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The Impact of Regulatory Fit on Working Memory

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concentration in Behavioral Neuroscience

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Abstract

Researchers have demonstrated that regulatory focus and the reward structure of a task interact to influence cognitive performance (Maddox, Baldwin, & Markman, 2006). Regulatory focus is a person's sensitivity to potential gains or losses in the environment. When participants' focus matches the task reward structure (known as a regulatory fit) they demonstrate cognitive flexibility, but when it does not they demonstrate cognitive perseveration. However, little is known about the cognitive mechanism that underlies this effect. I explored the possibility that working memory may be the mechanism through which regulatory fit exerts its effects on cognition by assessing the working memory of 180 participants with a computerized Operation span task on two occasions: 1) at baseline (no manipulation) and 2) after inducing regulatory fit or regulatory mismatch. For participants with the highest baseline working memory scores, there was no effect of regulatory fit. Among participants with poorer baseline working memory performance, those in fit recalled more than those in mismatch. Critically, however, those in fit also responded more slowly than those in mismatch, suggesting that the regulatory fit manipulation induced a speed-accuracy trade-off, rather than improving working memory. Supporting this, there was no effect of regulatory fit on speed-corrected recall scores. These results, while inconsistent with the hypothesis that regulatory fit increases working memory, are consistent with other research suggesting that fit induces a more deliberative (i.e., slower and more accurate) mode of processing (Maddox et al., 2006, Markman et al., 2007; Grimm et al., 2008, Otto et al., 2010).

Key words: regulatory fit; regulatory mismatch; working memory; operation span; explicit processing

Introduction

Traditionally, cognitive psychology has paid little heed to motivational factors that may influence performance on cognitive tasks. However, it is certainly the case that what motivates us helps determine the actions that we take, whether it is deciding what college to attend or what movie to rent. A central idea that has driven motivation research is that of approach and avoidance goals: People are sensitive to potential gains or losses in their environment (Carver & Scheier, 1998), with some people focused more on avoiding losses (prevention focus) and others on achieving gains (promotion focus; Higgins, 1998). Although early research demonstrated some effects of regulatory focus (promotion versus prevention) on cognition (e.g., Friedman & Förster, 2001), recent work has emphasized that being in a regulatory fit (i.e., a match between a person's focus and the reward structure of the task) may be more important to cognitive performance (Keller & Bless, 2006; Markman, Baldwin, & Maddox, 2005; Shah, Higgins, & Friedman, 1998). The goal of the current paper was to determine the mechanism via which regulatory fit exerts its effects on cognition.

A common means of manipulating regulatory focus in cognitive research entails telling participants that they need to meet a certain performance level for a chance to win $50 (Higgins, 1997; Shah & Higgins, 1997; Maddox, Baldwin & Markman, 2006; Grimm, Markman, Maddox, & Baldwin, 2008; Maddox, Filoteo, Glass, & Markman, 2010). A promotion focus is induced by informing participants that if they perform well enough, meeting a preset bonus criterion, they will be given a ticket for the drawing while a prevention focus is induced by giving participants a ticket at the beginning of the experiment and informing them they will lose it if they do not meet the bonus criterion. A regulatory fit or mismatch is induced by further manipulating the reward structure of the task (see Table 1). The task can be structured so that participants earn points towards the criterion (gains reward structure), or so that they start with a number of points and lose points, with the goal of not dropping below the criterion (losses reward structure). When manipulated this way, the interaction of regulatory focus and reward structure produces either a regulatory fit or regulatory mismatch (as depicted along the diagonals of Table 1).

Table 1.

The interaction of a person's regulatory focus and the reward structure of any given task results in either regulatory fit or regulatory mismatch.

		Reward Structure	
		Gains	Losses
Focus	Promotion	Fit	Mismatch
	Prevention	Mismatch	Fit

A general finding across a range of cognitive domains is that being in a regulatory fit induces flexibility in cognitive performance, while being in a regulatory mismatch induces perseveration (e.g., Maddox et al., 2006; Grimm et al., 2008; Worthy, Maddox, & Markman, 2007; Markman, Maddox, Worthy, & Baldwin, 2007). Cognitive flexibility is the willingness to explore alternative strategies or means for performing a task, while perseveration is repeated production of a previously appropriate response or the repeated use of a strategy that has been successful in the past. Depending on the cognitive demands and goal of the task, it may be more beneficial to be in a state of fit or mismatch. These findings were first demonstrated in perceptual classification learning (e.g., Maddox et al., 2006). The researchers induced a regulatory fit or mismatch while participants performed rule-based classification learning. When optimal classification performance depended on switching from a salient, obvious dimension for categorization to a less-obvious dimension (Exp. 1), participants in a regulatory fit out-performed those in a mismatch. However, when optimal classification performance depended on sticking with an obvious classification rule (Exp. 2), participants in a regulatory mismatch out-performed those in a fit. Commensurate with these results, when performing an information-integration classification task, for which flexibly switching between classification rules would lead to sub-optimal performance, participants in a regulatory fit performed more poorly than those in a mismatch (Grimm et al., 2008; Maddox et al., 2006, Exp. 3).

Similar regulatory fit effects have been observed in decision making and other cognitive paradigms. Using a modified version of the Iowa Gambling task, in which participants gained or lost points by drawing cards from one of two different decks, Worthy et al. (2007) found that when the task favored exploring alternate strategies by sampling from both decks, those in regulatory fit performed better. However, when the task favored repeated sampling from the same deck, participants in a mismatch performed better. Similarly, on the Wisconsin Card Sort task, a neuropsychological assessment of perseveration and the ability to shift set, regulatory fit induced an enhanced ability to shift away from previously-correct, but now incorrect, sorting rules, while regulatory mismatch impaired the ability to shift to new sorting rules (Maddox et al., 2010). Being in a regulatory fit has also improved performance when solving anagrams (Shah et al.,1998), improved solutions on a difficult remote associates task (Markman et al., 2007), and led to a more systematic exploration of options in a decision making environment (Otto, Markman, Gureckis, & Love, 2010).

What may be the underlying mechanism of the effect of regulatory fit in these diverse domains? Because the effect of regulatory fit is observed across domains, its underlying mechanism likely involves a domain-general cognitive resource such as attention or working memory. Here, I test the hypothesis that regulatory fit leads to an increase in working memory (i.e., our ability to store and transform information, Baddeley & Hitch, 1974). An increased working memory capacity is associated with better performance on number of cognitive functions (e.g., reading comprehension, Daneman & Carpenter, 1980; episodic memory, Kane & Engle, 2000; reasoning, Barrouillet, & Lecas, 1999). It is possible that the cognitive flexibility observed with a regulatory fit derives from an increased ability to store and manipulate items "online" while performing a cognitive task. People with an increased working memory capacity might be better able to keep in mind multiple strategies for performing a task, remember recent outcomes of those strategy attempts and better integrate those outcomes for evaluating the strategies

Current Study

In the current study I tested the hypothesis that regulatory fit increases working memory capacity. Participants performed the automated version (Unsworth, Heitz, Schrock & Engle, 2005) of the Operation Span (Ospan) task (Turner & Engle, 1989), which is an assessment of working memory. In the Ospan task participants must remember a series of letters in order, but math problems are interleaved between the presentation of each of the letters. Thus, the task assesses participants' ability to hold a number of items in memory while simultaneously processing distracting information. Although the total number of letters recalled is the typical measure of working memory capacity, with the computerized version of the Ospan task I was also able to assess participants' response time to ensure that any benefits of regulatory fit potentially observed in the recall measure would not occur at the cost of response time (i.e., what might be considered a change in response bias; Glass, Maddox, & Markman, 2011).

Because I was concerned that variability associated with individual differences in working memory may obscure the effects of regulatory fit, participants first performed a baseline assessment of their Ospan performance. Approximately one week later, participants performed the Ospan again while I manipulated their regulatory focus and the task reward structure to produce two "fit" (promotion-gains; prevention-losses) and two "mismatch" groups (promotion-losses; prevention-gains). I predicted that participants in regulatory fit would show increased working memory performance by accurately recalling more letters than those in mismatch.

Methods

Participants

One-hundred eighty Seton Hall University undergraduates with normal or corrected-to-normal vision participated to fulfill a course requirement.

Procedure

Participants took the operation span (Ospan) on two occasions, separated by a minimum of 6 days. The first session served as a baseline measure and participants performed the Ospan without any experimental manipulation. In the second session, I manipulated two between-groups variables: Regulatory focus (promotion, prevention) and task reward structure (losses, gains). Hence, participants were randomly assigned to one of two "fit" (promotion-gains, prevention-losses) or one of two "mismatch" groups (promotion-losses, prevention-gains). I induced a promotion focus by informing participants that if they met the bonus criterion (i.e., earned 200 of 243 points) on the recall portion of the Ospan task they would receive a ticket for a 1-in-25 chance to win a $50 American Express™ gift card. I induced a prevention focus by giving the participants a ticket for the prize drawing at the beginning of the session and telling them they would lose the ticket if they did not meet the bonus criterion. In the gains reward structure participants gained three points for every individual letter recalled in the correct position and one point for every incorrect letter. In the losses reward structure participants lost one point for a letter recalled in the correct position and three points for an incorrect answer. Participants tracked their progress towards the bonus criterion: After each trial of the operation span task, they saw a screen (5000 ms) depicting their current score and reminding them of the bonus criterion.

Operation Span (Ospan)

In the Ospan task, adapted from Unsworth, et al. (2005), participants remembered a series of letters that were presented one at a time, interleaved with math problems (see Figure 1). After seeing the entire set of letters (and solving the same number of math problems), participants recalled the letters in order. The sets of letters varied from three to seven in length. On each trial, participants first saw a math operation whose final answer was no more than a two digit number. The participants were instructed to solve the operation as quickly as possible without sacrificing accuracy and then click the space bar to advance to the next screen. If the space bar was not pressed within 7000 ms, the screen automatically advanced. Here a digit (e.g., 3) was presented and the participants pressed a green key on the left side if they believed the answer to be the correct answer, or a red key on the right if they believed it to be incorrect. After responding, they saw a to-be-remembered letter for 1000 ms. At recall, participants saw the list of possible letters (across all trials) and were to type the letters from the current trial in the order in which they appeared. If participants did not respond within 7500 ms, the trial terminated and was considered incorrect. Participants first completed two practice trials, with a set size of three and four letters. Participants then completed the scored trials, which consisted of three trials of each set size (three, four, five, six, and seven). This made for a total of 81 letters and 81 math problems. The order in which set lengths were presented varied randomly for each participant.

The primary dependent measure for the task was participant's recall score. The recall score was based on the number of letters correctly recalled at the end of each trial. Points were awarded based on each individual letter in the string. If the correct letter was typed in the correct position, it counted as a correct response. For example, if the participant was presented with the letters F, K, and M and during the recall slide they entered K, L, M, they would be told they answered one out of three correctly (as the M was the only letter recalled in the proper position).

I also assessed recall response time, math accuracy and math response time. Although not a typical measure of working memory, I chose to measure math accuracy and response time to ensure participants were not ignoring the math problems and skipping straight to the recall portion of the task.

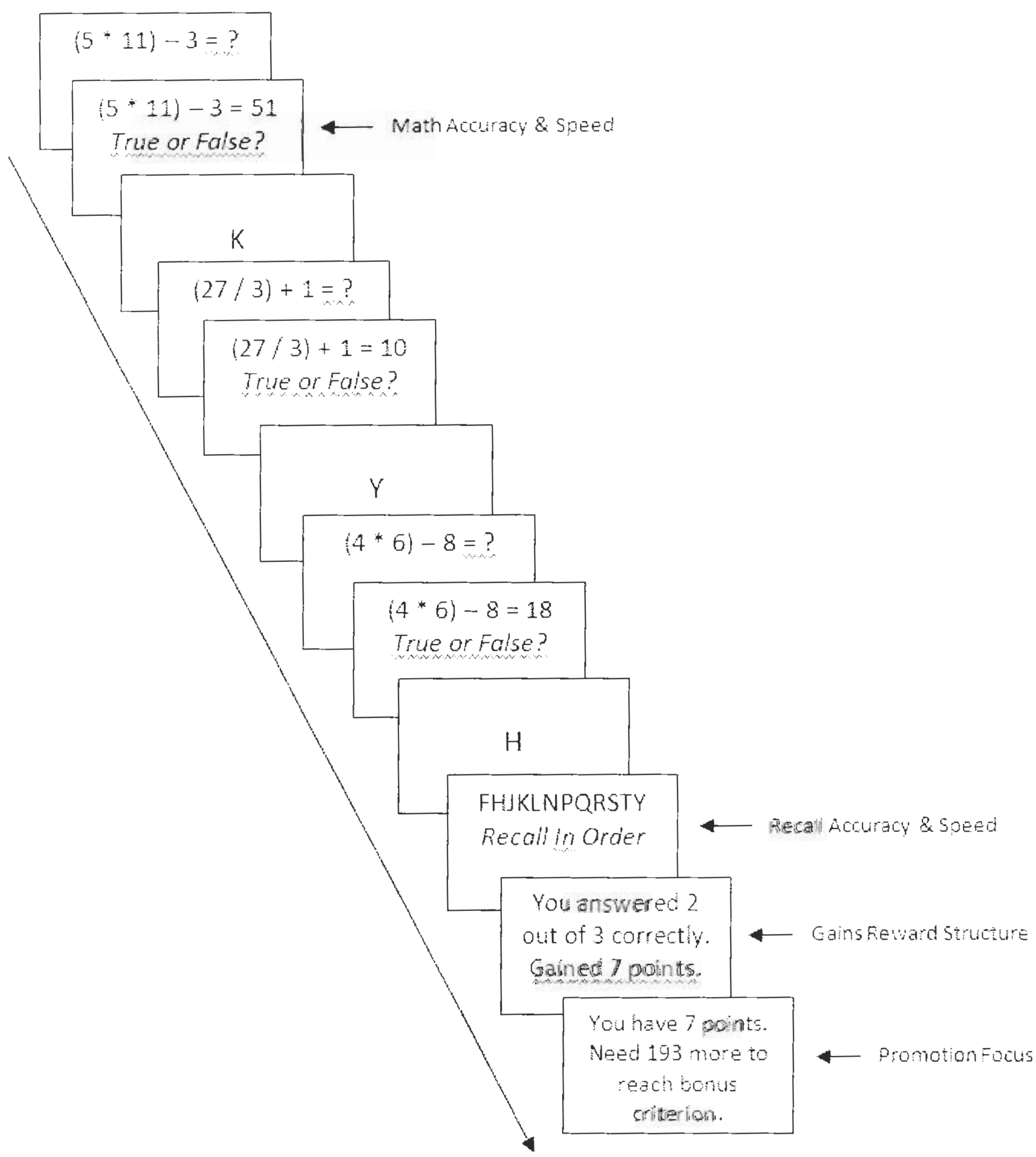

Figure 1. Chronological order of Operation Span for a participant in Promotion – Gains group.

Results

Four participants (1 from promotion-gains, 1 from promotion-losses, 2 from prevention-gains) were excluded from the analyses because they did not perform the math operation portion of the task as directed.[1] I performed separate 2 (regulatory focus: prevention, promotion) x 2 (reward structure: gains, losses) ANOVAs on each of the dependent measures, adopting an alpha of .05 throughout. Due to concerns about a potential ceiling effect, a median split was performed on all of the data using session one recall accuracy. The two resultant groups represented those participants having the top 50% working memory capacities and the bottom 50%.

Session 1 – Baseline

There were no significant differences among the groups at baseline on any of the dependent measures (all F's < 2.25, all p's > 0.07). This result is unsurprising given that the regulatory fit manipulation was not yet introduced.

Session 2 – Regulatory Fit Manipulation

Preliminary analyses revealed no effects of regulatory fit on any of the dependent measures. I was, however, concerned about possible ceiling effects, particularly among high-performing participants. One might expect a motivational manipulation to have little effect on those already performing at a very high level, while indeed having an influence on poorer-performing participants. Thus, using baseline accuracy scores, I performed a median-split and separately analyzed the performance of the top and bottom 50% of participants. Tables 2 and 3 depict performance on each of the dependent measures for the bottom and top 50%, respectively.

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[1] These participants spent less than 250 ms inspecting the math problem, indicating they did not read the problem. This amount of time falls below what is necessary to make judgments as to whether the problem may be solved correctly (Paynter, Reder, & Keiffaber, 2009).

Table 2

Operation Span task performance at session two for the bottom 50%

Group	Recall Score	Recall Response Time (ms)	Adjusted Recall (score / time)	Math Accuracy	Math Response Time (ms)
Promotion Focus					
Gains (Fit)	63.83 (9.03)	4633.08 (887.09)	0.13 (.044)	41.83 (4.09)	1257.89 (318.71)
Losses (Mismatch)	57.21 (9.58)	4308.21 (828.09)	0.15 (.040)	40.6 (5.25)	994.8 (237.97)
Prevention Focus					
Gains (Mismatch)	60.41 (8.88)	4472.82 (908.17)	0.15 (.038)	40.12 (5.95)	1090.88 (427.422)
Losses (Fit)	63.71 (7.96)	5058.65 (977.31)	0.14 (.037)	41.5 (5.78)	1194.39 (354.41)

Standard Deviations are presented in parentheses.

Table 3

Operation Span task performance at session two for the top 50%.

Group	Recall Score	Recall Response Time (ms)	Adjusted Recall (score / time)	Math Accuracy	Math Response Time (ms)
Promotion Focus					
Gains (Fit)	63.64 (8.08)	4312.18 (822.17)	0.16 (.037)	40.31 (8.29)	1003.31 (273.64)
Losses (Mismatch)	65.25 (7.98)	4108.69 (495.39)	0.17 (.029)	41.6 (5.34)	1056.80 (235.65)
Prevention Focus					
Gains (Mismatch)	67.5 (5.20)	3967.81 (745.51)	0.17 (.035)	43.31 (4.99)	963.00 (228.92)
Losses (Fit)	69.38 (6.45)	4014.63 (690.59)	0.17 (.042)	42.13 (4.16)	1104.67 (310.22)

Standard Deviations are presented in parentheses.

Number of Letters Correctly Recalled.

As expected, I found positive effects of regulatory fit in the bottom 50% of participants, but not in the top 50%. In the bottom 50%, the analysis revealed only an interaction between focus and reward structure, $F(3, 59) = 4.63$, $p = 0.036$, $\eta_p^2 = 0.08$ As can be seen in the leftmost column of Table 3, participants in regulatory fit ($M = 63.83$, $SD = 8.32$) correctly reported more letters than those in mismatch ($M = 58.91$, SD = 9.22), $F(1, 59) = 4.49$, $p = 0.038$, $\eta_p^2 = 0.07$. Among the top 50% of participants, neither main effect, nor the interaction approached significance, Fs < 1. At first pass, this result suggests that among the poorer-performing participants, those in a regulatory fit had larger working memory capacities than those in a regulatory mismatch. This interpretation is countered, however, by analysis of the response times.

Response Time for Recall Task.

Were there positive effects of regulatory fit on response time, I would expect to see participants in fit perform faster than those in mismatch. Among the bottom 50% of participants, I observed the opposite trend: Those in a fit took longer to respond ($M = 4882.55$ ms, $SD = 948.91$) than those in a mismatch ($M = 4398.48$ ms, $SD = 862.54$), $F(1, 59) = 4.28$, $p = 0.043$, $\eta_p^2 = 0.07$. Although, the focus by reward structure interaction, $F(3, 59) = 3.71$, $p = 0.059$, $\eta_p^2 = 0.06$, failed to reach significance, likely due to reduced power associated with the interaction analysis. Neither main effect reached significance. These response time results indicate that while participants in fit recalled more letters correctly, they took longer to do so. Similar to what we observed for recall accuracy, neither main effect, nor the interaction, approached significance among the top 50% of participants (all Fs < 1.63, ps > .206)

Speed-Adjusted Recall Accuracy

To assess whether any effects of regulatory fit on recall remained once differences in response time were controlled, I created a speed-adjusted measure of recall accuracy by dividing the number of letters each participant correctly recalled by their response time. Higher numbers on this measure indicate better performance.

In the bottom 50%, neither main effect (all Fs < 1.38, ps > 0.245), nor the previously observed interaction, reached significance, $F(3,59) = 1.38$, $p = 0.245$. This result suggests that the significant focus by reward structure interaction, previously observed in the bottom 50%, did not reflect an increase in working memory capacity induced by regulatory fit, but rather that the regulatory fit manipulation induced a speed-accuracy tradeoff, such that those participants in a fit produce more accurate and slower responses than those in a mismatch.

Math Operations Accuracy & Speed

I did not expect to necessarily observe an effect of the regulatory fit manipulation on math accuracy or speed for two reasons: 1) the motivational manipulation was applied to the recall accuracy score – participants received neither feedback nor points for their math accuracy, and 2) math accuracy is not a traditional measure of working memory capacity (McElree, 2001). However, analysis of math accuracy and speed reveals whether participants sacrificed performance on the distracting math task in order to better perform the recall task.

No significant differences emerged in the number of math problems correct among the bottom or top 50% of participants, Fs < 1. However, among the bottom 50% of the participants, I observed a slowing of response times for participants in a regulatory fit, similar to that observed for response times in the recall portion of the task. Only the interaction of focus by reward structure reached significance, $F(3, 59) = 4.03$, $p = 0.049$, $\eta_p^2 = 0.06$, with participants in a regulatory fit ($M = 1267$ ms, $SD = 373.62$) responding more slowly than those in a mismatch ($M = 1069.58$ ms, $SD = 305.56$), $F(1, 59) = 5.05$, $p = 0.028$, $\eta_p^2 = 0.08$. Among the top 50% of participants, neither main effect, nor the interaction approached significance, Fs < 1. It appears that the lower 50% participants in fit took longer than those in mismatch to make judgments about whether the answer displayed was correct or not.

Discussion

I expected that regulatory fit would exert its cognitive effects by selectively enhancing working memory. The current results are not consistent with this hypothesis. However, I observed a speed-accuracy trade off among participants who had poorer working memory performance at baseline. In this group, participants in fit recalled more letters correctly than those in a mismatch, but they also responded more slowly than those in a mismatch. Hence it appears that regulatory fit induced a slower, more deliberative mode of processing.

These results are consistent with work in perceptual classification learning showing that regulatory fit enhances explicit, but not implicit, processing (Maddox et al., 2006, Markman et al., 2007; Grimm et al., 2008). Rule-based classification tasks are thought to rely disproportionately on explicit knowledge because participants can verbalize a rule for classification performance, while information-integration classification tasks are thought to rely disproportionately on implicit knowledge because classification learning relies on trial-by-trial feedback and does not engender a rule that can be explicitly stated (Ashby & Gott, 1988). Participants in a regulatory fit performed better on explicit rule-based classification while those in mismatch performed better on information-integration classification (Maddox et al., 2006; Grimm et al., 2008; Markman et al., 2007). Being in a motivational state that favors deliberative processing could potentially explain selective enhancement of explicit, as opposed to implicit, processes.

Friedman & Förster (2001) actually first proposed that having a promotion focus enhances elaborative processing, while having a prevention focus impairs elaborative processing.

Inconsistent with the idea that it is a participant's focus that influences elaborative processing, I did not find main effects of focus in the current study. The current study is consistent with other studies demonstrating that regulatory fit may be a more important moderator of cognitive processing than regulatory focus. Engaging in more deliberative processing may explain the performance gains associated with being in a regulatory fit when solving anagrams (Shah et al.,1998), when solving difficult remote associates (Markman et al., 2007), and when systematically exploring a decision space (Otto et al., 2010).

Otto et al. (2010) have suggested that regulatory fit exerts its effects on cognition by inducing a more systematic exploration of a problem or decision space. However, as they point out, the specifics of such a mechanism are in need of further exploration. The idea that regulatory fit induces a more systematic exploration of a problem space is not inconsistent with the notion that regulatory fit leads to more deliberative processing. Indeed, the systematic exploration of a problem space *is* more deliberative.

Implications for Research Procedures

It is clear that the interaction of focus and reward structure that results in regulatory fit or mismatch has cognitive effects across a broad range of domains. The current results further support the idea that motivational states influence human cognition. If participants enter an experiment with a chronic focus, or if they are unknowingly situationally primed with a focus, it may result in more or less deliberative processing. This processing could systematically affect the results of the experiment, and be erroneously attributed to the topic under study when in actuality it is simply a motivational state exerting effects on cognition.

Further, my results suggest that researchers need to be mindful of the potential for speed-accuracy tradeoffs and ceiling effects when employing motivational manipulations. If I had failed to assess response time in the current study, I would have erroneously concluded that regulatory fit exerts its effects by increasing working capacity, when in fact regulatory fit induced a speed-accuracy trade-off.

When individuals are already performing optimally, there is little room for motivational effects to improve performance further. Thus, failing to find an effect of regulatory fit (or of any manipulation) at the group level should be interpreted with caution. Here I failed to find effects of regulatory fit at the whole-group level, but found effects of this motivational manipulation among the relatively poorer performing participants. Commensurate with the expressed need to separately consider the effects of motivation on more or less difficult tasks, Glass et al., (2011) found an influence of regulatory fit on accuracy (i.e., sensitivity in a signal detection paradigm) when participants made difficult perceptual discriminations, but an influence of regulatory fit on response bias when participants made relatively easy perceptual discriminations

Conclusion

I set out to examine if working memory was implicated in the cognitive changes brought about by the interaction between regulatory focus and the reward structure of a task. Working memory does not appear to be the underlying mechanism responsible for the effects of regulatory fit. However, I did observe participants in fit engaging in a more deliberative mode of processing. This is consistent with other findings suggesting that regulatory fit may enhance deliberative, systematic processing.

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