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Peter S. Whitehead and Tobias Egner
Duke University

Recent studies have demonstrated that maintaining task-sets in working memory (WM) for prospective implementation can interfere with performance on an intervening task when the same stimulus requires incompatible responses in the ongoing versus the prospective task. This prospective task-set interference effect has previously been conceptualized as an obligatory process, resulting from instruction-based reflexivity (IBR). However, the extent to which strategic control can be exerted over interference in ongoing behavior from prospective task-sets held in WM has heretofore not been tested directly. To probe for strategic control over this effect, the authors conducted 3 experiments using a common inducer-diagnostic task design that manipulated the proportion compatibility of trials in the ongoing task. They hypothesized that if prospective task-set interference were malleable by control, participants would suppress the influence of the prospective set on ongoing processing when incompatible trials are frequent. Consistent with this prediction, the results show that prospective task-set interference is subject to modulation by strategic control such that the magnitude of interference is reduced, eliminated, or reversed in the presence of frequent incompatible trials. Thus, the influence on ongoing behavior of a prospective task-set held in WM is not obligatory, but subject to strategic control.

Public Significance Statement

Things kept in mind for completion later on can bias our attention and interfere with what we are doing right now. Understanding the mechanisms of this interaction between mental content and ongoing behavior is important, because it may allow us to help people avoid unintended actions or accidents. In this study, we show that the impact of future goals in ongoing behavior can be moderated; when people know that what they have in mind will likely affect ongoing behavior in a negative way, they can in fact intentionally suppress this influence.

Keywords: prospective task-set interference, working memory, strategic control

Supplemental materials: http://dx.doi.org/10.1037/xhp0000493.supp

Everyday life requires us to balance attending to internal thoughts and plans, on the one hand, with focusing on our ongoing interactions with the external world, on the other hand. The ability to temporarily maintain and manipulate internal representations, known as working memory (WM), greatly enriches our behavioral repertoire, but it can also incur costs: On the upside, we use WM representations to guide attention and behavior in a top-down, goal-directed manner (Baddeley, 1986; Cowan, 1998; e.g., Miller, Galanter, & Pribram, 1960); on the downside, the ability of active WM representations to bias perception and action can also have unwelcome side effects, as information kept in mind for future use can interfere with an intervening task at hand (for reviews, see Kiyonaga & Egner, 2013; Olivers, Peters, Houtkamp, & Roelfsema, 2011; Soto, Hodsoll, Rotshtein, & Humphreys, 2008). The present study seeks to elucidate the extent to which we can exert control over this behavioral cost to maintaining WM representations for future use, specifically in the context of keeping in mind behavioral rules, or task sets.

Attentional Capture by WM Content

A substantial research literature has documented that keeping a particular stimulus in WM (known as *declarative WM*) strongly biases attention toward matching or similar items (e.g., Desimone & Duncan, 1995). Importantly, this holds even for an unrelated task, such as a visual search task carried out during a WM delay period. Here, WM content is helpful when the search target spatially coincides with a WM-matching item, but interferes with search when the WM-matching item coincides with a nontarget (distracter) item (e.g., Downing, 2000; Olivers, Meijer, & Theeuwes, 2006; Soto, Heinke, Humphreys, & Blanco, 2005). This bias is highly reliable within and across subjects (Dowd, Pearson, & Egner, 2017), and people appear to have limited control over it: when task trials are blocked such that the WM cue always coin-

Peter S. Whitehead, Center for Cognitive Neuroscience, Duke University; Tobias Egner, Center for Cognitive Neuroscience, and Department of Psychology & Neuroscience, Duke University

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Correspondence concerning this article should be addressed to Peter S. Whitehead, Center for Cognitive Neuroscience, Duke University, LSRC, Box 90999, Durham, NC 27708. E-mail: peter.whitehead@duke.edu

cides with a distracter, participants are able to reduce but not abolish the harmful effect of the WM cue on search performance (Carlisle & Woodman, 2011; Kiyonaga, Egner, & Soto, 2012). This apparently obligatory link between declarative WM content and attentional orienting can be explained by "sensory recruitment" models of WM, which posit that keeping a stimulus in mind is mediated by activation of the same neural substrates as the perception of that stimulus (e.g., Awh & Jonides, 2001; Postle, 2006).

Prospective Task-Set Interference

A more recent and much smaller research literature has moved from investigating the effects of declarative WM content on attention to examining how holding simple behavioral rules, such as stimulus-response (S-R) mappings, in mind for future use may also exert an influence on intervening behavior (Liefooghe, Wenke, & De Houwer, 2012; Meiran, 1996; Meiran, Pereg, Kessler, Cole, & Braver, 2015; Theeuwes, Liefooghe, & De Houwer, 2014; Wenke, Gaschler, & Nattkemper, 2007). This can be conceptualized as probing the effect of procedural WM content (see Oberauer, 2009) on information processing, although the more commonly used terminology in this emerging field is that it investigates prospective task-set interference with performance on an intervening task.

The basic experimental approach to investigating this phenomenon has used an inducer-diagnostic task design, where the *inducer task* is an instructed prospective task that has to be kept in WM for future execution, and the *diagnostic task* is an intervening task that has to be performed before implementation of the inducer task (Liefooghe et al., 2012; Theeuwes et al., 2014). Crucially, the diagnostic task, although technically unrelated to the prospective task, involves some overlap in S-R mappings such that some responses to stimuli during the diagnostic task are compatible with those that would be required by the inducer task, and others are incompatible with the inducer task instructions; the magnitude of interference from the instructed prospective task is measured via differences in response times to compatible and incompatible stimuli. Studies using this set-up have repeatedly documented a prospective task-set interference effect, whereby responses to stimuli in a current task are slower when the current correct response is incompatible with the instructed, prospective response for the same or similar stimuli in the prospective task that is maintained in WM (Liefooghe et al., 2012; Meiran et al., 2015; Theeuwes et al., 2014). Moreover, this effect is observed when S-R instructions are encoded for future implementation, but not when they are encoded for declarative recall (Liefooghe et al., 2012).

Further research has shown that prospective tasks can interfere even with highly practiced and dominant response biases: for instance, the Simon effect—where responding to a lateralized stimulus with the contralateral hand is slower than with the ipsilateral hand—can be eliminated when prospective S-R rules instruct an incompatible position task (i.e., press left if stimulus is on the right side of the screen, and press right if stimulus is on the left; Theeuwes et al., 2014). Taken together, these studies have convincingly demonstrated that a prospective task-set can lead to task-rule compatibility effects in an intervening task, and this prospective task-set interference effect has been interpreted as reflecting an automatic, reflex-like phenomenon (Liefooghe, De Houwer, & Wenke, 2013; Theeuwes et al., 2014). However, unlike in the case of the declarative WM literature, whether the task-set interference effect is truly automatic has not been addressed directly in previous studies. We pursued this goal in the present study, by adapting a recently developed task protocol by Meiran and colleagues (2015).

The NEXT Protocol

Meiran et al. (2015) recently designed the NEXT task, a novel protocol for assessing prospective task-set interference while controlling for a number of potential confounds in prior studies. Most notably, the NEXT paradigm rules out possible confounds due to practice or long-term memory effects: specifically, in previous studies, episodic retrieval of prior task execution—due to the repeated use of a limited set of inducer tasks and stimuli—may have confounded the interpretation of the prospective task-set interference effect as truly reflecting a consequence of new, actively maintained WM representation. To resolve this issue, the NEXT protocol borrows from the rapid instructed task learning design of Cole, Laurent, and Stocco (2013) to deliver on each trial novel prospective task-set instructions for an inducer task (termed the *GO phase*). Prior to implementing the prospective instructions of the "GO" phase, subjects perform an intervening diagnostic task (termed the *NEXT phase*) during which a potential prospective task-set interference effect (here called the *NEXT effect*) is assessed. The NEXT phase consists of a sequence of zero to five diagnostic trials preceding two inducer task "GO" phase trials, which together constitute a "mini-block." At the start of each miniblock, novel instructions were given and new task stimuli were chosen from a set of English and Hebrew letters, pictures, and symbols to circumvent any long-term memory confounds stemming from stimulus and S-R mapping repetitions between different miniblocks.

Meiran et al. (2015) observed robust prospective task-set interference effects, including for the very first trial of the NEXT phase. Although the initial experimental designs of Meiran et al. (2015) were potentially confounded by covert execution of the GO phase instructions, this possibility was addressed in their Experiment 3 by comparing the NEXT compatibility effects between two conditions—one in which the GO phase instructions were executed before and after the NEXT phase and another where GO phase instructions were implemented after the NEXT phase only, as in the previous experiments. This experiment yielded no significant difference in the NEXT compatibility effect (a small numerical difference existed, however), especially in the advanced trials of a miniblock. Noting that the small difference in GO phase performance between the conditions would have been reduced if GO phase instructions were covertly executed in the NEXT phase, Meiran et al. (2015) concluded that covert execution of GO phase instructions during the NEXT phase was unlikely, though not altogether impossible. The resulting, putatively confound-free prospective task-set interference effect was interpreted as stemming from instruction-based reflexivity (IBR; Meiran et al., 2015), the reflexive or obligatory triggering of an action that results from preparing to execute instructions for a future task. IBR can be distinguished from a more general class of prepared reflex (Hommel, 2000; Meiran et al., 2015; Woodworth, 1938) based on the fact that it does not stem from prior practice or long-term memory based knowledge. In sum, even in the absence of long-term memory confounds, instructed and actively maintained task-set representations for a prospective task negatively impact the behavioral performance in a current, diagnostic task when there is incompatible overlap between current and prospective S-R mappings.

The Current Study

Previous work has focused on assessing the capabilities of a broad, top-down strategy on the encoding or preparation of prospective task-set instructions to modulate subsequent interference. Past studies of task-set implementation determined that prospective task-set instructions must be encoded for future use, be in preparation for execution, and consistently implemented to create prospective task-set interference effects (Wenke, Gaschler, Nattkemper, & Frensch, 2009; Liefooghe et al., 2012; Liefooghe et al., 2013). This work has primarily been conducted through experimental manipulations of the inducer/GO phase, by frequently cancelling the execution of inducer/GO phase instructions (Wenke et al., 2009), manipulating the time allotted to prepare and encode prospective task-set instructions (Liefooghe et al., 2013), or by explicitly manipulating the length of the GO phase, thus allowing subjects more or less time to prepare for the implementation of prospective task-set instructions (Meiran et al., 2015). This work has established that top-down control of the encoding and preparation of task-set instructions modulates subsequent prospective task-set interference.

Once a task set is encoded and prepared for immediate future use, Meiran and colleagues (2015), as well as other authors (Liefooghe et al., 2013; Theeuwes et al., 2014), have conceptualized the prospective task-set interference effect as a reflexive, obligatory process, but the implied inability of subjects to yield strategic control over this effect has not yet been tested directly. Seeming to support the proposed reflexive nature of the prospective task-set interference effect, Meiran et al. (2015) showed that practice of prospective task instructions prior to storing them in WM for future use does not modulate their interference in current behavior. Conversely, within the declarative WM literature, the ability for some degree of strategic control over the biasing effect WM representations exert on attention was demonstrated in a block-wise manipulation of WM cue validity; when WM cues were reliably detrimental to an intervening visual search, participants manage to dampen this effect (Kiyonaga et al., 2012). Moreover, context effects—created by the addition of contextual information that defines relevant screen locations where stimuli will appear when implementing the prospective task-set S-R mappings—can shape prospective task-set interference (Braem, Liefooghe, De Houwer, Brass, & Abrahamse, 2017). Specifically, the presentation of stimuli in compatible and incompatible contexts in relation to the prospective task-set instructions determines whether interference by those instructions occurs in a current task (Braem et al., 2017). In demonstrating implicit contextual modulation of prospective task-set interference, this study provides circumstantial evidence suggesting strategic modulation of prospective task-set interference effect may also be possible.

The present study seeks to directly test whether strategic control can modulate the biasing influence that a prospective task-set held in WM exerts on current behavior. Over the course of three experiments, using a modified version of the NEXT paradigm (Meiran et al., 2015), we employ a proportion compatibility (PC) manipulation, systematically varying the proportion of compatible to incompatible trials, in order to modulate strategic control-demands. The manipulation of PC level is one of the most commonly used approaches to probe the malleability of interference effects by strategic processing adjustments (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Bugg & Crump, 2012; Engle & Kane, 2003; Gratton, Coles, & Donchin, 1992; Logan, 1980; Logan & Zbrodoff, 1979; Logan, Zbrodoff, & Williamson, 1984). The canonical finding is a progressive scaling of interference effect magnitude with the proportion of compatible trials, such that interference effects are small (or even absent/reversed) when most trials are incompatible and large when most trials are compatible (Logan & Zbrodoff, 1979). This data pattern is thought to demonstrate strategic processing adjustments to expected task demands (i.e., cognitive control; Botvinick et al., 2001; Logan & Zbrodoff, 1979; Logan et al., 1984). In line with this assumption, we here systematically varied the PC levels of NEXT task trials to probe whether subjects would be able to modulate the prospective task-set interference effect.

In addition to manipulating PC levels, we also used English words as stimuli instead of the heterogeneous stimulus set of letters (English and Hebrew), symbols, and pictures used by Meiran et al. (2015). This provided us with the large number of trial-unique task stimuli required by the NEXT protocol while using a stimulus set that is consistent in the linguistic domain and uniform in the nature of stimulus-items. Overall, this design allowed us to investigate whether the prospective task-set interference effect is subject to strategic control. An interaction between the prospective task-set interference effect and PC level would indicate that the prospective task-set interference effect is malleable by strategic control, whereas a lack of such an interaction would be consistent with the viewpoint that this effect is reflexive or automatic in nature.

Experiment 1

To test whether prospective task-set interference can be modulated by the frequency or likelihood of incompatible trials, we adapted the NEXT paradigm from Meiran et al. (2015) to a PC manipulation. To create highly conducive conditions for strategic modulation of task-set interference, we combined "local" and "global" PC manipulations. The local PC manipulation consisted of varying the proportion of compatible trials within each miniblock, whereas the global PC manipulation consisted of grouping the presentation of miniblocks of a particular PC level into runs, thus producing runs of low versus high PC miniblocks.

Method

Participants. For .80 power to detect a prospective task-set compatibility effect, using effect size estimates based on Meiran et al. (2015), a sample size of at least 14 subjects was necessary. However, given possible attrition and an added experimental factor of varying PC levels, we targeted a recruitment of 20 subjects per experiment. Twenty Amazon Mechanical Turk workers provided informed consent in accordance with the policies of the Duke University Institutional Review Board (*M* age = 39.10, *SD* = 13.25; 8 males, 12 females). The use of Amazon Mechanical Turk works as participants in cognitive psychology experiments using reaction time (RT) and accuracy as dependent measure has been previously validated (Crump, McDonnell, & Gureckis, 2013). Participants could sign up for the experiment regardless of age or country of residence. However, they were informed that they needed to complete the task with >75% accuracy to be paid. No participants performed under this accuracy threshold.

Stimuli and procedure. The task was modeled after the NEXT paradigm (Meiran et al., 2015) and the rapid-instructed task-learning paradigm (Cole et al., 2013). The paradigm consisted of 128 miniblocks, with each miniblock presenting a unique two-alternative-forced-choice (2AFC) task (see Figure 1). At the beginning of each miniblock an instruction screen appeared, which was followed by a series of trials that presented a single word in the center of the screen. Each instruction screen presented the two word stimuli that would make up the subsequent trials. The word stimuli were unique and randomly chosen, without replacement, for every miniblock. Word stimuli were between 4 and 6 letters in length, did not contain proper nouns, were close in frequency rating by logarithmic scale (8.49–12.99; Lund & Burgess, 1996), and were gathered from the English Lexicon Database (Balota et al., 2007).

The two word stimuli on the instruction screen were accompanied by two sets of stimulus-response mapping instructions. Which mapping to apply on a given trial depended on the color (red vs. blue) in which the word stimulus was displayed on that trial. One of the two instructions was invariant across miniblocks, asking subjects to press the D-key in response to any word stimuli appearing in red ink. Thus, for red-word trials, the identity of the word did not matter for selecting the response, and this instruction could be held in long-term memory, as it remained the same throughout the task. The second instruction varied from trial to trial, in that it arbitrarily mapped one of the two word stimuli to the D-key and the other one to the J-key, and subjects were told to apply this 2AFC stimulus-response mapping to word stimuli shown in blue ink. Thus, unlike in red-word trials, in blue-word trials the identity of the word stimuli determined the correct response, and this task-set had to be held in WM.

Crucially, if red-word trials appeared in a given miniblock (the NEXT phase), they always preceded the blue-word trials (the GO phase). The intuition here is that subjects push the D-key to advance through the series of red-word trials to get to the "real" task, that is, the 2AFC task embodied by the blue-word trials. Within each miniblock, the NEXT phase lasted either zero, three, four, or five trials. The GO phase was consistently two trials long and presented each of the two word stimuli once.

The key characteristic of this task protocol is that NEXT phase stimuli fall into one of two possible categories (compatible vs. incompatible) as a function of their relationship with the GO phase stimulus-response mapping: NEXT trials are compatible when the word on the current trial corresponds to the word that is mapped to the D-key in the prospective GO phase (thus requiring the same response in both phases), and incompatible when the word on the current trial corresponds to the one that is mapped to the J-key in the GO phase. The prospective task-set compatibility effect seen in the NEXT phase (slowed and less accurate responses for incompatible compared to compatible trials) therefore represents the metric by which one measures the degree of prospective task-set interference (Meiran et al., 2015).

To assess whether the compatibility effect is obligatory or malleable by strategic adaptation, we manipulated PC: within each miniblock, the NEXT phase either had a low or high PC level, with the ratio of compatible-to-incompatible trials (in the low PC condition) or of incompatible-to-compatible trials (in the high PC condition) being 1:2, 1:3, or 1:4 for NEXT phase trial lengths

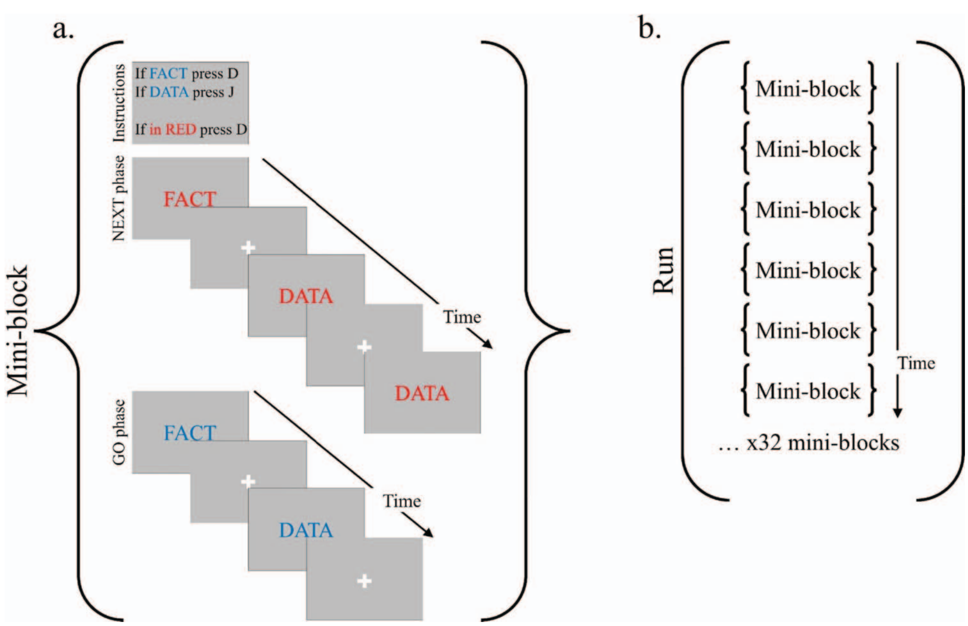

Figure 1. Experiment paradigm. (a) Example miniblock with a NEXT phase trial length 3. Here, FACT represents a congruent stimulus and DATA an incongruent one. (b) Illustration of the combination of multiple miniblocks into a run. See the online article for the color version of this figure.

three, four, or five, respectively. Moreover, miniblocks of low versus high PC levels were grouped into 32 miniblock runs. Subjects were not informed about the PC manipulation and grouping of miniblocks. There were four runs in total, presented in alternating order, with either a high PC level or low PC level run randomly chosen to begin the experiment. Within each run, there were an equal number of NEXT phase miniblock lengths presented randomly, without replacement.

In the first two miniblocks of the entire experiment, subjects were given 30 s and 12 s, respectively, to read the instructions, immediately followed by a 5-s countdown before stimuli presentation began. This was done to acclimatize subjects to the instruction format and task demands. These miniblocks were included in the analysis, however, their inclusion or exclusion did not significantly alter the results of our analysis. For all subsequent miniblocks, subjects were given 10 s to read the instructions, followed by a 3-s countdown to stimuli presentation.

Analysis. Our hypothesis centered on performance in the NEXT phase, testing whether the prospective task-set compatibility effect would be modulated by PC level. If prospective task-set interference is truly automatic, the NEXT phase compatibility effect should not vary with PC condition. By contrast, if the compatibility effect can be subject to strategic control, we would expect to observe reduced compatibility effects in the low PC compared to the high PC conditions. To assess whether prospective task-set interference varied between the high and low PC miniblocks of the NEXT phase we used a 2 (PC level: high vs. low) × 2 (Compatibility: compatible vs. incompatible) × 3 (Length of NEXT phase: 3, 4, or 5) repeated measures analysis of variance (rmANOVA) on response time (RT) in milliseconds (ms). Additionally, in line with previous work (Meiran et al., 2015), we also submitted the data to a 2 (PC level: high vs. low) × 5 (Trial in NEXT phase: 1, 2, 3, 4, or 5) × 2 (Compatibility: compatible vs. incompatible) rmANOVA on RT in ms, similarly focused on the PC level by Compatibility interaction as a marker for strategic control modulation. We report η_p^2 as an effect-size estimate for each level of both rmANOVAs.

Performance in the GO phase was not central to our hypothesis. Nevertheless, to test for potential effects of the PC manipulation on GO trial performance, we used a 2 (PC level: high vs. low previous NEXT phase) × 2 (Trial: First or second trial in GO phase) × 4 (Length: 0, 3, 4, or 5 trials in preceding NEXT phase) rmANOVA of response times and accuracy.

Results and Discussion

NEXT. NEXT phase trial accuracy was at ceiling (98.6%) and did not constitute a dependent variable of interest. Before the RT analysis, errors were removed, as were trials with RTs shorter than 100 ms or longer than 3,000 ms (1.1% of remaining data; the same RT boundaries were used in Meiran et al. (2015). Resulting from the random presentation of stimuli, two subjects were excluded from the second rmANOVA analysis—2(PC Level) × 5(Trial) × 2(Compatibility)—due to data missing completely at random from one cell. See Table 1 for complete descriptive statistics.

Critically, in both rmANOVAs, the PC level of the miniblocks modulated the prospective task-set compatibility effect of the NEXT phase, as reflected in a significant PC level × Compatibility interaction (Table 2A): the prospective task-set compatibility effect for the high PC level (41 ms; compatible RTs < incompatible RTs) was reversed for the low PC level (–38 ms; Table 1; Figure 2). No other main effects or interactions were significant in the initial rmANOVA (Table 2A). However, our second rmANOVA also showed a significant effect of Trial, consistent with previous work (Meiran et al., 2015), and a significant three-way interaction between PC level, trial, and compatibility (Table 2B), indicating potential differences in the compatibility effect varying by PC Level as the NEXT phase progresses through the miniblock. Following these results, post hoc, Bonferroni corrected *t* tests were conducted and indicated that while the prospective task-set interference effect is significant at Trials 1, 3, 4, and 5 at the high PC level, the compatibility effect of the low PC level is modulated such that there is no significant compatibility effect at any Trial level (see supplemental materials). Taken together, these results—strengthened by the significant interaction between PC level and compatibility—indicate support for the hypothesis that prospective task-set interference can be subject to strategic control.

GO. Because of the two-choice nature of the GO phase, trial accuracy did constitute a dependent variable of interest, unlike in the NEXT phase. Before the analysis was undertaken, errors were removed from the RT data (5.4% of data), as were trials with RTs shorter than 100 ms or longer than 3,000 ms (2.4% of remaining data (Meiran et al., 2015), and for the accuracy data, trials with RTs outside the same 100- to 3,000-ms boundary were removed (2.4% of data). See Table 3 for complete descriptive statistics.

There was a main effect of trial, such that on average the first trial in the GO phase was slower and less accurate than the second

Table 1
Mean and Standard Deviation for Response Times (ms) in the NEXT Phases of Mini-Blocks from Experiment 1

	High PC		Low PC		Compatibility effect	
NEXT Mini-Block	Compatible	Incompatible	Compatible	Incompatible	High PC	Low PC
Length: 3	469 (127)	485 (142)	468 (169)	466 (133)	16	−2
Length: 4	428 (88)	468 (141)	491 (146)	451 (116)	40	−40
Length: 5	430 (79)	486 (163)	506 (222)	443 (113)	56	−63
Trial: 1	641 (253)	678 (233)	692 (316)	665 (266)	37	−27
Trial: 2	382 (89)	362 (97)	406 (143)	380 (90)	−20	−26
Trial: 3	360 (62)	420 (124)	393 (156)	373 (85)	60	−20
Trial: 4	376 (63)	437 (126)	451 (164)	399 (100)	61	−52
Trial: 5	399 (76)	499 (286)	525 (209)	413 (130)	100	−112

Note. PC = proportion compatibility.

Table 2A
Results from the 2 (PC Level: High vs. Low) × 2 (Compatibility: Compatible vs. Incompatible) × 3 (Length of NEXT Phase: 3, 4, or 5) Repeated Measures Analysis of Variance on Response Time (ms) for the NEXT phase Trials of Mini-Blocks from Experiment 1

Variable	*F*	*df*	*p*	η_p^2
PC level	.690	1,19	.416	.035
Compatibility	.041	1,19	.842	.002
Length	1.239	2,38	.301	.061
PC level × Compatibility	7.900	1,19	.011	.294
PC level × Length	3.134	2,38	.055	.142
Compatibility × Length	.399	2,38	.674	.021
PC Level × Compatibility × Length	3.204	2,38	.052	.144

Note. PC = proportion compatibility.

Table 2B
Results from the 2 (PC Level: High vs. Low) × 5 (Trial of NEXT Phase: 1, 2, 3, 4, or 5) × 2 (Compatibility: Compatible vs. Incompatible) Repeated Measures Analysis of Variance on Response Time (ms) for the NEXT phase Trials of Mini-Blocks from Experiment 1

Variable	*F*	*df*	*p*	η_p^2
PC level	.661	1,17	.427	.037
Compatibility	35.825	4,68	<.001[a]	.678
Length	.315	1,17	.582	.018
PC level × Compatibility	.185	4,68	.808[a]	.011
PC level × Length	11.457	1,17	.004	.403
Compatibility × Length	.166	4,68	.832[a]	.010
PC Level × Compatibility × Length	4.696	4,68	.018[a]	.216

Note. PC = proportion compatibility.
[a] Results from that level were corrected with the Greenhouse-Geisser correction due to a violation of sphericity.

(691 ms vs. 445 ms; 6.67% vs. 3.98% error; see Table 3 and Table 4). There was also a main effect of length, which was complemented by a significant Length × Trial interaction, which demonstrated an increased trial effect with fewer preceding NEXT trials (311 ms vs. 213 ms vs. 219 ms vs. 217 ms, and 1.4% vs. 4.8% vs. 2.7% vs. 1.8% error, respectively, for preceding lengths 0, 3, 4, and 5; see Table 3 and Table 4). Our hypothesis did not make specific predictions related to the GO phase, however, importantly these results were consistent with previously observed effects in the literature (Meiran et al., 2015). That is, the implementation of the novel GO phase task rules presumably caused an increase in response times for the first trial as compared to the second, reflecting a switch cost between the NEXT and GO phase tasks. This switch cost was further negatively modulated by the length of the NEXT phase, suggesting an increased readiness to switch to the GO phase with an increasing number of NEXT trials. In addition, it could be argued that the main effect of trial could be due to an implicit learning of the NEXT length presentation sequence by participants. However, this seems an unlikely explanation as not only were NEXT length sequences presented randomly within each run, but an additional analysis—submission of the initial run data to a 2 (Trial) × 4 (Length) ANOVA—revealed that a significant main effect of Length remained present in the initial run, before subjects would have been able to learn the total number of each NEXT length sequence in each run and implicitly develop a strategy in order to anticipate the GO phase from this knowledge. However, anticipating the GO phase by learning the likely maximum NEXT phase length after completion of several miniblocks cannot be ruled out.

In relation to the PC level manipulation, there was also a significant Proportion × Length interaction on overall GO performance (see Table 4). GO phase performance improved in both RT and accuracy as the preceding NEXT length increased, and this occurred to a greater degree when the preceding NEXT phase was of high rather than low PC level (see Table 3). This result suggests that the preceding PC level of the NEXT phase, and the resulting strategic control over the prospective task-set interference, influenced successful implementation of the GO phase instructions. The greater level of strategic control implemented in the NEXT phase in the low PC condition negatively impacted the subsequent

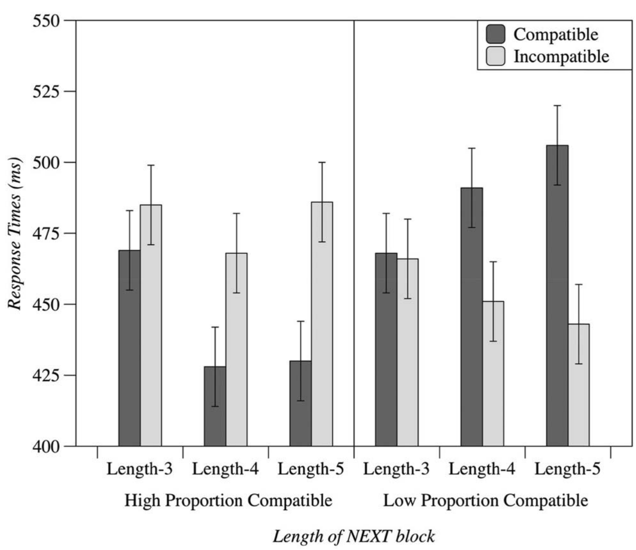

Figure 2. Experiment 1 reaction time (RT) results. Mean RT (ms ± mean squared error) for trials in the NEXT phase are plotted as a function of compatibility and mini-block length.

Table 3
Mean and Standard Deviation for Response Times (ms) and Accuracy (% Error) in the GO Phases of Mini-Blocks from Experiment 1

	High PC		Low PC	
Length	First trial	Second trial	First trial	Second trial
Length: 0	826 (346)	484 (166)	794 (283)	512 (287)
Length: 3	659 (273)	436 (182)	686 (334)	454 (245)
Length: 4	622 (262)	406 (162)	664 (290)	426 (219)
Length: 5	604 (207)	414 (172)	682 (318)	433 (220)
Length: 0	10.76 (9.95)	6.15 (5.81)	5.73 (5.31)	7.52 (9.83)
Length: 3	9.97 (9.39)	4.59 (5.32)	8.13 (7.74)	3.96 (5.63)
Length: 4	2.83 (6.24)	1.29 (3.27)	7.81 (8.11)	3.88 (3.75)
Length: 5	3.76 (4.71)	1.94 (4.25)	4.39 (5.01)	2.6 (4.37)

Note. PC = proportion compatibility.

Table 4
Results from the 2 (PC Level: High vs. Low) × 2 (Trials: First or Second Trial in the GO Phase) × 4 (Length of NEXT Phase: 0, 3, 4, or 5) Multivariate Repeated Measures Analysis of Variance on Response Time (ms) and Accuracy (% Error) for the GO phase Trials of Mini-Blocks from Experiment 1

Variable	F	df	p	η_p^2
PC level	1.048	2,18	.371	.104
Trial	28.163	2,18	<.001	.758
Length	10.081	6,114	<.001	.347
PC Level × Trial	.628	2,18	.545	.065
PC Level × Length	2.869	6,114	.012	.131
Trial × Length	3.492	6,114	.003	.155
PC Level × Trial × Length	1.690	6,114	.130	.082

Note. PC = proportion compatibility.

implementation of the prospective task-set instructions for the GO phase. However, there was no significant main effect of Proportion on GO phase performance.

In sum, the results of Experiment 1 replicated the basic prospective task-set interference (or NEXT) effect of Meiran et al. (2015) and, crucially, showed that this effect is subject to modulation by the proportion of compatible/incompatible trials. In line with the assumption that frequent incompatible conditions would trigger a strategic processing adjustment to minimize the influence of the prospective set on NEXT responses, we observed a significant interaction between compatibility and PC level, whereby the prospective task-set compatibility effect was reversed. Moreover, we also replicated the basic GO phase findings of Meiran et al. (2015), but in addition observed an intriguing influence of NEXT trial PC level on GO trial performance, whereby frequent incompatible NEXT trials impaired subsequent GO trial performance. This interaction effect suggests that the strategic suppression of the influence of the prospective task-set on the NEXT trial responses in low PC conditions makes it more difficult to instantiate that task-set when it is required in the subsequent GO phase (cf. Kiyonaga et al., 2012).

Experiment 2

The significant modulation of the NEXT effect observed in Experiment 1 occurred in the context of grouping miniblocks of a given PC level into extended runs, such that strategic control of task-set interference may have been driven by the PC conditions within miniblocks (phasic adjustments) and/or by the more global biased context (tonic adjustments), or both. We had grouped miniblocks in this fashion to foster optimal conditions for observing strategic modulation of the NEXT effect. Given that we did observe that modulation, an important follow-up question to address is whether PC-driven modulation of prospective task-set interference can in fact occur at the level of the local, within-block manipulation alone. The latter would suggest that control over task-set interference can be triggered and implemented on a short time scale, in a phasic fashion, and does not require a more sustained manipulation of conflict-likelihood. Therefore, in Experiment 2, we manipulated exclusively the local PC level of each miniblock in the absence of a global grouping of miniblocks by PC level. This allowed us to determine whether implementation of strategic control occurred at the local level or was a product of the combined local and global PC manipulation.

Method

Participants. A power analysis using the effect size (η_p^2 = .294) of the critical PC Level × Compatibility interaction of Experiment 1 indicated that for .80 power to detect a significant Proportion × Compatibility interaction, a sample size of approximately 12 subjects was required. Under the same conditions as Experiment 1, 20 Amazon Mechanical Turk workers provided informed consent in accordance with the policies of the Duke University Institutional Review Board (*M* age = 37.45, *SD* = 11.87; 10 males, 10 females).

Stimuli and procedure. All stimuli and procedures were the same as for Experiment 1, except for the following changes. The paradigm consisted of 120 miniblocks. High PC and low PC miniblocks were presented in a randomized manner throughout the entirety of the experiment, and not grouped by PC level into runs.

Analysis. The same analyses as in Experiment 1 were undertaken for the Experiment 2 data. If strategic modulation of prospective task-set interference can operate on short time-scales, we would expect the NEXT compatibility effect to be modulated by PC level within miniblocks. If the results in Experiment 1 were driven by a combination of local and global PC manipulations, then the modulatory effect in Experiment 2 would be expected to be less strong than in Experiment 1. Finally, if the Experiment 1 results were entirely dependent on presenting PC-biased miniblocks in runs, we would expect to see no modulation of the NEXT compatibility effect in Experiment 2.

Results and Discussion

NEXT. NEXT phase trial accuracy was at ceiling (98.0%) and did not constitute a dependent variable of interest. Before the RT analysis, errors were removed, as were trials with RTs shorter than 100 ms or longer than 3,000 ms (1.2% of remaining data). See Table 5 for complete descriptive statistics.

Critically, as in Experiment 1, there was a significant PC level × Compatibility interaction (see Table 6A and 6B) in both rmANOVAs such that the prospective task-set compatibility effect for the high PC level (50 ms; compatible RTs < incompatible RTs) was diminished or reversed for low PC level (–21 ms; Table 5; Figure 3). In the initial rmANOVA, there was again no significant interaction between PC level and Length. In line with previous work, and in addition to findings critical to our hypothesis, there was also a main effect of compatibility and a main effect of length (Table 6A), showing that compatible trials were overall faster than incompatible trials and RTs generally became faster as the NEXT phase length of a miniblock increased (see Table 5).

In our second rmANOVA there was again a main effect of trial such that trials toward the end of a miniblock were faster than at the beginning (see Table 5), as well as a significant main effect of compatibility. Both results were consistent with our previous analysis as well as previous work. Again, there was a three-way interaction between PC level, trial, and compatibility (Table 6b) indicating that the compatibility effect varied by PC level and trial. Bonferroni-corrected post hoc *t* tests were conducted on the compatibility effect at each PC by trial level. These results yielded a

Table 5
Mean and Standard Deviation for Response Times (ms) in the NEXT Phases of Mini-Blocks from Experiment 2

	High PC		Low PC		Compatibility effect	
NEXT Mini-Block	Compatible	Incompatible	Compatible	Incompatible	High PC	Low PC
Length: 3	508 (139)	554 (186)	511 (163)	525 (141)	46	14
Length: 4	460 (98)	504 (183)	490 (169)	484 (143)	44	−6
Length: 5	455 (97)	497 (138)	523 (190)	472 (123)	42	−51
Trial: 1	685 (159)	723 (213)	683 (225)	732 (195)	38	49
Trial: 2	398 (118)	436 (231)	424 (189)	405 (160)	38	−19
Trial: 3	399 (113)	450 (153)	433 (143)	409 (130)	51	−24
Trial: 4	397 (97)	498 (236)	532 (216)	414 (113)	101	−118
Trial: 5	421 (104)	516 (125)	527 (198)	441 (140)	95	−86

Note. PC = proportion compatibility.

similar conclusion as in Experiment 1, demonstrating a significant compatibility effect across all trial levels under the high PC level condition, but only a significant compatibility effect for the initial trial under the low PC level condition (see the online supplemental materials). Importantly, the qualitative pattern of the compatibility effect for the initial trial of the low PC level condition was representative of the traditional compatibility effect (incompatible > compatible); however, Trials 2–5 of the low PC level condition exhibited a qualitative pattern in which the compatibility effect was reduced or reversed (see Table 5). This result is unsurprising, as unlike in the blocked PC level run design of Experiment 1, without the structure of a run-level proportion manipulation, control enacted at the level of a miniblock in Experiment 2 would require multiple trials to be strategically implemented based solely on the proportion compatibility of an individual miniblock.

GO. Before the analysis was undertaken, errors were removed from the RT data (6.3% of data), as were trials with RTs shorter than 100 ms or longer than 3,000 ms (2.7% of remaining data; Meiran et al., 2015), and for the accuracy data, trials with RTs outside the same 100- to 3,000-ms boundary were removed (3.3% of data). See Table 7 for complete descriptive statistics.

Although we made no specific predictions relating to the GO phase, our data were consistent with the findings of Meiran et al. (2015) and with Experiment 1. There was a main effect of trial, whereby the first trial in the GO phase was slower and less accurate than the second (765 ms vs. 481 ms; 6.84% vs. 4.51% error; Table 7; Table 8). There was also a main effect of length, in addition to a significant Length × Trial interaction due to an increased trial effect with fewer preceding NEXT trials (387 ms vs. 273 ms vs. 240 ms vs. 238 ms, and 1.8% vs. 4.4% vs. 1.5% vs. 1.6% error, respectively, for preceding lengths 0, 3, 4, and 5; see Tables 7 and Table 8).

In sum, the results of Experiment 2 corroborated and extended the findings of Experiment 1 by showing that strategic modulation of prospective task-set interference can occur on a phasic miniblock by miniblock level, in the absence of a more extended context of low or high PC levels across miniblocks. However, when comparing the effect of PC level on the NEXT compatibility effect between Experiments 1 and 2 (cf. Figures 2 and 3), it is evident that the magnitude of this effect was smaller in Experiment 2, suggesting that the modulation of task-set interference in Experiment 1 was driven both by local and global PC levels. In line with the notion that the exclusively local PC manipulation in Experiment 2 produced a less extensive modulation of the prospective task-set, unlike in Experiment 1, in Experiment 2 we also did not observe a significant impact of NEXT phase PC level on GO phase performance.

Table 6A
Results from 2 (PC Level: High vs. Low) × 2 (Compatibility: Compatible vs. Incompatible) × 3 (Length of NEXT Phase: 3, 4, or 5) Repeated Measures Analysis of Variance on Response Time (ms) for the NEXT phase Trials of Mini-Blocks from Experiment 2

Variable	*F*	*df*	*p*	η_p^2
PC level	.898	1,19	.355	.045
Compatibility	6.117	1,19	.023	.244
Length	6.662	2,38	.003	.260
PC Level × Compatibility	7.783	1,19	.012	.291
PC Level × Length[a]	1.175	1.55,29.55	.312	.058
Compatibility × Length	2.516	2,38	.094	.117
PC Level × Compatibility × Length	1.705	2,38	.195	.082

Note. PC = proportion compatibility.
[a] Results from that level were corrected with the Greenhouse-Geisser Correction due to a violation of sphericity.

Table 6B
Results from the 2 (PC Level: High vs. Low) × 5 (Trial of NEXT Phase: 1, 2, 3, 4, or 5) × 2 (Compatibility: Compatible vs. Incompatible) Repeated Measures Analysis of Variance on Response Time (ms) for the NEXT phase Trials of Mini-Blocks from Experiment 2

Variable	*F*	*df*	*p*	η_p^2
PC level	.359	1,17	.557	.021
Trial	53.81	4,68	<.001[a]	.760
Compatibility	6.655	1,17	.019	.281
PC Level × Trial	.534	4,68	.711	.030
PC Level × Compatibility	17.252	1,17	.001	.504
Compatibility × Trial	1.876	4,68	.125	.099
PC Level × Compatibility × Trial	7.804	4,68	.001[a]	.315

Note. PC = proportion compatibility.
[a] Results from that level were corrected with the Greenhouse-Geisser Correction due to a violation of sphericity.

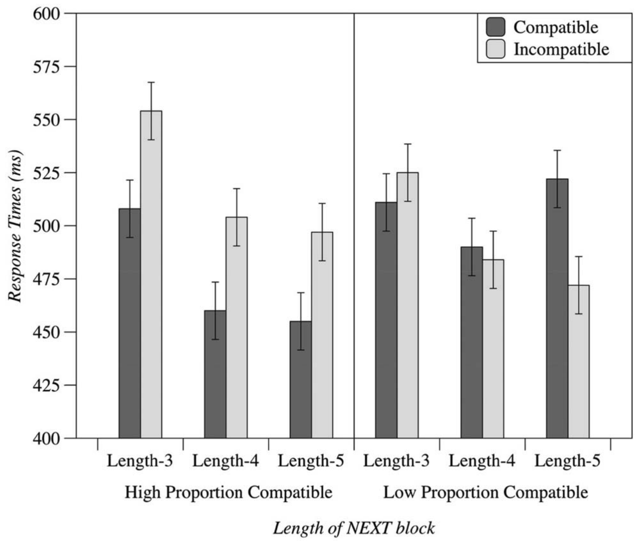

Figure 3. Experiment 2 reaction time (RT) results. Mean RT (ms ± mean squared error) for trials in the NEXT phase are plotted as a function of compatibility and mini-block length.

Experiment 3

The previous two experiments demonstrated reliable modulation by strategic control processes of prospective task-set interference, however, one concern that could be raised in relation to these experiments is that the PC manipulation involved having only a single trial of the rare type within each miniblock (involving 1:2, 1:3, 1:4 ratios). To ensure that the results we obtained so far are not dependent on having a single, surprising "odd-one-out" trial in each miniblock, in Experiment 3 we sought to replicate the above results while adding miniblocks of 2:3 and 2:4 rare-to-frequent trial type ratios. Apart from testing whether the modulation of prospective task-set interference by PC level extends beyond the odd-one-out scenarios of Experiments 1 and 2, this addition also produced a different spread of PC levels. In Experiment 1 and 2, PC levels ranged from 66%-80% (depending on length of the NEXT phase in the miniblock) whereas in Experiment 3, the level of PC ranged from 60%-75%. Thus, Experiment 3 also probed whether the strategic modulation of prospective task-set interference is robust to a variety of different (and less extreme) PC levels.

Table 7
Mean and Standard Deviation for Response Times (ms) and Accuracy (% Error) in the GO Phases of Mini-Blocks from Experiment 2

	High PC		Low PC	
Length	First trial	Second trial	First trial	Second trial
Length: 0	884 (281)	473 (189)	873 (278)	510 (209)
Length: 3	780 (285)	493 (229)	759 (259)	501 (228)
Length: 4	722 (238)	470 (244)	710 (275)	482 (272)
Length: 5	686 (267)	453 (207)	712 (303)	469 (230)
Length: 0	8.00 (7.98)	5.84 (12.61)	6.48 (6.72)	5.10 (11.47)
Length: 3	9.06 (11.54)	2.83 (6.20)	7.46 (6.86)	4.88 (5.81)
Length: 4	5.41 (7.59)	5.19 (11.97)	7.72 (10.19)	4.86 (8.75)
Length: 5	6.14 (8.45)	3.9 (6.39)	4.39 (5.06)	3.45 (7.03)

Note. PC = proportion compatibility.

Table 8
Results from the 2 (PC level: High vs. Low) × 2 (Trials: First or Second Trial in the GO Phase) × 4 (Length of NEXT Phase: 0, 3, 4, or 5 Multivariate Repeated Measures Analysis of Variance on Response Time (ms) and Accuracy (% Error) for the GO phase Trials of Mini-Blocks from Experiment 2

Variable	F	df	p	η_p^2
PC level	.510	2,18	.609	.054
Trial	45.375	2,18	<.001	.834
Length	6.186	6,114	<.001	.246
PC Level × Trial	.742	2,18	.490	.076
PC Level × Length	.470	6,114	.829	.024
Trial × Length	5.730	6,114	<.001	.232
PC Level × Trial × Length	1.268	6,114	.278	.063

Note. PC = proportion compatibility.

Method

Participants. A power analysis using the effect size (η_p^2 = .291) of the critical PC Level × Compatibility interaction of Experiment 1 indicated that for .80 power to detect a significant Proportion × Compatibility interaction, a sample size of approximately 12 subjects was required. Under the same conditions as Experiment 1, 22 Amazon Mechanical Turk workers provided informed consent in accordance with the policies of the Duke University Institutional Review Board (mean age = 33.50, *SD* = 9.04; 14 males, 8 females).[1] Two participants were excluded from analysis due to falling below the 75% accuracy threshold, resulting in a sample size of 20 participants for analysis.

Stimuli and procedure. All stimuli and procedures were the same as in Experiment 1, except for the following changes. Within each miniblock, the PC level of the NEXT phase was either high or low, such that the ratio of compatible/incompatible to incompatible/compatible trials in each was 1:2, 1:3, 2:3, or 2:4 for NEXT phase trial lengths three, four, five, or six, respectively. In the first two miniblocks of the entire experiment, subjects were given 30 s and 22 s, respectively, to read the instructions, immediately followed by a 5 second countdown before stimuli presentation began. These miniblocks were included in the analysis, but their inclusion or exclusion did not significantly alter the results of our analysis. For all subsequent miniblocks, subjects were given 6 seconds to read the instructions, followed by a 3-s countdown to stimuli presentation.

Analysis. We expected to replicate the results from the previous two experiments and to observe reduced compatibility effects in the low PC compared to the high PC conditions, thus providing evidence for strategic control over the prospective task-set interference effect. As the biasing of the PC level in this experiment was more moderate than in previous versions, a com-

[1] An initial nine subjects were also run, however, a coding error caused an error in the number of different proportion manipulation blocks and their presentation order. Thus, these subjects were dropped from all analyses.

mensurate attenuation of effects was expected, as well. To assess performance between the high and low PC miniblocks of the NEXT phase we applied the same analysis as in the previous two experiments, with the addition of another level to the length factor (where the NEXT length was 6 trials long) and the trial factor (where there are 6 trial levels). The same analysis was performed for the GO phase as in the previous two experiments, with again, the addition of another level to the length factor.

Results and Discussion

NEXT. NEXT phase trial accuracy was at ceiling (97.8%) and did not constitute a dependent variable of interest. Before the RT analysis, errors were removed, as were trials with RTs shorter than 100 ms or longer than 3,000 ms (1.1% of remaining data). See Table 9 for complete descriptive statistics.

In support of the prediction that PC manipulations would again lead to modulation of the prospective task-set compatibility effect, there was a significant PC level × Compatibility interaction (Figure 4; Table 10A). However, the magnitude of this interaction was less pronounced than in Experiments 1 and 2 (high PC compatibility 24 ms vs. low PC compatibility–1ms; see Table 9 and Table 10A). In the initial rmANOVA, there was also a main effect of Compatibility and a main effect of Length, which reiterated the patterns of the previous experiments (see Table 9 and Table 10A). In addition, and unique to Experiment 3, an apparent difference in biasing between NEXT miniblock lengths of 3 and 4 as compared to 5 and 6 caused the latter miniblocks to have an attenuated biasing of PC level, resulting in the PC level × Compatibility interaction to be modulated by length in a significant three-way interaction (see Figure 4 and Table 10A).

In the second rmANOVA, there were significant main effects of trial and compatibility, as in Experiment 2. Critically, there was also a PC Level × Compatibility interaction indicating implementation of strategic control in the NEXT phase. In addition, a significant interaction between trial and compatibility was observed (Table 10B). However, unlike the previous two experiments, there was no significant three-way interaction between PC Level, Trial, and Compatibility (Table 10B). Again, post hoc t tests, with Bonferroni corrected p values, were conducted on each PC by trial level (see supplemental materials). Differing from previous findings, the high PC level exhibited significant compatibility effects only for Trials 1, 3, and 6. Like in Experiment 2, the low PC level exhibited a significant compatibility effect only for trial one. As previously, the qualitative pattern for the significant compatibility effect on the initial trial of the low PC level was consistent with the standard prospective task-set compatibility effect (incompatible > compatible; Table 9) but reduced or reversed thereafter. Although the design of this experiment had blocked PC level runs, like Experiment 1, the attenuated proportion manipulation may have contributed to this result. Overall, the results of the second rmANOVA are still consistent with the modulation of prospective task-set interference by strategic control.

GO. Before the analysis was undertaken, errors were removed from the RT data (4.0% of data), as were trials with RTs shorter than 100 ms or longer than 3,000 ms (5.3% of remaining data; Meiran et al., 2015), and for the accuracy data, trials with RTs outside the same 100- to 3,000-ms boundary were removed (1.4% of data). See Table 11 for complete descriptive statistics.

Our hypothesis made no specific predictions on performance in the GO phase. The analysis revealed a significant main effect of PC level on GO performance accuracy (see Table 12). Inspection of the data showed that this effect of PC level was due to performance in GO phases following high PC level NEXT phases being more accurate than following low PC level NEXT phases. Though the effect was small—a 1.4% difference—this indicates that strategic control implemented in low PC level NEXT phases potentially interfered with prospective GO task-set instructions, as indexed by decreased successful implementation after low PC level NEXT phases (see Table 11). The contributions of the increased NEXT trial length of 6 versus the attenuated PC level biasing in the production of this result, however, remains unclear. It could be that either of those two factors that differed in the current experimental design from that of Experiments 1 and 2 contributed to a now significant main effect of PC level on GO phase performance.

The rest of the data were consistent with the findings of Meiran et al. (2015) and with our previous results. There was a main effect of trial (653ms vs. 414ms; 5.27% vs. 2.72% error), a main effect of length, and a significant Length × Trial interaction (295 ms vs. 216 ms vs. 241 ms vs. 230 ms vs. 210 ms, and 2.3% vs. 6.1% vs.

Table 9
Mean and Standard Deviation for Response Times (Ms) in the NEXT Phases of Mini-Blocks from Experiment 3

	High PC		Low PC		Compatibility effect	
NEXT Mini-Block	Compatible	Incompatible	Compatible	Incompatible	High PC	Low PC
Length: 3	443 (88)	459 (99)	434 (95)	455 (97)	16	21
Length: 4	420 (75)	458 (96)	443 (87)	428 (76)	38	−15
Length: 5	428 (74)	443 (85)	423 (69)	425 (72)	15	2
Length: 6	411 (68)	439 (103)	426 (75)	418 (64)	28	−8
Trial: 1	572 (125)	594 (144)	559 (113)	587 (138)	22	28
Trial: 2	376 (72)	394 (103)	376 (84)	387 (86)	18	11
Trial: 3	369 (69)	402 (96)	389 (79)	373 (71)	33	−16
Trial: 4	383 (74)	401 (90)	392 (69)	380 (72)	18	−12
Trial: 5	402 (82)	408 (77)	406 (66)	396 (65)	6	−10
Trial: 6	394 (63)	444 (92)	411 (60)	399 (55)	50	−12

Note. PC = proportion compatibility.

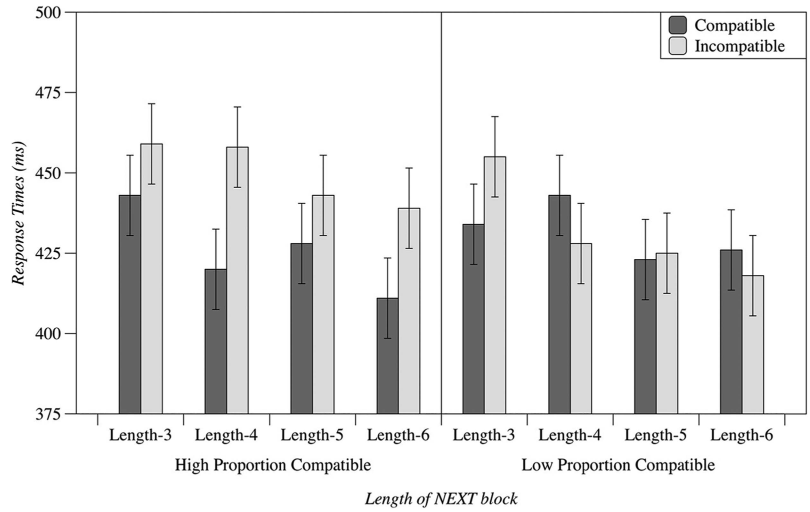

Figure 4. Experiment 3 reaction time (RT) results. Mean RT (ms ± mean squared error) for trials in the NEXT phase are plotted as a function of compatibility and mini-block length.

1.0% vs. 2.2% vs. 1.2% error, respectively, for preceding Lengths 0, 3, 4, 5, and 6; see Tables 11 and Table 12). This demonstrates that the attenuated biasing of the PC level in the NEXT phase had no other effects on performance in the GO phase.

These results, when taken together with those of Experiments 1 and 2, further strengthen the claim that strategic control can be imposed to regulate prospective task-set interference, as documented by the interaction between PC level and the prospective task-set compatibility effect. The Experiment 3 results extend the previous findings, showing that even an attenuated level of PC biasing still elicited implementation of strategic control. Furthermore, these results also indicate that the significant interaction between PC level and Compatibility observed in Experiments 1 and 2 was not caused by having just one single, odd-one-out low-frequency trial in each miniblock. It is noteworthy, however, that the qualitative pattern of the modulation of the prospective task-set compatibility effect by PC level at each NEXT length level was different in Experiment 3 compared to Experiments 1 and 2. In Experiments 1 and 2, a steady increase in the degree to which the PC level modulated the magnitude of the prospective task-set compatibility effect was seen with increasing NEXT mini-block length; this pattern was not observed in Experiment 3. This was likely due to the differing PC levels of the respective experiments: Experiments 1 and 2 had a steady proportional increase of biasing between high and low PC as the NEXT trial length increased (1:2, 1:3, 1:4), but Experiment 3, to eliminate the "rare" biased trial in some NEXT miniblocks, did not have the same steady increase in proportion bias with increase in NEXT length. This design feature potentially also resulted in the significant three-way effect between PC level, compatibility, and NEXT length.

General Discussion

This study sought to test whether strategic control could modulate the magnitude of interference in a current task that results

Table 10A
Results from the 2 (PC Level: High vs. Low) × 2 (Compatibility: Compatible vs. Incompatible) × 4 (Length of NEXT Phase: 3, 4, 5, or 6) Repeated Measures Analysis of Variance on Response Time (Ms) for the NEXT phase Trials of Mini-Blocks from Experiment 3

Variable	*F*	*df*	*p*	η_p^2
PC level	.538	1,19	.472	.028
Compatibility	6.827	1,19	.017	.264
Length[a]	4.592	1.98,37.77	.017	.195
PC Level × Compatibility	14.936	1,19	.001	.440
PC Level × Length[a]	.158	2.33,44.18	.883	.008
Compatibility × Length	.482	3,57	.696	.025
PC Level × Compatibility × Length	3.528	3,57	.020	.157

Note. PC = proportion compatibility.
[a] Results from that level were corrected with the Greenhouse-Geisser Correction due to a violation of sphericity.

Table 10B
Results from the 2 (PC Level: High vs. Low) × 5 (Trial of NEXT Phase: 1, 2, 3, 4, 5, or 6) × 2 (Compatibility: Compatible vs. Incompatible) Repeated Measures Analysis of Variance on Response Time (ms) for the NEXT phase Trials of Mini-Blocks from Experiment 3

Variable	*F*	*df*	*p*	η_p^2
PC level	.764	1,19	.393	.039
Trial	53.220	5,95	<.001[a]	.737
Compatibility	11.312	1,19	.003	.373
PC Level × Trial	.261	5,95	.933	.014
PC Level × Compatibility	27.046	1,19	<.001	.587
Compatibility × Trial	2.666	5,95	.027	.123
PC Level × Compatibility × Trial	2.059	5,95	.077	.098

Note. PC = proportion compatibility.
[a] Results from that level were corrected with the Greenhouse-Geisser Correction due to a violation of sphericity.

Table 11
Mean and Standard Deviation for Response Times (Ms) and Accuracy (% Error) in the GO Phases of Mini-Blocks from Experiment 3

	High PC		Low PC	
Length	First trial	Second trial	First trial	Second trial
Length: 0	753 (246)	441 (119)	726 (221)	448 (123)
Length: 3	647 (167)	429 (127)	641 (169)	428 (109)
Length: 4	628 (186)	396 (103)	651 (154)	401 (110)
Length: 5	637 (183)	390 (112)	611 (157)	398 (114)
Length: 6	610 (168)	411 (101)	624 (163)	402 (105)
Length: 0	5.97 (10.04)	2.89 (6.49)	5.06 (6.61)	3.53 (6.49)
Length: 3	5.99 (8.23)	1.9 (3.57)	11.25 (11.40)	3.22 (5.35)
Length: 4	3.44 (6.56)	1.29 (3.34)	4.42 (6.14)	4.5 (7.08)
Length: 5	3.12 (5.91)	1.58 (3.44)	5.31 (7.39)	2.56 (4.71)
Length: 6	3.76 (5.88)	2.87 (4.84)	4.39 (7.88)	2.89 (5.37)

Note. PC = proportion compatibility.

from the maintenance of prospective task-set instructions in WM. In three experiments, we demonstrated a robust modulation of the prospective task-set interference effect by PC level. We further examined this modulation at the global (tonic control) and local (phasic control) levels by blocking or randomizing PC biasing conditions and found that the reduction or reversal of the prospective task-set interference effect occurred in both cases, though it was more pronounced when local and global manipulations were combined. We also demonstrated the robustness of this modulation on prospective task-set interference in the face of attenuated PC level biasing. Although several studies have previously investigated prospective task-set interference as an obligatory, reflexive process once a task-set is encoded and prepared for future implementation (Braem et al., 2017; Liefooghe et al., 2013, 2012; Meiran et al., 2015; Theeuwes et al., 2014; Wenke et al., 2007), to our knowledge, the present study is the first to demonstrate the ability to impose strategic control over this behavioral effect of WM content for future use.

In the first experiment, we used a combined local (miniblock) and global (groups of miniblocks) PC level manipulation. We found clear evidence of an effect of the PC level manipulation, as the magnitude of the prospective task-set interference effect in the NEXT phase was modulated such that in the low PC condition the interference effect was reversed in comparison to the high PC condition. In the second experiment, we manipulated the PC level only at the local level, presenting high and low PC miniblocks in random order. This manipulation allowed us to demonstrate that strategic control was fast/flexible enough to be implemented at the local, phasic level. We showed a similar interaction between the prospective task-set interference effect and the PC level modulation as seen in Experiment 1, although the magnitude of PC effect was comparably attenuated, presumably as a result of removing the global bias. Finally, in the third experiment, we avoided having only "odd-one-out" trials and employed an attenuated level of local PC biasing in a combined global and local PC level manipulation similar to Experiment 1. The results replicated the PC effect, thus extending the findings of the previous two experiments by demonstrating that strategic control was still effective under these conditions. In sum, the results from these three experiments clearly support the proposition that strategic control can modulate the magnitude of interference a prospective task-set maintained in WM exerts on current behavior.

A prospective task-set can be conceptualized as the combination of declarative and procedural representations in WM; the declarative representation is comprised of the items (here, word stimuli) for which the procedural representation codes the associated response-mappings (Anderson & Lebiere, 1998; Oberauer, 2009; Oberauer, 2010). In maintaining the instructed task set in an active, preparatory state, IBR proposes that external stimuli that match declarative WM representations reflexively trigger their associated procedural representation (Meiran, Cole, & Braver, 2012; Meiran et al., 2015). From this point of view, the interference caused by the prospective task set is an obligatory result of maintaining the fidelity of instructed task-set representations for rapid, future implementation. However, the modulation of the prospective task-set compatibility effect by PC level that we demonstrate in the current study runs counter to the idea that prospective interference stems from a reflexive or obligatory process, and thus negates a strict IBR interpretation of the effect. Rather, it appears that—similar to findings on attentional capture by declarative WM content (e.g., Kiyonaga et al., 2012)—procedural WM representations can be strategically suppressed or uncoupled from ongoing information gating based on the statistical structure of the task. This is in line with the general idea that the procedural representations that bridge actions to declarative item representations are highly flexible (Liefooghe et al., 2012; Meiran et al., 2012; Oberauer, 2009, 2010; Oberauer, Souza, Druey, & Gade, 2013).

Although we have emphasized the parallels between the current results and previous findings of control over output gating in the declarative WM domain, unlike the findings from Kiyonaga et al. (2012), however, we here observed not only an attenuation of the interference effect but the complete disappearance or reversal of the interference effect under some condition. A reversed interference effect suggests that the PC biasing did not only result in an uncoupling of the prospective task-set from the NEXT phase responses but rather that the prospective S-R mapping was temporarily reweighted, such that an incompatible stimulus could produce a faster response than a compatible one (a phenomenon often observed in proportion-biased cognitive control tasks; see, e.g., Logan & Zbrodoff, 1979). One way that this could occur is

Table 12
Results from the 2 (PC Level: High vs. Low) × 2 (Trials: First or Second Trial in the GO Phase) × 5 (Length of NEXT Phase: 0, 3, 4, 5, or 6) Multivariate Repeated Measures Analysis of Variance on Response Time (ms) and Accuracy (% Error) for the GO Phase Trials of Mini-Blocks from Experiment 3

Variable	F	df	p	η_p^2
PC level	3.746	2,18	.044	.294
Trial	22.989	2,18	<.001	.719
Length	8.533	8,152	<.001	.310
PC Level × Trial	.363	2,18	.701	.039
PC Level × Length	1.044	8,152	.406	.052
Trial × Length	4.507	8,152	<.001	.192
PC Level × Trial × Length	1.283	8,152	.256	.063

Note. PC = proportion compatibility.

that the PC level manipulation may modify the link or association weight between declarative and procedural representations. This in turn would require a readjustment in S-R mapping weights once the GO phase begins, which is of course in line with our findings of an interaction effect between NEXT PC levels and GO phase performance, as discussed below. Overall, this pattern of results suggests that while both declarative and procedural WM output gating are amenable to control, there might nevertheless be fundamental differences in the degree to which declarative and procedural WM contents can be uncoupled from ongoing processing of external stimuli. One reason for this may be that although procedural and declarative WM operate on analogous principles (Liefooghe et al., 2012; Meiran et al., 2012; Oberauer, 2009, 2010; Oberauer et al., 2013), the procedural bridge between declarative representations and actions is more flexible in its ability to reorganize or influence the association strength between item and action representations compared to the control we have over attentional capture by declarative WM content.

Alternative explanations and potential limitations of our NEXT phase results and task design remain, however. Our prospective task-set interference effect may be influenced by covert execution of the prospective task-set instructions during the NEXT phase. The design of our task does not allow for an explicit test of this scenario, however, prior work conducted by Meiran et al. (2015), to specifically address this possibility would seem to indicate that this is an unlikely explanation for our results, though future work should consider this possibility. In addition, the reversal of the compatibility effect seen in some low PC level miniblocks could result from the reversal of a task strategy stored in WM, which then operates reflexively on the newly instructed S-R mappings. In this way, it is conceivable that our PC Level × Compatibility interactions result from an obligatory process much like IBR—essentially a reverse rule reflexivity—and are not the result of strategic control. Yet, if this were the case, we would expect to observe a very consistent change between high PC and low PC levels in the implementation of the GO task-set, such that GO trials following low PC NEXT phases would show an improvement in performance. Instead we observe the opposite, in that low PC level NEXT phases preceding GO phases seem to harm the implementation of the GO instructions. The current design of our experiments prevents us from directly ruling out the possibility a "reverse rule" application during the low PC NEXT phase, however.

Furthermore, the current task design does not—and was not intended to—tease apart effects of cognitive control from processes of learning and/or episodic memory in NEXT phase effects. Rather, we view the proportion congruent manipulation that we used as inherently assessing a symbiotic collaboration between learning and control processes (e.g., Egner, 2014; see also Bugg, 2014; Bugg, Jacoby, & Chanani, 2011): We assume that the frequent incidence of congruent (or incongruent) stimuli is being learned to generate an expectation of low (or high) conflict likelihood, which in turn guides the implementation of strategic processing adjustments. Moreover, the present results suggest that learning takes place both at the level of runs as well as within miniblocks. On one hand, the former is supported by the fact that the grouped PC level run manipulation in Experiments 1 and 3 produced stronger PC × Compatibility interaction effects than Experiment 2, and that in the low PC level condition of Experiment 1, classic compatibility effects were not even detected for the first trial in the miniblock. Within-block learning, on the other hand, is supported by the observation that the PC × compatibility interaction effects grew stronger over trials within miniblocks. Within-block learning is especially clear in the low PC condition of Experiment 2, where the first trial of the block shows a standard compatibility effect, which over the subsequent trials becomes reduced and reversed. In fact, it is difficult to imagine a scenario in which a nonblocked PC level version of this experiment would demonstrate a PC level modulation of the compatibility effect at the initial trial of a miniblock. The implementation of control prior to accumulating evidence of its necessity would seem maladaptive.

However, it is also possible that the present data were in part affected by episodic memory (or feature integration) effects on a trial-by-trial basis (e.g., Hommel, Proctor, & Vu, 2004; Hommel, 2004; for review, see Egner, 2007). Specifically, executing the (incongruent) response key with a given NEXT stimulus may have created a new event file of those stimulus and response features in episodic memory, which might then be retrieved the next time that said stimulus is again presented, which could lead to successively faster responses to repeated occurrences of that stimulus. Although we cannot rule out a contribution of such episodic trial-by-trial effects to our findings, it seems unlikely that they would be the sole driver of the present results, given that the blocking of miniblocks produced stronger modulation of compatibility effects and that we observed abolished compatibility effects even on the first trial of low PC miniblocks in Experiment 1. However, teasing apart possible contributions of trial-by-trial feature integration effects and learning-guided cognitive control clearly represents an important goal of future studies.

In considering the precise manner in which learning and control mechanisms might interact in the NEXT paradigm, a potential avenue for future research might be informed by recent ideas in task-switching that propose the strength of target-response associations mediates the involvement of top-down mechanisms acting on behavior in conflict-situations (Bugg, 2014; Bugg & Braver, 2016; Schneider, 2015). When target-response associations are weak, control is enacted to guide behavior, overriding the influence of bottom-up effects. Although speculative, this could potentially be applicable to prospective task-set interference. As such, future investigations should seek to find ways to specifically address, or potentially control for, the precise influences of learning and episodic memory and their interaction with strategic control when characterizing the ability of control to be implemented on prospective task-set interference.

The data from the GO phases of the current study were not of primary concern but have nevertheless produced some interesting results. In the first experiment, GO phase performance improved in response time and accuracy as the preceding NEXT phase length increased. This improved performance was modulated by the NEXT phase PC level manipulation, such that the magnitude of improvement was greater for the high than the low PC level. The third experiment—which, similar in design to the first experiment, also contained a global PC level manipulation—also showed an effect of PC level on the implementation of the prospective task-set instructions in the GO phase, such that accuracy in the GO phases in high PC conditions was greater than for low PC levels. The second experiment, which differed from the first and third in that there was only a local PC manipulation, did not show any effects of PC level on GO phase performance. These results, when taken together, suggest that the implementation of strategic control to dampen the effect of a prospective task set on ongoing processing leads to a less efficient subsequent implementation of that task-set. However, the pattern of results between experiments seems to indicate this remains true only in the designs using a combined local and global PC level manipulation, which presumably leads to a stronger suppression of the prospective task-set or reweighting of S-R associations. Furthermore, this tendency increased with the number of NEXT trials executed prior to the implementation of the prospective task set. Importantly, additional analyses were carried out to determine whether the effect of improved GO phase performance as NEXT phase length increases could be explained as a result of repetition versus switching effects in relation to the previous NEXT phase trial. However, these analyses yielded no support for this interpretation.

These GO phase results are similar to the findings in Kiyonaga et al. (2012) that the suppression of the biasing effects exerted by declarative items held in WM delayed their later successful retrieval. Here, we see circumstantial evidence that this finding extends to prospective task-sets held in WM. Potentially, the effects of strategic control during the diagnostic NEXT phase affect the prospective task-set instructions held in WM in a similar way as item-level representations are affected in Kiyonaga et al. (2012), in that the prospective task-set representations may be transferred to a less active or "accessory" state in WM as a result of the control (cf. Olivers et al., 2011), which subsequently negatively impacts their implementation or recall. An important caveat to this interpretation is that our experiments were not designed explicitly to test the effects of strategic control on the implementation of prospective task-sets. Instead, these results indicate the need for future investigation to understand more precisely how the suppression of prospective task-set interference affects the representation and application of the suppressed task-set.

The PC level manipulation has long been used to investigate relatively sustained strategic control processes but cannot tap into trial-by-trial adjustments in information processing. Therefore, another important future research question is whether control over prospective task-set interference is possible at the more local, trial-by-trial level. This could be investigated by examining within-miniblock sequential trial effects of compatible and incompatible stimuli in the NEXT phase, comparing the prospective task-set interference effect following compatible trials in comparison to following incompatible trials, akin to the well-known sequential congruency effect in conflict tasks (Gratton et al., 1992). One popular interpretation of this type of effect is that conflict incurred on an incompatible trial triggers an up-regulation of top-down control that reduced conflict in the following trial (for review, see Egner, 2014). However, the current NEXT task is poorly suited for addressing this question, as the frequent stimulus repetitions that occur in the NEXT phase confound any analysis of sequential compatibility effects with the repetition of the stimulus item, a well-documented confound within the sequential compatibility effect literature (Hommel et al., 2004; Mayr, Awh, & Laurey, 2003). Testing whether prospective task-set interference can be modulated at the trial-by-trial level would thus require a novel task design.

Conclusion

A fast-growing literature has begun to explore how prospective task-sets held in WM can influence ongoing behavior, extending the findings of previous research demonstrating the ability of item representations in WM to bias behavior. Previous studies into prospective task-set interference have suggested this effect is reflexive or obligatory. The present study shows that this is not the case: By manipulating PC level over the course of three experiments, we show that the prospective task-set interference effect is reliably subject to modulation by strategic control processes, such that the interference is reduced, abolished, or reversed when strategic control is implemented on the basis of frequent incompatible stimuli.

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