating that top-down regulation is likely to implement the suggestion and recruit executive functions before stimulus onset. This early outcome reflects the central difference we observed between both groups as a function of the alexia suggestion. At the same time, however, this observation hardly precludes the involvement of reactive cognitive control. As delta plot analysis and our present work are suboptimal to test the involvement of reactive control in hypnosis, we must therefore entertain the possibility that reactive control processes--in addition to proactive systems--may also influence the suggestion's suppression of congruency effects. We nevertheless concede that the current set of results somewhat downplays the role of reactive control. Future research can address such issues with more careful consideration.

Evidence for the involvement of proactive control arises along two fronts. First, our results emphasize the rapid suppression of the congruency effect in HHSIs, while LHSIs were incapable of such fast responses for resolving cognitive conflict. The early emergence of word-blindness therefore provides fodder for the proactive mill, as this outcome implies that prior response preparation and anticipation likely support such quick and efficient mitigation of conflicting processing. Second, we also explored the temporal dynamics of the word-blindness phenomenon by assessing the slope of a linear model we fitted through quantile estimates. This approach follows from the Ridderinkhof activation-suppression framework that contends that conflict resolution gradually builds up across quantiles (Ridderinkhof, 2002a, 2002b). We accordingly reasoned that changes in the slope value would correspondingly index variations of this gradual process. Here we found that while the slope estimates varied as a function of suggestion, hypnotic susceptibility hardly impacted this component. Hence, the suggestion prompted mitigation of conflict-related processing for both HHSIs and LHSIs; a somewhat unexpected finding that demonstrates how individuals less susceptible to hypnosis are not completely impervious to the suggestion. Nevertheless, evidence weighting against the interaction of hypnotic susceptibility and suggestion for the slope component intimates that word-blindness hardly occurs through the gradual advent of executive functions. Corroborating our primary analyses, we instead find that this key interaction pattern is present when we evaluate the linear model's predicted value at the first quantile estimate. This observation means that the interaction pattern reported in the literature between susceptibility and suggestion proceeds from such early mitigation of conflicting task-irrelevant information. This result not only supports a proactive view of word-blindness, but it also alludes to the limited role of reactive control in this context. Specifically, one would expect that changes in reactive control as a function of hypnosis and hypnotic susceptibility would have been captured by the analysis of the slope - i.e, the gradual build-up of the suppression of interfering information. Instead, we found that word blindness is best explained by early benefits already present at the first quantile estimate.

The active-suppression framework promotes the idea that the earliest quantiles reflect automatic processes which are relatively impervious to executive control. Previous work supports this assertion by showing how efficient cognitive control typically occurs for slower responses, as it deploys slowly after target onset (i.e., later quantiles; Ridderinkhof, 2002b). Drawing from this framework, our findings imply that hypnosis therefore modulates automatic processes for HHSIs given that early suppression of the congruency effect. This result is consistent with previous neurophysiological assays exhibiting changes in early event-related components (Raz et al., 2005; Zahedi et al., 2019), and further supports the notion that hypnotic suggestion is capable of derailing automatic processes (Lifshitz et al., 2013). Previous findings submit that word-blindness results from a shift in response selection, which occurs late in the process. The current work additionally argues that the implementation of the suggestion occurs through anticipation and response preparation, thus corroborating the role of proactive control to seemingly deautomatize responses and ultimately unring a rung bell.

The Stroop Interference Effect encompasses several components, including semantic and response conflict-related processing (Augustinova, Silvert, Spatola, & Ferrand, 2018). Based on this multifaceted account, findings show that word-blindness hardly interferes with semantic processing (Augustinova & Ferrand, 2012). Following this previous work, the current results accordingly support the idea that the regulation process recruited during hypnotic alexia taps higher level brain functions by minimizing response conflict early on. The current findings nicely dovetail with previous research, sketching how a gain in efficiency over response selection follows, at least in part, from proactive systems of control. In sum, HHSIs are capable of limiting conflict-related processing by engaging and maintaining goal-relevant information prior to target onset. Seemingly, top-down regulation thereby ultimately benefits response selection. This result further emphasizes the centrality of expectations and preparation in shaping our experience and link hypnotic phenomena to a growing body of research on placebos (Colloca & Miller, 2011; Kirsch, 1997).

Conclusion

Hypnosis can be a formidable tool for illuminating the nature of cognitive control (Egner & Raz, 2007). Following the dual framework of executive control, the present findings support a proactive view of hypnosis, which highlights the important role anticipation and preparedness play in hypnotic response. Combined with previous work demonstrating how word-blindness occurs at the level of response selection, our present findings align with earlier efforts and posit an integrative synthesis in which suggestion-induced alexia in HHSIs manifests by boosting selection processes through top-down regulation. Overall, our results emphasize the centrality of expectancy in hypnotic phenomena and pave the road to a more scientific understanding of the computational and electrophysiological dynamic surrounding suggestion.

Data Availability

Data and codes for analyses will be made available upon request. The ethics approval for some of the data sets we used in the current study do not permit us to make the data freely available for download.

References

Alladin, A. (2008). *Cognitive hypnotherapy: An integrated approach to the treatment of emotional disorders*. West Sussex, England: John Wiley & Sons.

Augustinova, M., & Ferrand, L. (2012). Suggestion does not de-automatize word reading: evidence from the semantically based Stroop task. *Psychon Bull Rev, 19*(3), 521-527. doi:10.3758/s13423-012-0217-y

Augustinova, M., Silvert, L., Spatola, N., & Ferrand, L. (2018). Further investigation of distinct components of Stroop interference and of their reduction by short response-stimulus intervals. *Acta psychologica, 189*, 54-62.

Balota, D. A., & Yap, M. J. (2011). Moving beyond the mean in studies of mental chronometry: The power of response time distributional analyses. *Current Directions in Psychological Science, 20*(3), 160-166.

Bargh, J. A. (1989). Conditional automaticity: Varieties of automatic influence in social perception and cognition. *Unintended thought, 3*, 51-69.

Bargh, J. A. (1994). The Four Horsemen of automaticity: Awareness, efficiency, intention, and control in social cognition. In R. S. Wyers & T. K. Srull (Eds.), *Handbook of social cognition* (2nd ed., pp. 1-40). Hillsdale, NJ: Guilford.

Braver, T. S. (2012). The variable nature of cognitive control: a dual mechanisms framework. *Trends in cognitive sciences, 16*(2).

Chiew, K. S., & Braver, T. S. (2017). Context processing and cognitive control: From gating models to dual mechanisms *The Wiley handbook of cognitive control.* (pp. 143-166): Wiley-Blackwell.

Cohen, N., Mor, N., & Henik, A. (2015). Linking executive control and emotional response: A training procedure to reduce rumination. *Clinical Psychological Science, 3*(1), 15-25.

Colloca, L., & Miller, F. G. (2011). Role of expectations in health. *Current opinion in psychiatry, 24*(2), 149-155.

De Jong, R., Liang, C.-C., & Lauber, E. (1994). Conditional and unconditional automaticity: a dual-process model of effects of spatial stimulus-response correspondence. *Journal of Experimental Psychology: Human Perception and Performance, 20*(4), 731.

Diamond, A. (2013). Executive functions. *Annual review of psychology, 64*, 135.

Eftekhari, A., Zoellner, L. A., & Vigil, S. A. (2009). Patterns of emotion regulation and psychopathology. *Anxiety, Stress, & Coping, 22*(5), 571-586.

Egner, T., & Raz, A. (2007). Cognitive Control Processes and Hypnosis. In G. A. Jamieson (Ed.), *Hypnosis and conscious states: The cognitive neuroscience perspective* (pp. 29-50). New York, NY: Oxford University Press.

Evans, J. S. B. T. (2008). Dual-processing accounts of reasoning, judgment, and social cognition. *Annu Rev Psychol, 59*, 255-278. doi:10.1146/annurev.psych.59.103006.093629

Evans, J. S. B. T., & Stanovich, K. E. (2013). Dual-process theories of higher cognition advancing the debate. *Perspectives on Psychological Science, 8*(3), 223-241.

Gonthier, C., Braver, T. S., & Bugg, J. M. (2016). Dissociating proactive and reactive control in the Stroop task. *Memory & Cognition, 44*(5), 778-788.

Kihlstrom, J. F. (2008). The automaticity juggernaut—or, are we automatons after all. In J. Baer, J. C. Kaufman, & F. Roy (Eds.), *Are we free? Psychology and free will* (pp. 155-180). New York, NY: Oxford University Press Oxford.

Kirsch, I. (1985). Response expectancy as a determinant of experience and behavior. *American Psychologist, 40*(11), 1189.

Kirsch, I. (1997). Response expectancy theory and application: A decennial review. *Applied and preventive Psychology, 6*(2), 69-79.

Kirsch, I., Wickless, C., & Moffitt, K. H. (1999). Expectancy and suggestibility: Are the effects of environmental enhancement due to detection? *International Journal of Clinical and Experimental Hypnosis, 47*(1), 40-45.

Lifshitz, M., Aubert Bonn, N., Fischer, A., Kashem, I. F., & Raz, A. (2013). Using suggestion to modulate automatic processes: from Stroop to McGurk and beyond. *Cortex, 49*(2), 463-473.

Luce, R. D. (1986). *Response times: Their role in inferring elementary mental organization*. New York: Oxford University Press.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: an integrative review. *Psychological bulletin, 109*(2), 163.

Melara, R. D., & Algom, D. (2003). Driven by information: a tectonic theory of Stroop effects. *Psychological review, 110*(3), 422.

Moors, A., & De Houwer, J. (2006). Automaticity: a theoretical and conceptual analysis. *Psychological bulletin, 132*(2), 297.

Parris, B. A., Dienes, Z., & Hodgson, T. L. (2013). Application of the ex-Gaussian function to the effect of the word blindness suggestion on Stroop task performance suggests no word blindness. *Frontiers in psychology, 4*.

Pratte, M. S., Rouder, J. N., Morey, R. D., & Feng, C. (2010). Exploring the differences in distributional properties between Stroop and Simon effects using delta plots. *Attention, Perception, & Psychophysics, 72*(7), 2013-2025.

Raz, A., Fan, J., & Posner, M. I. (2005). Hypnotic suggestion reduces conflict in the human brain. *Proceedings of the National Academy of Sciences U S A, 102*(28), 9978-9983.

Raz, A., Landzberg, K. S., Schweizer, H. R., Zephrani, Z. R., Shapiro, T., Fan, J., & Posner, M. I. (2003). Posthypnotic suggestion and the modulation of Stroop interference under cycloplegia. *Consciousness and cognition, 12*(3), 332-346.

Raz, A., Moreno-Íniguez, M., Martin, L., & Zhu, H. (2007). Suggestion overrides the Stroop effect in highly hypnotizable individuals. *Consciousness and cognition, 16*(2), 331-338.

Raz, A., Shapiro, T., Fan, J., & Posner, M. I. (2002). Hypnotic suggestion and the modulation of Stroop interference. *Archives of General Psychiatry, 59*(12), 1155-1161.

Ridderinkhof, K. R. (2002a). Activation and suppression in conflict tasks: Empirical clarification through distributional analyses. In W. Prinz & B. Hommel (Eds.), *Common Mechanisms in Perception and Action. Attention & Performance* (Vol. XIX, pp. 494-519). Oxford: Oxford University Press.

Ridderinkhof, K. R. (2002b). Micro-and macro-adjustments of task set: activation and suppression in conflict tasks. *Psychological research, 66*(4), 312-323.

Rouder, J. N., & Speckman, P. L. (2004). An evaluation of the Vincentizing method of forming group-level response time distributions. *Psychonomic Bulletin & Review, 11*(3), 419-427.

Rouder, J. N., Speckman, P. L., Sun, D., Morey, R. D., & Iverson, G. (2009). Bayesian t tests for accepting and rejecting the null hypothesis. *Psychonomic Bulletin & Review, 16*(2), 225-237.

Shor, R. E., & Orne, E. C. (1962). *Harvard Group Scale of Hypnotic Susceptibility: Form B: an Adaptation for Group Administration with Self-report Scoring of the Stanford Hypnotic Susceptibility Scale, Form A*: Consulting Psychologists Press.

Speckman, P. L., Rouder, J. N., Morey, R. D., & Pratte, M. S. (2008). Delta plots and coherent distribution ordering. *The American Statistician, 62*(3), 262-266.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of experimental psychology, 18*(6), 643.

Teachman, B. A., Joormann, J., Steinman, S. A., & Gotlib, I. H. (2012). Automaticity in anxiety disorders and major depressive disorder. *Clinical psychology review, 32*(6), 575-603.

Van Zandt, T. (2000). How to fit a response time distribution. *Psychonomic Bulletin & Review, 7*(3), 424-465.

Wagenmakers, E.-J. (2007). A practical solution to the pervasive problems of p values. *Psychonomic Bulletin & Review, 14*(5), 779-804.

Wasserman, T., & Wasserman, L. D. (2016). *Depathologizing Psychopathology: The Neuroscience of Mental Illness and Its Treatment*: Springer.

Weitzenhoffer, A. M., & Hilgard, E. R. (1962). *Stanford hypnotic susceptibility scale, form C* (Vol. 27): Palo Alto, CA: Consulting Psychologists Press.

Wylie, S. A., Ridderinkhof, K. R., Bashore, T. R., & van den Wildenberg, W. P. M. (2010). The effect of Parkinson's disease on the dynamics of on-line and proactive cognitive control during action selection. *Journal of cognitive Neuroscience, 22*(9), 2058-2073.

Zahedi, A., Abdel Rahman, R., Stürmer, B., & Sommer, W. (2019). Common and specific loci of Stroop effects in vocal and manual tasks, revealed by event-related brain potentials and posthypnotic suggestions. *Journal of experimental psychology: General, 148*(9), 1575.