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The effects of awareness and secondary task demands on Stroop performance in the pre-cued lists paradigm☆

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ABSTRACT

Prior research has demonstrated that explicit pre-cues informing participants of the proportion congruence of an upcoming list of Stroop trials affect performance in mostly congruent lists but not mostly incongruent lists. This pattern suggests a limited role for expectations in influencing Stroop performance. An alternative explanation, however, is that the effects of pre-cues may be masked by a bleed-over of awareness (of the proportion congruence manipulation) from cued to uncued lists given use of a within-subjects manipulation of cueing in prior research. One aim of the current study was to test this explanation by examining patterns of cueing effects when cueing is manipulated between subjects. A second aim was to examine the effects of a secondary, stimulus detection task on expectation and experience-driven effects in the pre-cued lists paradigm. Countering the bleed-over of awareness account, the prior finding of a selective effect of expectations in mostly congruent lists was again observed in the current experiments, and post-experimental assessments of awareness in the uncued condition were unrelated to Stroop performance. Additionally, it was demonstrated that the secondary task did not disrupt experience-driven control but did disrupt the expectation-driven use of pre-cues especially when participants did not know that secondary task stimuli would appear in advance of a list. These findings advance our understanding of the role of awareness in patterns of Stroop performance, and raise interesting questions about the types of advance knowledge that can be integrated in an expectation-driven fashion to optimize Stroop performance.

Cognitive control enables the goal-oriented coordination of attention, such as in the classic Stroop task (Stroop, 1935) in which participants name the ink color in which color word stimuli are rendered while ignoring the word. The Stroop effect refers to the slowed and sometimes more errant performance on incongruent (e.g., BLUE in red ink) relative to congruent (e.g., RED in red ink) trials. Researchers have long been concerned with the intriguing question of the extent to which the seemingly automatic tendency to read the word may be controlled. Various manipulations produce a reduction in the magnitude of the Stroop effect (see Raz, Shapiro, Fan, & Posner, 2002; Raz et al., 2003, for evidence that the Stroop effect can even be *eliminated* in response to a post-hypnotic suggestion to perceive the words as meaningless symbols,) and one of the most extensively researched is the list-wide proportion congruence manipulation (for reviews see Bugg, 2012; Bugg & Crump, 2012). Participants encounter lists (i.e., blocks) of trials that are comprised mostly of congruent (MC) stimuli (i.e., MC list) or mostly of incongruent (MI) stimuli (i.e., MI list). The list-wide proportion congruence effect is the finding that the magnitude of the Stroop effect is significantly larger in the MC list than the MI list (e.g., Gratton, Coles, & Donchin, 1992; Hommel, 1994; Kane & Engle, 2003; Lindsay & Jacoby, 1994; Logan & Zbrodoff, 1979; Logan, Zbrodoff, & Williamson, 1984; Lowe & Mitterer, 1982; Toth et al., 1995; Wendt & Luna-Rodriguez, 2009; West & Baylis, 1998; for reviews, see Bugg, 2012; Bugg & Crump, 2012).

A central theoretical question concerns the mechanisms that are responsible for this list-wide proportion congruence effect. For purposes of the current study, we will delineate those accounts that attribute the effect to an *expectation-driven* mechanism that operates strategically on the basis of advance knowledge about proportion congruence from those accounts that attribute the effect to on-line adjustments in attention that arise implicitly from accumulating exposure to varying stimulus frequencies, which we refer to as *experience-driven* (Bugg, Diede, Cohen-Shikora, & Selmeczy, 2015). Although the purpose of the current study is not to isolate the effects of a particular experience-driven mechanism, it bears mention that there are various such mechanisms: those that modulate attention based on the informativeness of the irrelevant dimension within a given list (e.g., attention is attracted to the word dimension in the MC list but repelled from it in the MI list; Melara & Algom, 2003), those that modulate attention based on the monitoring

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of conflict (in an item-specific fashion; Blais, Robidoux, Risko, & Besner, 2007; Bugg & Hutchison, 2013; Bugg, Jacoby, & Chanani, 2011; Verguts & Notebaert, 2008; or global fashion; Botvinick, Braver, Barch, Carer, & Cohen, 2001), and those that do not modulate attention but may instead produce the list-wide proportion congruence effect via alternative learning processes (e.g., temporal learning; Schmidt, 2013).

In some of the earliest investigations of the list-wide proportion congruence effect, it was assumed that the effect reflected a strategic shift in attention across lists (e.g., Logan & Zbrodoff, 1979; Lowe & Mitterer, 1982; West & Baylis, 1998; cf. Tzelgov, Henik, & Berger, 1992), consistent with an expectation-driven mechanism. A clear statement in support of this view was Lowe and Mitterer's (1982) assertion that "attentional strategies may be actively chosen to suit prevailing conditions" (p. 684). In other words, at their will, participants were purported to distribute attention across the color and word when most trials were congruent, capitalizing on the generally facilitative effects of words in the MC list, and select the relevant color when most trials were incongruent.

In recent years, the expectation-driven account has been challenged (e.g., Bugg, Jacoby, & Toth, 2008; Blais & Bunge, 2010; but see Bugg, 2014; Bugg & Chanani, 2011). One important study that casted doubt on the role of strategies tackled a key assumption of this account—that participants are aware of the proportion congruence manipulation. The rationale was that to the extent participants are using knowledge about list composition to actively guide attention, they should be able to express this knowledge when probed. Blais, Harris, Guerrero, and Bunge (2012) had participants complete 190 lists of 100 Stroop trials over several weeks. The lists varied in proportion congruence from 5% to 95%. Following each list, participants estimated the proportion of congruent and incongruent trials and rated their confidence in their judgments of which trial was more frequent. Participants were more accurate the higher their confidence, but critically, awareness was unrelated to the magnitude of the proportion congruence effect. In other words, participants who were more aware of list composition did not show a larger list wide proportion congruence effect, as would be anticipated by a strategic account. Blais et al. concluded that the effect is likely due to implicit adjustments in control; in other words, it is experience-driven.

However, Blais et al. (2012) did not address the possibility that participants may still be able to use information about the proportion congruence of a list in an expectation-driven fashion if that information were explicitly provided by the experimenter (see e.g., Bugg & Smallwood, 2016; Hutchison, Bugg, Lim, & Olsen, 2016; Goldfarb & Henik, 2013, for evidence of explicit pre-cueing effects at the trial level). Two recent studies tested precisely this possibility. Entel, Tzelgov and Bereby-Meyer (2014, Experiment 1) instructed half of the participants that the proportion congruence of the upcoming list would be MC. The other half was told the list would be MI. The instructions yielded valid expectations only for the second half of the list. The first half was actually 50% congruent across both conditions. The key finding was a list-wide proportion congruence effect for the first half of the list—the condition that expected a MC list showed a larger Stroop effect than the condition that expected a MI list (see also Bugg et al., 2015, Experiment 5). This finding demonstrated a role for explicit expectations in the list-wide proportion congruence effect.

In a related vein, Bugg et al. (2015, Experiment 1; see also Experiment 2) employed a *pre-cued lists paradigm* in which abbreviated lists of 10 trials were preceded either by a pre-cue that explicitly informed participants of the proportion congruence of the upcoming list (MC or MI) or a non-informative pre-cue (question marks). The lists preceded by the non-informative pre-cue were also either MC or MI. Comparing the magnitude of the Stroop effect in the cued condition to the uncued (non-informative pre-cue) condition for each list type (e.g., MC) allowed for an examination of the role of expectations independent of experience. One key finding was a *cue-induced shift* for MC lists—the Stroop effect was *larger* in cued than uncued lists, consistent with Lowe and Mitterer's (1982) assertion that participants can willingly distribute attention across the word and color dimensions, and doing so exacerbates the Stroop effect. A second key finding was that a cue-induced shift was not observed for MI lists. That is, the Stroop effect was statistically equivalent across cued and uncued lists, consistent with the experience-driven account, but inconsistent with the view that participants can intentionally heighten control (i.e., more attention afforded to the color and less to the word) when they expect to encounter interference. If the explicit expectations about proportion congruence had influenced performance, the Stroop effect should have been *smaller* in the cued MI compared to uncued MI lists.

One interpretation of the findings from the pre-cued lists paradigm is that expectations play a limited role in the list-wide proportion congruence effect (as may also be the case in the paradigm of Entel et al., 2014). That is, expectations affect patterns of Stroop performance in the MC list but do not affect Stroop performance under conditions in which a high degree of conflict is expected (i.e., in the MI list where one must overcome the tendency to process the word; cf. Goldfarb, Aisenberg, & Henik, 2011). One potential reason why there is not an effect of expectations on performance in the MI lists (i.e., no cue-induced shift) is that the default may be to expect conflict when performing the Stroop task. As such, the MI pre-cue may not be guiding participants to adopt a strategy that differs from the default strategy of engaging control in this task. This contrasts with the MC lists in which the pre-cue leads participants to expect congruency—in this case, participants do show a cue-induced shift with expectations (the MC pre-cue) leading to a relaxation of control. This reasoning is consistent with prior findings from a trial-by-trial pre-cueing study demonstrating that MC, but not MI pre-cues, led to a shift in strategy use (Gratton et al., 1992, Experiments 3a and 3b; cf. Bugg & Smallwood, 2016, Experiment 3).

Relatedly, another possible explanation is that experience-driven mechanisms alone produce a Stroop effect that is near floor in the uncued MI lists, such that there is insufficient room for a reduction in the Stroop effect to be observed on the basis of expectation-driven control in the cued MI lists (cf. Goldfarb & Henik, 2013). Countering this account, however, no cue-induced shift was found in an invalidly cued MI condition when both cued and uncued lists were in fact 50% congruent and consequently produced Stroop effects that were off floor (Bugg et al., 2015, Experiment 5).

Still, a third explanation of the findings is that use of a within-subjects manipulation of cueing may lead to a *bleed-over of awareness* from cued to uncued lists, thereby masking the potential effects of expectations in the MI list. In other words, because cued and uncued lists were randomly intermixed, on uncued lists participants may have been sensitized to the fact that the lists varied in proportion congruence and thus attempted to quickly determine the list type. This information could then be used to bias attention in an expectation-driven fashion across the remainder of the uncued list, leading to the absence of a cue-induced shift in the MI condition. The fact that a cue-induced shift *was* observed in the MC condition does, however, challenge the bleed-over of awareness account because it requires an explanation as to why participants would determine or use the information about proportion congruence in uncued MI but not uncued MC lists. One possibility is that participants may perceive MI but not MC lists to be difficult and selectively try to gain an advantage in such lists (i.e., when they detect that the first couple of trials are incongruent). Thus, this explanation should not be dismissed until further experimentation is conducted to test the account.

1. Experiment 1

Experiment 1 investigated patterns of the Stroop effect in the pre-cued lists paradigm using, for the first time, a between-subjects manipulation of cueing. Half the participants received pre-cues regarding proportion congruence and half did not (i.e., were in an uncued condition). If the pattern that was observed previously in within-subjects designs is again observed in the current study (i.e., a cue-induced shift in the MC condition but not the MI condition; Bugg et al., 2015), this would counter the view that the bleed-over of awareness of the proportion congruence manipulation is responsible for the absence of a cue-induced shift in the MI condition. The logic is that a between-subjects design precludes a bleed-over of awareness from cued to uncued lists. Consequently, if the same pattern of results is found as in prior experiments using the within-subjects manipulation of cueing (Bugg et al., 2015), then the findings cannot be attributed to factors unique to the within-subjects design (e.g., potential for bleed-over of awareness).

1.1. Method

1.1.1. Participants

Sixty-one undergraduates from Washington University in St. Louis participated for course credit. All participants were aged 18–25, and reported normal or corrected vision and color vision. Participants were randomly assigned to the cued condition ($N = 30$) or the uncued condition ($N = 31$).

1.1.2. Design and stimuli

The design and procedure closely followed Bugg et al. (2015, Experiment 1) save for the exception of a between-subjects manipulation of cueing that resulted in a 2 (cueing: cued vs. uncued) × 2 (list-wide proportion congruence: MC vs. MI) × 2 (trial type: congruent vs. incongruent) mixed subjects design. All other factors were manipulated within-subjects. There were 32 lists in the experiment, half of which were MC and half of which were MI. In the cued condition, participants were informed of proportion congruence in advance of MC and MI lists via a pre-cue indicating "80% of trials will be MATCHING" or "80% of trials will be CONFLICTING", respectively. In the uncued condition, participants were not informed of proportion congruence.

Each list was comprised of 10 trials. In MC lists, there were eight congruent and two incongruent trials randomly intermixed; the reverse frequencies were represented in MI lists. Four words (RED, BLUE, GREEN, and YELLOW) and their corresponding colors were used to create the Stroop stimuli. To minimize repetitions of words and colors within a list, congruent and incongruent stimuli were sampled randomly without replacement from lists representing all possible congruent and incongruent stimuli.

1.1.3. Procedure

Following instructions and practice with the Stroop color-naming task, participants in the cued condition were informed of the procedure (i.e., distinct lists with a break between each list). The cued condition was also informed that pre-cues would be provided in advance of each list, that the pre-cues could be used to improve performance, and were encouraged to try their best to use the pre-cues. Finally, they were reminded of the general Stroop instructions to name aloud the color as quickly and accurately as possible without sacrificing accuracy. Participants in the uncued condition were also informed of the procedure and reminded of the general Stroop instructions but were not provided any information regarding pre-cues.

On each list, the pre-cue (or, in the case of the uncued condition, a screen simply instructing participants to press the left key on the response box when they were prepared and ready to begin the next list) remained on screen until participants pressed the left key on a response box indicating their readiness to begin the list. The first stimulus appeared immediately thereafter. Stroop stimuli were centrally presented in 24 point Arial font on a light gray background and remained on screen until a vocal response was detected by the voice-key. An experimenter coded the response using a keyboard. A blank screen then appeared for 1000 ms after which the next stimulus appeared. Trials on which voice responses were imperceptible or the voice key was triggered by external noise or irrelevant sounds (e.g., coughing) were coded as scratch trials and excluded from further analysis. The MC and MI lists were randomly intermixed, and reaction time (RT) and error rate were recorded.

1.2. Results

For the current and all subsequent experiments, following Bugg et al. (2015), trials on which RTs were faster than 200 ms or >3000 ms were trimmed. In addition, error trials were excluded from the RT analysis. The alpha was 0.05 and no effects other than those reported were significant. Because the findings observed in error rate did not contradict the RT patterns, for brevity, we report only the analysis of RT. Mean error rates are reported in Table 1.

A 2 × 2 × 2 mixed-subjects ANOVA was conducted on color-naming RTs with cueing as a between-subjects factor and list-wide proportion congruence and trial type as within-subjects factors. There was a main effect of trial type, $F(1, 59) = 303.26$, $p < 0.001$, $\eta^2_p = 0.837$ (i.e., the Stroop effect), and a Proportion Congruence × Trial Type interaction, $F(1, 59) = 106.02$, $p < 0.001$, $\eta^2_p = 0.642$ (i.e., the list-wide proportion congruence effect). Most importantly, there was a significant three-way interaction, $F(1, 59) = 6.33$, $p = 0.015$, $\eta^2_p = 0.097$, with the list-wide proportion congruence effect being larger in cued lists (see Fig. 1). To decompose the interaction, and in particular to determine if a cue-induced shift was apparent in either the MC or MI lists, we conducted 2 (Cueing) × 2 (Trial Type) ANOVAs for each list type (MC and MI). For the MC lists, the Stroop effect was nominally though not statistically larger in the cued ($M = 159$ ms) than the uncued ($M = 137$ ms) condition, $F(1, 59) = 2.24$, $p = 0.140$, $\eta^2_p = 0.037$. For the MI lists, the Stroop effect was nominally though not significantly smaller in the cued ($M = 63$ ms) than the uncued ($M = 78$ ms) condition, $F(1, 59) = 1.15$, $p = 0.288$, $\eta^2_p = 0.019$.

1.3. Discussion

Using a between-subjects manipulation of cueing in the pre-cued lists paradigm, Experiment 1 replicated the patterns observed previously with a within-subjects manipulation of cueing (Bugg et al., 2015). This included the presence of the list-wide proportion congruence effect and, of most relevance to the current study, the three-way interaction between cueing, list-wide proportion congruence, and trial type that signifies the influence of expectations on the Stroop effect. The follow up contrasts were also in line with Bugg et al. (2015), though with overall weaker effects. The cue-induced shift was twice as large in MC lists as compared to MI lists, despite the lack of conventional significance in the MC contrast (i.e., the Stroop effect increased, as expected, in the cued compared to the uncued MC lists, but the increase was not significant in the current study). In the MI lists, as in Bugg et al. (2015), the cue-induced shift (i.e., reduction in Stroop effect in cued compared to uncued MI lists) had a very small effect size and was not statistically significant. A limiting factor for why the cueing effect failed to reach significance in the MC contrast may be because of the decrease in power due to use of a between-subjects manipulation of cueing. Another possibility may be that the uncued condition represents a mixture of aware (those who become aware of the proportion congruence manipulation based on experience with the lists) and unaware participants, such that error variance within the uncued condition may be precluding detection of differences related to cueing.

2. Experiment 2

One purpose of Experiment 2 was to address the above possibilities. Thus, we collected data from another sample of 60 participants with the aim of combining the data across Experiments 1 and 2 to conduct a more powerful test of the effects of the between-subjects manipulation of cueing. In addition, to gauge awareness of the proportion congruence manipulation in the uncued condition, we probed participants about any differences they noticed between lists post-experimentally (cf.

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Table 1
Mean error rates (SE) as a function of cueing, list-wide proportion congruence, and trial type in Experiments 1, 2, and 3.

		Mostly congruent				Mostly incongruent			
		Cued		Uncued		Cued		Uncued	
Experiment	Secondary task	Congruent	Incongruent	Congruent	Incongruent	Congruent	Incongruent	Congruent	Incongruent
1	Standard (none)	0.006 (0.002)	0.058 (0.010)	0.007 (0.002)	0.051 (0.010)	0.009 (0.002)	0.022 (0.004)	0.001 (0.002)	0.022 (0.004)
2	Standard (none)	0.005 (0.002)	0.106 (0.016)	0.009 (0.002)	0.070 (0.016)	0.008 (0.003)	0.032 (0.005)	0.008 (0.003)	0.033 (0.005)
	Divided attention	0.005 (0.003)	0.122 (0.017)	0.012 (0.003)	0.096 (0.017)	0.019 (0.006)	0.033 (0.006)	0.009 (0.006)	0.031 (0.006)
3	Standard (none)	0.004 (0.001)	0.051 (0.013)	0.003 (0.001)	0.036 (0.013)	0.003 (0.002)	0.017 (0.003)	0.001 (0.002)	0.016 (0.003)
	Divided attention	0.004 (0.001)	0.057 (0.011)	0.004 (0.001)	0.048 (0.011)	0.008 (0.004)	0.021 (0.004)	0.009 (0.004)	0.017 (0.004)

Blais et al., 2012), and examined whether awareness affected performance.

A second purpose, unrelated to the bleed-over of awareness account, was to examine the influence of a secondary task load on the patterns used to infer a role for experience and expectations in the list-wide proportion congruence effect. In general, we were interested in whether the list-wide proportion congruence effect was at all mutable, or if instead the effects of experience were rather immune to the division of attentional resources toward two concurrent goals, as might be expected given the seemingly implicit nature of many experience-driven adjustments that have been hypothesized to support this effect (e.g., Blais et al., 2012; Melara & Algom, 2003). Conversely, we were also interested in examining whether patterns representing the effects of expectations (i.e., cueing) would be observed in the presence of a secondary task.

We elected to use a visual, stimulus-detection task as the secondary task in this initial, exploratory study. Participants were told that asterisks would occasionally appear on screen in between color naming stimuli and that it was very important that they detect the asterisks when they appeared. Two asterisks appeared unpredictably in one-third of the lists (half of which were MC and half of which were MI). This task was chosen because it required participants to continuously look ahead in anticipation of the potential occurrence of an asterisk. In other words, the secondary task might be conceived of as encouraging participants to be "on guard" during the Stroop task. There is some suggestion in the literature that such demands might interfere with the list-wide proportion congruence effect. For instance, individuals with obsessive compulsive disorder, who may be routinely on guard and thereby have trouble relaxing control when merited, did not show the typical modulation of the Stroop effect that accompanies list-wide manipulations of the frequency of particular trial types (Kalanthroff, Anholt, & Henik, 2014). In addition, in a non-clinical sample, it was demonstrated that the list-wide proportion congruence effect was reduced under conditions of high stress (loud noise), at least for high span participants (Booth & Sharma, 2009). These findings favor the prediction that the secondary task will interfere with experience-driven processes (e.g., accumulation of episodes that lead to setting of attentional weights for word and color dimensions; detection of conflict), such that the list-wide proportion congruence effect may not be observed in the presence of the secondary task.

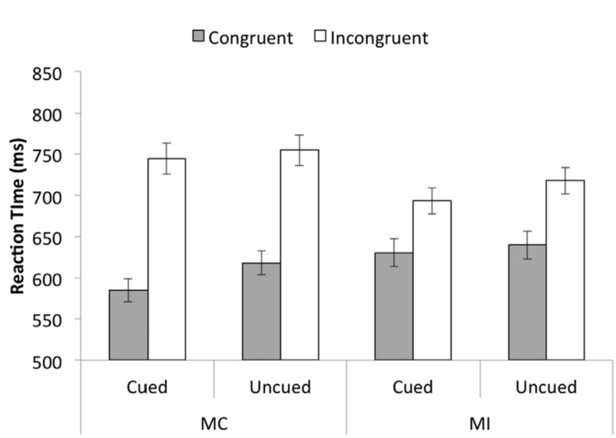

Fig. 1. Mean reaction time on congruent and incongruent trials as a function of proportion congruence in the cued and uncued conditions in Experiment 1.

With respect to the expectation-driven component, it was predicted that the secondary task would interfere with use of the pre-cues. For instance, having to allocate attention to the secondary task on a transient basis might detrimentally affect participants' ability to sustain an attentional bias in an expectation-driven fashion across a list (cf. Braver, Gray, & Burgess, 2007). The latter is thought to involve preparatory attentional processes (i.e., proactive control; cf. De Pisapia & Braver, 2006) that have been found to be vulnerable to the effects of some secondary task loads (Kalanthroff, Avnit, Henik, Davelaar, & Usher, 2015). Moreover, to the extent that the performance of individuals with obsessive-compulsive disorder reflected an inability to *intentionally* relax control in the study of Kalanthroff et al. (2014), one might similarly predict a disruption in the ability to use the pre-cue to relax control in MC lists when participants are on guard (i.e., thereby washing out the cue-induced MC shift).

2.1. Method

2.1.1. Participants

Sixty undergraduates from Washington University in St. Louis participated for course credit. All participants were aged 18–25, and reported normal or corrected vision and color vision. Participants were randomly assigned to the cued condition ($N = 30$) and the uncued condition ($N = 30$).

2.1.2. Design and stimuli

The design and stimuli closely mirrored Experiment 1 with two notable exceptions. First, there were 48 lists total (half MC and half MI) and 1/3 of the lists included the stimulus detection task while the remainder of the lists did not resulting in a 2 (secondary task: standard [no asterisks] vs. divided attention [with asterisks]) × 2 (cueing: cued vs. uncued) × 2 (list-wide proportion congruence: MC vs. MI) × 2 (trial type: congruent vs. incongruent) mixed subjects design. Cueing was again the only between-subjects factor. Of the 16 lists that included an asterisk, half were MC and half were MI.

2.1.3. Procedure

The procedure was identical to Experiment 1 save for the exception that on a randomly presented, one-third of the lists, participants had to detect an asterisk that appeared during the otherwise blank 1000 ms inter-stimulus interval. Participants were informed that asterisks would occasionally appear on screen between color naming stimuli and it was VERY IMPORTANT that they detected asterisks when they appeared. They were told to press the left key on the response box (placed to their left) when they saw an asterisk. They rested the index finger of their left hand on that key throughout the task thereby precluding the need to look away from the screen to respond to asterisks. Asterisks were presented in 12-point font, and in each list in which asterisks were presented (i.e., divided attention lists), two total asterisks randomly appeared. One was presented following a congruent trial and one was presented following an incongruent trial. Participants did not know that exactly two asterisks would appear nor which lists contained asterisks in advance of the list.

After completion of the pre-cued lists paradigm, participants in the uncued condition were asked the following questions: “Did you notice any differences between the lists of trials?” (yes or no). If they answered yes, they were provided a blank sheet of paper and asked to describe the differences they noticed on the paper. If they answered no, they were not asked to do so.

2.2. Results

2.2.1. Stroop performance in standard condition

Mean error rates are presented in Table 1. First, to evaluate the bleed-over of awareness account, we examined performance on the standard lists (without the secondary task). A 2 × 2 × 2 mixed-subjects ANOVA was conducted on color-naming RTs with cueing as a between-subjects factor and list-wide proportion congruence and trial type as within-subjects factors. As in Experiment 1, there was a main effect of trial type, $F(1, 58) = 347.83$, $p < 0.001$, $\eta^2_p = 0.857$ (i.e., the Stroop effect), and a Proportion Congruence × Trial Type interaction, $F(1, 58) = 138.69$, $p < 0.001$, $\eta^2_p = 0.705$. Most importantly, the three-way interaction was again observed, $F(1, 58) = 6.60$, $p = 0.013$, $\eta^2_p = 0.102$, with the list-wide proportion congruence effect being larger in cued lists (see Fig. 2). Decomposing the interaction, a 2 (cueing) × 2 (trial type) ANOVA revealed a marginally significant cue-induced shift in the MC lists, $F(1, 58) = 3.25$, $p = 0.077$, $\eta^2_p = 0.053$, indicating a larger Stroop effect in the cued ($M = 170$ ms) than the uncued ($M = 140$ ms) condition. In the MI lists, the 2 × 2 ANOVA was non-significant, $F < 1$, $\eta^2_p = 0.009$, indicating equivalent Stroop effects in the cued ($M = 65$ ms) and uncued ($M = 73$ ms) conditions.

2.2.2. Combined analysis of experiments 1 and 2

A 2 × 2 × 2 mixed-subjects ANOVA was performed on the combined data from Experiment 1 and Experiment 2 (standard lists), thereby doubling the sample size. The three-way interaction was significant, $F(1, 58) = 12.99$, $p < 0.001$, $\eta^2_p = 0.098$. Most importantly, when this interaction was decomposed via 2 (cueing) × 2 (trial type) ANOVAs, a significant cue-induced shift was observed in the MC condition, $F(1, 119) = 5.52$, $p < 0.001$, $\eta^2_p = 0.044$. The Stroop effect was larger in the cued MC condition ($M = 165$ ms) than the uncued MC condition ($M = 139$ ms). In contrast, there was not a significant cue-induced shift in the MI condition, $F(1, 119) = 1.69$, $p = 0.196$, $\eta^2_p = 0.014$. Equivalent Stroop effects were found in the cued MI condition ($M = 64$ ms) and the uncued MI condition ($M = 75$ ms).

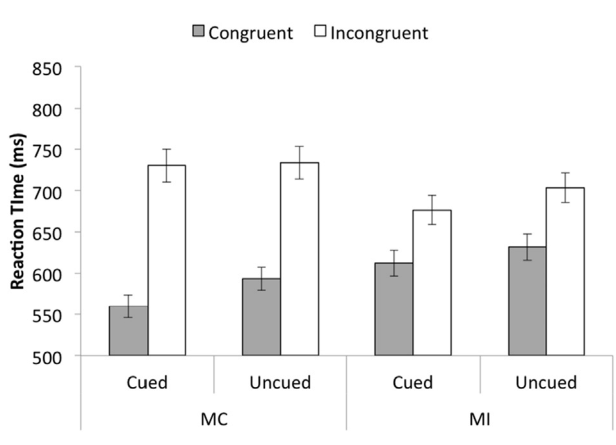

Fig. 2. Mean reaction time on congruent and incongruent trials as a function of proportion congruence in the cued and uncued conditions on standard lists in Experiment 2.

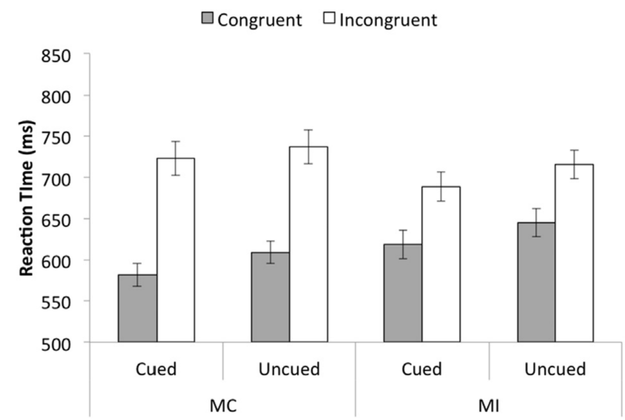

Fig. 3. Mean reaction time on congruent and incongruent trials as a function of proportion congruence in the cued and uncued conditions on divided attention lists in Experiment 2.

2.2.3. Stroop performance in divided attention condition

Performance on the secondary stimulus-detection task, as expected, was very high (99% accuracy on average) and accuracy did not vary as a function of list type or cueing. To evaluate Stroop performance in the presence of the secondary task, a 2 × 2 × 2 mixed-subjects ANOVA was conducted on color-naming RTs with cueing as a between-subjects factor and list-wide proportion congruence and trial type as within-subjects factors. As in the standard lists, a main effect of trial type was observed, $F(1, 58) = 322.53$, $p < 0.001$, $\eta^2_p = 0.848$ (i.e., the Stroop effect). More interestingly, in spite of the presence of the secondary task, the Proportion Congruence × Trial Type interaction (i.e., list-wide proportion congruence effect) was also again observed, $F(1, 58) = 56.17$, $p < 0.001$, $\eta^2_p = 0.492$. However, in contrast, there was no longer a three-way interaction, $F < 1$, $\eta^2_p = 0.010$. As shown in Fig. 3, the cue-induced shift in the MC lists was small (Stroop effect $Ms = 141$ ms and 128 ms, respectively, in cued and uncued condition) and there was no shift in the MI lists (Stroop effect $Ms = 71$ ms and 71 ms, respectively, in cued and uncued condition; see Fig. 3).[1]

2.2.4. Comparison of standard and divided attention conditions for purposes of isolating expectation- and experience-driven processes

Although the list-wide proportion congruence effect was observed in the divided attention condition, it is notable that the effect size corresponding to this effect (i.e., the Proportion Congruence × Trial Type interaction) was much smaller ($\eta^2_p = 0.492$) than in the standard condition ($\eta^2_p = 0.705$). On the view that the list-wide proportion congruence effect reflects experience-driven processes, this finding suggests that dividing attention interfered with these processes. However, in the analyses above, the Proportion Congruence × Trial Type interaction represented an averaging of the cued and uncued conditions. As such, it is unclear if the apparent reduction in the list-wide proportion congruence effect in the divided attention condition is due to the effects of the secondary task on experience- or expectation-driven processes.

[1] Considering that there were fewer divided attention lists compared to standard lists, a reader may wonder whether there was reduced power to detect the three-way interaction within the divided attention lists. To address this question, we randomly chose 16 standard lists (8 MC, 8 MI) per participant and generated means for each of the conditions. We did the same thing with the remaining 16 standard lists such that we had two data sets that were of the same size as the divided attention data set to investigate the three-way interaction. The logic was, if we still find the three-way interaction in these smaller sets of data, then this counters the idea that the reduced number of lists (in the divided attention condition) led to less precision (more variability) and a failure to find the three-way interaction. The analysis showed mixed results. In one subset of the standard lists, the three-way interaction was found ($p = 0.006$, $\eta^2_p = 0.122$) whereas in the other subset it was not ($p = 0.168$, $\eta^2_p = 0.033$). While both effect sizes were larger than that observed in the divided attention lists ($p = 0.439$, $\eta^2_p = 0.010$), the analyses suggest the smaller number of divided attention lists may have limited our ability to detect the three-way interaction in these lists in Experiment 2.

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To gain traction on this question, we performed two follow-up analyses that directly contrasted performance across the standard and divided attention lists.

First, we performed a 2 × 2 × 2 within-subjects ANOVA with list-wide proportion congruence, trial type, and secondary task as factors selectively on the data from the cued condition. The purpose was to examine whether divided attention interferes with the list-wide proportion congruence effect when expectations are at play. The Proportion Congruence × Trial Type × Secondary Task interaction was significant, $F(1,29) = 5.30$, $p = 0.029$, $\eta^2_p = 0.155$. The list-wide proportion congruence effect was larger in the standard condition ($MI_{Stroop\ Effect} =$ 65 ms vs. $MC_{Stroop\ Effect} = 170$ ms) than in the divided attention condition ($MI_{Stroop\ Effect} = 71$ ms vs. $MC_{Stroop\ Effect} = 141$ ms). Notably, this converges with the finding within the divided attention condition that the modulation of control in response to the pre-cues was disrupted by divided attention (i.e., there was no Cueing × Proportion Congruence × Trial Type interaction within the divided attention lists). Next, we performed the same 2 × 2 × 2 within-subjects ANOVA with list-wide proportion congruence, trial type, and secondary task as factors selectively on the data from the uncued condition. The rationale was that examining the uncued condition would permit a window into the operation of experience-driven processes without or with minimal influence of expectations. In this case, there was not a Proportion Congruence × Trial Type × Secondary Task interaction, $F < 1$, $\eta^2_p =$ 0.021. For participants in the uncued condition, this indicates that the list-wide proportion congruence effect did not differ across the standard and divided attention conditions.

2.2.5. Awareness

We considered participants in the uncued condition who answered "yes" to the first question and then described the proportion congruence manipulation on the sheet of paper to be "aware" (e.g., by referring to some lists having more trials where color and word matched, were compatible, corresponded, etc. than others) and those who answered "no" to the first question to be "unaware". There were 13 aware participants and 17 unaware, suggesting that the uncued condition does represent a mixture of these two types of participants. However, when the performance of aware and unaware participants was compared via a 2 × 2 × 2 mixed-subjects ANOVA on color-naming RTs with awareness, list-wide proportion congruence and trial type as within-subjects factors, there was no main effect of awareness nor interactions with any other factor, *F*s < 2.14.

2.3. Discussion

There were three primary findings in Experiment 2. First, the critical three-way interaction among proportion congruence, trial type, and cueing was again evident, indicating a larger effect of expectations (cueing) in the MC lists compared to the MI lists. The follow up contrasts used to decompose the three-way interaction indicated a cue-induced shift in the MC condition but no cue-induced shift in the MI condition. The results of the combined analysis of Experiments 1 and 2 converged with these patterns. These findings align with those observed previously using within-subjects manipulations of cueing (Bugg et al., 2015), and thereby further challenge the bleed-over of awareness account, which posits that the absence of a cue-induced shift in the MI condition may be due to participants' awareness of the proportion congruence manipulation when cueing is manipulated within-subjects. According to this account, participants' awareness motivates them to determine the list composition in uncued lists and then engage expectation-driven control accordingly, thereby eliminating any differences in the Stroop effect between cued and uncued MI lists.

Second, it was found that the uncued condition does appear to consist of a mixture of aware and unaware participants, at least according to the current measure of awareness. After the experiment was complete, about 43% of participants in the uncued condition reported that the lists differed in proportion congruence (albeit not in those terms). However, consistent with the findings of Blais et al. (2012), variation in awareness did not appear to influence the list-wide proportion congruence effect.

Third, performance of the secondary, stimulus detection task did affect participants' use of the pre-cues such that there was no longer a three-way interaction between cueing, proportion congruence, and trial type within the divided attention condition. There was not a cue-induced shift in either the MC or the MI condition. In contrast, the list-wide proportion congruence effect was evident when participants' attention was divided. Converging with these patterns, it was found that the list-wide proportion congruence effect was smaller in the divided attention lists than the standard lists when examining the cued condition; however, the list-wide proportion congruence effect did not differ between the standard and divided attention lists when examining the uncued condition. These patterns suggest that dividing attention, at least in the fashion employed here, affects expectation-driven control (i.e., effect of cueing) but has little if any effect on experience-driven processes (i.e., list-wide proportion congruence effect, perhaps especially within the uncued condition). Although one cannot be certain expectations had zero effect in the uncued condition, the awareness data speak against this possibility because the list-wide proportion congruence effect was not larger in subjects that expressed awareness of the proportion congruence manipulation. This limitation notwithstanding, these patterns support the view that experience-driven adjustments underlying the list-wide proportion congruence effect are not susceptible to interference from a secondary task, unlike expectation-driven adjustments. Likely, this is related to the implicit nature of the experience-driven adjustments.

It is interesting to consider why expectation-driven control was compromised by the addition of the secondary task. Possibly, when individuals are on guard (e.g., as in obsessive compulsive disorder; Kalanthroff et al., 2014), the challenge is in *intentionally* relaxing control and not implicitly modulating control. If so, this would explain the absence of a cue-induced shift in MC lists in the divided attention condition. A second possible explanation is that having to transiently produce a secondary task response via a different modality (manual key press) than that used during the Stroop task (vocal response) interfered with the ability to sustain an attentional bias (e.g., disrupted the task set of willfully distributing attention across word and color; Lowe & Mitterer, 1982). A final possibility may be that it is not the demand on response coordination or task switching processes per se that is the locus of the disruption in expectation-driven control; rather, it may be the unpredictable nature of the stimulus detection task. Recall that in Experiment 2, standard and divided attention lists were randomly intermixed such that participants did not know at the start of the list whether an asterisk would appear. As such, participants were not able to *or* elected not to (i.e., based on an evaluation of costs and benefits given that only a third of the lists contained asterisks; Shenhav, Botvinick, & Cohen, 2013) develop an integrated task set that enabled them to bias attention according to the pre-cue and at the same time coordinate this attentional bias with performance of the stimulus detection task (including responding and switching). The purpose of Experiment 3 was to gain further insight into the effects of the secondary stimulus detection task on the ability to sustain an expectation-driven attentional bias during the Stroop task.

3. Experiment 3

We aimed to identify conditions under which, if any, the cue-induced shift in the MC condition may be observed in spite of the need to concurrently allocate attention to the stimulus-detection task. Toward this end, we increased response/task coordination demands by increasing the number of asterisks presented in each list from two in Experiment 2 up to four in Experiment 3 and at the same time we made the secondary task predictable (i.e., participants knew in advance of a list whether the list would include asterisks). If the lack of an effect of cueing (as indicated by the three-way interaction) in the divided attention condition is attributable to demands on response and/or task coordination processes, then the three-way interaction again should not be observed in the present experiment. However, if it is attributable to the unpredictability of the secondary task, then the three-way interaction should be observed in the divided attention condition in the present experiment.

3.1. Method

3.1.1. Participants

Sixty undergraduates from Washington University in St. Louis participated for course credit. All participants were aged 18–25, and reported normal or corrected vision and color vision. Participants were randomly assigned to the cued condition ($N = 30$) and the uncued condition ($N = 30$).

3.1.2. Design, stimuli, and procedure

The design, stimuli, and procedure were identical to Experiment 2 with two exceptions. First, the manipulation of secondary task demands was blocked and applied to 1/2 of the lists (i.e., 24 lists: half MC and half MI) in Experiment 3. The first half of the experiment comprised standard lists (or divided attention lists in a counterbalance) and the second half comprised divided attention lists (or standard lists in a counterbalance). Participants were explicitly informed in advance of a given half of lists whether they would be tasked with detecting the asterisks while performing the Stroop task or not. Second, each divided attention list included between two and four asterisks. This was done to increase demands on response and task coordination processes, including pushing participants to be "on guard" across the entire list (as compared to Experiment 2, where participants may have noticed that only two asterisks were presented in each list and stopped looking for asterisks once the second was detected; cf. "satisfaction of search" phenomenon; Tuddenham, 1962). As in Experiment 2, an equal number of asterisks were presented following a congruent as an incongruent trial across the divided attention lists.

3.2. Results

3.2.1. Stroop performance in standard condition

Mean error rate is presented in Table 1. First, to further evaluate the bleed-over of awareness account, a 2 × 2 × 2 mixed-subjects ANOVA was conducted on color-naming RTs within the standard lists with cueing as a between-subjects factor and list-wide proportion congruence and trial type as within-subjects factors. As in the preceding experiments, a main effect of trial type, $F(1, 58) = 224.95$, $p < 0.001$, $\eta^2_p = 0.795$, and a Proportion Congruence × Trial Type interaction, $F(1, 58) = 82.81$, $p < 0.001$, $\eta^2_p = 0.588$, was observed. In addition, a Cueing × Trial Type interaction was found, $F(1, 58) = 4.46$, $p = 0.039$, $\eta^2_p = 0.071$. The Stroop effect was larger in the cued condition ($M = 119$ ms) than the uncued condition ($M = 89$ ms). Most importantly, these interactions were qualified by the three way interaction, $F(1, 58) = 7.85$, $p = 0.007$, $\eta^2_p = 0.119$, again demonstrating a larger list-wide proportion congruence effect in the cued condition (see Fig. 4). Follow-up 2 (cue) × 2 (trial type) ANOVAs indicated that there was a significant cue-induced shift in MC lists resulting in a larger Stroop effect in the cued ($M = 180$ ms) compared to the uncued ($M = 122$ ms) condition, $F(1, 58) = 8.19$, $p = 0.006$, $\eta^2_p = 0.124$. In contrast, there was not a cue-induced shift in MI lists, $F < 1$, $\eta^2_p < 0.001$. Stroop effects were equivalent across the cued ($M = 58$ ms) and uncued ($M = 57$ ms) condition.

3.2.2. Stroop performance in divided attention condition

As in Experiment 2, performance on the stimulus-detection task was very high (99% accuracy on average) and did not vary as a function of the proportion congruence of the list or cueing. It also did not vary

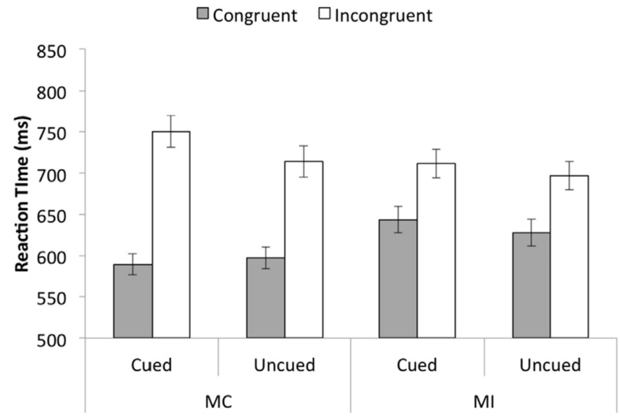

Fig. 4. Mean reaction time on congruent and incongruent trials as a function of proportion congruence in the cued and uncued conditions on standard lists in Experiment 3.

based on the number of asterisks within the list (range = 98% to 99% across all cells). To evaluate Stroop performance in the presence of the secondary task, a 2 × 2 × 2 mixed-subjects ANOVA was conducted on color-naming RTs with cueing as a between-subjects factor and list-wide proportion congruence and trial type as within-subjects factors. A main effect of trial type, $F(1, 58) = 265.83$, $p < 0.001$, $\eta^2_p = 0.821$, and a Proportion Congruence × Trial Type interaction, $F(1, 58) = 100.75$, $p < 0.001$, $\eta^2_p = 0.635$, was observed. Most importantly, as with the standard lists, there was also a significant three way interaction, $F(1, 58) = 11.98$, $p = 0.001$, $\eta^2_p = 0.171$, and an identical pattern of effects emerged in the follow-up 2 (cue) × 2 (trial type) ANOVAs (see Fig. 5). There was a significant cue-induced shift in the MC lists resulting in a larger Stroop effect in the cued ($M = 165$ ms) compared to the uncued ($M = 117$ ms) condition, $F(1, 58) = 8.18$, $p = 0.006$, $\eta^2_p = 0.124$. There was not a cue-induced shift in the MI lists, $F < 1$, $\eta^2_p < 0.001$. Stroop effects were again equivalent in the cued ($M = 68$ ms) and uncued ($M = 69$ ms) condition.

3.2.3. Comparison of standard and divided attention conditions for purposes of isolating expectation- and experience-driven processes

A comparison of the effect size corresponding to the list-wide proportion congruence effect in the standard ($\eta^2_p = 0.59$) and divided attention ($\eta^2_p = 0.64$) conditions indicates that this effect was not reduced in the divided attention condition (unlike in Experiment 2). This is logical because, unlike in Experiment 2 where the reduction of the list-wide proportion congruence effect was attributable to a weaker effect of cueing in the divided attention condition, the cueing effect was observed in the divided attention condition in the current experiment

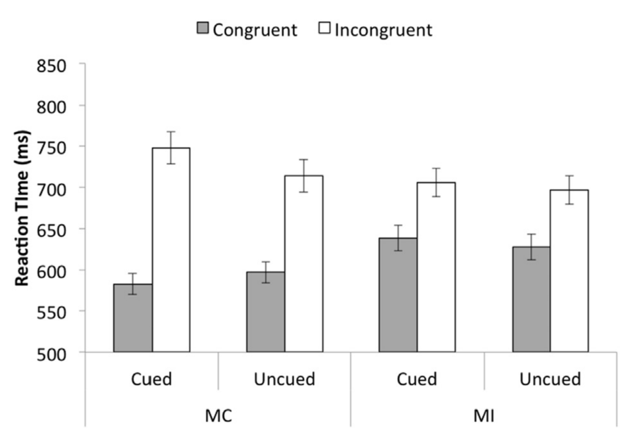

Fig. 5. Mean reaction time on congruent and incongruent trials as a function of proportion congruence in the cued and uncued conditions on divided attention lists in Experiment 3.

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(and in fact had a nominally larger effect size compared to the standard condition). Still, for consistency with Experiment 2, we performed the two follow-up analyses that contrast performance across the standard and divided attention conditions.

First, we performed the 2 × 2 × 2 within-subjects ANOVA with list-wide proportion congruence, trial type, and secondary task as factors selectively on the data from the cued condition. Again, this analysis aimed to target expectation-driven influences on the list-wide proportion congruence effect. The Proportion Congruence × Trial Type × Secondary Task interaction was not significant, $F(1,29) = 3.00$, $p = 0.094$, $\eta^2_p = 0.094$. Similarly, when this analysis was restricted to the uncued condition, there was also not a Proportion Congruence × Trial Type × Secondary Task interaction, $F(1, 29) = 1.36$, $p = 0.254$, $\eta^2_p = 0.045$.

3.2.4. Awareness

Awareness was defined in the same way as Experiment 2. There were 8 aware participants and 22 unaware (73% unaware) in the uncued condition. The performance of aware and unaware participants was compared by performing a 2 × 2 × 2 mixed-subjects ANOVA on color-naming RTs with awareness, list-wide proportion congruence and trial type as within-subjects factors. There was no main effect of awareness nor did awareness interact with any other factor, $Fs < 1.87$. Note that these patterns did not change when data from Experiments 2 and 3 were combined (to increase sample sizes in each awareness condition), $Fs < 1.67$, though this could be done only for the standard lists given the differences between the divided attention lists across experiments.

3.3. Discussion

There were three key findings. First, the findings from the standard lists converged with those reported in the combined analysis of Experiment 1 and Experiment 2 in countering the bleed-over of awareness account. That is, there was a cue-induced MC shift and not a cue-induced MI shift, just as has been observed previously when cueing was manipulated within-subjects (Bugg et al., 2015).

Second, consistent with the finding of Experiment 2, there was a mixture of aware and unaware participants in the uncued condition, but awareness again did not influence the list-wide proportion congruence effect (see also Blais et al., 2012). Interestingly, fewer participants (27%) were aware of the proportion congruence manipulation in Experiment 2. When we combined the data from the uncued condition across experiments, there was again no influence of awareness on the list-wide proportion congruence effect.

Of particular note, the third finding was that in the presence of the secondary task, there was both a list-wide proportion congruence effect *and* an effect of cueing as indicated by the three-way interaction. More specifically, there was a cue-induced MC shift and no cue-induced MI shift, the precise pattern observed on the standard lists. This finding contrasts starkly with that of Experiment 2, in which there was not a three-way Proportion Congruence x Trial Type x Cueing interaction for the divided attention lists. The fact that an effect of cueing was observed in the divided attention condition in Experiment 3 counters the explanation that demands on response and/or task coordination processes were responsible for the disruption to expectation-driven control observed in Experiment 2 because those demands were increased in Experiment 3 (i.e., there were up to four asterisks within each list). At the same time, the effect of cueing in Experiment 3 supports the explanation that predictability matters. That is, participants knew precisely which lists would include asterisks and were therefore privy to the divided attention demands (e.g., shifting between tasks) in advance of the start of a list (see Dreisbach & Haider, 2006). This suggests that under predictable task conditions, participants may be able to coordinate an expectation-driven attentional bias in a Stroop task with a secondary task that requires them to intermittently detect and respond to another stimulus.

4. General discussion

The current set of experiments aimed to investigate the roles of awareness and secondary task demands in patterns of Stroop performance in the pre-cued lists paradigm, in particular those that provide insight into experience-driven mechanisms and those that provide insight into expectation-driven mechanisms. A major contribution of the current study was demonstrating that the typical pattern representing the effects of expectation-driven control, namely there being a cue-induced shift in the MC condition but not a cue-induced shift in the MI condition, is not attributable to the bleed-over of awareness account. This was accomplished by demonstrating that the effect of cueing was still observed when a between-subjects manipulation of cueing was employed (as most clearly evidenced in the combined analysis of Experiments 1 and 2, and in the analysis of Experiment 3). This finding is important in supporting the view that expectations play a limited albeit important role in affecting Stroop effects within MC but not MI lists.

Also challenging the bleed-over of awareness account was the finding that in the uncued condition, awareness appeared to have little effect on the list-wide proportion congruence effect. If, as the bleed-over of awareness account posits, participants become aware of proportion congruence during uncued lists, use this information to establish an expectation about the remainder of each list, and then bias attention accordingly, one would have anticipated awareness to alter the list-wide proportion congruence effect similar to cueing. That is, aware participants should have differed from unaware participants, with aware participants exhibiting a larger list-wide proportion congruence effect (due to the influence of expectations) than unaware participants. However, they did not. This finding converges with Blais et al. (2012).

An interesting implication of the finding that awareness did not influence the list-wide proportion congruence effect, but cueing did (as demonstrated by the three-way interaction of cueing, proportion congruence, and trial type) is that expectations regarding list composition (likelihood of encountering conflicting trials) may be uniquely apt to have an effect on Stroop performance when such expectations are explicit. To the extent that modulating attention in an expectation-driven fashion is effortful (see Bugg et al., 2015, Experiment 4 for preliminary evidence), one explanation may be that participants are unwilling to engage this effort when expectations emerge via experience because these expectations may be invalid and therefore the effort may be difficult to justify (Shenhav et al., 2013). Alternatively, it is possible that our retrospective, post-experimental assessment of awareness was limited in addressing awareness during task performance. In other words, upon reflection, participants may have been able to report that lists differed in proportion congruence but they may not have been sensitive to this information during the Stroop task, nor may they have picked up on the proportion congruence of a particular list as the list unfolded. Further research is necessary to tease apart these possibilities.

The current study also contributed to our understanding of the role of experience and expectations in the list-wide proportion congruence effect by exploring how secondary task demands affected Stroop performance. Quite neatly, the list-wide proportion congruence effect was observed even in the presence of the stimulus-detection task, both in Experiments 2 and 3. Moreover, in the uncued condition, which represents arguably the purest indicator of the contribution of experience-driven control to the list-wide proportion congruence effect (see also awareness data for a similar interpretation), the magnitude of the list-wide proportion congruence effect did not differ between the standard and divided attention conditions in either Experiment 2 or 3. This suggests that experience-driven adjustments to attention that affect Stroop performance are not disrupted by dividing attention, which fits with the view that such adjustments are likely implicit (e.g., Blais et al., 2012).

In contrast, expectation-driven adjustments in attention do appear to be affected by secondary task demands (see also Kalanthroff et al., 2015), at least under certain conditions. The typical cueing effect (i.e., cue-induced shift in MC condition but not in MI condition) was not found in Experiment 2 in the lists in which an asterisk was presented. However, the cueing effect was observed in Experiment 3 in spite of there being more asterisks to respond to within each list. We attribute this difference across experiments to the fact that participants did not know in advance of a list whether an asterisk would appear in Experiment 2 but they did know this information in Experiment 3. However, further research is needed to determine the validity of this conclusion. For instance, we cannot rule out that the reduced number of divided attention lists in Experiment 2 (as compared to Experiment 3) may have resulted in reduced power to detect the Cueing x Proportion Congruence x Trial Type interaction (see Footnote 1).

There is also clearly a need to examine the generality of our conclusions. For example, it is uncertain as to whether the current findings are limited to the particular secondary task employed in the present study. Ongoing research in our lab suggests this may not be the case as we are finding both intact list-wide proportion congruence effects and intact cueing effects (e.g., cue-induced MC shift) in the presence of a much more demanding working memory task that participants perform concurrently with the pre-cued lists Stroop paradigm (see also Bugg, McDaniel, Scullin, & Braver, 2011, for evidence of intact list-wide proportion congruence effects in the presence of a secondary prospective memory task). Possibly this is because, as in Experiment 3, participants know which lists will require coordination of the secondary task demands and which will not (see also Bugg et al., 2011a). Contrary to this view, however, Kalanthroff et al. (2015) observed a detrimental effect of a high working memory load on proactive control in the Stroop task under conditions in which participants knew the load would be present in advance of the block of Stroop trials. Further research is needed to determine if these differences relate to the degree of load or type of secondary task (e.g., Kalanthroff et al., 2015, used an *n*-back), or another factor.

Further research is also necessary to better understand the types of advance knowledge that facilitate the coordination of a secondary task with the expectation-driven biasing of attention in the Stroop task, as well as the limits of such knowledge. For instance, it may be that it is more challenging to coordinate a secondary task with the expectation-driven biasing of attention when that bias is directed at narrowing the scope of attention (i.e., ignoring the word or selecting the color as in an MI list) rather than relaxing attention (i.e., distributing it across the word and color as in MC lists). On the other hand, predictability may again matter such that participants can coordinate the former type of bias when the presence of secondary task stimuli is predictable (see Tipper, Weaver, Cameron, Brehaut, & Bastedo, 1991, for finding that inhibition is not disrupted by predictable intervening events that are unrelated to primary task stimuli). However, testing this question requires that one first discover a way to encourage participants to engage expectation-driven control in a sustained fashion in MI lists, which has remained elusive to date (see Bugg et al., 2015, Experiments 3 and 4, for manipulations that lead to short-lived but not sustained biases in MI lists).

5. Conclusion

In conclusion, the list-wide proportion congruence effect reflects contributions of experience-driven and expectation-driven mechanisms (Bugg et al., 2015). In three experiments, we provided further evidence of the utility of the pre-cued lists paradigm for dissociating the effects of experience from the effects of expectations. Using between-subjects manipulations of cueing, expectations were again found to play a limited albeit important role in affecting Stroop effects within MC but not MI lists, consistent with prior findings (using within-subjects designs; Bugg et al., 2015). These findings challenge the bleed-over of awareness account and thereby justify use of the more powerful, within-subjects manipulation of cueing in future studies. Furthermore, our findings demonstrated that performance of a secondary task had dissociable effects on indices of experience (i.e., the list-wide proportion congruence effect especially within the uncued condition) and indices of expectations (cueing effects). Experience-driven adjustments were not vulnerable to the effects of dividing attention whereas expectation-driven adjustments were vulnerable, in particular when participants did not know their attention would be divided. This raises intriguing questions about the various sources of advance knowledge that may be provided to participants (e.g., in the form of pre-cues), and the ability to integrate these sources to establish an attentional setting that optimizes performance on the Stroop task, or in other attentionally demanding situations.

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