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Trial-by-trial adjustments in control triggered by incidentally encoded semantic cues

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Cognitive control mechanisms provide the flexibility to rapidly adapt to contextual demands. These contexts can be defined by top-down goals—but also by bottom-up perceptual factors, such as the location at which a visual stimulus appears. There are now several experiments reporting contextual control effects. Such experiments establish that contexts defined by low-level perceptual cues such as the location of a visual stimulus can lead to context-specific control, suggesting a relatively early focus for cognitive control. The current set of experiments involved a word–word interference task designed to assess whether a high-level cue, the semantic category to which a word belongs, can also facilitate contextual control. Indeed, participants exhibit a larger Flanker effect to items pertaining to a semantic category in which 75% of stimuli are incongruent than in response to items pertaining to a category in which 25% of stimuli are incongruent. Thus, both low-level and high-level stimulus features can affect the bottom-up engagement of cognitive control. The implications for current models of cognitive control are discussed.

Keywords: Context-specific congruency proportion; Cognitive control; Selective attention; Categorization; Implicit learning

Our cognitive system has the flexibility to perform specific tasks through context-specific adjustments in response preparation and perceptual filtering. These processes are collectively referred to as *cognitive control* and are the focus of a growing literature across cognitive psychology, cognitive neuroscience, and the cognitive sciences. Several theories have been proposed for how cognitive control is accomplished (Baddeley & Della Sala, 1996; Cohen, Dunbar, & McClelland, 1990; Norman & Shallice, 1986), and the neural correlates for many of these processes have been identified (Cohen, Braver, & O'Reilly, 1996; Cohen & Servan-Schreiber, 1992; Desimone & Duncan, 1995; Goldman-Rakic, 1996).

Performance-monitoring hypotheses have stressed the importance of a wide variety of situational cues. The majority of research examines adjustments via explicit task rules—that is, goal-directed or "top-down" control. However, incidentally encoded information can also trigger performance adjustments—that is, "bottom-up" triggers of

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control. For example, Botvinick and colleagues (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick, Cohen, & Carter, 2004) have argued that response conflict is one cue that serves to signal the need for top-down regulation. In this model, the level of cognitive control on a given trial is proportional to the level of response conflict detected on the current trial and trials in the recent past. Similarly, Brown and Braver (2005) showed that the likelihood of committing an error serves as a cue that regulates cognitive control. These are but two of many performance-monitoring cues. Collectively, these control triggers explain several behavioural and neural effects including proportion effects (Lindsay & Jacoby, 1994), sequential effects (Gratton, Coles, & Donchin, 1992), and error-related slowdown (Rabbitt, 1968; Yeung, Botvinick, & Cohen, 2004).

These effects are observed in a variety of conflict paradigms (e.g., Eriksen & Eriksen, 1974; Simon, 1969; Stroop, 1935). Two of these effects are particularly interesting because they demonstrate rapid and relatively effortless adjustments of control. The first is the sequential congruency effect (Gratton et al., 1992), whereby the size of the conflict effect is larger following a low-conflict item (e.g., larger Stroop effect following a congruent trial). The second is the proportion congruency effect, whereby the size of the conflict effect is larger when there is a larger proportion of low-conflict items in a block of trials (e.g., a larger Stroop effect in a block of 80% congruent trials than in a block of 20% congruent trials).

The Gratton effect demonstrates trial-to-trial adjustments in performance; conflict from the previous trial(s) prepares the system for the subsequent trial. The proportion congruency effect demonstrates context-related adjustments in performance; the high conflict associated with the mostly incongruent blocks sets up the system to focus on processing the colour. In addition to these general adjustments in performance, adjustments can also be quite specific. For example, if one subset of stimuli within a block of trials is mostly congruent, and another subset is mostly incongruent, the size of the Stroop effect is larger for the mostly congruent items (Jacoby, Lindsay, & Hessels, 2003) even though the congruency level of the upcoming trial is unpredictable, and even after controlling for priming effects (e.g., Mayr, Awh, & Laurey, 2003; Schmidt & de Houwer, 2011). These context-specific proportion effects have been replicated using a number of contextual cues including location (Corballis & Gratton, 2003; Crump, Gong, & Milliken, 2006), form (e.g., font, Bugg, Jacoby, & Toth, 2008; words, Jacoby et al., 2003; shape under certain conditions, Crump, Vaquero, & Milliken, 2008), colour (Vietze & Wendt, 2009; but see, Jacoby et al., 2003), and even social categories such as gender (Cañadas, Rodríguez-Bailón, Milliken, & Lupiáñez, 2013).

Although these findings are not the result of feature priming (see, Crump & Milliken, 2009), they are consistent with the idea that control settings are "primed". Computational models of these effects (e.g., Blais, Robidoux, Risko, & Besner, 2007; Verguts & Notebaert, 2008) rely on a conflict-mediated association mechanism. Response conflict is used to mediate the strength of connection weights between any active features by increasing the strength for relevant features and decreasing it for features that are detrimental to performance (such as an irrelevant dimension). For example, on an incongruent Stroop trial, such as the word BLUE printed in red, conflict will be relatively high, and the connection between the colour red and the response "red" will be increased while simultaneously decreasing the connection between the word BLUE and the possible response "blue". Now if blue/red items are mostly congruent, and yellow/green items are mostly incongruent, the perception of the word YELLOW, even if printed in yellow, engages control to limit word processing resulting in a slower response than the word BLUE printed in blue. This effect is referred to as the item-specific proportion congruency effect.

Here, we take a different approach. To date, all of the cues that drive these contextual effects—colour, location, and form—can be considered perceptual. One characteristic of perceptual cues is that processing begins immediately at stimulus onset. Thus, if the stimulus is presented in a historically difficult context, it is possible that the stimulus retrieves the prior, or "primes", control set. The advantage of such a mechanism is that it would be metabolically cheap (e.g., Anguera et al., 2012). However, if the contextual cue is the meaning of the item, then priming the control set is unlikely to be fast enough to have an impact unless subjects are actively maintaining the control set. That is, a context-specific proportion congruency effect in which the context is created by the semantic meaning of the item suggests some type of sustained attention to at least one of the categories, and not solely priming the contextual control set.

EXPERIMENT 1

A simple Flanker-like experiment (Eriksen & Eriksen, 1974) was constructed in which the semantic category to which a word stimulus belonged served as the contextual cue. Participants were simultaneously presented with two words, one in a large font size, and the other in smaller font size. The task was to read the smaller word aloud. Overall, the two words were the same (congruent) for half the trials, and on the other half they were different (incongruent). In addition, half of the item-pairs belonged to one semantic category (occupations) and the other half to a different semantic category (animals).

Critically, the congruency manipulation differed across these two categories; stimuli pertaining to the occupation (animal) category were designed to be more likely to be congruent than stimuli pertaining to the animal (occupation) category. Thus, before the context could be identified (and hence an optimal level of control applied), at least one of the word-pairs needs to be processed to the semantic level. If subjects adjust control levels on the basis of semantic contextual cues, then we expect to see a larger Flanker-like effect for occupations because they are congruent on most trials (see Figure 1a). That is, a word-pair like NUN–NUN would activate the semantic context "occupation", which would trigger the system to use the physically larger word to assist in processing of the smaller word. Conversely, if subjects do not adjust control levels on the basis of semantic contextual cues, then we would expect to see no difference in the size of the Flanker effect for stimuli from the occupation category compared to stimuli from the animal category (see Figure 1b).

Method

Participants

Sixteen individuals from the University of California (UC) Berkeley community served as participants using guidelines set forth by the institutional review board (IRB).

Task

The general task set-up is shown in Figure 2. Participants were seated approximately 60 cm from the screen where they viewed a green fixation crosshair on each trial for 300 ms, which was replaced by a pair of words in white. One word was presented in 12-point font, and the other was presented in 30-point font. These two words were either the same (congruent) or different (incongruent). Subjects were asked to name aloud the word in the small font, randomly appearing above or below the word in the large font, which triggered a voice key measuring response latency (RT). After the voice key was triggered, a white fixation marker replaced the words. While the white fixation marker was on the screen, the experimenter (M.H.S.) categorized the subjects' response as correct, incorrect, or a mistrial. After the experimenter keyed in his response the next trial was immediately initiated.

Stimuli

The word stimuli consisted of 192 occupations and 192 animals. The distractor word always belonged to the same category as the target, and it was either congruent (e.g., NUN_{NUN}) or incongruent (e.g., $\text{PIG}_{\text{LEMUR}}$) with the target word. Overall half of the trials were congruent, and the other half were incongruent. For example, if animals were congruent on 75% of trials, and occupations were congruent on 25% of trials, then the semantic context was created such that 144 trials contained matching

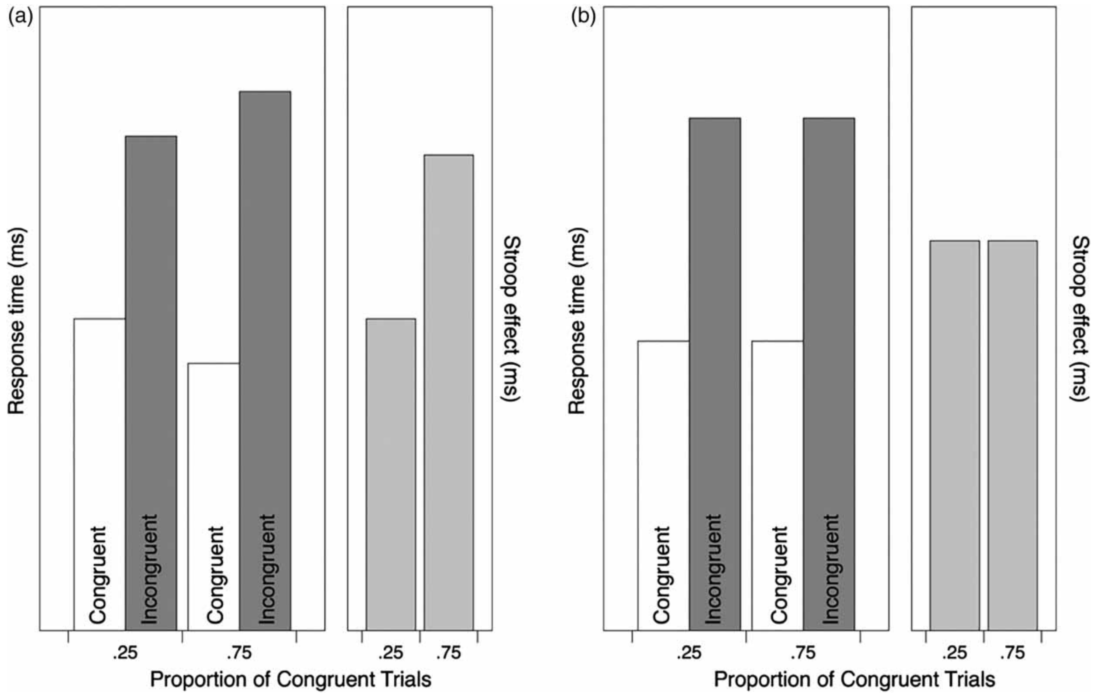

Figure 1. *The expected pattern of results if (a) the semantic context of the word-pair influences attention to a relevant item compared to (b) if it does not.*

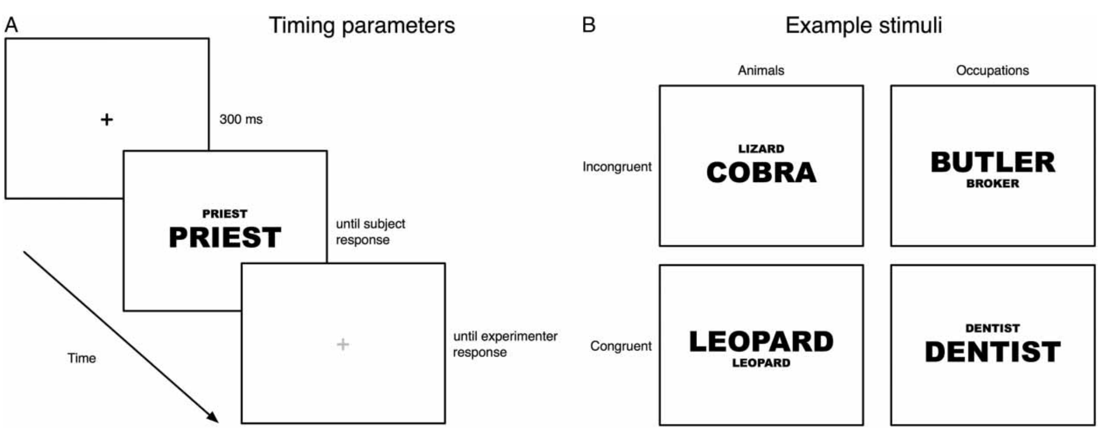

Figure 2. *The task is to name the smaller of the two words. (A) shows the timing parameters, and (B) shows examples of congruent and incongruent trials for the two categories in Experiment 1. The relative size of the small and large words is preserved.*

animal word-pairs (e.g., $\text{LEMUR}_{\text{LEMUR}}$), and the remaining 48 trials consisted of nonmatching animal word pairs (e.g., $\text{PIG}_{\text{LEMUR}}$). Conversely, there were 48 trials consisting of matching occupation word-pairs (e.g., NUN_{NUN}), and the remaining 144 trials consisted of nonmatching occupation word-pairs (e.g., $\text{NUN}_{\text{DOCTOR}}$). Individual words were repeated three times. Specifically, each word served as the target exactly once and as the distractor once. For example, if the target was "nun", then the subject would see it three times in total across two trials (NUN_{NUN} and NUN_{DOCTOR}). Participants' responses were categorized as correct, incorrect, or a microphone misfire by the experimenter (M.H.S.) seated off to the side. The experimental trials were preceded by 16 practice trials from a separate list of nouns to get participants familiar with the task and to adjust the microphone sensitivity. The category assigned to each proportion condition was counterbalanced across subjects, and subjects performed two blocks of 192 trials.

Analysis

Correct RTs were trimmed via a two-step process. First, correct RTs below 200 ms and above 2000 ms were excluded. Next, any RT more than 3.5 standard deviations from the mean for each condition, for each subject, was excluded as an outlier. This two-step procedure excluded 2.7% of correct trials. The remaining data were analysed using a 2 × 2 repeated measures analysis of variance (ANOVA) with semantic contextual proportion and congruency as repeated factors.

Results

The data are shown in Figure 3. The 2 × 2 ANOVA conducted on the remaining RTs showed the presence of a context-specific proportion effect based on the semantic category. The 25 ± 11 ms semantic context interaction effect, $F(1, 15) = 5.31$, $p < .05$, occurred because the 63 ± 9 ms Flanker effect in the 75% congruent condition was larger than the 39 ± 7 ms Flanker effect in the 25% congruent condition. There was also an overall Flanker effect (51 ± 6 ms), $F(1, 15) = 103.25$, $p < .001$, but no overall proportion effect (−8 ± 11 ms, $F < 1$). The error rate was very low overall (1.6%), and the same ANOVA on the error data yielded no reliable effects (Fs < 1.2).

Discussion

These results show that even a high-level contextual cue such as the semantic category an item belongs to can modulate cognitive control. Given the importance of this finding, it is particularly important to scrutinize the experiment in detail. Doing so reveals a potential perceptual confound: The average length of the words in one category is different from that in the other category. Specifically, items on the occupation list (8.4 ± 2.2 letters) were on average 2.5 letters longer than those on the animals list (5.9 ± 2.0; $p < .001$). This perceptual difference between the lists compromises the strong conclusion that cognitive control to an item pair can be adjusted based solely on the semantic category to which it belongs.

EXPERIMENT 2

The purpose of Experiment 2 is to assess the source of the context effect observed in Experiment 1. To this end, several new lists of semantic category exemplars were constructed that were matched on low-level perceptual features including target length and difference in word length between the target and distractor words.

Method

Participants

Twenty-four students from the University of California, Berkeley participated in the 20-minute experiment, for which they received course credit.

Task

The task was identical to that in Experiment 1, except for a new experimenter (M.B.H.).

Stimuli

Eight pairs of lists were constructed. Each list contained 32 items that were matched on two Gestalt-like perceptual features; mean word length of the target and the difference in the number of letters between the target and the distractor. Each subject received four of the eight pairs, in random order, thus performing four blocks of 64 trials. Items on one list (e.g., tools) were congruent on 25% of trials, and items on the other list (e.g.,

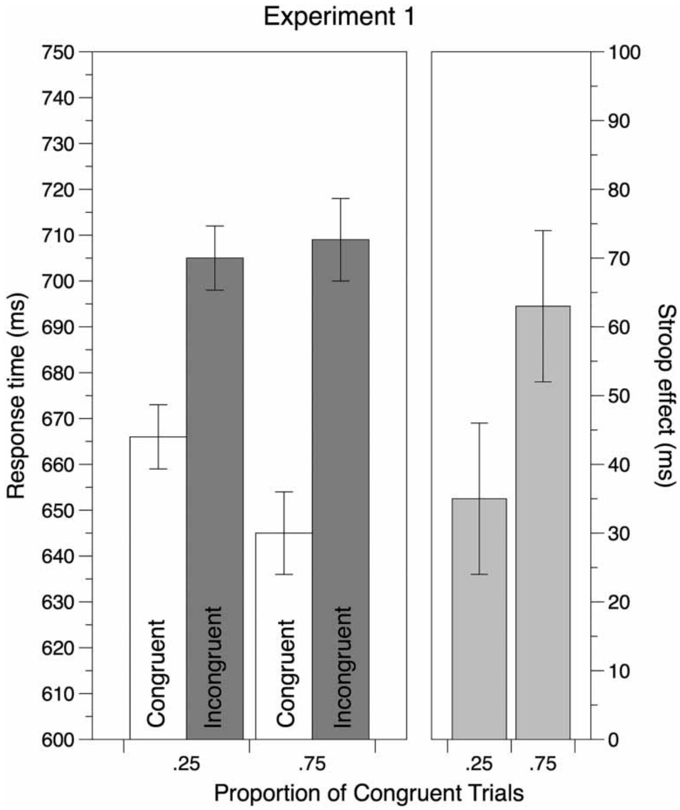

Figure 3. *Left: mean response times in Experiment 1 as a function of the proportion of congruent trials, which was dependent on the semantic category of the word-pair, and congruency. Error bars reflect the standard error of the difference in congruency. Right: the Stroop effect, incongruent—congruent, for each of the .25 and .75 proportion conditions. Error bars reflect the standard error of the interaction.*

mammals) were congruent on 75% of trials. The proportion condition (e.g., whether tools or mammals was the 75% congruent list) was counterbalanced across subjects. The category pairs are shown in Table 1, and the items on each list are in the Supplemental Material.

Results and discussion

Analysis

The same two-step RT trimming procedure as that used in Experiment 1 resulted in the exclusion of 1.0% of correct trials. These data are shown in Figure 4. The 2 × 2 ANOVA showed the presence of a context-specific proportion congruency effect based on the semantic category. The 21 ± 9 ms semantic context interaction effect, $F(1,\ 23) = 5.17$, $p < .05$, occurred because the 61 ± 8 ms Flanker effect in the 75% congruent condition was larger than the 40 ± 4 ms Flanker effect in the 25% congruent condition. There was also an overall Flanker effect of 51 ± 4 ms, $F(1,\ 23) = 136.18$, $p < .001$, but no overall proportion effect (0 ± 4 ms, $F < 1$). The overall error rate was low (1.8%), and the same ANOVA on the error data yielded no reliable effects (ps > .15).

Sequential analyses

Two 2 × 2 × 2 ANOVAs were conducted. Each included the previous two factors: *congruency* and *proportion congruent/semantic context*; the first analysis included previous *context* as a factor, and the second looked at whether the context repeated or switched from one trial to the next. Both

Table 1. *Average length of the words in each list and the average difference in length between the target and distractor item pairs*

List name	*Mean word length*	*Mean target–distractor difference*
Tools	5.3 ± 1.3	1.7 ± 1.1
Mammals	5.6 ± 1.7	1.9 ± 1.4
Clothing	5.8 ± 1.5	1.8 ± 1.5
Birds	5.8 ± 1.6	1.9 ± 1.5
Furniture	5.8 ± 1.8	2.1 ± 1.8
Insects	6.1 ± 2.3	2.3 ± 1.9
Fish	6.2 ± 1.7	1.8 ± 1.3
Elements	6.3 ± 1.5	1.8 ± 1.3
Transportation	6.3 ± 2.3	2.3 ± 1.9
Instruments	6.6 ± 2.2	2.3 ± 1.8
Cities	6.7 ± 1.6	2.1 ± 1.5
Fruit	6.7 ± 2.3	2.2 ± 1.7
States	7.0 ± 1.5	1.9 ± 1.2
Jobs	7.0 ± 1.8	2.0 ± 1.6
Disease	7.5 ± 1.9	2.2 ± 1.6
Sports	7.5 ± 1.8	2.3 ± 1.5

Note: Each pair within the group of four was assigned one proportion condition.

analyses failed to find significant three-way interactions (Fs < 1), and none of the two-way interactions, or main effects, involving the new factors approached significance (Fs < 1). For both analyses, however, the semantic context interaction effect remained, $F(1, 23) = 5.33$, $p < .05$, and $F(1, 23) = 5.37$, $p < .05$, respectively, for the two analyses. The outcomes of both of these analyses are consistent with the idea that subjects maintained one control setting throughout the task and did not alternate between two or more.

A $2 \times 2 \times 2$ analysis looking at previous congruency (i.e., the Gratton effect) was also conducted, even though there is no confound in the design due to repeating either the distractor or the target from one trial to the next (e.g., Mayr et al., 2003; Schmidt & de Houwer, 2011). That analysis also yielded no three-way interaction and no two-way interactions (including the absence of a Gratton effect) or main effect involving previous congruency (Fs < 1). Again, however, the semantic context interaction effect remained, $F(1, 23) = 4.54$, $p < .05$.

GENERAL DISCUSSION

It is well established that cognitive control can be contextually driven by perceptual cues such as the location (Crump et al., 2006), form (Bugg et al., 2008), or colour (Vietze & Wendt, 2009) of a stimulus. The typical account argues that one or more performance-monitoring cues, such as the response conflict associated with the trial, is bound to its contextual cue (e.g., via Hebbian learning, Verguts & Notebaert, 2008). The next time the cue is encountered, the cognitive control system is "primed" to reconfigure to itself to optimize performance. With perceptual cues, it seems likely that this involves the implementation of low-level perceptual filters that delay, or even prevent, irrelevant stimulus features from being processed.

In the two experiments reported here, it was demonstrated that semantic contexts could also serve to adjust cognitive control. In Experiment 1, a larger Flanker effect was observed in the 75% congruent condition than in the 25% congruent condition. Experiment 2 corrected for a potential perceptual cue, the differential length of the words between the two semantic categories, and replicated a larger Flanker effect in the 75% congruent condition than in the 25% congruent condition.

Bottom-up versus top-down control

The classic dissociation between automatic and controlled processes states that controlled processes are slow, are effortful, and require attention (Posner & Snyder, 1975; Shiffrin & Schneider, 1977). Traditional accounts focus on rule-based top-down components of control, while recent accounts suggest that control can be rapid, effortless, and implicit (Blais et al., 2007; Botvinick et al., 2001; Jacoby et al., 2003; Verguts & Notebaert, 2008) and focus on more bottom-up components of control (e.g., slowing down after an incongruent trial; see De Pisapia & Braver, 2006, for a computational model of this principle).

This apparent contradiction between traditional and contemporary models of control seems to arise

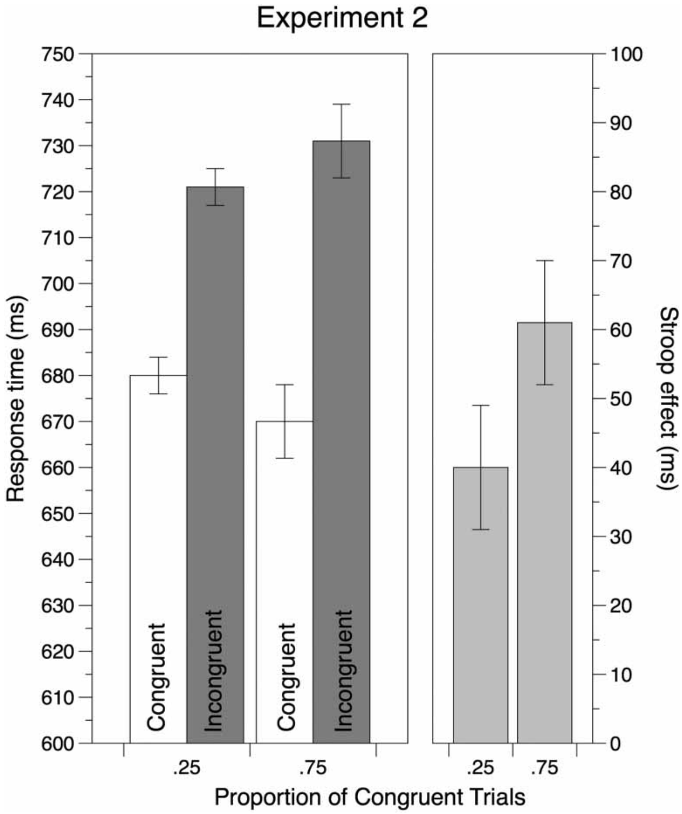

Figure 4. *Left: mean response times in Experiment 2 as a function of the proportion of congruent trials, which was dependent on the semantic category of the word-pair, and congruency. Error bars reflect the standard error of the difference in congruency. Right: the Stroop effect, incongruent−congruent, for each of the .25 and .75 proportion conditions. Error bars reflect the standard error of the interaction.*

from the fact that similar terminology is used to describe different phenomena. It is now generally recognized that there are multiple control systems (De Pisapia & Braver, 2006; Egner, 2008; Egner, Etkin, Gale, & Hirsch, 2008; Egner, Monti, et al., 2008) that act in concert with one another. Many of the examples of rapid performance adjustments that have been studied in recent years (e.g., the Gratton effect, global and local proportion effects) challenge the rigid distinction between bottom-up and top-down control.

The current observation of a semantically defined contextual control effect seems to be indicative of a rapid adjustment of top-down control. It seems unlikely that subjects had the time to identify the semantic category and *then* switch between two control sets. Analyses looking for switch effects also fail to find evidence for such a mechanism. Furthermore, Glaser and Glaser (1989) had subjects perform a similar word–word interference paradigm where the task was to categorize the target. Their subjects produced RTs more than 100 ms longer than those for our subjects (678 $\pm$ 143 ms in Experiment 1 and 698 $\pm$ 139 ms in Experiment 2 vs. $>$ 800 $\pm$ 150 ms; see, Glaser & Glaser, 1989, Experiment 6 for full details). In fact, our mean response times are the same as, if not slightly faster than, standard word naming times in the word recognition literature (735 $\pm$ 107 ms, see Balota et al., 2007, Table 1).

That said, it is entirely plausible that processing the items was sufficient to prime its basic-level category. Even though the semantic meaning of a word is assumed to occur later than orthographic processing (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), processing in these models is cascaded so that even brief exposure to a word can prime a related exemplar (cf. Collins & Loftus, 1975). Thus, the most plausible explanation is that subjects maintained one control setting—name the small word—throughout the task that was mediated by the semantic relevancy of the target. That is, the system learns rather quickly that there are two categories and that one of them is more difficult. When a word pair is presented, it activates its basic-level category via spreading activation (cf. Collins & Loftus, 1975). Now the category is primed, and it mediates selective attention to the small word as a function of difficulty. Thus, the context-specific congruency proportion effect results because the items semantically prime the category, which reactivates the category control set. This account seems plausible only if the category control set is maintained throughout the task.

These data also provide compelling evidence against a pure contingency account (e.g., Schmidt & De Houwer, 2011) of these contextual effects (see also Egner, 2014, who argues rather elegantly that both bottom-up and top-down features are important for cognitive control). Briefly, such an account predicts that the contingency between repeated features (e.g., the colour and word in a Stroop task) causes the distractor to predict the target. This contingency causes the participant to pay more attention to the distractor (e.g., Melara & Algom, 2003). It is difficult to imagine how this account could possibly work here given that each item is seen three times (as the target and distractor for one congruent trial, and as the distractor for one incongruent trial) and is not repeated a different number of times in incongruent and congruent trial types.

Limitations

The precise nature of this mechanism is unclear: Does processing a semantic cue trigger the application of a maintained selective attention process, or do participants learn that one of the categories contains a high proportion of difficult items, so activation for that category is sustained, and this subsequently primes exemplars from the category? A third possibility is a hybrid account in which sustained activation of the difficult category allows exemplars to be quickly activated, and these same exemplars are also associated with a selective attention set that has been maintained or is rapidly applied to processing of the current trial. Future studies comparing the neural correlates associated with semantic processing (e.g., the ERP N400 waveform) versus attention (e.g., the ERP N1 and N2 waveforms) may illuminate this issue.

CONCLUSION

Optimizing behaviour to meet goal states is an important cognitive skill. There is a large body of evidence showing that some of the processes involved in this skill are sustained over long periods of time and are resilient to change and interference. A growing literature demonstrates that relatively low-level processes that rapidly adjust to item-by-item and trial-to-trial events can refine these longer term, goal-oriented control processes in a contextually specific manner. The data reported in Experiments 1 and 2 show that high-level contextual representations, like semantic categories, can also refine goal-oriented control processes.

Supplemental Material

Supplemental content is available via the "Supplemental" tab on the article's online page (http://dx.doi.org/10.1080/17470218.2014.1000346).

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