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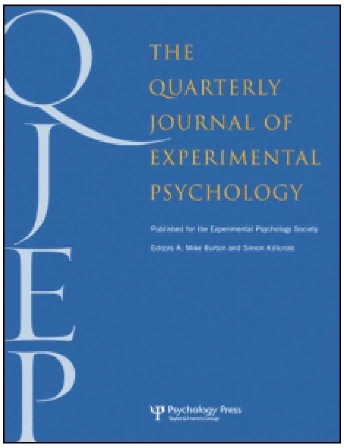

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The flexibility of context-specific control: Evidence for context-driven generalization of item-specific control settings

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Short article

The flexibility of context-specific control: Evidence for context-driven generalization of item-specific control settings

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In two experiments we address an ongoing debate concerning the processes driving context-driven modulations to the Stroop effect (Crump, Gong, & Milliken, 2006). In particular, we demonstrate that context-driven processes can modulate the size of the Stroop effect for frequency-unbiased item types. We also clarify the role of item frequency in producing context-driven modulations to the Stroop effect. Taken together, our results provide unambiguous support for the claim that contextual processing can impart fast and flexible control over the operation of selective attention processes during online performance.

Keywords: Stroop; Cognitive control; Contextual cueing; Generalization; Attention.

Performance in everyday life requires flexible and dynamic responses to negotiate rapidly changing task demands. From mundane activities like walking down a crowded street, or driving home from work, to exciting displays of skill in sport, dance, and music, people display a remarkable ability to exert control over fluctuating and uncertain demands. Although casual observation confirms that people are capable of controlling performance in a fast and flexible manner, the processes mediating fast and flexible control are not well understood.

Recently, some progress has been made in the study of processes that afford fast and flexible control over performance. In particular, several researchers have posited an important role for contextual cues dynamically modulating selective attention processes during online performance

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(for a review, see Egner, 2008). The purpose of the current set of experiments is to follow up on recent research in the Stroop domain (Crump, Gong, & Milliken, 2006; Crump, Vaquero, & Milliken, 2008; Jacoby, Lindsay, & Hessels, 2003) demonstrating that Stroop interference (ink-colour identification proceeds faster for congruent items—red in RED—than for incongruent items—red in BLUE; Stroop, 1935) can be modulated online, in response to the location context in which an item appears. Our goal is to provide unambiguous evidence that our previous contextual control findings reflect online context-driven modulations to selective attention processes and cannot be explained by more simple event-learning processes (e.g., Logan, 1988).

Crump et al. (2006) employed what they called a context-specific proportion congruent (CSPC) manipulation. Participants were presented with a colour word prime at fixation, followed by a to-be-named colour patch probe that appeared in a randomized fashion above or below fixation. Probes presented in one location were more likely (75%) to be congruent than probes presented in the other location (25%). It is important to note that because probe location was randomized from trial to trial, participants were unable to accurately predict whether a probe belonged to the high-proportion-congruent or low-proportion-congruent condition until probe onset. Despite participants' inability to prepare for likelihood of probe congruency, Stroop effects were larger in the high-proportion-congruent location context than in the low-proportion-congruent location context, an effect referred to by Crump et al. as a context-specific proportion congruent (CSPC) Stroop effect.

The current experiments aimed to clarify the nature of processes mediating the CSPC Stroop effect.[1] Following Jacoby et al. (2003), Crump et al. (2006) suggested that the CSPC Stroop effect could reflect rapid, context-driven modulations to selective attention processes controlling Stroop performance. On this view, each location context became associated with location-specific attention settings controlling selection of colour and word dimensions. For example, in the high-proportion-congruent location the word dimension usually predicted the appropriate colour response. According to the context-driven modulation view, the selective attention parameters for processing colour and word information in this location were biased to select word information, and this bias resulted in a larger Stroop effect. In contrast, in the low-proportion-congruent location the selective attention parameters for processing colour and word information were biased against selecting word information, and this bias resulted in a smaller Stroop effect. The context-driven modulation view of the CSPC Stroop effect is particularly interesting because it implies that a contextual cue can impart rapid online shifts in how attention selects incoming information during task performance.

The purpose of the current experiments was to directly address an alternative explanation of the CSPC Stroop effect that does not require assumptions about modulations to selective attention processes. In particular, Crump et al. (2006) acknowledged that the CSPC Stroop effect could be entirely explained by a simple learning process sensitive to the frequency of particular events (e.g., Logan, 1988). To elaborate, in Crump et al.'s experiments, particular word/location/colour events appeared more frequently than others. In the high-proportion-congruent location each congruent item was presented more frequently than each incongruent item, whereas in the low-proportion-congruent location each congruent and incongruent item was presented equally frequently. As a result, changes to the size of the Stroop effect in each proportion congruent location context could have been driven by different amounts of experience with particular item types. Considering this possibility, we acknowledged that the CSPC Stroop may not

[1] For a more comprehensive introduction to the kinds of processes potentially mediating the CSPC Stroop effect, and other proportion congruent effects, please refer to the introduction section contained in Crump, Vaquero, and Milliken (2008).

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reflect context-driven modulation of the attention processes controlling Stroop interference per se, but could instead reflect the joint and additive influences of Stroop interference on the one hand and a learning process sensitive to the frequency of particular word/location/colour events on the other hand. Indeed, there has been some speculation that item-specific proportion congruent effects (Jacoby et al., 2003), which are similar to CSPC Stroop effects, can be entirely explained by a simple stimulus/response learning process (Schmidt & Besner, 2008) and do not reflect item-specific modulations to attention processes.

The current experiments provide a definitive resolution to the possibility that CSPC Stroop effects are driven entirely by event-learning processes. Across two experiments we demonstrate that CSPC Stroop effects are not entirely driven by differences in event frequencies. Experiment 1 demonstrates that participants can learn context-specific attentional control settings established through experience with particular items that then generalize to the processing of other frequency-unbiased items. Experiment 2 replicates the findings from Experiment 1 and introduces a design measuring the separate contributions of event learning and context-specific control processes to the CSPC Stroop effect.

EXPERIMENT 1

Following Crump et al. (2006), we employ a CSPC manipulation to examine the generalization of control learned through experience with one set of items to a separate set of items. The current design involved two location contexts that were perfectly predictive of congruency for only a subset of the colour patch probes, referred to as the context probes. Critically, the location contexts were not predictive of congruency for the remaining colour patch probes, referred to as the transfer probes. That is, for the transfer probes, each word/location/colour event was experienced with equal frequency. The context and transfer probes were presented together randomly in a mixed design.

If the CSPC Stroop effect is driven entirely by a learning process sensitive to specific event frequency, then CSPC Stroop effects should not be observed for the transfer items. On the other hand, if the CSPC Stroop effect reflects context-driven modulation of selective attention processes, then this design may reveal CSPC Stroop effects for the transfer items. In particular, participants may learn to apply the selective attention parameters controlling performance on the context probes and generalize these attention settings to control performance on the transfer probes. Given that a CSPC Stroop effect for the transfer items would depend on participants' experience with context probes, we expected that evidence for a transfer-based CSPC Stroop effect would not be apparent at the beginning of the experimental session, but would emerge with practice. As such, we paid particular attention to contrasts between the first and last halves of the experimental session.

Method

Participants

The participants were 17 undergraduate students enrolled in psychology courses at McMaster University who volunteered for course credit. All participants spoke English as a first language, had normal colour vision, and had normal or corrected-to-normal visual acuity.

Materials and procedure

Participants were presented with a prime word, followed by a to-be-named colour patch probe. There were four colour-word primes (RED, GREEN, BLUE, YELLOW) and four colour-patch probes (red, green, blue, yellow). The colour-word primes were displayed in white on black background and were presented at fixation. The colour-patch probe was a coloured rectangle 1.6° in height and 5.2° in width that appeared above or below the fixation point (5.7°).

We constructed two separate prime–probe item types: context items and transfer items. Each item type consisted of a unique set of prime/probe pairs. Set 1 consisted of prime/probe pairs involving the colours red and green,

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while Set 2 consisted of prime/probe pairs involving the colours blue and yellow. We counterbalanced prime/probe sets for each item type across participants.

The critical context-specific proportion congruent manipulation was applied only to the context items. For example, in one counterbalancing condition, context items appearing above fixation were congruent 100% of the time, whereas context items appearing below fixation were incongruent 100% of the time. Importantly, location context was not predictive of congruency for the transfer items. Transfer items appearing in both the above fixation and below fixation contexts were congruent 50% of the time and incongruent 50% of the time. Context items and transfer items were presented equally frequently and mixed randomly across trials. In addition, the location context of an upcoming trial was varied randomly from trial to trial. Table 1 displays the frequency of each trial type for both context and transfer items appearing in both location contexts for a single block of trials. In total, participants completed 10 practice trials, followed by four blocks of 96 experimental trials.

The experiment was conducted on a PC with a 15″ SVGA monitor using MEL experimental software (Schneider, 1988). Participants were seated approximately 57 cm from the computer monitor. At the beginning of each trial, participants were presented with a fixation cross displayed in white against a black background for 1,000 ms, followed by a blank interval of 250 ms. Next, a prime word was presented centrally for 100 ms, followed immediately by a colour-patch probe displayed above or below fixation. The probe remained on the screen until the participant made a vocal response. Vocal response latencies were recorded using a microphone, and a voice-activated relay timed the response from the onset of the probe display. An experimenter coded each response as correct, incorrect, or spoil. A spoil was defined as a trial in which noise unrelated to the onset of the intended response triggered the voice-key.

Results and discussion

For all participants, reaction times (RTs) greater than 100 ms from correct trials for each condition

Table 1. *Event frequencies for the context-specific proportion congruent manipulation applied to context and transfer items for one block of trials in Experiments 1 and 2*

				Colour			
Experiment	*Proportion congruent*	*Probe type*	*Word*	*Red*	*Green*	*Blue*	*Yellow*
1	High	Context	RED	12	0	0	0
			GREEN	0	12	0	0
		Transfer	BLUE	0	0	6	6
			YELLOW	0	0	6	6
	Low	Context	RED	0	12	0	0
			GREEN	12	0	0	0
		Transfer	BLUE	0	0	6	6
			YELLOW	0	0	6	6
2	High	Context	RED	11	1	0	0
			GREEN	1	11	0	0
		Transfer	BLUE	0	0	6	6
			YELLOW	0	0	6	6
	Low	Context	RED	1	11	0	0
			GREEN	11	1	0	0
		Transfer	BLUE	0	0	6	6
			YELLOW	0	0	6	6

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were submitted to an outlier elimination procedure (Van Selst & Jolicoeur, 1994), which removed 2% of the observations across conditions. Mean RTs were then computed using the remaining observations. The results for the transfer probes were submitted to a 2 (learning phase: first half vs. last half) by 2 (proportion congruent: high vs. low) by 2 (congruency: congruent vs. incongruent) repeated measures analysis of variance (ANOVA). RTs and error rates for all conditions in the design, collapsed across participants, are displayed in Table 2. An alpha criterion of .05 was used for all statistical tests unless reported otherwise.

The critical three-way interaction between learning phase, proportion congruent, and congruency was significant, $F(1,\ 16) = 8.91$, $MSE = 214.30$, $\eta_p^2 = .36$. To examine the three-way interaction further, we conducted simple effects analyses by examining the first-phase and second-phase data separately. In the first phase, the proportion congruent × congruency interaction was not significant (CSPC effect = −7 ms), $F(1,\ 16) < 1$, whereas in the second phase this interaction was significant (CSPC effect = 23 ms), $F(1,\ 16) = 8.08$, $MSE = 288.07$, $\eta_p^2 = .34$. This finding provides the first demonstration that CSPC Stroop effects are not entirely driven by a learning process sensitive to differences in event frequency. Instead during the last half of the experiment, Stroop effects for the frequency-unbiased transfer probes were larger in the high-proportion-congruent location (85 ms) than in the low-proportion-congruent location (62 ms).

Of less theoretical importance was the significant main effect of congruency for the transfer probes, $F(1,\ 16) = 65.66$, $MSE = 2{,}509.87$, $\eta_p^2 = .80$. Responses for congruent trials were faster (488 ms) than responses for incongruent trials (558 ms). Similarly, there was a main effect of congruency for the context probes, which were analysed separately, $F(1,\ 16) = 52.26$, $MSE = 1{,}656.63$, $\eta_p^2 = .77$. Responses for congruent trials were faster (493 ms) than responses for incongruent trials (564 ms). There was no main effect of block for either the context or transfer probes. A corresponding analysis of error rates revealed no significant effects, and the pattern of error rates did not contradict the pattern of RTs.

EXPERIMENT 2

The transfer-based CSPC Stroop effect in Experiment 1 provides the first demonstration that the CSPC Stroop effect is not entirely driven by a learning process that depends on specific event frequencies. At the same time, it is worth considering the extent to which event frequency contributes to the size of the CSPC Stroop effect. Experiment 2 was designed to

Table 2. *Mean correct colour-naming response latencies, with standard errors and error rates, for Experiment 1*

			Congruency									
			Congruent (C)			*Incongruent (I)*			*Stroop I–C*		*CSPC effect*	
Probe type	*Half*	*Proportion congruent*	*RT*	*SE*	*ER*	*RT*	*SE*	*ER*	*RT*	*SE*	*RT*	*SE*
Transfer	First	High	488	13	.005	551	20	.005	63	11		
		Low	485	15	.002	554	18	.005	70	9	− 7	10
	Last	High	487	16	.01	572	18	.01	85	12		
		Low	494	15	.005	556	17	.01	62	11	23	8
Context	First	High	488	15	.001	—	—	—				
		Low	—	—	—	559	16	.01	71	10		
	Last	High	497	16	.002	—	—	—				
		Low	—	—	—	568	18	.01	71	13		

Note: CSPC = context-specific proportion congruent; RT = response time; *SE* = standard error; ER = error rate. Response latencies in ms.

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measure the separate contributions of event learning and context-driven control to the size of the CSPC Stroop effect. The design was similar to that of Experiment 1 with the exception that the context probes were not 100% predictive of congruency. Instead, the high-proportion-congruent context included 92% congruent and 8% incongruent probes; similarly, the low-proportion-congruent context included 8% congruent and 92% incongruent probes. As with Experiment 1, congruent and incongruent transfer probes were presented with equal frequency in both location contexts. This design allowed a measure of the CSPC Stroop effect for both the frequency-biased context probes and the frequency-unbiased transfer probes. If the CSPC Stroop effect depends partly on event learning then we would expect larger CSPC Stroop effects for the biased context than for unbiased transfer probes.

Method

Participants

The participants were 30 undergraduate students enrolled in psychology courses at McMaster University who volunteered for course credit. All participants spoke English as a first language, had normal colour vision, and had normal or corrected-to-normal visual acuity.

Materials and procedure

Experiment 2 employed the same materials and procedure as those in Experiment 1. The critical difference was that the proportions of congruent and incongruent items were changed for the context items. For example, in one counterbalancing condition, context items appearing above fixation were 92% congruent and 8% incongruent, whereas context items appearing below fixation were 92% incongruent and 8% congruent. Table 1 displays the frequency of each trial type for both context and transfer items appearing in both location contexts for a single block of trials. All other aspects of the design were the same as those in Experiment 1.

Results and discussion

Mean RTs in each condition were submitted to the same outlier procedure as that employed in Experiment 1, resulting in the elimination of 2% of the observations. The results for the transfer and context probes were submitted to a 2 (probe: context vs. transfer) by 2 (learning phase: first half vs. last half) by 2 (proportion congruent: high vs. low) by 2 (congruency: congruent vs. incongruent) repeated measures ANOVA. RTs and error rates for all conditions in the design, collapsed across participants, are displayed in Table 3. The

Table 3. *Mean correct colour-naming response latencies, with standard errors and error rates, for Experiment 2*

			Congruency									
			Congruent (C)			*Incongruent (I)*			*Stroop I–C*		*CSPC effect*	
Probe type	*Half*	*Proportion congruent*	*RT*	*SE*	*ER*	*RT*	*SE*	*ER*	*RT*	*SE*	*RT*	*SE*
Transfer	First	High	483	13	.003	561	14	.012	78	7		
		Low	484	12	.002	555	15	.009	71	8	7	7
	Last	High	488	14	.002	566	17	.01	78	7		
		Low	499	14	.004	557	16	.01	58	6	20	7
Context	First	High	483	13	.003	563	18	.002	80	11		
		Low	473	14	0	561	16	.02	88	11	−8	13
	Last	High	488	13	.005	584	21	.004	96	16		
		Low	502	16	0	554	15	.02	52	9	44	14

Note: CSPC = context-specific proportion congruent; RT = response time; *SE* = standard error; ER = error rate. Response latencies in ms.

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proportion congruent by congruent interaction was significant, $F(1, 29) = 7.46$, $MSE = 952.45$, $\eta_p^2 = .20$, as was the three-way interaction between block, proportion congruent, and congruency, $F(1, 29) = 9.92$, $MSE = 811.18$, $\eta_p^2 = .25$. No other higher order interactions were significant. The only significant main effect was that of congruency, $F(1, 29) = 157.81$, $MSE = 4{,}289.23$, $\eta_p^2 = .84$. Responses to congruent probes were faster (488 ms) than responses to incongruent probes (563 ms). To compare the relative contributions of the context and transfer probes to the size of the CSPC effect we conducted ANOVAs of the type reported in Experiment 1.

Looking first at the context probes, the three-way interaction between learning phase, proportion congruent, and congruency was significant, $F(1, 29) = 6.80$, $MSE = 1{,}551.26$, $\eta_p^2 = .19$. To examine the three-way interaction further, we conducted simple effects analyses by examining the first phase and second phase data separately. In the first phase, the proportion congruent × congruency interaction was not significant (CSPC effect = −8 ms), $F(1, 29) < 1$, but was significant in the last half of the experiment (CSPC effect = 44 ms), $F(1, 29) = 10.12$, $\eta_p^2 = .26$. Following the pattern of CSPC effects for the transfer probes in Experiment 1, by the last half of the experiment Stroop effects for the frequency-biased context probes were larger in the high-proportion-congruent location (96 ms) than in the low-proportion-congruent location (52 ms). Of less theoretical importance was the main effect of congruency, $F(1, 29) = 106.24$, $MSE = 3{,}509.12$, $\eta_p^2 = .79$. Responses for congruent trials were faster (487 ms) than responses for incongruent trials (567 ms). Participants' overall error rate was less than .007. Errors were not submitted to further analysis.

Interestingly, for the transfer probes, the three-way interaction between learning phase, proportion congruent, and congruency was not significant, $F(1, 29) = 1.61$, $MSE = 362.25$, $p < .22$, $\eta_p^2 = .05$. Instead, the two-way proportion congruent by congruency interaction was significant, $F(1, 29) = 7.48$, $MSE = 349.08$, $\eta_p^2 = .21$. We do note that, consistent with Experiment 1, the transfer-based CSPC Stroop effect was not significant in the first half (7 ms), $F(1, 29) < 1$, but was significant in the last half (19 ms), $F(1, 29) = 8.20$, $\eta_p^2 = .22$. Thus, and most important, Experiment 2 replicates the finding that CSPC Stroop effects can be demonstrated for frequency-unbiased transfer probes. Of less theoretical importance was the main effect of congruency, $F(1, 29) = 179.31$, $MSE = 1{,}704.71$, $\eta_p^2 = .86$. Responses for congruent trials were faster (489 ms) than responses for incongruent trials (560 ms). Participants' overall error rate was less than .007. Errors were not submitted to further analysis.

To evaluate the contribution of event learning to the size of the CSPC Stroop effect we compared the CSPC effect for the context probes (44 ms) in the last half to the CSPC effect for the transfer probes (19 ms) in the last half. A planned contrast of the difference between the CSPC effect for the context (44 ms) and transfer probes (19 ms) in the last half was significant according to a one-tail criterion, $F(1, 29) = 3.13$, $p < .05$, $\eta_p^2 = .10$. Although this finding is somewhat preliminary and should therefore be viewed with caution, it appears that learning processes tied to specific events may contribute to the overall size of the CSPC Stroop.

GENERAL DISCUSSION

In two experiments we set out to examine whether the CSPC Stroop effect (Crump et al., 2006; Crump et al., 2008) is entirely driven by a learning process sensitive to differences in event frequency. Both Experiments 1 and 2 provide the novel demonstration that CSPC effects can be observed for frequency-unbiased items. This transfer-based CSPC Stroop effect provides an unambiguous demonstration of generalizable context-driven control over selective attention. To restate, our findings provide direct support for the view that CSPC effects reflect rapid, online, context-driven modulations to filtering operations carried out by selective attention.

Although CSPC effects cannot be explained entirely by an event-learning process, the CSPC effect was larger for the frequency-biased context probes than for the frequency-unbiased transfer probes. An important consideration for future research will be to determine whether the larger effect was in fact driven by an event-learning process, or whether the context probes were simply better cues for the contextual control process modulating the Stroop effect.

Our broad focus in this research programme is in understanding how people exert fast and flexible control during online performance situations. Our results suggest that context-driven control processes play an important role in imparting fast and flexible control over performance. In the domain of attention, context-driven influences on performance are commonly thought to be guided by episodic retrieval processes (e.g., negative priming, Neill, 1997; sequential effects, Hommel, Proctor, & Vu, 2004; visual search, Chun, 2000), which are assumed to be driven by highly specific uses of specific episodes (e.g., Logan, 1988).

Outside the domain of attention there are demonstrations that specific episodic information can generalize to improve identification (Palmeri, 1997) or categorization (Brooks & Vokey, 1991) performance for similar novel items. In these cases, the representational similarity between items in memory and novel items is assumed to support generalization effects. The overall similarity between the context and transfer probes employed in the present experiment is probably an important factor mediating the transfer-based CSPC Stroop effect. At the same time, we propose that our findings have additional implications that extend our understanding of how episodes are represented in memory and how memory and attention processes interact online to influence task performance.

To explain how people make general use of specific episodic knowledge we follow Kolers and Roediger (1984) and Jacoby & Brooks (1984) in assuming that memory representations for specific events include generalizable aspects of processing. We assume that contextual information in the task environment can become bound together, or associated with, selective attention parameters controlling the filtering of incoming information in a context-specific fashion. For example, in a CSPC Stroop task, episodic representations for a particular Stroop trial could include a particular prime–probe pair and response, a contextual cue (e.g., probe location), and a set of selective attention weights employed to filter word and colour information on that trial. From our perspective, the generalizable aspects of the episodic representation are the selective attention weights bound up in the episodic experience for a given trial.

To clarify our perspective, episodic influences are commonly thought to involve the retrieval of particular stimulus/response episodes, which are assumed to produce highly specific influences on performance (Logan, 1988). In contrast, selective attention processes (e.g., Logan, 2002) are assumed to provide generalizable control over the weighting of different stimulus dimensions. We are proposing that context-driven control reflects some combination of both episodic and selective attention processes. In particular, we assume that the generalizable selective attention weights applied during a particular experience are represented as part of the episodic representation for that experience. In this way, when particular episodes are retrieved by cues in the environment, we assume that prior selective attention weights are also retrieved and are applied to current processing. In this way, contextual cues can provide fast and flexible control over performance. Context-driven control is fast because it is mediated by episodic retrieval, which is assumed to be relatively automatic (Logan, 1988). Context-driven control is flexible because it involves context-triggered adjustments to selective attention processes, which are assumed to apply generally to the weighting of stimulus dimensions independently of specific items carrying those dimensions.

We suggested that attention processes may be embedded within episodic representations. An important topic for future research will be to clarify the online interaction between memory retrieval processes and selective attention processes. We are suggesting that memory retrieval processes can play an important role in the online updating of selective attention processes.

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One possibility is that online updating process could unfold across iterations of processing in which memory for particular experiences constrains perception. In other words, attention processes mediating event encoding may simultaneously mediate the retrieval of previous attention procedures that feedback and control the ongoing attention processes mediating event encoding. A current research aim is to develop a computational theory that brings together global-memory models of performance with the notion of iterative resonance (Mewhort & Johns, 2005) to gain a formal understanding of how attention and memory processes interact to influence online performance.

The transfer-based CSPC Stroop effect provides a novel demonstration that CSPC effects can reflect context-driven modulations to attention processes. At the same time, our explanation of how context-specific processing can mediate online task performance also fits well with a growing range of recent findings (Egner, 2008), particularly in the task switching (Mayr & Bryck, 2007), Eriksen flanker (Wendt, Kluwe, & Vietze, 2008), visual search (Chun, 2000), and attentional cueing (Awh, Sgarlata, & Kliestik, 2005) paradigms. Taken together, all of these lines of research demonstrate that control over various aspects of selective attention can be outsourced to environmental or contextual cues associated with particular attentional demands.

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