Subjective Aspects of Cognitive Control at Different Stages of Processing

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Abstract

While research on cognitive control has addressed the effects that different forms of cognitive interference have on behavior and the activities of certain brain regions, until recently scientific approaches have been silent regarding the effects of interference on subjective experience. We demonstrate that, at the level of the individual trial, participants can reliably introspect the subjective aspects (e.g., *perceptions of difficulty*, *competition*, and *control*) of responding in interference paradigms. Similar subjective effects were obtained for both expressed and unexpressed (subvocalized) actions. Few participants discerned the source of these effects. These basic findings illuminate aspects of cognitive control and cognitive effort. In addition, these data have implications for the study of response interference in affect and self-control, and they begin to address theories regarding the function of consciousness.

Subjective Aspects of Cognitive Control at Different Stages of Processing

More than 30 years ago, the classic flanker task first appeared in this journal (then called *Perception and Psychophysics*; Eriksen & Eriksen, 1974). Since that time, empirical and theoretical developments (Brown & Braver, 2005; van Veen & Carter, 2006) have examined the impact that cognitive interference of various kinds has on behavior and the activity of certain brain regions (Botvinick, 2007; Botvinick, Braver, Carter, Barch, & Cohen, 2001; Brown & Braver, 2005; Curtis & D'Esposito, 2009; Gazzaley, Cooney, Rissman, & D'Esposito, 2005; van Veen & Carter, 2006), but for the most part scientific approaches have been silent regarding the effects of interference on subjective experience[1] (see exceptions in Mayr, 2004; Mayr, Awh, & Laurey, 2003; Mulert, Menzinger, Leicht, Pogarell, & Hegerl, 2005; Rosen, Joseph McGuire, & Botvinick, 2007). Today, the relationship between the objective and subjective indices of cognitive control/effort remains mysterious (Baumeister & Vohs, 2004; Grahek, 2007; Preston & Wegner, 2009). Thus, the fleeting 'urges,' 'inclinations,' and 'tendencies' that thousands of participants have experienced when performing interference tasks such as the flanker task or Stroop task[2] (Stroop, 1935) continue to be a scientific *terra incognita*.[3] Are these subjective effects ephemeral and capricious, or systematic and reliable?

Consider the classic flanker task (Eriksen & Schultz, 1979). In this task, participants are first trained to press one button with one finger when presented with the letter S or M and to press another button with another finger when presented with the letter P. After training, participants are instructed to respond to targets that are 'flanked' by distracters. For example, they are instructed to respond to the stimulus presented in the center of an array (e.g., SSPSS, SSMSS, SSSSS, targets underscored) and to disregard the flanking stimuli (the distracters). It is well established that interference (as indexed by errors and response times [RTs]) depends on the nature of the distracters: Greater RTs are found when the distracters are associated with a response that is different from that of the target (*response interference* [RI]; e.g., SSPSS) than when the distracters are different in appearance but associated with the same response (*stimulus interference* [SI]; e.g., SSMSS). Of the three examples above, shortest RTs are found when the distracters are identical to the target (e.g., SSSSS; Eriksen & Schultz, 1979; van Veen, Cohen, Botvinick, Stenger, & Carter, 2001).

It is obvious to the participant and experimenter alike that notable changes in subjective experience accompany each response on every trial, rendering the task qualitatively different from that of everyday perception-action mapping (e.g., flicking a light switch). Yet, less has been documented about the subjective aspects of such interference tasks than about their behavioral and neural aspects.[4]

If these subjective effects are systematic and reliable, then which kinds of cognitive interference lead to the strongest modulations in subjective experience, and which lead to little or no modulations? In agreement with recent views (Gazzaley & D'Esposito, 2007; van Veen & Carter, 2006), we believe that answering such questions is essential for understanding the dynamics of more 'hot' (Metcalfe & Mischel, 1999) kinds of conflict, such as those involving self-control and motivation (e.g., approach-approach conflicts; Livnat & Pippenger, 2006; Miller, 1959). In short, the cognitive dynamics underlying the subjective effects found in interference paradigms may reveal principles about the fundamental ‘tuggings and pullings’ and ‘ups and downs’ of the human emotional experience (Morsella, 2005). In addition, we believe that subjective data can illuminate aspects of cognitive processing that may not be revealed in traditional dependent measures such as RT and error rates.

Hence, in a series of experiments, we examined the subjective effects from different kinds of cognitive interference in variants of Stroop and flanker tasks.

In addition to documenting the trial-by-trial subjective effects from the Stroop and flanker tasks (an important corpus of data in its own right), we took the opportunity to examine the hypothesis (Bargh & Morsella, 2008; Vygotsky, 1962) that internalized actions such as subvocalizations should feature the same subjective dynamics as externalized actions. If so, this would rule out the hypothesis that the subjective effects of these tasks stem only from proprioceptively-detected conflict at the level of effectors (McGuigan, 1966; see also Pickering & Garrod, in press). Considering that response interference from flankers can lead to subthreshold muscular activations (e.g., Coles, Gratton, Bashore, Eriksen, & Donchin, 1985; cf., Morsella & Krauss, 2005), there is the possibility that subjective effects may be constituted in part by proprioception of activation in effector systems (cf., Wegner, 2002). Showing that covert and overt action are similar with respect to subjective effects would illuminate a basic aspect of human action (itself an under-explored area of investigation; Morsella, 2009; Rosenbaum, 2005).

Overview of Experiments

We designed a series of experiments to test the claim that subjective effects are systematic, measurable, reliable, and arise from cognitive interference in a principled fashion. Specifically, using vocal and subvocal versions of the classic Stroop task, in

Studies 1 through 3 we examined whether participants can reliably introspect on the subjective aspects (e.g., *difficulty*, *competition*, and *control*) of their responses at the level of the individual trial and whether similar effects are obtained for externalized and internalized actions.

Study 1: Are Subjective Urges Systematic?

Our primary goal in Study 1 was to establish that participants can reliably introspect the urge to err on each trial of a motionless, subvocal version of the Stroop task. We predicted that participants would report the strongest urges to err for incongruent conditions and weaker urges to err for congruent conditions. Because the task involves an internalized form of action, finding this pattern of results would cast doubt on the hypothesis that the subjective effects arise from conflict occurring at the level of motor effectors (cf., Coles et al., 1985; McGuigan, 1966).

Method

Participants. Yale University students (*n* = 15) participated for class credit or $8.

Procedure. Participants were run individually. The session consisted of a block of trials in which participants responded to Stroop stimuli subvocally. Each block consisted of 40 Stroop trials having 8 congruent (e.g., RED written in red), 16 incongruent (e.g., RED in blue), 8 control (e.g., HOUSE in green), and 8 neutral (e.g., XXXX in pink) stimuli presented in random order. The 8 colors used were correctly identified by all participants. In the incongruent condition, targets (colors) and distracters (words) were re-paired systematically (e.g., if RED was written in blue then BLUE was written in red). Participants were instructed, “In this task, you must respond to the words presented on the screen by naming the colors in which the words are written as fast and as accurately as you can, but you must name the colors only ‘in your head’ and not aloud. Speaking in your mind but not aloud is called *subvocalizing*. For example, if the word FLOWER is presented in blue, you must think to yourself the color name ‘blue.’ As soon as you are done thinking the color name, you must press the space bar with your dominant hand. Pressing the space bar will allow you to proceed to the next trial.” It is important to emphasize that we never considered the RTs associated with pressing the space bar to be an informative or valid dependent measure. Participants performed this action only to indicate that they finished responding subvocally, were paying attention to the task, and were ready to commence the next trial. In short, the motor aspect of the task in this and subsequent subvocal experiments was not designed to render an accurate measure of the latency of cognitive processing or the onset of subvocalizing. Rather, for subvocal tasks, our focus was on the nature of the reported subjective effects.

Each trial proceeded as follows. A ready prompt (question mark) appeared onscreen until participants indicated that they were ready to proceed by pressing the space bar. Thereafter, a fixation point (+) was shown at the center of the screen for 1,500 ms. It was followed by a blank screen (700 ms), after which time a randomly selected Stroop stimulus appeared (48-point Helvetica), remaining onscreen until the space bar was depressed. After the response and 700 ms, participants were asked “How strong was the urge to make a mistake?”, which they rated on an 8-point scale, in which 1 signified “almost no urge” and 8 signified “extremely strong urge.” Thereafter, the next trial began after 500 ms. For this and the following experiments, stimuli were always presented in random order on a white background of a 43 cm Apple eMac computer monitor with a viewing distance of approximately 48 cm, and stimulus presentation was controlled by PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993).

Results

Subjective effects: As illustrated in Figure 1, Stroop condition did produce systematic effects on urges to err, F (3, 42) = 33.679, $p < .0001$ ($\eta_p^2 = .71$), in which urges were strongest for the incongruent (*M* = 4.01, *SEM* = .39), followed by the control (*M* = 2.38, *SEM* = .30), the neutral (*M* = 1.59, *SEM* = .16), and congruent conditions (*M* = 1.34, *SEM* = .14). *Fisher's PLSD* revealed that all differences between conditions were significant (*p*s < .01), except for that between neutral and congruent conditions (*p* = .497). Omitted responses and typing errors resulted in the loss of 1 (0.2%) of 600 ratings.

Supplementary analysis: Again, for this and the subsequent subvocal experiments, the RT associated with pressing the space bar was never considered to be a dependent measure of interest, for various reasons. Nevertheless, we did take the opportunity to analyze RTs associated with the space bar responses. Following Woodworth and Schlosberg (1954), RTs below 200 ms and above 2 s were excluded from analysis, resulting in the loss of 78 (13%) out of 600 trials. We repeated this trimming procedure for all subsequent RT measures. See Appendix for mean proportion of trials removed per condition. Condition influenced the proportion of trimmed scores, F (3, 42) = 4.61, $p < .01$ ($\eta_p^2 = .24$). However, *Fisher's PLSD* revealed that the only significant difference in these proportions was between congruent and incongruent conditions, *p* = .04. Corroborating to some extent that participants were in fact responding to the stimuli subvocally, a trend mirroring the Stroop effect was manifested in the RTs associated with pressing the space bar, in which RT was greatest for the incongruent (*M* = 1059.04, *SEM* = 86.27), followed by the neutral (*M* = 949.15, *SEM* =

92.52), control (*M* = 930.18, *SEM* = 85.20), and congruent conditions (*M* = 905.29, *SEM* = 83.85), F (3, 39) = 4.068, p = .0132 (η_p^2 =.24). However, *Fisher's PLSD* revealed that there were no significant differences between conditions, *p*s > .05.

Only 3 of the 15 participants had significant (*p*s < .05) correlations between RT and urge to err (mean r = .16, Fisher's r to z, p > .05), suggesting that participants were not basing their judgments solely on observing their own RTs. For this and all subsequent analyses, the mean correlation was calculated by including ratings and RTs from all conditions. The small number of trials (e.g., n = 8) comprising each condition was inadequate for drawing strong conclusions regarding the relationship between RT and subjective measures within each condition.

Discussion

As predicted, we found that the pattern of reported urges to err mirrored that of RT effects in the standard Stroop task. Because the task was subvocal, this finding casts doubt on the notion that subjective effects arise from interference at the level of the effector system. It seems that urges result from a process that is more centralized and that features the subjective dynamics of externalized actions (Vygotsky, 1962).

Study 2: Urge to Read during Vocal and Subvocal Stroop Tasks

Based on Cohen et al. (1990), we believe that the urges to err reported for the incongruent Stroop condition in Study 1 stem in part from the conflict arising between the dominant word-naming and weaker color-naming plans, though one of course cannot rule out that urges could simply reflect difficulty, effort, arousal, or a combination of the three. Evidence suggests that, in the congruent condition, participants often read the stimulus word inadvertently (MacLeod & MacDonald, 2000). With respect to this condition, in which word-reading and color-naming lead to the same response, MacLeod and MacDonald (2000) state, “The experimenter (perhaps the participant as well) cannot discriminate which dimension gave rise to the response on a given congruent trial” (p. 386). The authors then review substantial evidence from diverse sources that participants often do read the stimulus word inadvertently in the congruent condition. However, it remains unknown whether participants are aware of this phenomenon.

Method

Participants. Yale University students (n = 112) participated for class credit or $8.

Procedure. Participants were run individually. The session consisted of two blocks of Stroop trials. In one block, participants responded to Stroop stimuli aloud (vocal condition) and in the other they responded subvocally (subvocal condition). Block order was randomized across participants to minimize order effects (54 participants began with the vocal condition, and 58 began with the subvocal condition). Each block consisted of 40 Stroop trials having 8 congruent, 16 incongruent, 8 control, and 8 neutral stimuli presented in random order. For the vocal condition, participants were instructed, “In this task, you must respond to the words presented on the screen by naming aloud as fast as you can the colors in which the words are written. For example, if the word FLOWER is written in blue, you must say ‘blue’ as fast as you can. The microphone will record your response and measure your response time.” Vocal responses were detected by microphone (Model 33-3014; Radio Shack; Fort Worth, TX) connected to a PsyScope button box (Model 2.02; New Micros; Dallas, TX). For the subvocal condition, participants received the instructions from Study 1. Each trial proceeded exactly as in Study 1 except that participants were now asked, “How strong was the urge to read the word?", which they rated on an 8-point scale, in which 1 signified "almost no urge" and 8 signified "extremely strong urge."

Results

Vocal Condition

Subjective effects: As illustrated in Figure 2b, Stroop condition produced effects on the urge to read, F (3, 333) = 180.497, $p < .0001$ ($\eta_p^2 = .62$), in which urges were strongest for the incongruent (*M* = 5.87, *SEM* = .11), followed by congruent (*M* = 5.20, *SEM* = .20), control (*M* = 4.46, *SEM* = .14), and neutral conditions (*M* = 2.18, *SEM* = .13), *Fisher's PLSD*, *p*s < .01. Omitted responses and typing errors resulted in the loss of 166 (3.7%) of 4,480 ratings.

Response times: RT trimming resulted in the loss of 157 (3.5%) out of 4,480 vocal trials. See Appendix for mean proportion of trials removed per condition. Condition did not influence the proportion of trimmed scores, F (3, 333) = 2.85, $p > .05$. We replicated the Stroop RT effect, in which RTs are longest for the incongruent condition (*M* = 859.00, *SEM* = 13.98), followed by control (*M* = 808.24, *SEM* = 13.82), neutral (*M* = 719.67, *SEM* = 11.85), and congruent conditions (*M* = 698.58, *SEM* = 11.66), F (3, 333) = 134.085, $p < .0001$ ($\eta_p^2 = .55$). *Fisher's PLSD* revealed that all differences between conditions were significant (*p*s < .01), except for that between neutral and congruent conditions ($p = .25$).

Only 6 of the 112 participants had significant (*p*s < .05) correlations between RT and urge to read (mean $r = .01$, Fisher's r to z, $p > .05$), suggesting that participants were not basing their judgments solely on observing their own RTs.

Subvocal Condition

Subjective effects: Stroop condition did produce clear effects on the urge to read, F (3, 333) = 189.246, $p < .0001$ ($\eta_p^2 = .63$), in which urges were strongest for the incongruent (M = 5.60, SEM = .13), followed the congruent (M = 4.92, SEM = .21), control (M = 4.54, SEM = .16), and neutral conditions (M = 1.95, SEM = .12)(Figure 2a). *Fisher's PLSD* revealed that all the differences between the means were significant (ps < .01), except for that between control and congruent conditions (p = .25). Omitted responses and typing errors resulted in the loss of 267 (6.0%) of 4,480 ratings.

Supplementary analysis: As one would expected, the Stroop RT effect was again not manifested clearly in the RTs associated with pressing the space bar. The mean RT for pressing the space bar was comparable in the incongruent (M = 907.62, SEM = 34.83) and control conditions (M = 907.63, SEM = 36.54), but was shorter for congruent (M = 821.43, SEM = 31.50) and neutral conditions (M = 805.78, SEM = 31.92), F (3, 324) = 16.499, $p < .0001$($\eta_p^2 = .13$). *Fisher's PLSD* revealed that the only significant differences between means were between control and neutral conditions, and between incongruent and neutral conditions (ps < .05). Our trimming procedures resulted in the loss of 659 (14.7%) out of 4,480 subvocal trials. See Appendix for mean proportion of trials removed per condition. Condition influenced the proportion of trimmed scores, F (3, 99) = 3.194, $p < .05$ ($\eta_p^2 = .25$). *Fisher's PLSD* revealed significant differences in these proportions between the incongruent condition and each of the other conditions, ps < .05. Only 16 of the 112 participants had significant (ps < .05) correlations between RT and urge to read (mean $r = .07$, Fisher's r to z, $p > .05$), suggesting, again, that participants were not basing their judgments solely on observing their motor RTs.

General analysis: An omnibus within-subjects ANOVA revealed that the vocal and subvocal conditions lead to similar patterns of results with respect to the urge to read the stimuli (Figure 2). The urge to read was judged to be stronger in the vocal than the subvocal conditions, F (1, 111) = 4.562, p = .0349 (η_p^2 = .04), but *Fisher's PLSD* revealed that this difference is unreliable (p = .1130). As is clear above, there was a significant main effect of Stroop condition, F (3, 333) = 217.863, p < .0001 (η_p^2 = .66), *Fisher's PLSD*, *ps* < .001. There was also a subtle interaction between Stroop condition and task (vocal/subvocal), F (3, 333) = 3.359, p = .0191 (η_p^2 = .03), an unpredicted interaction that will require further investigation.

Discussion

We present for the first time participants' urges to read in the Stroop task. Participants reported the strongest urges to read the stimuli when responding in the incongruent condition and reported less of an urge to read when responding in the congruent condition, though it is known that reading tendencies may actually be equal in both conditions (MacLeod & MacDonald, 2000). This may support the interpretation that participants were underestimating their urge to read words in the congruent condition.[5] This reduction in the urge to read in the congruent condition may be an instance of *double-blindness*—the notion that one has diminished awareness that two distinct cognitive processes have taken place when those processes lead to identical action plans (Morsella, 2005; Morsella, Gray, Krieger, & Bargh, 2008). Of course, this experiment cannot rule out the alternative hypothesis that color-naming actually suppresses the cognitive processes involved in word-reading, but this hypothesis is inconsistent with the findings of MacLeod and MacDonald (2000).

Study 3: Subjective Dimensions of Cognitive Interference

To further examine the subjective aspects of cognitive interference, in Study 3 participants performed the same vocal and subvocal Stroop tasks but now answered additional questions following each trial. Comprising our *urge to err* measure, the first question was, “How strong was the urge to make a mistake?”. Comprising our *perception of control* measure, the second question was, “How much personal control did you feel when saying the name of the color?” (for the vocal condition) or “How much personal control did you feel when thinking the name of the color?” (for the subvocal condition). The last question was, “How strong was the thought of a competing response (e.g., the thought of the word name)?”, which served as our measure of *perception of competition.*

We predicted that, for both vocal and subvocal versions of the task, when response interference is low or absent during the Stroop task (as in neutral and congruent conditions), urges to err and perceptions of competitions will tend to be low while perceptions of control will tend to be high; when response interference is high (as in the incongruent condition), urges to err and perceptions of competition will tend to be high while perceptions of control will tend to be low. Such a finding would illuminate the nature of the subjective effects associated with interference tasks and would also suggest that participants can introspect, not just about task difficulty, but about a richer set of subjective dimensions. Of course such a finding cannot rule out the possibility that judgments simply reflect overall difficulty or folk knowledge regarding how one should make judgments while experiencing cognitive conflict/effort in psychological experiments (see *Limitations* in General Discussion).

Method

Participants. Yale University students (*n* = 35) participated for class credit or $8.

Procedure. The procedures were identical to those of Study 2, except that participants were told that they would have to answer three questions following each Stroop trial. Each of the three questions was separated from the next by a span of 700 ms following the participant's response.

Results

All the data from one session were excluded from analysis because the participant failed to follow instructions. Of the remaining data, omitted responses and typing errors resulted in the loss of 414 (5.1%) of 8,160 ratings. With task (vocal/subvocal) and Stroop condition as within-subjects factors, we conducted omnibus ANOVAs for each of the three dependent measures (urge to err, control, and competition). There was no main effect of task (ps > .05), no interaction between task and Stroop condition (ps > .05), and only a main effect of Stroop condition (ps < .0001), the nature of which is elaborated below for each task.

Vocal Condition

Response times. Trimming resulted in the loss of 44 (3.2%) of 1,360 RT data points from the vocal task. See Appendix for mean proportion of trials removed per condition. Condition influenced the proportion of trimmed scores, F (3, 99) = 3.194, $p < .05$ ($\eta_p^2 = .08$). *Fisher's PLSD* revealed significant difference in these proportions between the neutral and incongruent conditions, $p < .05$. We replicated the Stroop effect, in which RTs are longest for the incongruent (M = 895.02, SEM = 22.34), followed by the control (M = 805.21, SEM = 23.43), neutral (M = 719.15, SEM = 18.84), and congruent conditions (M = 716.39, SEM = 23.41), F (3, 99) = 45.792, $p < .0001$ (η_p^2

=.58). As in Study 2, *Fisher's PLSD* revealed that all the differences between conditions were significant (*p*s $< .01$), except for that between the congruent and neutral conditions ($p = .93$).

Urge to err. As illustrated in Figure 3b, Stroop condition produced systematic effects on urges to err, F (3, 99) = 58.453, $p < .0001$ ($\eta_p^2 = .64$), in which urges were greatest for the incongruent ($M = 4.41$, $SEM = .28$), followed by control ($M = 3.21$, $SEM = .30$), neutral ($M = 2.15$, $SEM = .25$) and congruent conditions ($M = 2.04$, $SEM = .22$). *Fisher's PLSD* revealed that all the differences between conditions were significant (*p*s < .01), except for that between the neutral and congruent conditions ($p = .78$). Twenty-seven of the 34 participants had significant (*p*s < .05) positive correlations between RT and urge to err (mean $r = .53$, Fisher's r to z, $p < .05$), suggesting that participants may have been basing their judgments on observing their own vocal RTs.

Perceptions of control. Stroop condition produced effects on the reported perception of control, F (3, 99) = 14.353, $p < .0001$ ($\eta_p^2 = .30$), in which perception of control was greatest for the neutral ($M = 6.52$, $SEM = .23$), followed by congruent ($M = 6.37$, $SEM = .24$), control ($M = 5.68$, $SEM = .24$), and incongruent conditions ($M = 5.19$, $SEM = .26$)(Figure 4b). *Fisher's PLSD* revealed that all the differences between conditions were significant (*p*s < .05), except for the differences between neutral and congruent conditions ($p = .68$) and the incongruent and control conditions ($p = .16$). Twenty-four of the 34 participants had significant (*p*s < .05) negative correlations between RT and perceptions of control (mean $r = -.34$, Fisher's r to z, $p < .05$), suggesting that participants may have been basing their judgments on observing their own RTs.

Perceptions of competition. Stroop condition produced effects on the perception of a competing response, F (3, 96) = 40.078, $p < .0001$ ($\eta_p^2 = .56$), in which competition was greatest for incongruent (*M* = 5.08, *SEM* = .27), followed by control (*M* = 4.06, *SEM* = .33), congruent (*M* = 2.46, *SEM* = .32), and neutral conditions (*M* = 2.33, *SEM* = .30)(Figure 5b). *Fisher's PLSD* revealed that all differences between conditions were significant (*p*s < .01), except for that between neutral and congruent conditions ($p = .77$). Twenty-six of the 34 participants had significant (*p*s < .05) positive correlations between RT and perceptions of competition (mean $r = .45$, Fisher's *r* to *z*, $p < .05$), suggesting that participants may have been basing their judgments on observing their own RTs.

Subvocal Condition

Urge to err. As in Study 1, condition did produce clear effects on urges to err, F (3, 99) = 38.214, $p < .0001$ ($\eta_p^2 = .54$), in which urges were strongest for the incongruent (*M* = 4.17, *SEM* = .33), followed control (*M* = 2.90, *SEM* = .29), neutral (*M* = 2.10, *SEM* = .25), and congruent conditions (*M* = 1.85, *SEM* = .22)(Figure 3a). *Fisher's PLSD* revealed that all the differences between conditions were significant (*p*s < .05), except for that between the neutral and congruent conditions ($p = .52$). Fourteen of the 34 participants had significant (*p*s < .05) correlations between RT and urges to err (mean $r = .29$, Fisher's *r* to *z*, $p = .07$).

Perceptions of control. Stroop condition produced effects on the reported perception of control, F (3, 99) = 17.896, $p < .0001$ ($\eta_p^2 = .35$), in which perceptions of control were greatest for neutral (*M* = 6.46, *SEM* = .27), followed by congruent (*M* = 6.42, *SEM* = .29), control (*M* = 5.82, *SEM* = .30), and incongruent conditions (*M* = 5.19, *SEM* = .28)(Figure 4a). *Fisher's PLSD* revealed that only the difference between congruent and incongruent conditions, and between the neutral and incongruent conditions, were significant (*p*s < .05). Twelve of the 34 participants had significant (*p*s < .05) negative correlations between RT and perceptions of control (mean r = -.25, Fisher's r to z, $p > .05$).

Perceptions of competition. Stroop condition produced effects on the reported perception of a competing response, F (3, 96) = 37.267, $p < .0001$ (η_p^2 = .54), in which perceptions of competition were greatest for the incongruent (*M* = 4.97, *SEM* = .33), followed the control (*M* = 3.83, *SEM* = .34), congruent (*M* = 2.55, *SEM* = .31), and neutral conditions (*M* = 2.39, *SEM* = .29)(Figure 5a). *Fisher's PLSD* revealed that all the differences between conditions were significant (*p*s < .05), except for that between the neutral and congruent conditions (p = .73). Only 9 of the 34 participants had significant (*p*s < .05) correlations between RT and perceptions of a competing response (mean r = .24, Fisher's r to z, $p > .05$), suggesting that participants were not basing their judgments solely on observing their own RTs.

Supplementary analysis: For the subvocal task, trimming resulted in the loss of 211 (15.5%) of 1,360 RT data points. See Appendix for mean proportion of trials removed per condition. Condition influenced the proportion of trimmed scores, F (3, 99) = 17.408, $p < .05$ (η_p^2 = .34). *Fisher's PLSD* revealed significant differences in these proportions between the incongruent condition and each of the other conditions, $p < .05$. Regarding response times, a trend mirroring the Stroop effect was manifested in the RTs associated with pressing the space bar, in which RT was greatest for the incongruent (*M* = 920.84, *SEM* = 56.35), followed by control (*M* = 860.65, *SEM* = 60.08), neutral (*M* = 801.88, *SEM* = 62.55), and congruent conditions (*M* = 787.46, *SEM* = 54.50), F (3, 96) =

7.144, $p = .0002$ ($\eta_p^2 = .18$). However, *Fisher's PLSD* revealed no significant differences between conditions, *p*s > .05.

Discussion

Vocal and subvocal versions of the Stroop task again lead to similar patterns of subjective effects: When interference was low or absent during the Stroop task (as in neutral and congruent conditions), urges to err and perceptions of competition tended to be low while perceptions of control tended to be high; when interference was high (as in the incongruent condition), urges to err and perceptions of competition tended to be high while perceptions of control tended to be low (see General Discussion for limitations of this approach).

Study 4A: Subjective Aspects of Response Interference Versus Stimulus Interference

In Studies 1 through 3, the perceived level of difficulty of the task alone could have guided subjects' self-reports, including those about perceptions of control and competition. To begin to illuminate this issue, in Study 4A we examined the subjective aspects of the flanker task mentioned in the introduction, a task that historically has been used to tease apart the subjective effects of stimulus interference and response interference (see van Veen et al., 2001). (The inherent limitations of such a dissociation are discussed in the General Discussion.) As one would expect, urges to err are greater for flanker conditions involving response interference than conditions involving stimulus interference (Morsella, Rigby, & Gazzaley, 2009). Perhaps this explains why the participants of the present studies assigned stronger urges to the incongruent condition than to the congruent condition.

A Subjective 'Localizer Task'

To have a better idea of whether the subjective effects from our experiments were driven in part by response interference, in a novel paradigm we first had participants rate their urge to err while performing the Stroop task and then had them introspect the same 'thing' while experiencing the conditions (stimulus interference and response interference) of the flanker task. In this way, the Stroop task served as a sort of within-subject 'localizer' task for the subjective dimensions of interest (i.e., response interference involving incompatible action plans). Following the Stroop task, participants were told that, when estimating their urge to err, what they were "looking inside their minds and measuring" was a psychological state known as 'activity,' and that they would be asked to measure this kind of 'activity' later in a different task. The rationale of the approach is that, if the subjective modulations associated with the Stroop task were driven to some extent by response interference, then participants should report a greater degree of such modulations for flanker response interference than stimulus interference.

To not bias participants, we defined the nondescript concept of activity only in terms of their experience. Thus, participants learned to introspect, not the general tendency to err on a task, but a specific urge or feeling that happens to be associated with increased urges to err in the Stroop task. No participant had difficulty understanding the concept of activity. It is important to note that we could have just as well called this dimension of interest something as arbitrary as 'H5' or 'Wundt Energy,' for the construct was defined only by the participant's own experience. We selected the term 'activity' only because it is unbiased and intuitive.

Our primary motivation for introspection training was that we wanted to be as certain as possible that participants were introspecting the same *thing* during both the flanker and Stroop tasks. Normally, this is difficult to establish because identical ratings could emerge from the measurement of distinct subjective dimensions. For example, on an 8-point scale, participants could judge a game of chess and the act of holding one's breath to be comparable with respect to difficulty, even though this does not imply that participants are measuring the same dimension(s) in each task. To circumvent this problem, for the flanker task we instructed participants to home in on what they measured during the Stroop task. Importantly, independent support for the notion that participants introspect the same dimension of interest for both tasks stems from a neuroimaging variant of this introspection training paradigm in which 'activity' ratings were proportional to the degree of activation in brain regions that were common for two different interference tasks (Kang, Morsella, Shamosh, Bargh, Gray, 2008).

Method

Participants. Yale University students (*n* = 30) participated for class credit or $8.

Procedure. Participants were run individually in two training phases and a test phase. Introspection training consisted of 24 Stroop trials having 8 congruent (e.g., RED written in red), 8 incongruent (e.g., RED in blue), and 8 control (e.g., HOUSE in green) stimuli in random order. After the response and 700 ms, participants were asked "How strong was the urge to make a mistake?", which they rated on an 8-point scale, in which 1 signified "almost no urge" and 8 signified "extremely strong urge." (We did not collect data for training in this experiment, but did collect them for identical training sessions in Studies 4B and 4C.) After introspection training, and following the exact procedures of van Veen et al. (2001), participants were trained to press specified computer keys when presented with certain letter targets (48-point Helvetica): When presented with S or M, they pressed a key (occupying the "4" position on the number pad of the keyboard) with their right index finger; when presented with a P or H, they pressed the adjacent ("5") key with their right middle finger. To make target keys perceptually salient, the 4 and 5 keys were replaced with blackened keys, which were the only blackened keys on the white keyboard. Targets were presented in the center of the screen and occupied less than 2 square cm. For training (32 trials), participants were told that accuracy is more important than speed.

After training, participants were told that the remainder of the experiment (96 trials) would involve a similar task and that they should continue to respond to the shape in the center of the screen (the target), though now they must also disregard whatever stimuli appear peripherally (the distracters). Participants were now encouraged to respond as quickly and as accurately as possible and to avoid anticipations. Following van Veen et al. (2001), distracters horizontally flanked the target in the center of the screen. In the *identical* condition, targets were flanked by distracters that were identical to it (e.g., SSSSS or HHHHH; 48 trials, 12 replications for each letter). In *stimulus interference*, targets and distracters were associated with the same response but were different letters (e.g., SSMSS or HHPHH; 24 trials, 6 replication of each possible combination). In *response interference*, targets and distracters were associated with different responses (e.g., SSPSS or MMHMM; 24 trials, 6 replications of each possible combination). Each trial began with a warning prompt (question mark) and beep, which preceded the stimulus display by 1,300 ms. After responding, participants were questioned "Activity?", which they rated on an 8-point scale, in which 1 signified "almost no urge" and 8 signified "extremely strong urge."

Results

Errors and response times: The data from two sessions were excluded from analysis because the participants failed to follow instructions. Of the remaining data, incorrect responses to targets resulted in the loss of 125 (4.7%) out of 2,688 data points. See Appendix for mean proportion of errors per condition. As expected, there was an effect of condition on error rate, F (2, 54) = 11.209, $p < .0001$ ($\eta_p^2 = .30$). *Fisher's PLSD* revealed significant differences between the error rates of SI and RI conditions and the SI and identical conditions (*p*s < .05). RT trimming resulted in the loss of 32 (1.2%) of 2,688 RT data points. See Appendix for mean proportion of trials removed per condition. Condition did not influence the proportion of trimmed scores, F (2, 54) = .912, $p > .40$. In this and subsequent analyses, errors were removed from the RT analysis. We replicated the findings of Eriksen and Schultz (1979) and van Veen et al. (2001). There was a main RT effect of condition, F (2, 54) = 23.749, $p < .0001$ ($\eta_p^2 = .47$), and RI produced greater RTs (*M* = 734.01, *SEM* = 31.78) than SI (*M* = 672.51, *SEM* = 33.52) and identical (*M* = 643.19, *SEM* = 29.29) conditions. Planned comparisons revealed that all these means are significantly different from each other, $ps_{paired} < .05$. The same pattern of results is obtained when trimming only RTs that are greater than 2.5 *SDs* or less than –2.5 *SD*s from each participant's mean score in each condition, F (2, 54) = 23.564, $p < .0001$ ($\eta_p^2 = .47$).

Subjective Activity: Typing errors and omissions resulted in the loss of 4 (0.1%) of 2,688 trials. As is clear in Figure 6, there were significant differences in subjective activity between the three conditions, F (2, 54) = 61.652, $p = .0001$ ($\eta_p^2 = .70$). Planned comparisons revealed that more activity was found for RI (M = 3.17, SEM = .21) than SI (M = 2.21, SEM = .17) and identical (M = 1.85, SEM = .17) conditions. All contrasts are significant, $ps_{paired} < .0001$. Twenty-six of the 28 participants had significant ($ps < .05$) positive correlations between RT and activity (mean $r = .50$, Fisher's r to z, $p < .05$), suggesting that participants may have based their judgments on RTs.

Discussion

It is worth noting that, in this experiment, the size of the subjective effect was larger than that of the behavioral RT effect, which underscores the importance of using subjective data to illuminate aspects of cognitive processing that may not be revealed in standard dependent measures such as RT and error rates. We found that more subjective activity accompanied the RI than the SI and identical conditions. In our next experiment, we replicated this effect with a different class of stimuli and included additional conditions that allowed for more precise appreciation of the influence of different kinds of interference on subjective experience.

Study 4B: Replication and Extension

In Study 4B, we replicated and extended Study 4A by including a *weak response interference* (weak RI) condition which could be construed as falling between the SI and RI conditions with respect to the amount of response interference it generates. In this condition, distracters were not part of the current response set. Although no responses had been learned toward these objects in the laboratory, it was assumed that, as environmental stimuli, they would still elicit action plans (e.g., exploratory behavior such as attending and orienting to them; Tinbergen, 1952). Moreover, these distracters should induce greater interference and subjective effects than those of the SI condition, because they are not associated with the correct response. We took the opportunity to replicate the procedures of Study 4A using shape stimuli instead of letter stimuli in order to weaken the strength of distracters in the weak RI condition, because it is well known that orthographic stimuli are already strongly linked to automatic action plans (see thorough treatment in Roelofs, Meyer, and Levelt, 1995).

Method

Participants. Yale University students (*n* = 22) participated for class credit or $8.

Procedure. Procedures were identical to those of Study 4A except that participants responded to shapes instead of letters, and, in addition to the three standard conditions of RI, SI, and identical, which served as our primary conditions of interest, we included a weak RI condition featuring distracters that were not part of the response set of (wavy lines and objects resembling lightning bolts) and presented each an equal number of times (6) with each kind of target, totaling 48 trials. For the sake of comparison, an *alone* condition presented targets by themselves (24 trials, 6 replications per shape).

During training, participants pressed a key (occupying the “4” position on the number pad of the keyboard) with their right index finger when presented with a circle or a square; when presented with a triangle or plus sign, they pressed the adjacent (“5”) key with their right middle finger. After training, participants were told that the remainder of the experiment (168 trials) would involve a similar task and that they should continue to respond to the shape in the center of the screen (the target), though now they must also disregard whatever stimuli appear peripherally (the distracters). Participants were now encouraged to respond as quickly and as accurately as possible and to avoid anticipations. Distracters horizontally flanked the target in the center of the screen (Figure 7), occupying a rectangular region less than 10 cm in length and 2 cm in height, so that stimuli would fit well within the participant's visual field. In the identical condition, targets were flanked by distracters that were identical to it (24 trials, 6 replications for each shape). In the SI condition, targets and distracters were associated with the same response but comprised different shapes (e.g., a square flanked by circles; 24 trials, 6 replication of each possible combination). In RI condition, targets and distracters were associated with different responses (e.g., a square flanked by triangles; 48 trials, 6 replications of each possible combination). Each trial began with a warning prompt (question mark) and beep, which preceded the stimulus display by 1,300 ms. After responding, participants were questioned "Activity?", which they rated on an 8-point scale, in which 1 signified "almost no urge" and 8 signified "extremely strong urge."

Results

Introspection Training

Trimming resulted in the loss of 6 (1.1%) of 528 RT data points. We replicated the Stroop effect, in which RTs are longest for the incongruent condition, followed by the control and congruent condition, F (2, 42) = 40.906, p < .0001 (η_p^2 = .66). Stroop condition produced analogous effects on urges to err, F (2, 42) = 40.627, p < .0001 (η_p^2 = .66), in which urges were greatest for the incongruent (*M* = 4.40, *SEM* = .28), followed control (*M* = 3.26, *SEM* = .26) and congruent conditions (*M* = 1.73, *SEM* = .16), *Fisher's PLSD*, *p*s < .01. Typing errors resulted in the loss of 2 (0.4%) of the 528 ratings. Fourteen of the 22 participants had significant (*p*s < .05) positive correlations between RT and activity (mean r = .50, Fisher's r to z, p < .05), suggesting that participants may have based their judgments on RTs.

Flanker Task

Errors and response times: Errors (n = 169) and trials on which no responses were made (28 trials) resulted in the loss of 197 (5.3%) of 3,696 data points. See Appendix for mean error rate per condition. Condition did influence error rates, F (4, 84) = .601, p > .50. RT trimming resulted in the loss of 38 (1.0%) of 3,696 trials. See Appendix for mean proportion of trials removed per condition. Condition did influence proportion of trimmed trials, F (4, 84) = 1.14, p > .34. RT data were analyzed in a within-subjects design ANOVA, with environment as a 5-level factor (alone, identical, SI, RI, weak RI). Mean RT across all conditions was 672.77 ms (*SEM* = 22.06). As shown in Table 1, and replicating previous findings (Eriksen & Schultz, 1979; van Veen et al., 2001), there was a main effect of condition, F (4, 84) = 5.307, p < .001 (η_p^2 = .20). As in Study 4A, planned comparisons revealed that RI produced greater RTs than SI and identical conditions, ps_{paired} < .05. Comparisons also revealed that the only nonsignificant differences (*ps* > .05) in RT were between the RI and weak RI, SI and weak RI, SI and alone, identical and weak RI conditions, SI and identical (difference = 18.14 ms, p = .199). Not having obtained a significant difference between SI and identical—traditionally a small but reliable effect which has been shown to range from 15 to 20 ms (cf. van Veen et al., 2001)—may simply reflect excessive noise from the peculiarities of our multiple conditions and stimuli. The same general pattern of results is obtained when trimming only RTs that are greater than 2.5 *SDs* or less than –2.5 *SD*s from each participant's mean score in each condition, F (4, 84) = 3.850, p = .006 (η_p^2 = .15).

Subjective Effects

The ratings from one session were excluded because the participant failed to follow instructions. Of the remaining data, typing errors and omissions resulted in the loss of 39 (1.1%) of 3,528 ratings.

Principal Results: As illustrated in Figure 8, reported activity increased as response interference increased, with activity being highest for RI, followed by the weak RI, SI, identical, and alone conditions. Statistically, there were significant differences in activity between the six conditions, F (4, 80) = 12.274, p = .0001 (η_p^2 = .38). Importantly, replicating the subjective effects of Study 4A, planned comparisons revealed that more activity was found for RI (M = 2.92, SEM = .14) than SI (M = 2.47, SEM = .13) and identical (M = 2.26, SEM = .15) conditions, ps_{paired} < .01. *Fisher's PLSD* revealed that all the differences between these three conditions were significant (ps < .05), except for that between the identical and SI conditions (p = .32).

Secondary Results: Planned comparisons revealed that more activity was reported for the RI than the weak RI condition (M = 2.60, SEM = .16), p_{paired} < .01, but that weak RI and SI conditions led to comparable activity (difference = 13 ms, p_{paired} = .17). *Fisher's PLSD* revealed that the only non-significant (ps > .05) post hoc comparisons of reported activity were between alone and identical, alone and SI, identical and SI, identical and weak RI, and SI and weak RI conditions. The same pattern of results is obtained when removing the trials of the weak RI condition in which novel distracters are presented for the first time and are presumably most distracting.

Every participant had significant (ps < .05) positive correlations between RT and activity (mean r = .495, Fisher's r to z, p < .05), suggesting, again, that participants may have based their judgments on RTs. After the experiment, 8 of the 21 participants reported that they did not know why the most difficult flanker conditions were so difficult, and only 4 participants surmised that task difficulty was somehow based on the actions associated with distracters. The remaining 9 participants provided other kinds of explanations, such as that task difficulty was based on the visual complexity of the distracters.

Discussion

We successfully replicated Study 4A with non-orthographic stimuli and with additional conditions that differed in the amount of response interference they elicit. Importantly, RI produced more subjective activity than weak RI and SI conditions, as predicted by the hypothesis that subjective modulations are driven primarily by response interference. Regarding our secondary results, it seems that responding to targets in the presence of distracters that are not in the response set is associated with relatively high subjective modulations, compared to, say, that of the identical condition. It is reasonable to propose that this is because the distracters in the weak RI condition elicit exploratory action tendencies that must be suppressed in order to perform the task successfully, or because they are not associated with the correct response. Further investigation is necessary to better understand the relationship between these subjective modulations and different forms of interference.

Studies 4A and 4B were not designed to rule out the alternative hypothesis that, in making their judgments, participants are not actually introspecting their subjective states but simply monitoring their response time or speed of processing. Conceptually, it is difficult to imagine how such confounding cognitive dynamics could be eradicated from these tasks. Both the properties of speed and fluency of processing will always be involved in cognitive interference tasks, and participants will always have direct or indirect access to these features (Winkielman, Schwarz, Fazendeiro, & Reber, 2003). Yet, this alternative hypothesis seems less likely given the time scales involved in our trials, time scales in which it is probably difficult for people to introspect and monitor their own RTs (Libet, 2004; but see recent evidence to the contrary in Corallo, Sackur, Dehaene, & Sigman, 2008). For example, the average RT difference between the SI and RI conditions was on the order of a mere 30 ms (a difference that would be challenging to introspect; Buzsáki, 2006; Libet, 2004), yet participants reported different degrees of subjective activity for these conditions. (Even the greatest mean RT difference between conditions was on the order of a mere 55 ms.) In addition, in Studies 1 and 2, RT did not always covary with the magnitude of subjective effects. In general, it may be that urges and RTs are both distinct consequences of cognitive interference, but that it is difficult, if not impossible, to separate the two. Observing one's RTs could influence judgments regarding urges; given the difficulty of introspecting RTs at this time scale, perhaps urges too could inform judgments about RTs.

Nevertheless, to weaken the potential influence of overt RTs on judgments, participants in Study 4C were instructed to respond to targets at the same time, after hearing a beep that always sounded 1,200 ms following stimulus presentation. Piloting (n = 4) and previous research (Eriksen & Schultz, 1979) suggests that such a delay is sufficient to eliminate flanker RT effects.

Study 4C: Reducing the Potential Influence of Overt RTs on Judgments

Method

Participants. Yale University students (n = 17) participated for class credit or $8.

Procedure. The procedures were identical to those of Study 4B, except that participants were instructed to prepare to respond as soon as targets appeared but to withhold responding until hearing a beep, which always sounded 1,200 ms following stimulus presentation. Specifically, they were told, “Prepare to respond only to the shape in the center of the screen and, while you are doing so, look inside your head and introspect how much ‘activity’ you feel as you prepare to respond. But respond as fast and as accurately as possible only once you hear the beep. Report the ‘activity’ that you experienced as soon as you saw the shapes and prepared to respond, although you withheld the response until you heard the beep.” It is important to emphasize that we did not regard the RT associated with this delayed response to be an informative dependent measure with respect to cognitive processing. Our primary goal was to obtain subjective data while diminishing the potential influence that overt RT has judgments.

Introspection Training

RT trimming resulted in the loss of 6 (1.5%) of 408 trials. Again, we replicated the Stroop effect, F (2, 32) = 19.93, $p < .0001$, and condition produced analogous effects on ratings, F (2, 32) = 55.61, $p < .0001$ ($\eta_p^2 = .78$), in which urges were greatest for the incongruent (M = 4.10, SEM = .30), followed the control (M = 2.49, SEM = .27) and congruent conditions (M = 1.36, SEM = .10), *Fisher’s PLSD*, *p*s < .01. Typing errors (1% of the data set) were excluded from analysis. Fifteen of the 17 participants had significant (*p*s < .05) positive correlations between RT and urges to err (mean $r = .61$, Fisher’s r to z, $p < .05$).

Flanker Task Results

Errors and response times: The RT data from one session were excluded from analysis because the participant button-pressed before the beep on every trial. Of the remaining data, errors resulted in the loss of 58 (2.2%) of 2,688 data points. See Appendix for mean error rate per condition. Condition did not influence error rates, *F* (4, 64) = .516, $p > .72$. Delaying a response and executing it upon hearing an anticipated beep is far easier than responding to the targets of the previous experiments. Thus, we now removed RTs below 100 ms and above 1 s. This resulted in the loss of 256 (9.5%) of 2,688 RT data, which was expected given that the task involves the unnatural delay of a response and requires participants to pay close attention to the auditory cue. See Appendix for mean proportion of trials removed per condition. Condition did influence proportion of trimmed trials, *F* (4, 60) = 4.005, $p < .05$, but *Fisher's PLSD* revealed that all these differences were not significant, *p*s > .05. (The same pattern of results is obtained with the previous trimming procedure and when removing RTs below 100 ms and above 2 s, though either procedure leads to a substantially greater loss of data.) Importantly, the same pattern of results is obtained when including all the RT data or when trimming only RTs that are greater than 2.5 *SDs* or less than –2.5 *SD*s from each participant's mean score in each condition, *F* (2, 56) = 1.096, $p > .35$ ($\eta_p^2 = .07$).

As anticipated (Eriksen & Schultz, 1979), by delaying responses, traditional flanker RT effects were effectively eliminated: RI (*M* = 374.53, *SEM* = 30.71), SI (*M* = 375.25, *SEM* = 28.98), and identical (*M* = 363.66, *SEM* = 31.71) conditions did not yield significant differences in RT, *F* (2, 30) = .58, $p > .58$ ($\eta_p^2 = .03$), planned comparison $ps_{paired} > .44$. Even when including all the conditions, there was no main effect of condition *F* (4, 60) = 1.937, $p > .10$ ($\eta_p^2 = .11$). Nine of the 16 participants had significant (*p*s < .05) positive correlations between RT and activity (mean *r* = .21, Fisher's *r* to *z*, $p < .05$).

Principal Results: Importantly, replicating the general pattern of results of Studies 4A and 4B, there were significant differences in activity between the six conditions, F (4, 60) = 9.568, $p = .0001$ ($\eta_p^2 = .39$), and more activity was found for RI (*M* = 2.56, *SEM* = .30) than SI (*M* = 2.21, *SEM* = .22) and identical (*M* = 1.67, *SEM* = .18) conditions, $ps_{paired} < .05$. Omitted responses and typing errors resulted in the loss of 20 (0.7%) of 2,688 ratings.

Secondary Results: Regarding the alone and weak elicitor conditions, additional planned comparisons revealed that the only nonsignificant differences in activity were between the RI and weak RI (*M* = 2.24, *SEM* = .26), and between weak RI (*M* = 2.24, *SEM* = .26) and SI (*M* = 2.21, *SEM* = .22). Again, the least reported activity was for the alone condition (*M* = 1.45, *SEM* = .17). After the experiment, 10 of the 17 participants reported that they did not know why the most difficult conditions were so difficult, and only 4 participants reported that task difficulty was somehow based on the actions associated with distracters. The remaining 3 participants provided other kinds of explanations such as that responses were influenced by the phonological similarity between targets and distracters.

General Discussion

Because of recent developments (e.g., Mayr, 2004; Mayr et al., 2003; Mulert et al., 2005; Rosen et al., 2007), the *Zeitgeist* has arrived to investigate the fleeting 'urges,' 'tendencies,' and 'inclinations' that thousands of laboratory participants have experienced when naming the color "blue" when it was presented on the word RED, or when performing other kinds of interference tasks (e.g., flanker and Simon tasks; Simon, Hinrichs, & Craft, 1970). In our initial enquiry to catalog and understand the nature of these elusive subjective phenomena, we demonstrated that participants appear to be able to introspect the subjective aspects (e.g., *perceptions of difficulty*, *control*, and *competition*) of responding in interference tasks and that they can do this reliably on a trial-by-trial basis. Stronger subjective effects were systematically associated with experimental conditions featuring high levels of response interference. Specifically, *when response interference was low or absent, urges to err and perceptions of competitions tended to be low while perceptions of control tended to be high; when response interference was high, urges to err and perceptions of competition tended to be high while perceptions of control tended to be low.* This observation was further corroborated by the results from Study 4, which was designed to tease apart the subjective effects of stimulus and response interference. Theories on cognitive control, effortful processing, and conscious processing will have to account for this catalog of basic, reliable findings.

More generally, these new data corroborate the notion that similar effects are obtained for externalized and internalized actions (Bargh & Morsella, 2008; Vygotsky, 1962) and that these subjective effects do not stem only from conflict at the level of effectors, though effectors are often engaged in subthreshold (imperceptible) ways during cognitive interference (Coles et al., 1985). In our experiments, it seems that the locus of the subjective effects involves a central process and that action execution is unnecessary for these effects. In addition, we have introduced some initial, tentative evidence for the phenomenon of double-blindness—diminished awareness that two distinct cognitive processes have taken place when those processes lead to identical action plans. Perhaps double-blindness is featured more strongly in the congruent conditions of countermanding tasks such as the anti-saccade task (Curtis & D'Esposito, 2009). In general, the notion of double-blindness is consistent with the view that one is conscious only of the outputs of processes, not of the processes themselves (Jackendoff, 1990; Lashley, 1951).

Limitations of the Current Approach

With these findings, one must be careful about making claims regarding the subjective effects of response interference versus other kinds of interference. At this stage of understanding, it is difficult, if not impossible, to eradicate the influence of processing speed, processing fluency, or a general sense of effort (or a combination thereof) on the judgments made by participants. As with other introspective measures, it is challenging to verify what participants were introspecting at the moment that they were making their judgment. Self-reports are far from infallible, even if they occur just seconds after the relevant conscious experience (Block, 2007).

Regarding speed, along with the observation that response times did not always correlate with reported urges, the positive results of Study 4C suggest that subjective effects obtained in our experiments may not have been just artifacts of participants basing their judgments on observed response times. Moreover, it is not obvious how simply basing one's judgments on RTs could lead to the rich kinds of subjective effects reported in Study 3, in which participants yielded systematic introspections regarding perceptions of difficulty, control, and competition. Then again, participants may have been basing all of their judgments on an overall sense of difficulty, which may be introspected directly or indirectly from inferences based on RT performance. If the former, one must then ask the question, What is it about interference in the Stroop that is so effortful and engenders changes in subjective experience? More generally, what is meant by 'effort'? It is known that subjective effort is a complex construct that, like subjective pain (see review in Grahek, 2007), is not linked to physiological processes in any straightforward manner (Bartley & Chute, 1947; Baumeister & Vohs, 2004; Botvinick, 2007; Kahneman, 1973; Preston & Wegner, 2009; Rosen et al., 2007). There is a whole world of literature demonstrating discrepancies between objective and subjective indices of cognitive effort. For example, participants may be oblivious to the occurrence of neural events that are metabolically or computationally costly, or they may conflate motivational states with subjective fatigue (Bartley & Chute, 1947; Baumeister & Vohs, 2004; Kahneman, 1973; Preston & Wegner, 2009). (For a case in which normal Stroop performance is dissociated from a subjective sense of effort, see Naccache et al., 2005.) Perhaps cognitive effort in tasks such as the Stroop paradigm stems from one's (to use a 'homuncular' description) having to experience incompatible action plans (Cohen et al., 1990; Morsella, 2005) or to suppress a prepotent response (Baumeister, Gailliot, & Tice, 2009). Regarding suppression, we ascribe to the 'non-homuncular' and 'anti-central executive' perspective that conflict stems, not from representations conflicting with an internal supervisor-like system (e.g., Norman & Shallice, 1980), but from the strength of competition among representations (Curtis & D'Esposito, 2009; Morsella, 2005).

A related limitation of these studies, which is perhaps inherent in all flanker paradigms (Coles et al. 1985; Eriksen & Eriksen, 1974; Eriksen & Schultz, 1979; van Veen et al., 2001), is that response interference still features some stimulus interference, possibly rendering it more complicated than the latter. This confound alone could lead to the kinds of subjective effects reported above. Unfortunately, a flanker-like paradigm that can induce response interference without also invoking stimulus interference has yet to be developed. Hypothetically, this could be instantiated by having targets and distracters be perceptually identical but somehow cue different responses, if such a scenario is possible. However, there is evidence that response interference is qualitatively distinct from stimulus interference and that its behavioral and subjective effects are not simply the outcome of increased difficulty. In a neuroimaging study, van Veen et al. (2001) demonstrated that, although both response and stimulus interference are associated with differences in performance, the former is the condition that most activates the anterior cingulate cortex (ACC), a brain region located on the medial surface of the frontal lobe that is interconnected with many motor areas and is believed to be involved in cognitive monitoring (cf., Brown & Braver, 2005; Botvinick, 2007; Botvinick et al., 2001). Consistent with the idea that the incompatibility of plans is what is primarily driving the subjective effects in interference paradigms, it has been shown that, independent of suppression or stimulus/perceptual interference, and on the basis of *a priori* theoretical predictions, merely sustaining incompatible intentions (e.g., to point left *and* right) leads to subjective effects that are greater than those associated with sustaining compatible intentions (e.g., to point left *and* utter a word; Kang et al., 2008; Morsella et al., 2008).

Due in part to how little is known about the nature of cognitive/subjective effort (but see Sanders, 1983), and because of the limitations inherent in all introspection paradigms, we cannot rule out that our pattern of subjective effects (e.g., perceptions of control and competition) stem from only a sense of difficulty, which could be deduced by participants directly or indirectly. Similarly, at this stage of understanding, we cannot rule out that judgments were based on self-observations involving RT performance or on folk beliefs regarding how one should comport oneself in an experiment about cognitive control. Perhaps participants based their ratings on heuristics such as, "if the Stroop trial is incongruent, then I will report 6 as the rating." Although this cannot be fully ruled out by the present studies, this alternative seems unlikely given that participants' ratings tended to vary across trials within each condition. For instance, for incongruent Stroop trials, the first 8 ratings from a participant selected at random from Study 1 were 1, 5, 3, 1, 5, 4, 7, and 7 (mean *SD*s for each condition of Study 1 were $.37_{Congruent}$, $.98_{Control}$, $.66_{Neutral}$, and $1.61_{Incongruent}$). Of course, it may well be that participants were using a more sophisticated and nuanced heuristic when engendering the current pattern of results.

Future investigations on cognitive effort and control will certainly be needed to qualify the kinds of conclusions that can be drawn from this present, initial project.

Observations to Spur Future Investigation

During training in Study 4, participants were capable of introspecting aspects of cognitive processing, despite the fleetingness of color-naming, an act lasting less than one second. Interestingly, for all flanker tasks, less than 23% of all participants were capable of discerning the source of these subjective effects, which is consistent with the view that one can be conscious of tendencies (e.g., urges and inclinations), but not necessarily of the factors engendering such tendencies (Baker, Piper, McCarthy, Majeskie, & Fiore, 2004). Consistent with findings from metacognition and social cognition research (Metcalfe, Funnell, & Gazzaniga, 1995; Nisbett & Wilson, 1977; Roser & Gazzaniga, 2004), we found in our informal post-session interviews that participants tended to provide varied accounts about the source of their judgments.

Our pattern of results is consistent with tenets of Sanders (1983) cognitive-energetic model. In the model, controlled processes such as response selection and top-down attentional control are energy/resource dependent while automatic processes such as stimulus preprocessing are not. In the model, different stages of processing rely on distinct energetical resources. Levels of *arousal* are most influential with respect to the input-end stages of processing (e.g., feature extraction), and levels of *activation* are most influential with respect to the response-end stages of processing. (Because stimulus preprocessing is automatic, it does not require a separate energetical resource.) For a given task, there is an optimal level of arousal and of activation (Fischer, Langner, Birbaumer, & Brocke, 2008; Kahneman, 1973). To reach this optimal level, 'effort' can adjust the levels of arousal and activation. If effort is overloaded or fails to implement the necessary energetical adjustments, *stress* arises. Consistent with our finding that strong changes in consciousness (e.g., urge to err) accompany interference that targets response selection, effort at the *response choice* stage is construed as being intimately associated with conscious processing and with the "conflict type of stress" (Sanders, 1983, p. 81).

More generally, our pattern of results is consistent with the observation that conflicts occurring at perceptual levels of processing (e.g., intersensory conflicts as in ventriloquism) are not as subjectively taxing as those occurring at response selection levels of processing, whether in approach-avoidance conflicts (Livnat & Pippenger, 2006; Miller, 1959) or the delay of gratification (Metcalfe & Mischel, 1999; Morsella, 2005). Figuratively speaking, people tend not to experience any mental strife while watching a ventriloquist or being subjected to the McGurk effect[6] (McGurk & MacDonald, 1976), but such is apparently not the case while they perform the Stroop task or exert self-control (Baumeister & Vohs, 2004).

According to Supramodular Interaction Theory (Morsella, 2005), these findings can be explained by the hypothesis that people are most likely to be conscious of conflicts involving competition for control of the skeletal muscle system, because the primary function of consciousness is to integrate such incompatible skeletomotor intentions. From this standpoint, *conscious conflicts* stem from incompatible skeletomotor intentions, such as when one suppresses a prepotent response, diets, suppresses emotions, holds one's breath while underwater, or inhibits a prepotent response in a laboratory interference paradigm (Morsella, 2005). From this standpoint, regarding the conflicts occurring at the different stages of processing, consciousness is required to integrate information at the response-selection end of processing.

Accordingly, incompatible skeletomotor intentions (e.g., to point right *and* left, to eat *and* not eat, to inhale *and* not inhale) produce strong, systematic changes in consciousness. For example, in a paradigm similar to that of Study 4, in which participants are trained to introspect conflict-related aspects of cognition during an interference task and then introspect the same 'thing' while sustaining compatible intentions (e.g., pointing left with a given finger and vibrating that finger) and incompatible intentions (e.g., to point left and right with the same finger), participants reported stronger systematic changes in subjective experience when sustaining incompatible than compatible skeletomotor intentions, even though participants were always in a motionless state (Kang et al., 2008; Morsella et al., 2008).

In conclusion, we believe that the limitations of this initial enquiry into the nature of the fleeting subjective effects that accompany cognitive interference will be remedied easily by future investigation. Theories on cognitive control and conscious processing will have to account for these reliable and replicable patterns of results. More generally, we believe that, just as response time can reveal aspects of cognitive processing that may not be detectable through less subtle behavioral measures (e.g., response accuracy), measures of subjective aspects of processing may illuminate features of cognitive processing that are undetectable in standard behavioral and psychophysiological measures. (For example, in Study 4A, the size of the subjective effect was larger than that of the behavioral RT effect.) We hope that, with the present paradigms and by targeting brain regions involved in cognitive control (cf., Kang et al., 2008), future research may identify the neural correlates of these subjective phenomena and assess their role in negative affect (e.g., stress and anxiety) and failures of self-regulation, where disharmony from strong forms of response conflict (as in the delay of gratification) seems to play a critical role (Baumeister & Vohs, 2004; Metcalfe & Mischel, 1999).

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Table 1. Mean response time (ms) as a function of distracter environment in Study 4B.

Distracter Environment	Response Times Mean	*SEM*
Alone	640.46	26.53
Identical	648.14	24.69
Stimulus Interference	666.28	22.68
Weak Response Interference	681.49	25.21
Response Interference	695.70	20.47

Figure Captions

Figure 1: Mean urges to err on a subvocal version of the Stroop task (Study 1). Error bars indicate *SEM*s.

Figure 2: Mean urges to read stimulus words in subvocal and vocal versions of the Stroop task (Study 2). Error bars indicate *SEM*s.

Figure 3: Mean urges to err in subvocal and vocal versions of the Stroop task (Study 3). Error bars indicate *SEM*s.

Figure 4: Mean perceptions of control in subvocal and vocal versions of the Stroop task (Study 3). Error bars indicate *SEM*s.

Figure 5: Mean perceptions of competition in subvocal and vocal versions of the Stroop task (Study 3). Error bars indicate *SEM*s.

Figure 6: Mean subjective ‘activity’ as a function of flanker condition, exemplified by stimuli from the Introduction (Study 4A). Not actual experimental stimuli.

Figure 7: Sample distracter conditions (Study 4B). From top to bottom: identical, stimulus interference, and response interference. Not drawn to scale.

Figure 8: Mean subjective ‘activity’ as a function of flanker condition (Study 4C).

Figure 1, Study 1

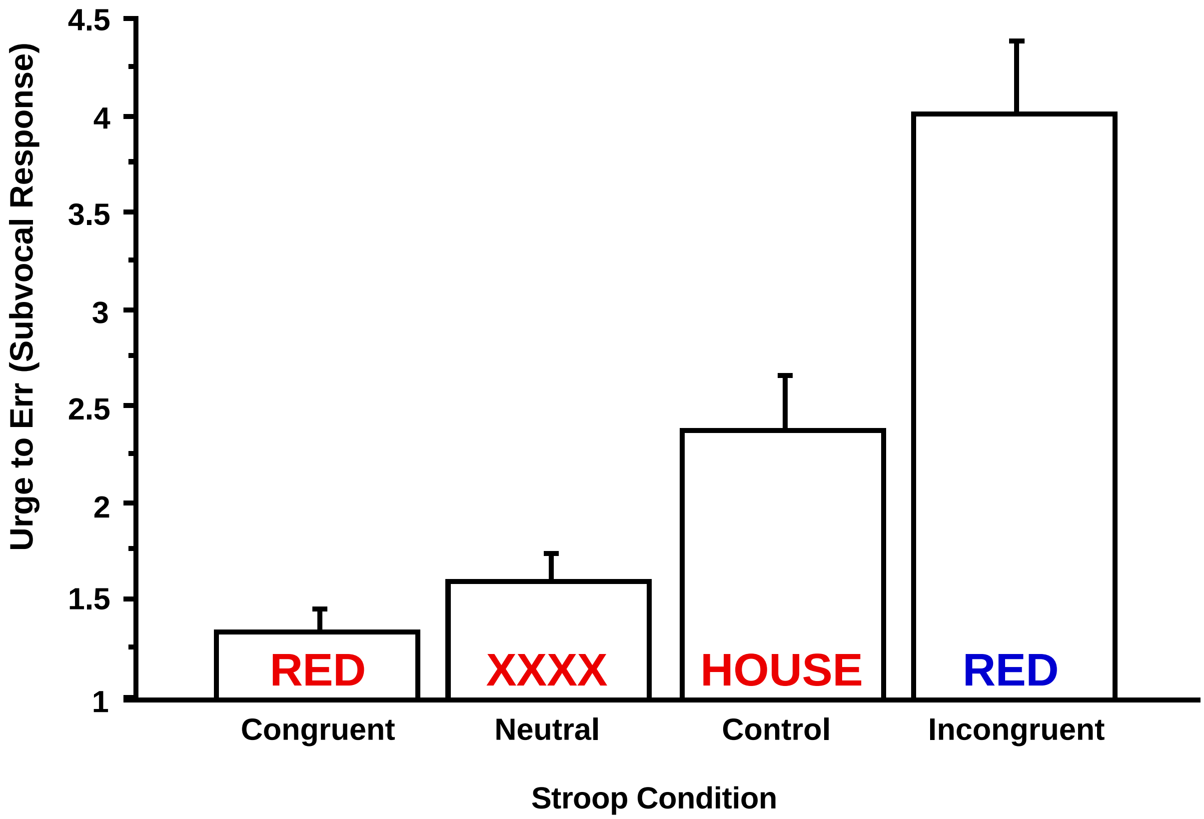


Figure 2, Study 2

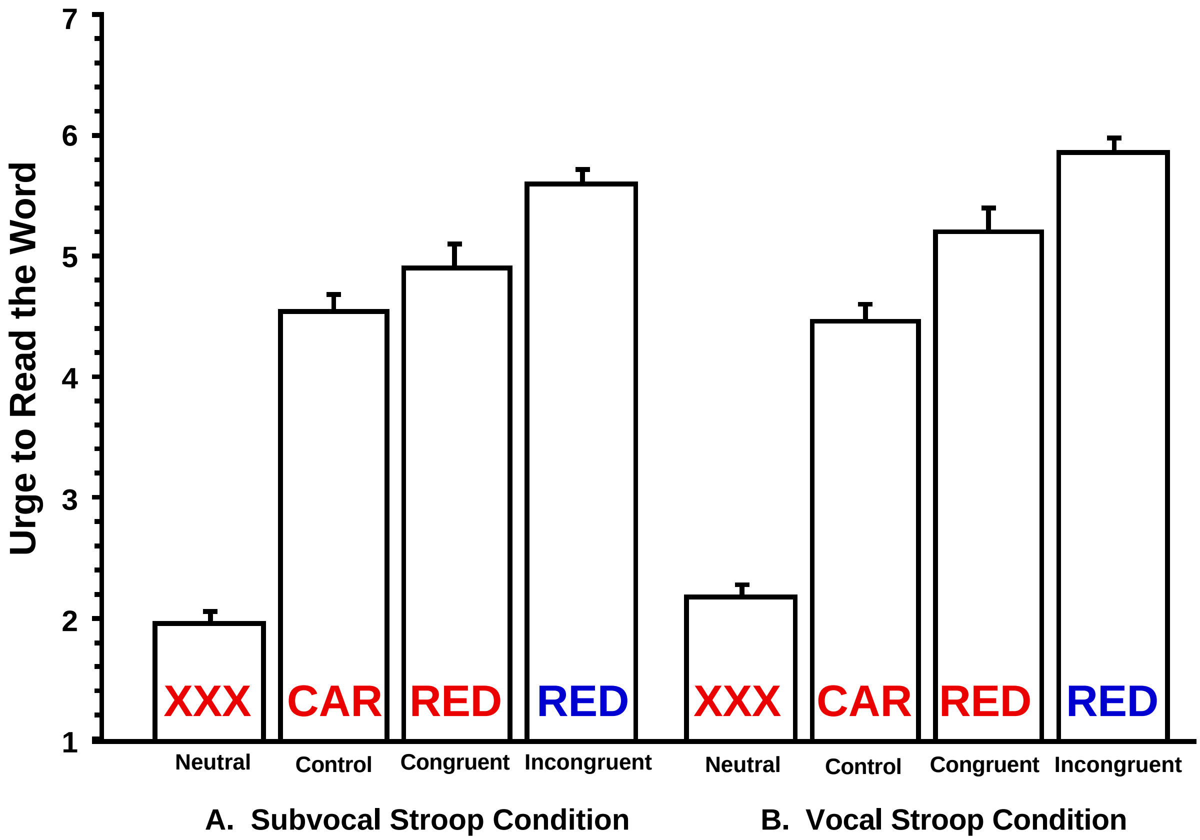


Figure 3, Study 3

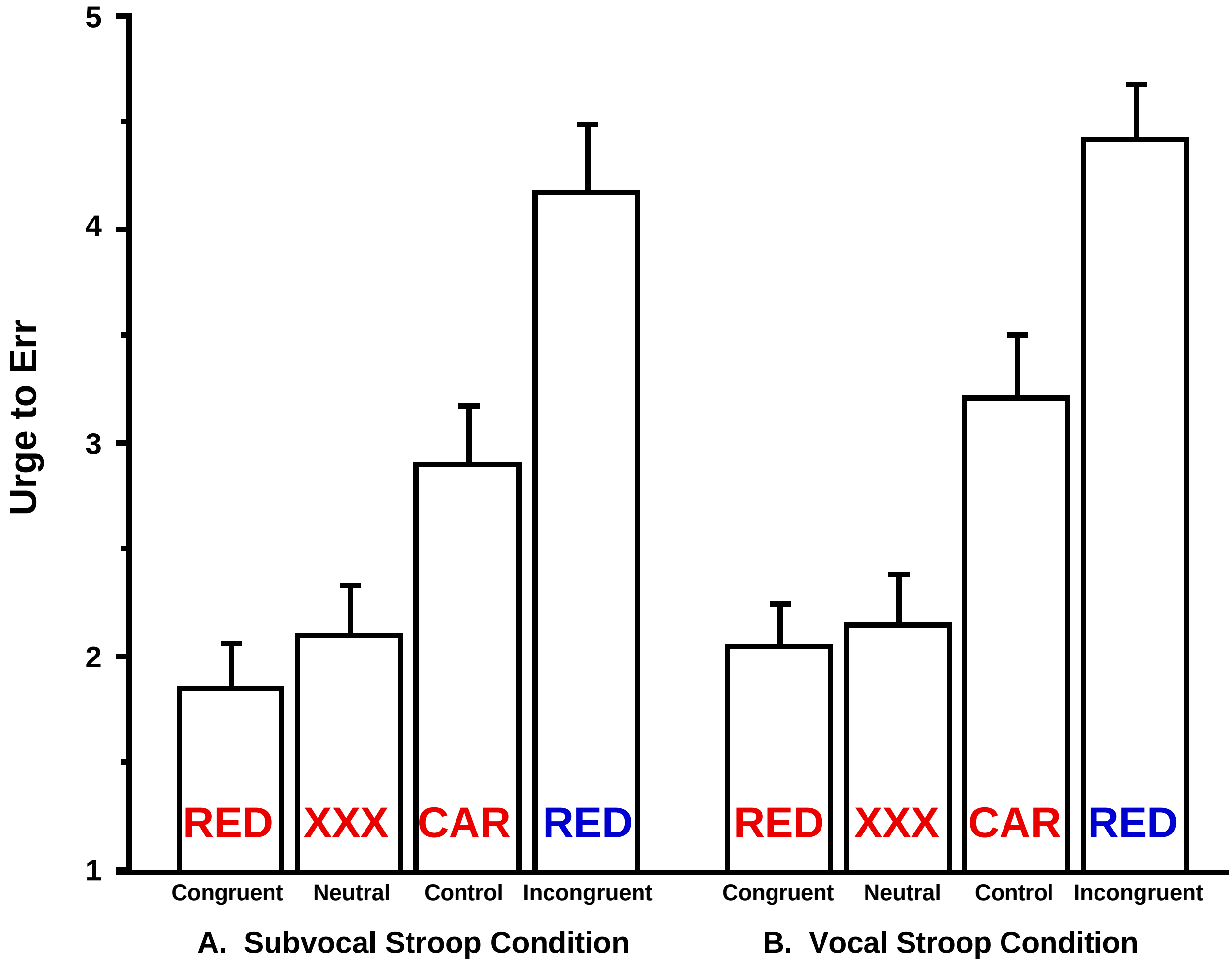


Figure 4, Study 3

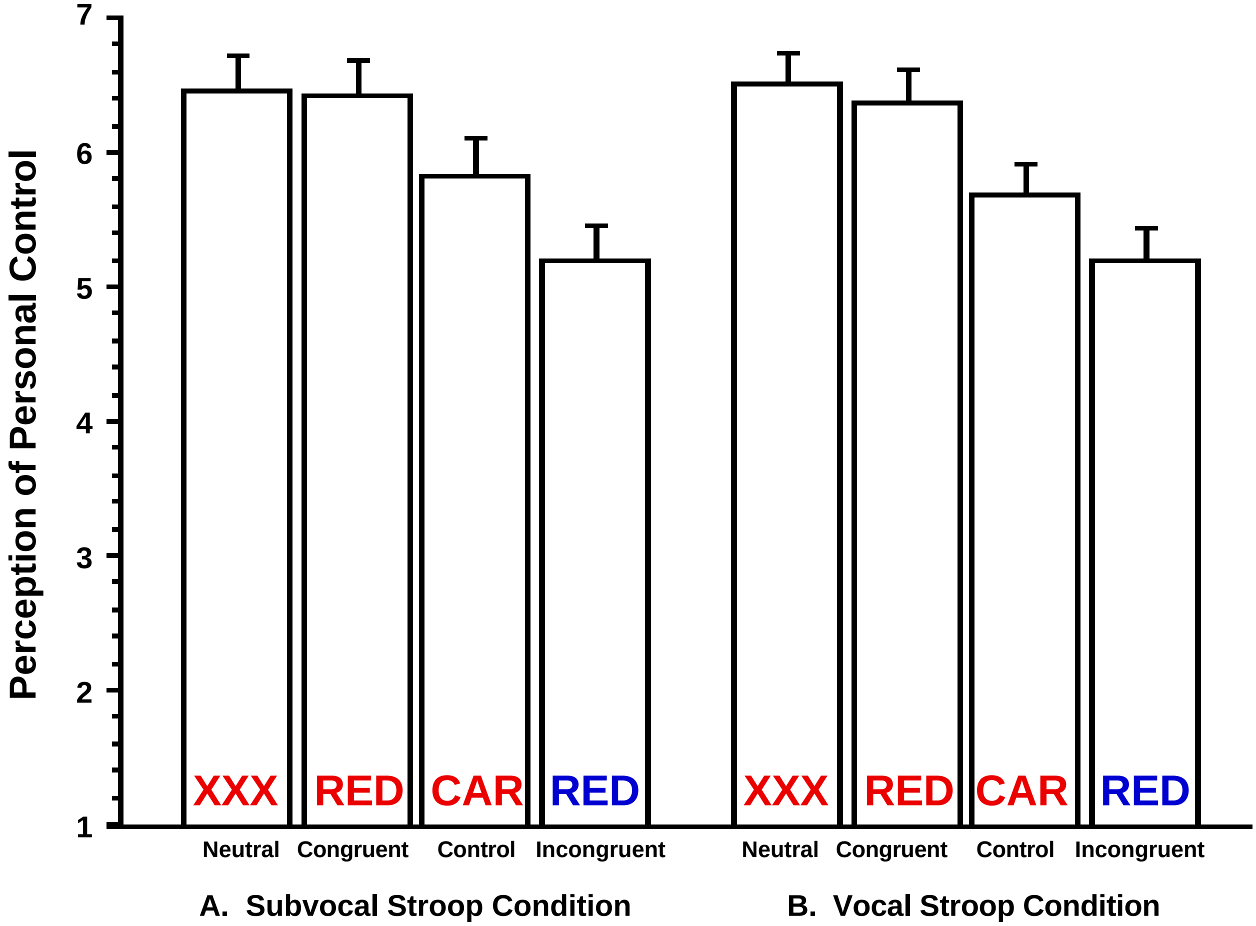


Figure 5, Study 3

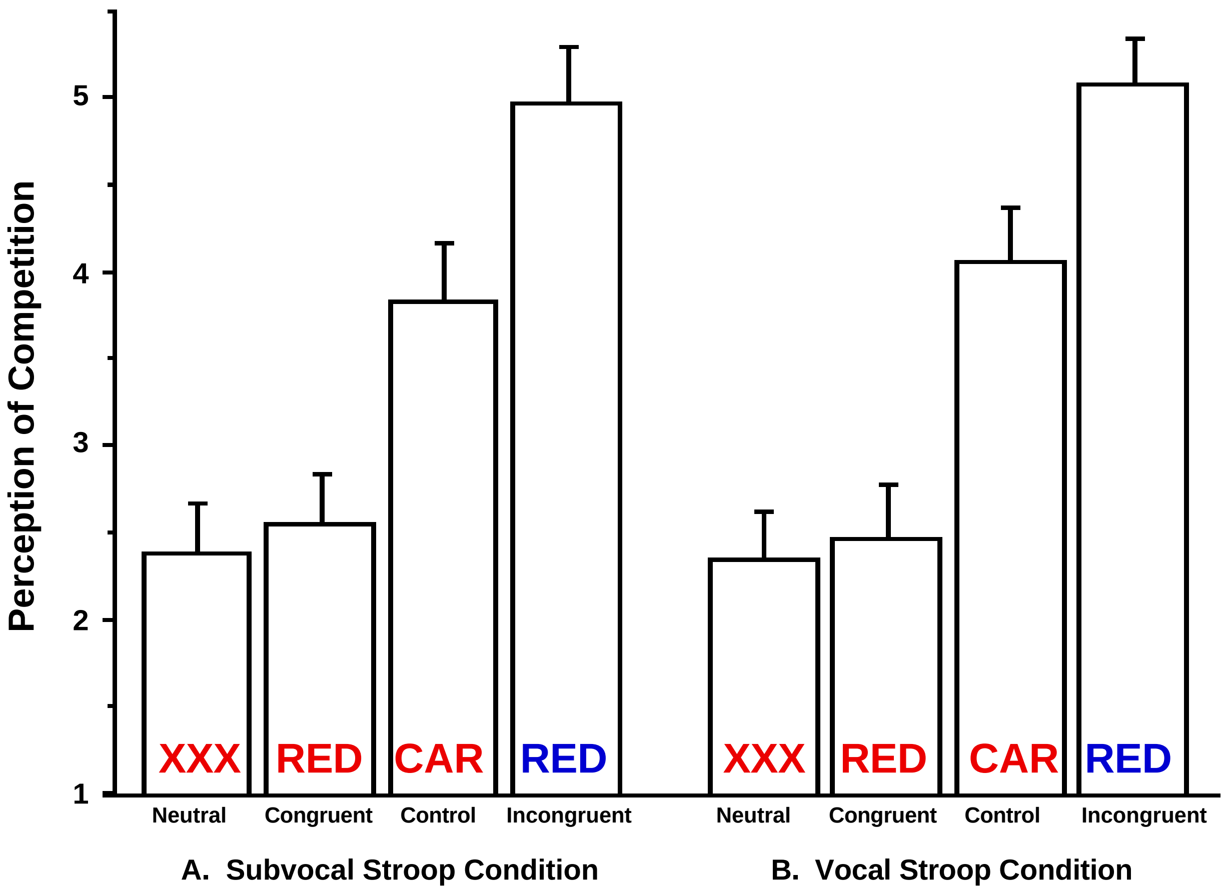


Figure 6, Study 4A

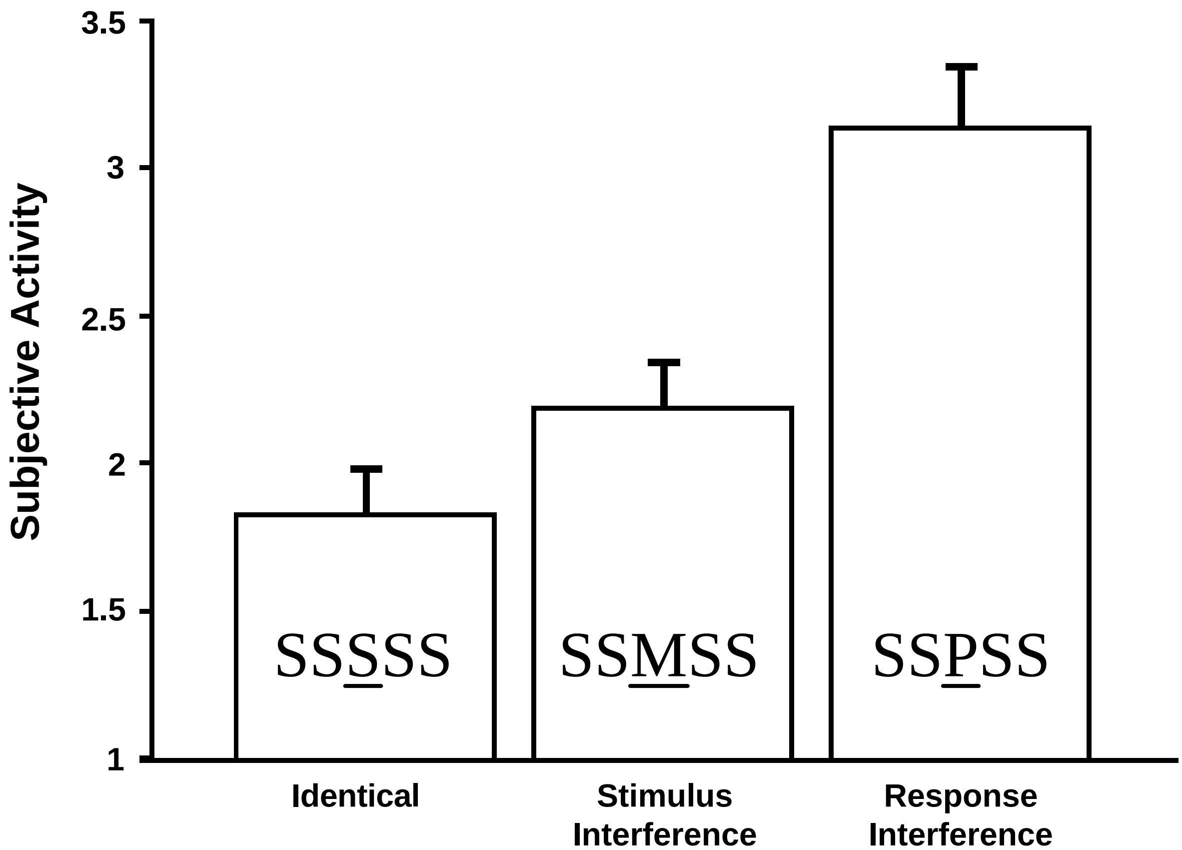


Figure 7, Study 4B

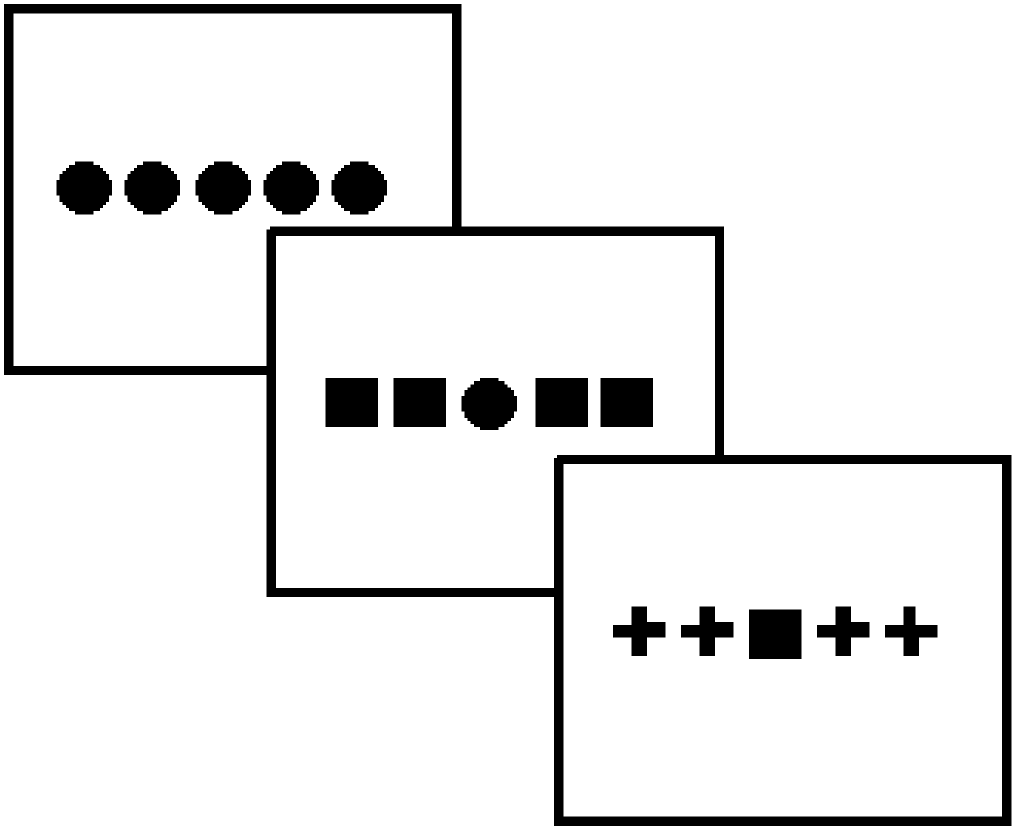
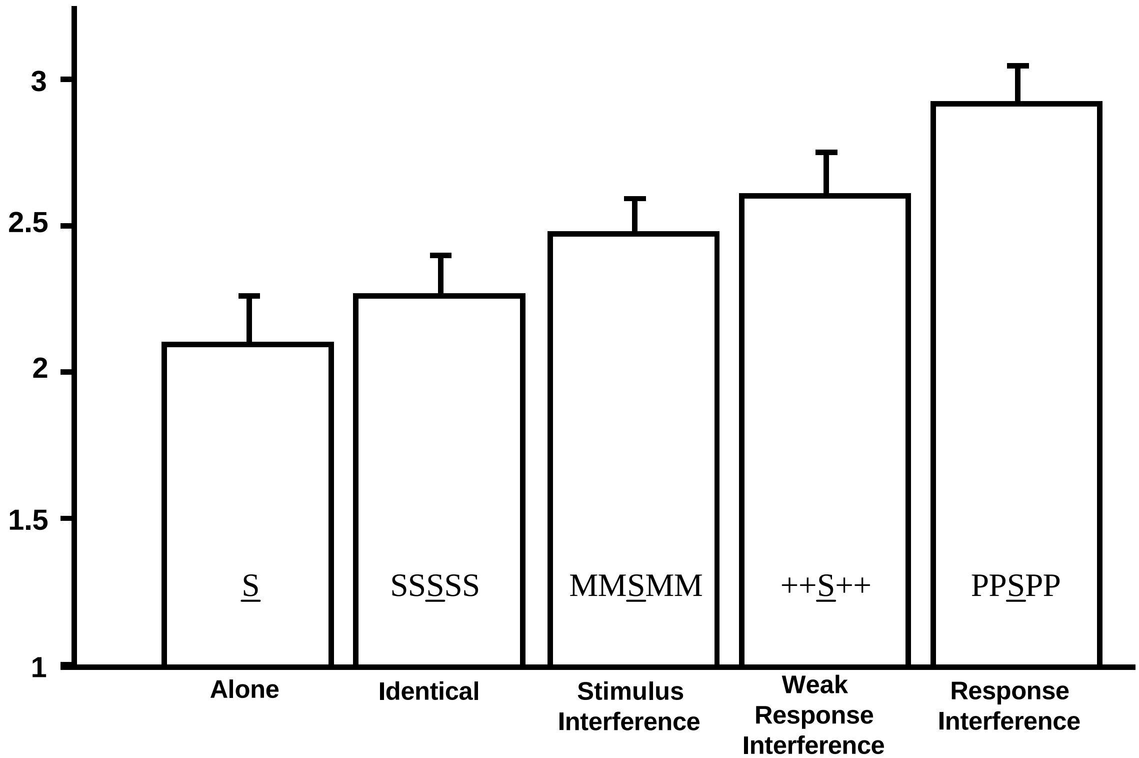


Figure 8, Study 4B



Appendix

Mean proportion of response trial data removed by trimming, as a function of study and condition. Also includes mean error rates for Study 4.

	Mean	*SEM*	Mean	*SEM*
Study 1	Subvocal			
Congruent	.017	.009		
Neutral	.022	.007		
Control	.029	.014		
Incongruent	.068	.028		
Study 2	Subvocal		Vocal	
Congruent	.017	.003	.002	.001
Neutral	.020	.004	.002	.001
Control	.027	.005	.002	.001
Incongruent	.058	.008	.004	.001
Study 3	Subvocal		Vocal	
Congruent	.024	.006	.008	.002
Neutral	.027	.007	.002	.001
Control	.030	.009	.009	.003
Incongruent	.074	.015	.013	.002
Study 4A	Data removed (Trimming)		Data removed (Errors)	
Identical	.009	.004	.047	.007
Stimulus interference	.012	.004	.021	.008
Response interference	.018	.008	.068	.012
Study 4B	Data removed (Trimming)		Data removed (Errors)	
Alone	.008	.004	.051	.012
Identical	.010	.005	.042	.009
Stimulus interference	.013	.005	.037	.007
Weak response interference	.007	.003	.050	.007
Response interference	.014	.005	.046	.009
Study 4C	Data removed (Trimming)		Data removed (Errors)	
Alone	.128	.026	.023	.008
Identical	.102	.025	.023	.008
Stimulus interference	.065	.014	.024	.009
Weak response interference	.082	.019	.014	.007
Response interference	.104	.023	.026	.013

Footnotes

[1] An organism is said to possess a subjective experience (the elusive phenomenon falling under the rubrics of ‘consciousness,’ ‘sentience,’ or ‘basic awareness’) if there is *something it is like* to be that organism—something it is like, for example, to be human and experience pain, breathlessness, or yellow afterimages (Nagel, 1974).

[2] In this task, participants name the colors in which stimulus words are written. When the word and color are incongruous (e.g., RED presented in blue), response conflict leads to increased error rates and response times (Cohen, Dunbar, & McClelland, 1990). When they are congruous (e.g., RED presented in red), there is little or no interference (see review in MacLeod & MacDonald, 2000).

[3] One reason these ineffable phenomena have remained under-explored may be because the basic relationship between nervous processes and subjective experience remains profoundly mysterious (Crick & Koch, 2003; Gray, 1995). Another reason may reflect the dominance of Behaviorism in the first half of the twentieth century; Behaviorism may have served as a healthy reaction to Structuralism, which attempted to explain all operations in terms conscious processes.

[4] This, however, cannot be said for the whole or most of experimental psychology, as the subjective aspects of cognitive processing have been examined systematically in research on psychophysics (e.g., Stevens, 1956), metacognitive processes (e.g., Fernandez-Duque, Baird, & Posner, 2000; Johnson & Raye, 1981), and memory and perceptual fluency (e.g., Jacoby, Kelley, & Dywan, 1989).

[5] To obtain a sense of the baseline urge-to-read for the words used in our Stroop task, following procedures similar to those of Study 2, another group of participants (n = 15)

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rated how strong their urge was to read the words when the words were presented in standard, uncolored (black) font. In this ‘passive viewing’ task, participants pressed the space bar when presented with the stimulus and then rated their urge to the word. Urges to read were comparable for the color and control words ($M_{Color\ Word}$ = 6.67, $SEM_{Color\ Word}$ = .47; $M_{Control\ Word}$ = 6.68, $SEM_{Control\ Word}$ = .44), t (14) = -.015, p = .99. Of course, it is difficult to compare these urges with the (weaker) reported urges-to-read for the congruent condition of the Stroop task, because urges are probably context-sensitive and the two tasks differ in various respects.

[6] For example, the McGurk effect (McGurk & MacDonald, 1976) involves a conflict between visual and auditory information: an observer views a speaker mouthing “ba” while presented with the sound “ga.” Surprisingly, the observer is unaware of conflict, perceiving only “da.”