Self-control conflict in the eating domain

A cognitive, affective, and behavioral perspective

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CHAPTER 2

Adaptation in Conflict:
Are Conflict-Triggered Control Adjustments Protected
in the Presence of Motivational Distractors?

This chapter is based on:

A hallmark of human goal-pursuit is the ability to stay focused on task-goals in the presence of strong but conflicting response tendencies. Strikingly, such *control* can dynamically carry over to the following situation, so that goal performance at an upcoming response conflict is generally improved. In experimental psychology, conflict-triggered control adjustments from the previous to the current trial are commonly referred to as *conflict adaptation* (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Gratton, Coles, & Donchin, 1992).Whereas conflict adaptation is a robust finding in task settings that involve a response conflict (e.g., the Stroop task and the flanker task), the effect is also sensitive to contextual information that has motivational significance (for a review, see Dreisbach & Fischer, 2012b). For example, cues indicating a monetary reward for successful completion of the previous trial strengthen conflict adaptation on the current trial (Braem, Verguts, Roggeman, & Notebaert, 2012; Stürmer, Nigbur, Schacht, & Sommer, 2011).

Previous research on the motivational modulation of conflict adaptation was interested in how reward and punishment cues strengthen or weaken the conflict signal triggered by the previous trial and thereby influence control on the current trial. The cues were generally presented in the interval between the previous and current trial, so that motivational influences had sufficient time to unfold. What has been largely neglected is how motivational cues influence conflict adaptation when they occur during the execution of control at the current trial. On the one hand, cues that occur at the current trial are potentially distracting, especially if they have motivational relevance and thus compete for attentional resources. One could therefore expect them to impair conflict adaptation (cf. Padmala, Bauer, & Pessoa, 2011; Pessoa, 2015). On the other hand, conflict adaptation is geared towards control at the current trial, which raises the expectation that distractors might be successfully inhibited even if they have motivational relevance. The question addressed in this line of studies is whether conflict adaptation is protected against *motivational distractors*, that is cues with motivational relevance that occur at the current trial. In the remainder of this paper we will first review the existing literature on motivational influences on conflict adaptation. Then we will present our predictions and four experimental studies that tested them.

The Conflict Adaptation Effect
Conflict adaptation is usually studied in tasks that involve a response conflict, such as the Stroop task (Stroop, 1935) or the flanker task (Eriksen & Eriksen, 1974). In a typical Stroop task, participants are presented with color words (e.g.,

"RED") that are themselves printed in either the same color (i.e., red) or another color (e.g., blue). The task is to indicate the color in which the word is printed (i.e., target information), and to ignore the meaning of the word (i.e., non-target information). [3] The standard finding is a *congruency effect*: responses are relatively slowed down when the meaning of the word is incongruent with the print color (e.g., "RED" printed in blue), compared to when it is congruent (e.g., "RED" printed in red). The response delay reflects the mobilization of control needed to inhibit the automatic tendency to process the non-target and to shift attention to the target instead.

The conflict adaptation effect, which is sometimes also labeled congruency sequence effect, refers to the finding that the congruency effect on the current trial is reduced if the previous trial was incongruent rather than congruent (Gratton et al., 1992). The common explanation is that top-down control mobilized during a previous incongruent trial is still high during the current trial, thereby biasing attention and performance towards task-relevant information (Botvinick et al., 2001; Egner, 2007). What exactly drives control mobilization is not yet fully understood. One possibility is that the aversive nature of conflict during the previous trial serves as an avoidance signal prompting control to minimize ongoing and future conflict (Dreisbach & Fischer, 2012a). Another possibility is that conflict serves as a learning signal reinforcing relevant features of the task (Verguts & Notebaert, 2008). A related explanation is that the execution of task rules (i.e., target activation and non-target inhibition) is more efficient after a conflict trial (Ridderinkhof, 2002).

One characteristic of the conflict adaptation effect is that it can occur in a more reactive fashion (i.e., control is maximal at the previous trial but remains effective for a short period of time) or in a more proactive fashion (i.e., control triggered by the previous trial further builds up in anticipation of the following conflict situation and is maximal at the current trial; Duthoo, Abrahamse, Braem, & Notebaert, 2014; Egner, Ely, & Grinband, 2010). Evidence so far suggests that conflict adaptation occurs in a proactive fashion when the current trial is predictable in terms of congruency and temporal spacing, and when task engagement is sufficiently high (e.g., when good performance is rewarded; Locke & Braver, 2008; Marsh, Sörqvist, & Hughes, 2015).

An alternative bottom-up explanation has also been proposed, arguing that conflict adaptation is caused by low-level feature binding (Hommel,

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[3] What we call 'non-target information' is more commonly referred to as distractor information (e.g., Egner, 2007). We chose a different terminology to prevent confusion with the term motivational distractors.

Proctor, & Vu, 2004; Schmidt & De Houwer, 2011). To illustrate, trials in which all features repeat across two consecutive trials (e.g., if the previous and the current trial are both "RED" printed in red) and trials in which all features alternate (e.g., if the previous trial is "RED" printed in blue, and the current trial is "BLUE" printed in red) are easier to respond to than trials in which some but not all of the features change (e.g., if the previous trial is "RED" printed in blue, and the current trial is "RED" printed in red). The reason is that the features of the previous trial are bound together in episodic memory and, if the current trial partially repeats some but not all of those features, they have to be "unbound". Unbinding is costly as reflected by longer response times. In the case of full repetitions and full alternations of features, unbinding is unnecessary and response times are therefore generally faster. It has been argued that because specific trial sequences (e.g., congruent followed by congruent, incongruent followed by incongruent) include more full repetition and more full alternation trials, the conflict adaptation effect might be a product of feature-based response biases rather than control processes. However, conflict adaptation still occurs when those response biases are controlled for, which supports a top-down control interpretation (Duthoo, Abrahamse, Braem, Boehler, & Verguts, 2014; Hengstler, Holland, van Steenbergen, & van Knippenberg, 2014; Weissman, Jijang, & Egner, 2014).

Motivational Modulation of Conflict Adaptation
Recently, there has been an increasing interest in how motivational and affective processes modulate conflict adaptation (for reviews see Dreisbach & Fischer, 2012b; van Steenbergen, 2015). The literature so far distinguishes between effects of reward versus affect (although confusingly the labels are sometimes used interchangeably). Reward refers to valenced stimuli that signal performance-contingent gains (or losses, when punishment signals are used), and are therefore motivational in nature. Affect, by contrast, refers to valenced stimuli (e.g., smiley faces) or mood inductions that have no explicit relation with task performance. The distinguishing feature between motivation and affect in the context of conflict adaptation is therefore performance contingency (Braem, King, Korb, Krebs, Notebaert, & Egner, 2013; Dreisbach & Fischer, 2012b).

One line of research found that performance-contingent (monetary) reward feedback presented between trials of a flanker task enhanced the conflict adaptation effect. Loss cues, however, had no effect (Braem et al., 2012; Stürmer et al., 2011). The authors argued that reward (but not loss) cues

amplified the learning signal triggered by conflict and thereby strengthened conflict adaptation (Verguts & Notebaert, 2008). In another line of research, performance-irrelevant monetary gain cues were presented between trials of a flanker task and were found to weaken conflict adaptation. Performance-irrelevant loss cues, on the other hand, strengthened conflict adaptation (van Steenbergen, Band, & Hommel, 2009, 2012). The authors concluded that the positive (negative) experience of randomly gaining (losing) money alleviated (enhanced) the aversive experience of conflict and thus undermined (strengthened) conflict adaptation (Dreisbach & Fischer, 2012a). In contrast with this interpretation, however, yet another study demonstrated that performance-irrelevant, arousing negative information (e.g., images of mutilated bodies), presented between trials, can also undermine conflict adaptation (Padmala et al., 2011). The proposed explanation for their finding is that processing affective information interferes with the execution of control (Pessoa, 2015). In sum, the literature so far suggests that motivational cues enhance conflict adaptation (only rewards, no effects for loss cues), while affective cues undermine conflict adaptation (with mixed results for negative cues).

Motivational Distractors

All studies discussed above focused on how control adjustments triggered by the previous trial could be further strengthened or weakened by motivational or affective cues. Those cues were always presented between the previous and the current trial, such that motivational and affective processes had sufficient time to unfold before conflict adaptation became manifest in actual behavior during the current trial. [4] This methodological choice was driven by their primary research goals, which were to examine whether conflict adaptation was based on the reinforcing (Verguts & Notebaert, 2008) or the aversive (Dreisbach & Fischer, 2012a) qualities of the conflict signal, respectively.

A question that has been left largely unaddressed is to what degree conflict adaptation, irrespective of the exact process by which it was triggered, is protected against motivational or affective distraction. A cue is a potential distractor when it is personally relevant enough to shift priorities and to consume attention. Motivational cues signaling the opportunity for reward or punishment should therefore be more distracting than, for instance, low-

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[4] To our knowledge, there is one study which inserted cues on the trial (rather than between trials), but this study looked at affective (rather than motivational) cues, and only at the modulation of the valenced-based response delay (rather than the modulation of the conflict adaptation effect, Kunde, Augst, & Kleinsorge, 2012).

arousing affective cues (e.g., smiley faces). Accordingly, motivational cues provide an ideal test case for the effectiveness of conflict adaptation in the context of distractors that compete for attention. As mentioned above, Padmala and colleagues (2011) found that arousing negative cues, which compete for attentional resources, impair conflict adaptation. Importantly though, because cues were presented between trials (presumably to allow for comparisons with van Steenbergen et al., 2009) this study does not give a conclusive answer to the question whether conflict adaptation can be protected against attention consuming distractors. Given that conflict adaptation is proactively geared towards exerting control at the following situation where it might be needed (provided that timing is predictable and task engagement is high), a stronger test would be to present motivational distractors at the current trial. Furthermore, considering that conflict-triggered control processes are specifically tuned towards enhanced target processing and decreased non-target processing (Botvinick et al., 2001; Ridderinkhof, 2002), the strongest test would be to present the motivational distractor at the non-target location of the current trial.

Another important characteristic of distractors is that they are, by definition, not directly relevant for task performance, so that processing them is not only unnecessary but also potentially detrimental. In previous research motivational cues were always operationalized as performance-contingent reward or punishment feedback on trial level, so that processing them was actually relevant for task performance (Braem et al., 2012; Stürmer et al., 2011). Those motivational cues can therefore not be classified as distractors. In the present study we therefore introduced a different kind of motivational cue, namely a cue that still signaled monetary reward or punishment, but which could be obtained or averted on the basis of sufficient overall task performance instead of correct current trial performance. This way, cues were personally relevant enough to be preferentially processed, but not directly related to current task performance. Processing them could therefore be distracting, especially when presented on the non-target location of a current trial. In fact, such more generally relevant motivational cues are quite frequent in daily life. For example, workers who receive payment for successfully completing an assignment rather than for every single work step, or tennis players who need to perform many series of movements before they actually win or lose the game. Moreover, previous research suggests that encountering such generally relevant motivational cues can indeed hamper performance through triggering

distracting and resource-consuming thoughts (e.g., Bijleveld, Custers, & Aarts, 2012).

The Present Studies

The present line of studies posed the question whether conflict adaptation is protected against motivational distractors. We reasoned that the strongest test would require presenting the motivational distractor at the non-target location of the current trial (rather than between trials), because this is when conflict-triggered control is ready to be executed. Moreover, we chose more generally (rather than directly) contingent motivational cues as distractors (e.g., rewards can only be obtained if overall task performance is sufficient) because they have the potential to compete for attention but at the same time they should be ignored as they are of no particular usefulness for the immediate trial context. Together, the present studies investigated whether conflict adaptation across two interference (e.g., Stroop) trials still occurred when the latter (i.e., current) trial also contained a general motivational (vs. neutral vs. no) distractor at the non-target location.

Would conflict adaptation be harmed or helped by motivational distractors? Considering that motivation takes time to unfold (Braem et al., 2012), we reasoned that the latter possibility is unlikely if distractors are presented together with the current trial. Would they then interfere with conflict adaptation? We considered the two following outcomes possible. On the one hand, specific control processes (i.e., target activation and non-target inhibition; Ridderinkhof, 2002) are in place so that any information presented on the non-target location should have minimal impact on conflict adaptation (which we call the *protection hypothesis*). This protective mechanism should be enhanced in a task-setting triggering a proactive cognitive control mechanism (e.g., through introducing monetary reward, Locke & Braver, 2008), because in that case control processes are maximally prepared when entering the current trial. On the other hand, motivational distractors might nonetheless be processed, because they remain signals of personal relevance. As such, they will attract and hold attention, so that disengagement will cost more resources (Anderson, Laurent, & Yantis, 2011; Vuilleumier & Huang, 2009). In that case, motivational distractors are competing for the same resources as target processing, which should impair conflict adaptation (which we call the *resource competition hypothesis*; see Padmala et al., 2011; Pessoa, 2009, 2015). The goal of the present series of studies was to experimentally distinguish between the two hypotheses.

General method and analysis plan. To test between our hypotheses, we developed a novel task, which allowed us to add motivational distractors (i.e., cues) into an otherwise neutral interference task. In this task participants had to indicate the color of the target figure while ignoring the color of a non-target figure. The color of both figures could be identical (congruent trials) or different (incongruent trials). The non-target figure was presented centrally, so that participants had to disengage from the 'automatic', or preferential, processing of the non-target and to shift attention to the target, thereby mimicking the structural properties of a Stroop task (see also Padmala et al., 2011). Presentation of trials was semi-controlled through presenting series of trial 'pairs'. The first ('previous') trial of a pair never contained a cue, whereas second ('current') trials could contain a motivational (vs. neutral vs. no) cue which was inserted at the non-target location. Cues were therefore spatially compatible with the non-target figure (with its color still visible) but not directly tied to the response dimension (i.e., color).

Presenting the motivational or neutral cues centrally controlled for differences in attentional orientating towards the non-target location, which ensured that the baseline conflict strength (between target and non-target response) was similar on all trials. More importantly, it also allowed us to specifically study the degree to which conflict adaptation is compromised by the simultaneous processing of (i.e., disengagement from) motivational cues (cf. Koster, Crombez, Verschuere, & De Houwer, 2004). Motivational cues represented monetary reward or loss, and were not directly performance-contingent, in that reward attainment was not tied to current trial performance, but to overall task performance. To make sure that any cue-modulation was due to the motivational meaning, motivational and neutral cues were matched on visual similarity and were presented equally often. Finally, in order to increase pro-active control processes, participants were explicitly told that they could win or lose real money.

The main dependent variable in all studies were log-transformed reaction times (RT), [5] which were subjected to the following within-design: 2(previous congruency: congruent vs. incongruent) × 2(current congruency: congruent vs. incongruent) × 3(current cue: motivational vs. neutral vs. no). Cues always appeared on the non-target location (except in Study 2.1b where they appeared on the target location). We predicted an overall congruency

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[5] Additional control analyses on error-rates indicated that the reported effects were not due to speed-accuracy tradeoffs.

effect on the current trial (responses to congruent trials should be faster than responses to incongruent trials) and a conflict adaptation effect (an interaction between previous and current congruency: the congruency effect should be reduced following incongruent trials). The effect of interest was the three-way interaction: we tested whether the conflict adaptation effect occurred for all three cue types, and whether it was significantly different for trials containing motivational cues as compared to trials with neutral or no cues.

Each study introduced additional between group factors: In Study 2.1 we tested whether the effect of interest was dependent on the location at which the motivational cue appeared (non-target vs. target, Study 2.1a + b). It might be possible that conflict adaptation is better protected when the motivational cue appears at the non-target location, because then specific control processes are in place (i.e., enhanced target and decreased non-target processing). In Studies 2.2 and 2.3, we manipulated whether the motivational cue signaled monetary reward or loss. That was done in order to differentiate between the resource competition and an alternative explanation. Studies 2.3 and 2.4 were replications that ruled out potential confounds. Finally, we present a merged analysis of all studies, in which we aim to test the robustness of our findings, and also control for feature binding response biases.

Participants were excluded from analyses if, during manipulation checks, they mistook the neutral cue for the motivational cue, if their averaged logged reaction time was outside the range of M +/- 2.5 SD (based on between factor subsample), and if their accuracy level was below 70%. At the end of the experiment, participants reported the amount of money signaled by the motivational cue. Participants who reported an inaccurate amount were not excluded from analyses, because inaccurate estimates only slightly diverged from the actual amount. Across all studies, exclusion or inclusion never changed the overall pattern of results. Individual difference measures were obtained in all studies (i.e., BIS/BAS, Carver & White, 1994), but did not influence the reported pattern of results and are therefore not further mentioned. We only report results of tests that were central to our hypotheses, and all significant main effects. Interested readers can consult the original data available at the Open Science Framework platform (https://osf.io/x93rq/).

Study 2.1a

Study 2.1a+b was a first test of our research question whether conflict adaptation, once triggered, is subsequently protected in the presence of a motivational distractor. In Study 2.1a distractors were presented on the non-

target location, in Study 2.1b on the target location. According to the protection hypothesis, conflict adaptation should be better protected from motivational distraction when it appeared on the non-target (vs. target) location. The resource competition hypothesis, however, does not make a special prediction about the exact location of the motivational distractor, as long as it remains in competition with target responding. Data from Study 2.1a and b were collected and analyzed in succession, which is why we present the results accordingly.

Method

      Participants. We recruited 45 people (37 female, 93% students, M_{age} = 21.67, SD = 2.86) who participated for course credit or financial compensation (5 euro).

      Materials and procedure. Participants signed informed consent and were seated in individual cubicles approximately 60 cm away from the screen. The experiment was implemented on a 24 inch monitor (screen resolution of 1920 × 1080 pixels) and a refresh rate of 60 Hz.

      Stimuli were composite figures which consisted of a circle in the center of the screen (3.5 cm diameter) surrounded by a rectangle (4 × 14 cm) and were presented against a black background (see Figure 2.1). Both the circle and the rectangle could be red or blue, so that the whole figure was either a combination of the same (congruent trial) or different colors (incongruent trial). Circles always had a fine black border, so that they remained visible even in congruent trials. Participants were asked to indicate the color of the *surrounding rectangle* by pressing the 'z' or '/' key on a QWERTY keyboard (color to key assignment was counterbalanced). To make sure participants did not only focus on one side of the rectangle, rectangles appeared either vertically or horizontally (random), and catch trials were included in which a square (3.5 × 3.5 cm) instead of a circle appeared in the center of the stimulus. In such catch-trials participants were asked to give no response. Those additional features were also implemented for two other reasons. First, to make sure that the circle (i.e., non-target) got equal initial attention in all trials, and not only in trials including the attention catching motivational cue. That was important in order to control for differences in attentional orientation towards the cues, and allowed us to specifically study disengagement processes (cf. Koster et al., 2004). And second, the randomized bar orientation as an additional stimulus feature had the advantage that full repetition and full alternation trials (identical vs. opposite target color, non-target color, and bar orientation) were

less frequent, so that differences in response biases due to bottom-up feature binding processes were minimized (see Nieuwenhuis et al., 2006).

Adding motivational meaning to the non-target location, circles could either be plain (no cue), or they could contain a picture of a flower (neutral cue) or of a euro-coin (motivational cue, see Figure 2.1). We used coins as motivational cues because of their ecological validity, and because they have been used in similar studies before where they were found to reliably trigger motivational processes (Pessiglione et al., 2007; Zedelius et al., 2014). The latter two were layered with partly transparent (70%) red or blue so that the color as well as cues remained visible. Participants were told at the beginning that they could win extra money in the task. Every time a euro-coin appeared in the circle they would automatically gain 5 cents. However, they would only receive the accumulated amount if they achieved an overall accuracy of at least 90%. This way, we secured that motivational cues were not performance-contingent on a trial level (as accurate performance on the specific trial on which the cue occurred was not necessary for receiving the monetary reward), but contingent on their overall performance.

The task started with 16 practice trials (including 2 catch trials) and was followed by the main task which consisted of six blocks of 68 trials (including a total of 24 uniformly distributed catch trials). Between blocks participant took self-timed breaks. In the middle of the task, participants also received interim accuracy feedback. Each trial started with the presentation of a fixation cross (500 ms) which was followed by the stimulus (i.e., composite figure) which remained on screen until the response was given (2000 ms timeout for catch-trials). The inter-trial interval was 1000 ms. Participants received accuracy feedback and the response-labels remained on screen throughout the entire experiment.

Trial-order was semi-controlled: stimuli at previous trials never contained a cue, while stimuli at current trials could contain no cue, a neutral or a motivational cue. That created a 2(previous congruency) × 2(current congruency) × 3(current cue) design. Each of the trial combinations occurred equally often, and their colors were completely balanced. Also, congruent and incongruent trials as well as their possible sequences appeared equally often.

After participants had finished the task a check question was asked (i.e., how much money they would gain per euro-coin) and they rated their current need for money on a visual analogue scale (VAS) ranging from 0 to 100. Only if

participants had an overall accuracy >= 90% they received the additional money (3 euro). [6]

Results and Discussion

All participants reported the correct amount of money they gained upon seeing the euro-coin. The RT data was prepared as follows: all incorrect responses were excluded and only correct trial sequences were analyzed. Also, individual RTs were excluded when below 200 or above 2000 ms (6% total trials excluded). The remaining RT scores were log-transformed (for ease of understanding descriptives will be given in milliseconds). One participant was identified as an outlier and excluded from analysis.

The overall accuracy rate of the sample was high (96%). We conducted a 2(previous congruency) × 2(current congruency) × 3(current cue) repeated measures ANOVA and observed an overall effect of current congruency, $F(1, 43) = 192.90$, $p < .001$, $\eta_p^2 = .82$. Responses to congruent trials ($M = 465$, $SD = 57$) were faster than responses to incongruent trials ($M = 500$, $SD = 66$). Previous congruency also affected overall reaction times, $F(1, 43) = 6.73$, $p = .013$, $\eta_p^2 = .14$. If the preceding trial was incongruent ($M = 486$, $SD = 62$) reaction times were slower than when it was congruent ($M = 480$, $SD = 61$). Further, there was a significant main effect of cue, $F(2, 86) = 11.28$, $p < .001$, $\eta_p^2 = .21$. Responses to trials containing motivational cues ($M = 493$, $SD = 67$) were significantly slower than trials containing neutral ($M = 476$, $SD = 57$) or no cues ($M = 479$, $SD = 63$, ps < .001). The interaction between previous and current congruency (i.e., conflict adaptation effect) reached significance, $F(1, 43) = 63.73$, $p < .001$, $\eta_p^2 = .60$. As predicted, the congruency effect (incongruent - congruent) was larger after congruent trials ($M = 49$, $SD = 27$) than after incongruent trials ($M = 20$, $SD = 18$).

Most interestingly though, the three-way interaction reached significance, $F(2, 86) = 5.37$, $p = .006$, $\eta_p^2 = .11$ (see Figure 2.2 Panel 1). The conflict adaptation effect was significant for trials with no cues, $F(1, 43) = 61.97$, $p < .001$, $\eta_p^2 = .59$, and for trials with neutral cues, $F(1, 43) = 11.83$, $p = .001$, $\eta_p^2 = .22$, but only a trend for trials with motivational cues, $F(1, 43) = 3.12$, $p = .085$, $\eta_p^2 = .07$. Conflict adaptation was weaker for motivational cues than for no cues, $F(1, 43) = 13.30$, $p = .001$, $\eta_p^2 = .24$, but similar across motivational and neutral cues, $F(1, 43) = 1.65$, $p = .206$, $\eta_p^2 = .04$.

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[6] Actually participants saw 64 affective cues, which would amount to 3.20 euro. For practical reasons we told them they saw 60 affective cues and therefore received 3 euro.
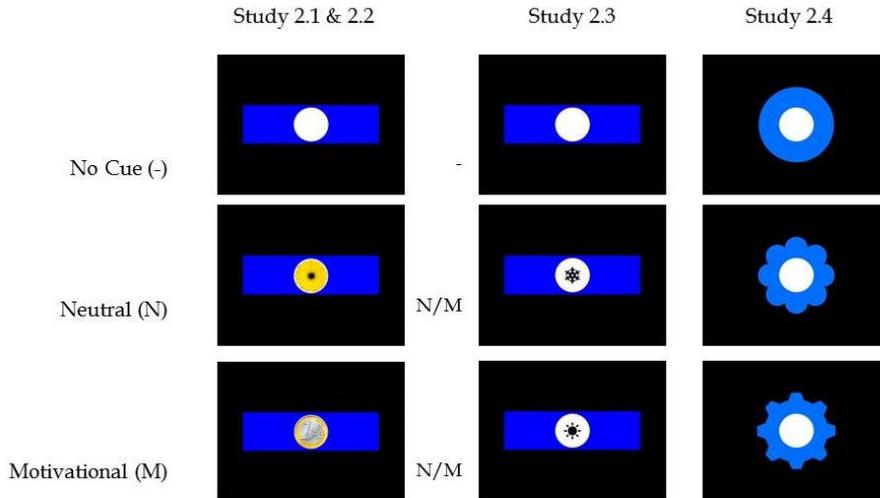
Figure 2.1. Examples of stimuli used in Studies 2.1-2.4. The first row depicts stimuli examples for incongruent no cue trials (-), the second row for incongruent neutral cue trials (N), and the third row for incongruent motivational cue trials (M). Note, in Study 2.3 and 2.4 motivational and neutral cues were counterbalanced across conditions (N/M).

Study 2.1b

In contrast to the protection hypothesis, Study 2.1a showed that the conflict adaptation effect was not fully protected in the presence of a motivational distractor. In Study 2.1b we wanted to test whether the same effect occurred when the motivational distractor is presented on the target location. Given that motivational distractors presented on the target location might still compete with target (color) processing, a similar modulation can be expected here, too. Combining Study 2.1a and b, we also tested whether the magnitude of the modulation was significantly stronger when the distractor appeared on the target (vs. non-target) location (four-way interaction).
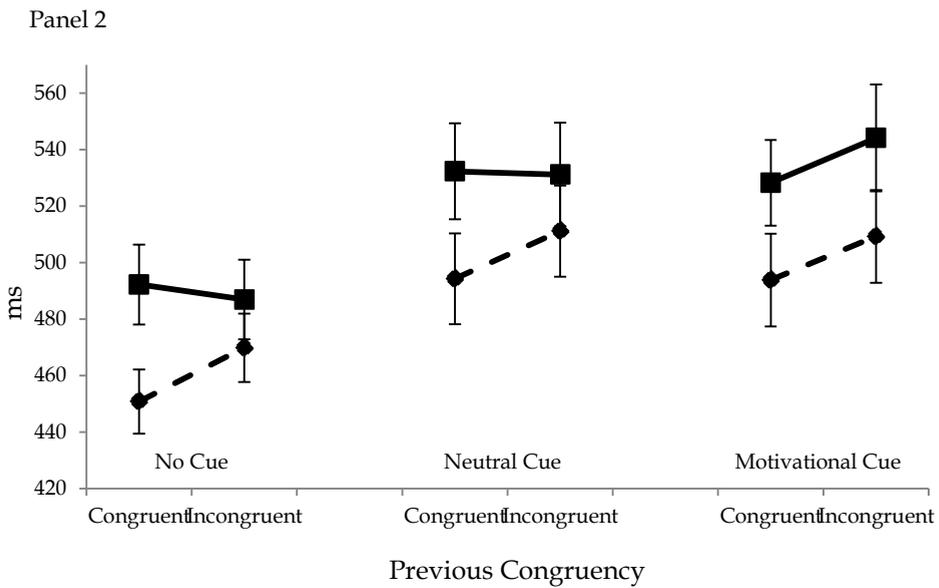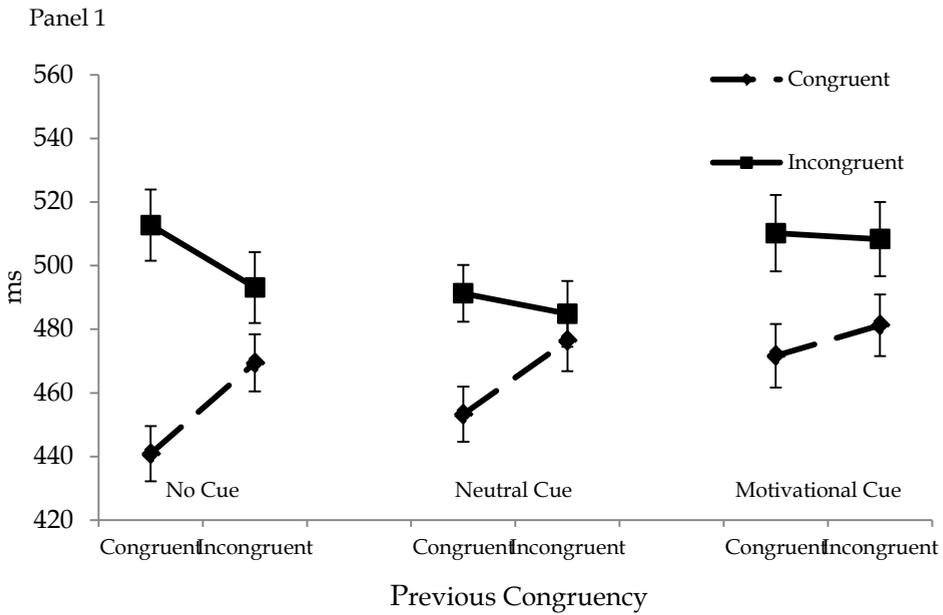
Panel 1

Panel 2

Figure 2.2. Panel 1 shows the conflict adaptation effect for each cue type in Study 2.1a. Panel 2 shows the conflict adaptation effect for each cue type in Study 2.1b. Lines represent responses to current trials, error-bars are +/- 1 *SE*.

Method

       Participants. Forty-three people participated for course credit or financial compensation (30 female, 98% students, M_{age} = 21.28, SD = 2.45). Study 2.1b was conducted directly after data collection and analysis for Study 2.1a was completed.

       Materials and procedure. The experiment was identical to Study 2.1a with the only difference that participants were instructed to indicate the color of the *inner circle*. The cues thus appeared on the target location.

Results and Discussion

Three participants reported an inaccurate amount of money they won upon seeing the euro-coin (min = 1 cent, max = 10 cents). No outliers were spotted. The RT data was prepared as in Study 2.1a (6% of trials removed). As before, overall accuracy levels were high (97%). We conducted a 2(previous congruency) × 2(current congruency) × 3(current cue) repeated measures ANOVA and obtained the main effect for current congruency, $F(1, 42)$ = 68.30, p < .001, η_P^2 = .62, with responses to congruent trials (M = 488, SD = 92) being faster than to incongruent trials (M = 519, SD = 103). Also, responses were slower after incongruent trials (M = 509, SD = 100) compared to after congruent trials (M = 499, SD = 94), $F(1, 42)$ = 15.40, p < .001, η_P^2 = .27. Moreover, there was a main effect of cue, $F(1.67, 70.05)$ = 57.28, p < .001, η_P^2 = .58 (Greenhouse-Geisser adjusted for non-sphericity). Responses to trials containing motivational cues (M = 519, SD = 106) were slower compared to trials with no cues (M = 475, SD = 82, p < .001) but no different from trials with neutral cues (M = 517, SD = 107, p = .915).

       We also obtained an interaction between previous and current congruency (conflict adaptation effect), $F(1, 42)$ = 15.12, p < .001, η_P^2 = .27. The congruency effect was larger following congruent trials (M = 38, SD = 35) than following incongruent trials (M = 24, SD = 33). The three-way interaction, however, was a trend, $F(2, 84)$ = 2.41, p = .095, η_P^2 = .06 (see Figure 2.2 Panel 2). Additional analyses revealed the same pattern as obtained in Study 2.1a, the adaptation effect was significant for trials with no cues, $F(1, 42)$ = 22.40, p < .001, η_P^2 = .35, and neutral cues, $F(1, 42)$ = 9.38, p = .004, η_P^2 = .18, but not for motivational cues, $F(1, 42)$ = 0.53, p = .473, η_P^2 = .01. Also, conflict adaptation was significantly reduced for trials containing motivational cues compared to no cues, $F(1, 42)$ = 4.10, p = .049, η_P^2 = .09, but no different to neutral cues, $F(1, 42)$ = 1.49, p = .229, η_P^2 = .03.

Merging Study 2.1a and 2.1b. To test whether the pattern of results from Study 2.1a and 2.1b diverged significantly, we ran an overall mixed model analysis with cue location (non-target vs. target) as additional between subject factor. Overall reaction times did not differ between the studies ($p = .274$). Besides the current and previous congruency, and the conflict adaptation effect (ps $< .001$) we also obtained the three-way interaction of interest $F(2, 170) = 7.68$, $p = .001$, $\eta_p^2 = .08$. Importantly, it was not qualified by cue location, $F(2, 170) = 0.88$, $p = .416$, $\eta_p^2 = .01$. Mirroring the above results, the adaptation effect was significant only for trials with no, $F(1, 86) = 75.22$, $p < .001$, $\eta_p^2 = .47$, and neutral cues, $F(1, 86) = 20.33$, $p < .001$, $\eta_p^2 = .19$, but only a trend for trials with motivational cues, $F(1, 86) = 3.07$, $p = .083$, $\eta_p^2 = .03$. Accordingly, the adaptation effect for motivational cues was significantly reduced compared to no cues, $F(1, 86) = 16.44$, $p < .001$, $\eta_p^2 = .16$, and also somewhat reduced compared to neutral cues, $F(1, 86) = 3.08$, $p = .083$, $\eta_p^2 = .04$. Finally, we explored whether participants' current need for money (which did not differ between the two groups, $M_{total} = 71.32$, $SD = 19.76$) was significantly related to the above effects, which was not the case.

Together, our findings provide first evidence that conflict adaptation is not fully protected in the face of motivational distractors. That was independent of whether the motivational distractors appeared at the non-target or target location. Therefore, our results support the resource competition hypothesis, which predicted that motivational distractors will be attended and processed independent of the current control state and thus interfere with target processing. However, that motivational distractors signaling monetary reward undermine conflict adaptation would also have been predicted by van Steenbergen's affect-based account (2009, 2012), which proposes that the positive valence of the motivational distractor neutralized the aversive conflict signal which consequentially reduced control. In the second study we pitted those two explanations against each other by introducing a condition in which the motivational distractor signaled monetary loss. The resource competition account predicted reduced conflict adaptation for motivational distractors signaling reward as well as loss. The affect-based account, on the other hand, predicted reduced conflict adaptation only when the motivational distractor signals reward, but not when it signals loss.

Study 2.2

Method

Participants. Eighty participants (56 female, 93% students, M_{age} = 21.61, SD = 3.16) were recruited for the present experiment. Their participation was rewarded with course credit or 5 euro. Everybody was randomly assigned to the reward (n = 40) or loss condition (n = 40).

Material and procedure. The task participants completed was almost identical to Study 2.1a except that in the loss condition participants automatically *lost* 5 cents each time a euro-coin appeared. Importantly, in the loss condition participants first received an extra 3 euro from which the 5 cents were gradually subtracted. Participants could, however, prevent the loss if their overall accuracy level was at least 90%. This way, participants in both conditions were equally likely to receive the extra 3 euro.

After they had completed the task, participants filled in several check questions (would they gain vs. lose money with the euro; how much would they gain/lose; how much they needed money at the moment) and additionally evaluated the flower and the euro-coin (VAS, 0 negative – 100 positive). That was done to check whether the reward vs. loss manipulation would impact on participants' evaluation of the cue.

Results and Discussion

RT data preparation was identical to that of Study 2.1 (8% of all trials excluded). Two people were removed from the sample, because they were identified as outliers. The data of two other participants was incomplete and thus not included in the analyses. The final sample consisted of 76 participants (37 in the loss condition).

There was a trend for participants in the loss condition to report a higher need for money (M = 78.46, SD = 24.62) compared to participants in the reward condition (M = 67.41, SD = 31.63; p = .095). All participants correctly reported whether they gained or lost money with the euro-coin. Four people reported the wrong amount of money they won/lost each time they saw the euro-coin (min 2 cents, max 50 cents). We first tested whether the reward vs. loss manipulation impacted participants' evaluations of the cues. A 2(cue: motivational vs. neutral) × 2(condition: reward vs. loss) mixed model ANOVA revealed an interaction between cue and condition, $F(1, 74)$ = 4.13, p = .046, η_p^2 = .05. Evaluations of the euro-coin were somewhat more positive in the reward condition (M = 77.69, SD = 18.25) than the loss condition (M = 70.35, SD = 16.47), $t(74)$ = -1.84, p = .070. Evaluations of the flower did not differ (p = .539).

To test our hypotheses, we ran a 2(previous congruency) × 2(current congruency) × 3(current cue) × 2(cue valence: reward vs. loss) mixed model ANOVA, in which the last factor varied between subjects. We obtained a main effect of current congruency, $F(1, 74) = 149.52$, $p < .001$, $\eta_p^2 = .67$. Responses were faster at congruent trials ($M = 449$, $SD = 79$) compared to incongruent trials ($M = 479$, $SD = 90$). Also, previous congruency had a significant effect, $F(1, 74) = 8.22$, $p = .005$, $\eta_p^2 = .10$. Responses after incongruent trials ($M = 467$, $SD = 85$) were slower compared to after congruent trials ($M = 461$, $SD = 83$). We also obtained a main effect of cue, $F(1.83, 135.39) = 11.22$, $p < .001$, $\eta_p^2 = .13$ (Greenhouse-Geisser adjusted for non-sphericity). Participants responded slower in motivational cue trials ($M = 471$, $SD = 92$) than in neutral cue ($M = 459$, $SD = 82$) and no cue trials ($M = 462$, $SD = 80$, ps = .001).

We also obtained an interaction between previous and current congruency (conflict adaptation effect), $F(1, 74) = 77.61$, $p < .001$, $\eta_p^2 = .51$, indicating that the congruency effect was larger after congruent trials ($M = 44$, $SD = 32$) compared to after incongruent trials ($M = 15$, $SD = 29$). The predicted three-way interaction did not reach significance, $F(2, 148) = 2.15$, $p = .120$, $\eta_p^2 = .03$, indicating that the conflict adaptation effect was present for all three cue types (ps < .001). The lack of a four-way interaction ($p = .185$) suggested that this pattern was similar for the reward and the loss condition.

Due to our valence-specific interests, we nevertheless explored the pattern of results for both conditions separately. We found that the motivational cue interrupted conflict adaptation in the loss condition (three-way interaction: $F(2, 72) = 3.49$, $p = .036$, $\eta_p^2 = .09$), but not in the reward condition (three-way interaction: $F(2, 76) = 0.01$, $p = .926$, $\eta_p^2 < .01$). In the loss condition there was an adaptation effect for all cues (ps < .05), but it was smaller for motivational cue trials than for no cue trials ($p = .014$) and no different to neutral cue trials ($p = .607$). In the reward condition, conflict adaptation was equally strong for all cues.

In this second study we failed to replicate the findings of Study 2.1 that the conflict adaptation effect is reduced when the current trial contained a motivational distractor. Interestingly, exploratory analyses showed that the previously observed pattern did reoccur to some extent – but only in the loss condition. One possible explanation for why the effect was not visible in the reward condition could be that participants' reported current need for money tended to be relatively low (compared to the loss condition and compared to the mean found in Study 2.1). This might have made them less susceptible to the motivational meaning of reward cues (see also Kahneman & Tversky, 1984).

Another plausible explanation is related to the overall power of our studies. Even though the post-hoc power in Study 2.2 was high (approximately 92%, based on the effect size of the three-way interaction in Study 2.1a+b, η_P^2 = .08), chances to find an effect four times in a row in four consecutive studies decreases the power to 72%. Thus, assuming a true effect it is not unlikely that an individual study fails to show a significant effect.

<div align="center">

Study 2.3

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In the next study we wanted to run the same design but in an improved experimental paradigm. Though euro-coins are ecologically valid motivational cues, which in the past have successfully been used to trigger motivational processes (e.g., Pessiglione et al., 2007), we wanted to use cues with high perceptual and conceptual similarity. This was important for two main reasons. First, compared to the flower the euro-coin is a more complex stimulus and we aimed to demonstrate that motivational meaning, and not cue complexity, explains our findings. Second, overlaying the euro-coin and flower cues with transparent color reduced their visibility as well as the intensity of the non-target color.

Method

  Participants. Eighty-three people participated in the third study (64 female, 92% students, M_{age} = 22.51, SD = 3.21) for either course credit or financial compensation (5 euro). Participants were randomly assigned to either the reward (n = 42) or loss (n = 41) condition.

  Materials and procedure. Participants were informed that they were to complete two tasks, in both of which they could gain additional money. They received an envelope which was initially empty in the reward condition, or contained 50 cents in the loss condition.

  Training task. Participants first completed a training task (adapted from Krebs, Boehler, & Woldorff, 2010) in order to establish a reward or loss association with one of the two – initially neutral – cues. The two cues were schematic (black) line-drawings of a snowflake and a sun, and selected based on their visual and evaluative similarity (see Figure 2.1). Their valence was varied across conditions (reward vs. loss) and within conditions (motivational vs. neutral). There were in total four different stimuli in the training task: a square, a circle, or a circle containing a snowflake or a circle containing a sun – all stimuli which would later return (in identical size) in the main task. All stimuli were white (cues were added in black) and presented in the center of

the screen on black background. Participants were instructed to indicate the identity of the stimulus by pressing the 'a', 's', 'k' and 'l' keys on a QWERTY keyboard (stimulus to key assignment was counterbalanced). Participants learned that one of the stimuli was a critical stimulus because they could either win (reward condition) 5 cent every time they responded to it accurately and fast enough (> 600 ms), or lose 5 cent (loss condition) if their response was inaccurate or too slow.

There were eight practice trials and 40 experimental trials. Each trial started with a fixation cross (500ms) and was followed by a stimulus (600 ms; intertrial interval 1000 ms). If participants' response was incorrect or too slow (> 600 ms) a red cross would appear (150 ms). Critical trials were always followed by unique feedback which remained on screen for 500 ms. If their response was correct and fast enough participants would read '+ 5 cent' (reward condition) or '- 0 cent' (loss condition), if incorrect or too slow they would read '+ 0 cent' (reward condition) or '-5 cent' (loss condition). No response labels were shown on the screen throughout the task. After they had completed the training, the experimenter returned and adjusted the amount of money in the envelope. Participants could maximally win/retain 50 cents.

Main task. The main task was almost identical to that of Study 2.2. The same composite figures were used, with the only difference being that the motivational and the neutral cue were now a snowflake and a sun (see Figure 2.1). For each participant, the motivational cue from the training task remained the motivational cue in the main task. Task instructions and trial compositions were identical to Study 2.2, and participants could still gain (vs. lose) 5 cents each time a motivational cue appeared on the non-target location (amounting to 3 euro). Monetary rewards (vs. losses) were still tied to overall task-performance rather than current trial performance. After participants had completed the main task, participants were asked several check questions (see Study 2.2) and evaluated both cues (VAS, 0 *negative* – 100 *positive*). Then, the experimenter returned to adjust the money in the envelope.

Results and Discussion

RT data for the main task were prepared identical to Study 2.1 (9% of all trials removed). The overall accuracy was high (95%). No outliers were detected. All participants correctly indicated the motivational cue, but two reported the wrong amount of money they won/lost upon seeing it (min = 25 cents, max = 50 cents). There was no difference in momentary need for money between the two conditions (M_{total} = 66.04, SD = 28.88), neither did it influence any of the

below results. We first tested whether the reward vs. loss manipulation affected participants' evaluation of the motivational cue. A 2(cue: motivational vs. neutral) × 2(condition: reward vs. loss) mixed model ANOVA revealed an interaction, $F(1, 81) = 62.01$, $p < .001$, $\eta_p^2 = .43$. Independent t-tests showed that participants in the loss condition were more negative about the motivational cue ($M = 37.76$, $SD = 18.08$) compared to participants in the reward condition ($M = 76.40$, $SD = 22.15$), $t(81) = -8.70$, $p < .001$. There was no difference between the conditions in the evaluation of the neutral stimulus ($p = .614$).

To test our hypotheses, a 2(previous congruency) × 2(current congruency) × 3(current cue) × 2(cue valence: reward vs. loss) × 2(cue identity: snowflake vs. sun) mixed model ANOVA was conducted, with the last two factors varying between participants. We obtained a significant main effect of current congruency, $F(1, 79) = 195.65$, $p < .001$, $\eta_p^2 = .71$. Responses to congruent trials ($M = 463$, $SD = 70$) were faster than to incongruent trials ($M = 497$, $SD = 81$). Further, we obtained a main effect for cue, $F(2, 158) = 26.57$, $p < .001$, $\eta_p^2 = .25$ indicating that responses to motivational cues were slower ($M = 487$, $SD = 80$) than to neutral cues ($M = 480$, $SD = 75$), and no cues ($M = 472$, $SD = 72$, $ps < .001$). Cue valence also had a main effect on participants' overall performance, $F(1, 79) = 14.78$, $p < .001$, $\eta_p^2 = .16$. Participants in the loss condition were generally faster ($M = 451$, $SD = 68$) compared to in the reward condition ($M = 508$, $SD = 71$).

There was also a significant interaction between previous and current congruency (conflict adaptation effect), $F(1, 79) = 89.80$, $p < .001$, $\eta_p^2 = .53$. The congruency effect was larger ($M = 46$, $SD = 28$) after congruent trials compared to after incongruent trials ($M = 20$, $SD = 28$). Most importantly though, the conflict adaptation effect was moderated by cue, $F(1.80, 142.06) = 4.13$, $p = .022$, $\eta_p^2 = .05$ (Greenhouse-Geisser corrected for non-sphericity). Separate analyses for each cue showed that the conflict adaptation effect was significant for no cue trials, $F(1, 82) = 63.08$, $p < .001$, $\eta_p^2 = .44$, neutral cue trials, $F(1, 82) = 53.37$, $p < .001$, $\eta_p^2 = .40$, and for motivational cue trials, $F(1, 82) = 12.38$, $p = .001$, $\eta_p^2 = .13$. However, the conflict adaptation effect for trials containing motivational cues was significantly less pronounced compared to trials containing no cues, $F(1, 82) = 5.86$, $p = .018$, $\eta_p^2 = .07$, or neutral cues, $F(1, 82) = 4.55$, $p = .036$, $\eta_p^2 = .05$ (see Figure 2.3). This pattern was independent of whether the cue signaled reward or loss (four-way interaction $p = .885$), and independent of whether the motivational cue was a sun or snowflake (four-way interaction $p = .833$).

In line with Study 2.1, results from Study 2.3 suggest that the magnitude of the conflict adaptation effect was significantly influenced by the

cue that appeared on the non-target location of a current trial. More specifically, conflict adaptation was reduced when the current trial contained a motivational distractor, compared to when it contained a neutral or no distractor. This finding was independent of whether the motivational distractor signaled reward or loss. That further supports our resource competition hypothesis (Pessoa, 2009), and eliminates the affect-based alternative explanation (van Steenbergen et al., 2009, 2012).
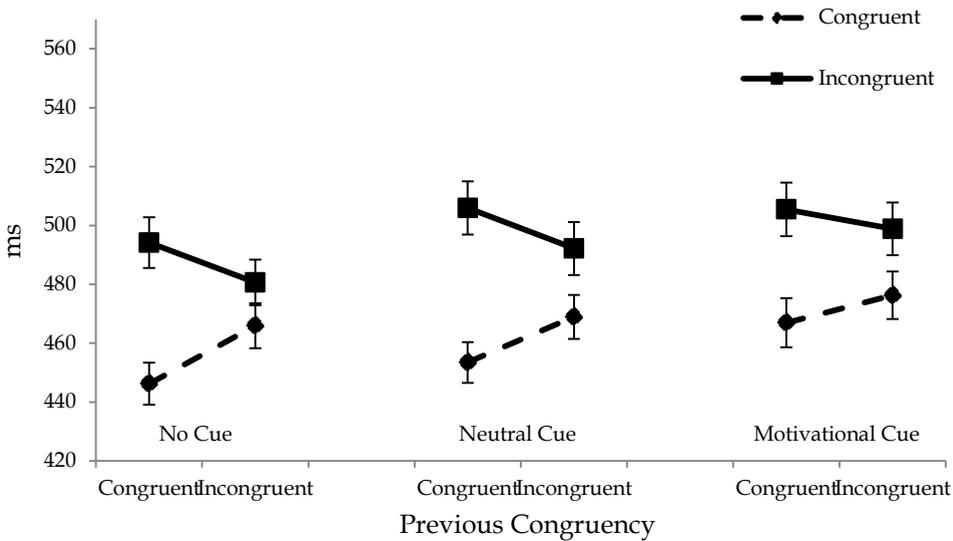

Figure 2.3. The conflict adaptation effect for each cue type in Study 2.3. Lines represent responses to current trials, error-bars are +/- 1 *SE*.

Study 2.4

We have argued that the motivational modulation of conflict adaptation is due to competition between motivational and cognitive control processes. However, in a 2 alternative forced choice task (2 AFC, as we have used in Studies 2.1 to 2.3) the conflict adaptation effect can also be due to feature binding effects (see Hommel et al., 2004). As we explained in the method section of Study 2.1, we took great care to minimize the operation of feature binding processes through adding the bar orientation feature. Nevertheless, we wanted to replicate our findings in a paradigm that is completely free of this confound. We were

confident to do so, because earlier studies on the interaction of motivation and control have also found effects when controlling for this confound (see Braem et al., 2012; Hengstler et al., 2014), and because another study has demonstrated that feature binding processes are relatively immune to affective modulation (Trübutschek & Egner, 2012).

The new task was closely modeled after the temporal flanker task (see Weissman et al., 2014), [7] which we successfully piloted without a motivational manipulation in an independent sample (i.e., it produced reliable congruency and conflict adaptation effects). Importantly, the cognitive operations (i.e., inhibition of 'automatic' non-target processing) implied in the present task was comparable to the ones used in Study 2.1 to 2.3. Specifically, whereas in our first studies non-target information was preferentially processed because it was presented centrally and catch trials directed attention towards that central position, in the present study the same preferential processing was achieved through priming the non-target *before* the target stimulus appeared (see below for more detail). Since Study 2.3 found that the effect of interest was similar for reward and loss cues we only tested the loss condition.

Method

Participants. Forty-three participants took part in the present study (36 female, M_{age} = 22.88, SD = 3.63, 88% students). Participation was compensated with course credit or 5 euro.

Materials and procedure. As in Study 2.3, participants learned that there was money at stake in the present task. They also received an envelope with an initial amount of 50 cents.

Training task. As in Study 2.3, participants first completed a training task in which they learned to associate one of two cues with monetary loss. The two cues used in the present study were a flower and gear-wheel and were selected because of their similar outer silhouettes. That was important because they would later re-appear in the main task as outer distractor shapes, representing either a motivational or a neutral cue (see Figure 2.1). We had to depart from the snowflake and sun symbols as used in Study 2.3, since inserting them into the non-target shape which had a circular target shape in its center (see description below) distorted their visual appearance significantly. Again, the task contained four different stimuli: a flower, a gear-wheel, a circle and a

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[7] One additional unreported study was conducted to control for this confound. This study did, however, not produce a conflict adaptation effect, which is why we developed a new, improved, task which is now reported as Study 2.4.

square (all about 3.5 cm diameter; the latter was a filler stimulus and would not appear in the main task). All stimuli were white and presented on black background. Since there was only a loss condition, all participants read that one of the stimuli (flower vs. gear-wheel; counterbalanced between participants) was a critical stimulus which implied that inaccurate or too slow performance (> 600 ms) was punished with the loss of 5 cents. All other aspects of the task were identical to that of Study 2.3.

Main task. The stimuli were composite figures similar to those used in the previous studies. There was still a circle (3.5 cm diameter) at the center of the screen, surrounded by a second figure, which could either have the shape of a bigger circle (7.5 cm diameter), or a flower or a gear-wheel (see Figure 2.1). To ensure a similarly strong color experience, all surrounding figures had roughly the same surface area (approximately 40 cm²). Composite figures were always combinations of either blue and yellow, or of red and green (exact complementary colors). This way, we turned a 4-AFC task into two 2-AFC tasks (see e.g., Kunde & Wühr, 2006; Weissman et al., 2014). In line with Weissman and colleagues' suggestion, color-combination trials always alternated throughout the task to control for feature binding confounds.

Importantly, in the present task the inner circle was the target, and the outer figure the non-target. Participants were instructed to focus on the color of the inner circle and to ignore the color of the surrounding non-target figure. As in previous studies, they were told that each time the non-target figure had the shape of the loss cue (flower or gear-wheel), they would automatically lose 5 cents from their extra 3 euro. They could, however, prevent the loss if their performance reached an overall accuracy of at least 80%. The accuracy threshold was lowered, because we expected this task to be more difficult than the one used in our previous studies. [8]

Each experimental trial of the modified temporal flanker task consecutively displayed three stimuli. First a fixation cross (500 ms; stimulus 1), which was followed by the short presentation of the non-target figure (inner circle was filled with the same color as the overall non-target figure; 133 ms; stimulus 2). After a delay of 233 ms (black screen) the third stimulus appeared which was similar to the second stimulus with respect to the non-target features (shape and color). The color of the inner circle (i.e., target) could, however, either be the same (congruent trial) or different (incongruent trial). Participants

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[8] In hindsight, this lowered criterion would not have been necessary (mean accuracy was 95%).

responded to the third stimulus and indicated the color of the target by pressing one of four possible keys: 'z', 'm', 'x', or 'n' (color-to-key assignment was counterbalanced). There was an inter-trial interval of 1000 ms. Catch trials were not necessary anymore, because the non-target figure got equal initial attention through being primed shortly before the target stimulus appeared, and were thus omitted.

Participants completed two practice phases. The first practice phase consisted of 32 trials of centrally presented colored circles (after a fixation cross, 500ms). In the second practice phase, participants completed 24 trials which were identical to experimental trials (including all three types of cues). In both practice phases, response labels were displayed on top of each side of the screen reminding participants of which key was assigned to which color, and participants received accuracy feedback. The task consisted of four blocks of 96 experimental trials, which were separated by self-timed breaks (min 10 s). Trial presentation was semi-controlled due to trial packaging (see Study 2.1). In first (i.e., previous) trials the non-target figure was always a circle, whereas in second (i.e., current) trials the non-target figure could have the shape of a circle, a flower or a gear-wheel. Importantly, since sequential trials always had alternating color-combinations, we counterbalanced the color-combination of the first trial between blocks. Participants received accuracy feedback throughout the task, but there were no response labels on the screen anymore. Half-way through the task participants received interim accuracy feedback. After completing the main task participants evaluated both shapes (VAS, 0 negative – 100 positive) and rated their current need for money.

Results and Discussion
Data preparation was identical to that of previous studies (10% trials excluded). The overall accuracy was high (95%). One outlier was spotted and excluded from analysis. Two participants in the gear-wheel condition reported the wrong loss cue and were thus excluded from analysis. One participant reported the wrong amount of money (10 cents). The final sample consisted of 40 participants and did not show a differential evaluation of the loss vs. neutral cue (p = .291).

We conducted a 2(previous congruency) × 2(current congruency) × 3(current cue) × 2(cue identity: gear-wheel vs. flower) mixed model ANOVA. We obtained a main effect of current congruency, $F(1, 38)$ = 199.73, p < .001, η_P^2 = .84, with responses to congruent trials (M = 634, SD = 119) being faster than to incongruent trials (M = 768, SD = 121). We also obtained a main effect of

previous congruency, $F(1, 38) = 8.75$, $p = .005$, $\eta_p^2 = .19$. Participants' responses after congruent trials ($M = 695$, $SD = 113$) were generally faster than responses after incongruent trials ($M = 707$, $SD = 120$). Unexpectedly, we also obtained a main effect of cue identity, $F(1, 38) = 8.20$, $p = .007$, $\eta_p^2 = .18$. Participants for whom the gear-wheel was the loss cue ($M_{gear-wheel} = 642$, $SD = 107$; $M_{flower} = 745$, $SD = 103$) responded faster across all trials.

We obtained an interaction between previous and current congruency (conflict adaptation effect), $F(1, 38) = 38.24$, $p < .001$, $\eta_p^2 = .50$. The congruency effect was significantly reduced following incongruent trials ($M = 109$, $SD = 81$) compared to congruent trials ($M = 160$, $SD = 67$). Crucially, the predicted three-way interaction was not significant, $F(2, 76) = 1.33$, $p = .270$, $\eta_p^2 = .03$. However, there was a trend for a four-way interaction, $F(2, 76) = 2.84$, $p = .065$, $\eta_p^2 = .07$, again suggesting that cue identity had a more profound effect on participants' performance than expected. To follow-up, we ran the within design for both cue identities separately. For the flower condition ($n = 23$), apart from the congruency ($p < .001$) and conflict adaptation effect ($p < .001$) we also obtained a significant three-way interaction, $F(2, 44) = 3.36$, $p = .044$, $\eta_p^2 = .13$ (see Figure 2.4). As in previous studies, the adaptation effect was significant for no cue trials, $F(1, 22) = 62.01$, $p < .001$, $\eta_p^2 = .74$, and neutral cue trials $F(1, 22) = 10.31$, $p = .004$, $\eta_p^2 = .32$, but only a trend for trials containing a motivational cue $F(1, 22) = 3.93$, $p = .060$, $\eta_p^2 = .15$. Moreover, the adaptation effect for trials containing motivational cues was significantly reduced compared to trials containing no cues, $F(1, 22) = 7.38$, $p = .013$, $\eta_p^2 = .25$, but not different to neutral cues, $F(1, 22) = 0.74$, $p = .400$, $\eta_p^2 = .03$. In the gear-wheel condition ($n = 17$) we only obtained the congruency ($p < .001$) and adaptation effect ($p < .001$). Cue did not have an influence on the latter ($p = .303$).

As in previous studies, we also explored whether participants' current need for money affected the above results. Across the whole sample, we found a negative correlation between need for money and the magnitude of the conflict adaptation effect involving motivational cues on the current trial ($r = -.40$, $p = .011$), suggesting that the higher their need for money the weaker the adaptation effect on motivational cue trials. That overall relationship was, however, mainly driven by the flower condition (flower: $r = -.53$, $p = .009$; gear-wheel: $r = .11$, $p = .671$). Current need for money was neither related to the magnitude of the conflict adaptation effect containing neutral or no cues, nor to their differences in magnitude.
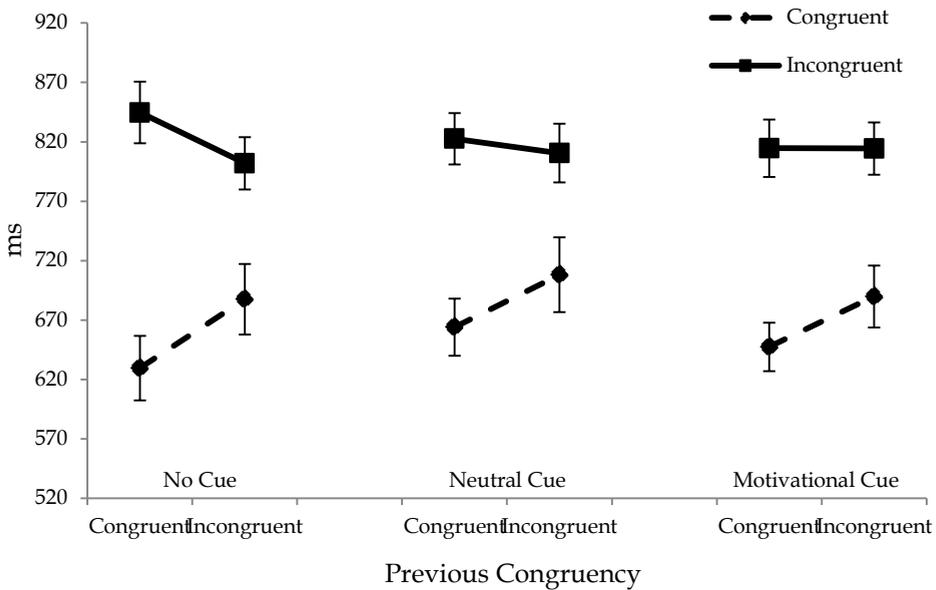
Figure 2.4. The conflict adaptation effect for each cue type in the 'flower' condition in Study 2.4. Lines represent responses to current trials, error-bars are +/- 1 *SE*.

Though the evidence of the last study is not univocal, the results in the flower condition suggest that even when we controlled for feature binding confounds we obtained the usual pattern of findings. Remarkably, the observed effect sizes for the conflict adaptation effect and the moderation by cue were comparable across studies, adding further confidence in our resource competition explanation of our effects. It remains unclear though why cue identity mattered in the present study. Though we can only speculate, one possibility could be the difference in familiarity between flowers and gear-wheels: Participants have probably encountered flowers more frequently in the past than gear-wheels. Although all participants were able to distinguish the two visually and semantically, maybe the flower was more easily remembered and monitored and therefore more readily influenced ongoing task-performance. Alternatively, it is possible that the focus on the gear-wheel put participants in a more achievement oriented state (a gear-wheel is frequently used as symbol for 'getting things in motion'), which might explain the overall speeding up of responses and might have led to a lowered susceptibility to task-irrelevant cues on the whole. Future research is needed to disentangle those different potential explanations.

Merged Analysis and Controlling for Feature Binding Confounds

Across four studies we investigated the degree to which conflict adaptation is protected in the presence of motivational distractors. Whereas most studies support our main finding that conflict adaptation is reduced when the current trial contains a motivational distractor, the pattern of findings was not always equally strong (e.g., Study 2.2 and Study 2.4). Therefore, to get a reliable and fully-powered estimate of our effect of interest, we merged the data of all studies and tested the overall within-subject design, and added the factor 'study' (four levels) as well as 'cue valence' (two levels). [9]

Moreover, we are aware that the design used in Study 2.1 to 2.3 remains susceptible to feature binding confounds (see Hommel et al., 2004), which potentially undermine our conclusion that motivational distractors reduce conflict-triggered control processes. Even though we have already addressed and controlled for those confounds in Study 2.4, we still wanted the merged analysis to be as unbiased as possible. To this end we repeated the merged analysis after having excluded all trials of Study 2.1 to 2.3 which were either complete repetition trials or complete alternation trials (for a similar method see Hengstler et al., 2014; Nieuwenhuis et al., 2006). Complete repetitions were trials in which all three features (i.e., target and non-target color, bar orientation) were the same across two trials, complete alternations were trials in which all of the three features changed across two trials. Through only analyzing partial repetition trials we controlled for differences in feature binding related response biases.

Results and Discussion

We first tested the main model on the merged data including all original trials. We conducted a 2(previous congruency) × 2(current congruency) × 3(current cue) × 4(study) × 2(cue valence) mixed model ANOVA (total $N = 286$) and obtained the three-way interaction of interest, $F(2, 560) = 11.26$, $p < .001$, $\eta_p^2 = .04$, which was not qualified by study (four-way $p = .449$, $\eta_p^2 = .01$), nor by cue

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[9] We also ran an additional exploratory analysis, in which we tested a related but different question. Namely, whether conflict adaptation was protected when the motivational distractor occurred on the previous trial, rather than the current trial. Note that we did not have clear predictions about this analysis, nor was the study designed to reliably test this question. The overall analysis only produced the congruency and conflict adaptation effects (all ps < .001), but no three-way interaction ($p > .100$). This suggests that in the present set-up conflict adaptation is protected from motivational distractors when they appear at the control-triggering stage (i.e., during the previous trial).

valence (four-way p = .414, η_p^2 < .01). Separate analyses for each cue showed that the conflict adaptation occurred for no cues, $F(1, 285)$ = 217.49, p < .001, η_p^2 = .43, neutral cues, $F(1, 285)$ = 97.99, p < .001, η_p^2 = .26, and motivational cues, $F(1, 285)$ = 35.66, p < .001, η_p^2 = .11. However, the adaptation effect was significantly reduced for trials containing motivational cues compared to no cues, $F(1, 285)$ = 25.51, p < .001, η_p^2 = .08, and compared to neutral cues, $F(1, 285)$ = 6.97, p = .009, η_p^2 = .02.

In preparation for the second analysis, we rebuilt the datasets of Study 2.1 to 2.3 excluding all full repetition (12.5%) and all full alternation trials (11.2%). Conducting the same mixed model ANOVA, we observed a reliable conflict adaptation effect, $F(1, 180)$ = 108.41, p < .001, η_p^2 = .28. More importantly, we retained the three-way interaction of interest $F(1.94, 542.19)$ = 10.06, p < .001, η_p^2 = .04 (Greenhouse-Geisser corrected for non-sphericity). The adaptation effect was significant for trials with no cues, $F(1, 285)$ = 139.88, p < .001, η_p^2 = .33, for trials with neutral cues, $F(1, 285)$ = 18.73, p < .001, η_p^2 = .06, and for trials involving motivational cues, $F(1, 285)$ = 6.34, p = .012, η_p^2 = .02. The contrast between trials containing no cues and motivational cues remained significant, $F(1, 285)$ = 25.90, p < .001, η_p^2 = .08, whereas the contrast between neutral and motivational cues did not, $F(1, 285)$ = 1.96, p = .135, η_p^2 = .01.

Together, the merged analysis including all original data showed that the magnitude of the conflict adaptation effect was significantly affected by the presence of a motivational distractor. Follow-up analyses showed that conflict adaptation was significantly less pronounced when the current trial contained a motivational distractor, compared to when it contained a neutral or no distractor. Importantly, when controlling for feature binding confounds, we retained the overall conflict adaptation effect, and its motivational modulation (although one follow-up contrast was weaker, which could be due to the non-random exclusion of about 25% of all trials). We therefore conclude that the presence of motivational distractors is more likely to have undermined the conflict-triggered control mechanism, rather than feature binding processes. This conclusion is in line with other work demonstrating that feature binding processes are immune to affective modulation (Trübutschek & Egner, 2012), and corresponds to earlier work showing the motivational modulation of conflict adaptation after controlling for the confound (e.g., Braem et al., 2012; Hengstler et al., 2014).

General Discussion

The goal of the present research was to test whether conflict adaptation is protected in the presence of motivational distractors. More specifically, we tested whether the conflict adaptation effect across two neutral interference (i.e., Stroop-like) trials was weaker or even absent when the current trial also contained a motivational (i.e., monetary reward or loss) distractor at the non-target location (or, as in Study 2.1b, at the target location). Results from the merged analysis across all four studies demonstrated that conflict adaptation was significantly reduced when the current trial contained a motivational distractor at the non-target location, compared to when the current trial contained a neutral or no distractor. These findings suggest that the motivational meaning of the distractor shaped our effects rather than the mere presence of the cue. Interestingly, this motivational modulation was found to be independent of whether the motivational distractor signaled reward or loss.

Two other findings from the merged analyses should, however, be stressed and taken into account when evaluating our findings: First, although motivational distractors reduced conflict adaptation, they did not make it fully disappear. Second, the average effect size of the motivational modulation of conflict adaptation (three-way interaction) was considerably smaller and more variable across studies (see the non-replication in Study 2.2) than the much more robust conflict adaptation and congruency effects. Taken together, the present set of studies demonstrate that conflict adaptation is both a robust mechanism which still operates to some degree in face of motivational distraction (partially supporting the protection hypothesis), but which is also not fully protected as motivational distractors reduced its strength significantly (supporting the resource competition hypothesis).

Our finding that conflict adaptation is reduced in the presence of motivational distractors, independent of whether they signaled reward or loss, is in line with the resource competition account, according to which cognitive and affective processes rely on the sufficient availability of shared resources (Pessoa, 2009, 2015). Therefore, if both types of processes are engaged at the same time – as was the case in trials in which a motivational distractor was present – they are likely to interfere and thus compromise each other's efficiency (see also Padmala et al., 2011). Such an interference is especially likely to occur when the cue is personally relevant (e.g., signaling real monetary reward or loss contingent on overall task performance) but not directly facilitating the target response (e.g., not being performance-contingent on the trial level). As this was the case in our study, we conclude that the motivational

distractors attracted and thereby diverted processing resources from the current task (see Pessoa, 2015). This conclusion was further supported by the finding that our pattern of results neither followed the effects of performance-contingent motivational cues (Braem et al., 2012), nor of purely affective cues (van Steenbergen et al., 2009, 2012). If anything, our results are line with the distractive effects of highly arousing affective information (Padmala et al., 2011), which is also characterized by an attention consuming aptitude.

One prediction that follows directly from the resource competition interpretation of our findings is, that the degree to which conflict adaptation is protected depends on the relative strength, or prioritization, of the control process and the motivational 'pull' from the distractor. To illustrate, we would expect even stronger modulation effects when the motivational distractor increases in value or personal relevance. For example, this could be achieved through increasing the associated monetary reward (e.g., signaling 50 cents instead of only 5 cents), or through increasing the overall need for the money (e.g., triggering consumption goals before the experimental session). In line with this notion, exploratory analyses in Study 2.4 showed that there was a positive relationship between the magnitude of the motivational modulation of conflict adaptation and participants' self-reported current need for money. Alternatively, one could increase the frequency of incongruent trials (see Lowe & Mitterer, 1982; Wirth, Pfister, & Kunde, 2015), which has been found to lead to generally higher levels of sustained control (i.e., smaller congruency effects) and could possibly also lead to better protected conflict adaptation. We would predict that conflict adaptation could be more (vs. less) protected when control processes are relatively stronger (vs. weaker) than the motivational 'pull'.

Our resource competition explanation rests on the assumption that the conflict adaptation effect is driven by conflict-triggered adjustments in cognitive control (Botvinick et al., 2001). However, we could not fully rule out the possibility that in Studies 2.1 to 2.3 the conflict adaptation effect was (partly) due to feature binding instead of cognitive control processes (see Hommel et al., 2004). Still, there are several reasons why we considered this alternative interpretation rather unlikely. First, we took great care to decrease the influence of feature binding through introducing the additional feature of the target-bar orientation (horizontal vs. vertical). This way, the majority of trials in each study were partial repetition trials, which implies that our analyses in Studies 2.1 to 2.3 were much less biased than in usual alternative forced choice tasks. Second, we could partly replicate our pattern of results in Study 2.4, in which we used a confound-free conflict adaptation paradigm (Weissman et al., 2014).

Third, in our merged analysis we controlled for the feature binding confound by only including partial repetition trials (for a similar method see Hengstler et al., 2014; Nieuwenhuis et al., 2006). Although the pattern of the follow-up contrast analyses was somewhat weakened (perhaps also due to the non-random omission of about 25% of all individual trials), the conflict adaptation effect and the motivational modulation thereof (three-way interaction) remained significant. In the light of those findings, we conclude that our resource competition interpretation of our findings is warranted. Importantly, this conclusion is also in line with previous research demonstrating that feature binding processes are immune to affective modulation (Trübutschek & Egner, 2012), whereas cognitive control processes are not (e.g., van Steenbergen et al., 2009, 2010).

As mentioned in the introduction, the literature so far suggests that motivational cues enhance conflict adaptation (only rewards, no effects for loss cues, Braem et al., 2012; Stürmer et al., 2011), while affective cues undermine conflict adaptation (with mixed results for negative cues, Padmala et al., 2011; van Steenbergen et al., 2009, 2012). The present set of findings contributes to that literature on conflict adaptation, and the motivational modulation thereof, in several ways. First, we are the first to show that motivational cues do not always help but can also hurt conflict adaptation, namely when in direct competition with target processing. This is in line with research from outside the domain of conflict adaptation, which highlights the disruptive effect motivational cues can have on behavior regulation (e.g., Bijleveld et al., 2011; Dolcos & McCarthy, 2006; Krebs et al., 2010).

Second, we have shown that motivational cues modulate conflict adaptation not only when they appear between trials, but even when they appear on the non-target location of the current trial itself. That is remarkable given that this is the place and time at which non-target information should have the least impact, especially in pro-active conflict adaptation. In fact, results from the merged analysis suggested that even though conflict adaptation was significantly reduced in the presence of motivational distractors, it did not fully disappear. Our findings therefore highlight both the flexibility as well as the robustness of the conflict adaptation effect.

As a third contribution of the present research, the development of our new task (especially as used in Study 2.4) can help investigate novel hypotheses (see below). The introduction of motivational distractors into an otherwise neutral interference task makes it possible to study the interplay between motivation and control in several different ways (see Supplementary Materials

1). Such knowledge could be especially relevant for research on anxiety disorders, addiction, or other psychopathologies characterized by poor controllability of motivationally charged but highly distracting and 'to-be-ignored' cues.

Limitations and Future Directions

The goal of our studies was to investigate the degree to which conflict adaptation is compromised when in direct competition with a motivational distractor. To provide a strong test of our research question, we chose a motivational cue that is maximally distracting. Accordingly, our motivational cues were presented directly at the trial, and were not performance-contingent in the immediate trial context. Our studies are thus different in comparison to earlier studies, in which motivational cues were always presented between trials and operationalized as directly performance-contingent cues. An interesting question for future research would be to test how cues that are performance-contingent in the immediate trial context would influence conflict adaptation if they were presented on the current trial. We would speculate that in such a case performance-contingent reward cues might be less effective, because there is less time for the alleged reinforcement of the conflict signal to evolve (Verguts & Notebaert, 2008). They might even distract from target processing considering that participants might enter trials anticipating a reward cue at the same time as the target is presented. If that was the case, then motivational distraction is mostly determined by the degree to which it is in competition with target processing, rather than by whether the motivational cue is directly or remotely performance-contingent. Conversely, it would be interesting to test how our general motivational cues would influence conflict adaptation if they were presented between trials. Whereas they could still be distracting and thus undermining conflict adaptation (cf. Padmala et al., 2011), they could also act like performance-contingent reward cues and thus enhance conflict adaptation (cf. Braem et al., 2012).

Another point of discussion concerns our choice of experimental paradigms, and how that influences the interpretation of our findings. All of our tasks were designed so that the non-target location, on which the motivational distractor was presented (except Study 2.1b where it was presented on the target location), received preferential processing (for similar methods see e.g., Padmala et al., 2011; Weissman et al., 2014). In Studies 2.1a, 2.2 and 2.3 this was achieved through presenting the non-target centrally, and through including catch trials on the non-target location. In Study 2.4 this was

achieved through priming the non-target before the target appeared. Controlling for participants' initial attention for the non-target location across all trials ensures that baseline conflict strength (between non-target and target response) was comparable on all trials, which enabled us to test the degree to which conflict adaptation is compromised by resource-consuming disengagement from the motivational distractor. What remains to be tested is whether conflict adaptation would be equally susceptible to motivational modulation if participants' attention was not initially guided to the non-target location. This could, for example, be tested in a standard flanker task in which participants are required to shield their attention from non-target information that appears on the periphery. The disadvantage of such a design is, however, twofold. First, if the motivational modulation was replicated, it would be unclear whether it is due to fast orienting towards, or to slow disengagement from the motivational distractor, or both (for a similar point see Koster et al., 2004). And second, recent research argues that preferential non-target processing is a necessary precondition for conflict adaptation to occur (Weissman, Egner, Hawks, & Link, 2015; Weissman et al., 2014). We therefore are confident that controlling for initial attentional orienting provided a more informative test of motivational modulation of conflict adaptation.

Concluding Remarks

In the current set of studies we showed that conflict adaptation is not fully protected in the presence of motivational distractors. We have argued that this is because processing the motivational distractor competes for the same resources as the control processes necessary for task performance, thereby compromising each other's efficiency. Though this overall finding may appear like a weak spot in the controllability of behavior, it may actually illustrate the strengths of cognitive adaptability. Instead of focusing exclusively on one specific task rule, control processes remain open to relevant signals of potential reward or loss. To conclude, in line with recent theorizing (Pessoa, 2009, 2015) our studies suggest that top-down control does not completely shut off bottom-up processing, but that they continue to shape behavior together.