RESPONSE CONFLICT
AND FLUENCY OF PROCESSING
AS AFFECTIVE SIGNALS
FOR CONTROL ADAPTATION

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Anja Berger
aus Steinberg am See

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Erstgutachterin: Prof. Dr. Gesine Dreisbach
Zweitgutachter: Prof. Dr. Andreas Mühlberger

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Hint: The cage is not locked.

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PREFACE

In our daily lives, we often experience situations in which we tend to respond and act automatically in a certain way. However, in many cases this immediate response is not the most appropriate one: Our way to work may be convenient by car, but as this action would contradict the goal to behave in an ecofriendly manner, we choose to go by bicycle instead. Chocolate may be delicious, but eating it interferes with our goal to maintain a healthy lifestyle, so we resist the temptation.

Cognitive psychology has long been investigating comparable events in experimental settings. Scientifically speaking, the abovementioned situations contain so-called response conflicts: There is a conflict between an automatic or habitual response and another, more appropriate one, which may in turn be more effortful. One activated response is incongruent to the other activated response (or to a certain component of the stimulus). In the past decade, cognitive psychology has intensively researched human behavior in such conflicting situations. There are effects of adaptation in sequences of incongruent and congruent events and in contexts that cue a certain density of response conflicts: It is easier to respond appropriately to a response conflict, if it is preceded by another response conflict or if it occurs in a context in which it typically occurs. Researchers have discovered that it is not the conflict between two response options per se, but the affective component that goes with it that motivates adaptation. Response conflict harbors an aversive signal that the organism wants to overcome and prevent, which leads to adaptations of the way it focuses its attention and the way it responds. With this insight, it was found that all aversive signals, also those decoupled from response conflict, lead to similar effects. That is, not only situations in which we must choose between response options, e.g. going to work by car or by bicycle, are affected by this field of cognitive research. It also concerns other events that are experienced as aversive, such as disfluency in stimulus processing. A book with faded ink or a bad copy of a document, for example, are visually disfluent stimuli which might feel unpleasant when we encounter them. Like with response conflicts, adaptation of the response mode is possible. When getting a phone call at a train station – and hence encountering auditory disfluency – we know that the background noises will make it difficult to understand the person at the other end, so we listen more closely, turn the volume of our phones up or use headphones. It is scientifically conceivable that there is adaptation of control and of resulting behavior that is motivated by affective signals.

It is also ecologically relevant to understand when and how these adaptations emerge. The purpose of this dissertation is therefore to scrutinize the functioning and characteristics of affective signals as the driving force of control adaptations. In three peer-reviewed studies, different aspects of control adaptations are examined. The roots and scope of the proposed control mechanism are investigated in a behavioral study with slight methodological changes as compared to traditional experimental investigations. A psychophysiological study allows for online measurement of affective responses throughout a response conflict task and leads to further insight on the relation between experienced affect and behavioral adaptation. Finally, in a behavioral study using ecologically relevant auditory stimulus material, the boundary conditions of contextually driven adjustment of control is investigated.

To look at response conflict and other aversive signals from different angles can be beneficial for this field of research. Introducing variation in levels of (in)congruency to traditional experimental paradigms, measuring experienced affective valence with objective methods and trying to create experiment properties that are less artificial than other laboratory studies increases the insight that is gained from experimental investigations and the validity of them. Here, the aim of presenting the three different studies together is therefore to identify potential room for improvement in existing theories and to be able to draw universally valid conclusions about the executive functioning in human behavior. While, of course, a laboratory paradigm is not the same as deciding what vehicle to choose to go to work in the morning, it is discussed what we can learn for making this decision from experimental psychology and how we can learn from it in the most fruitful way.

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ABSTRACT

Response conflict has been a frequent topic of research for the last two decades. Behavioral adaptations to conflicts have often been replicated and reported and yet the theoretical debate about their origin is still going on. While some claim that the underlying mechanism of characteristic response patterns is adjustment of cognitive control, others argue that the effects that are typically found in standard conflict paradigms, such as the Stroop-, Simon-, or Eriksen-Flanker-Task, are entirely caused by contingencies and repetitions that are caused by the way the task is presented. There are several hints towards an affective-motivational component of control adaptations which go way beyond basic processes such as contingency learning and repetition priming. Research presented in this dissertation suggests a theoretical account of conflicts as aversive disfluency signals, which set control processes in motion.

First of all, the often unattended question about the role of congruent trials in typical response conflict paradigms is asked in **Study I**. A typical paradigm is extended by a neutral reference condition, so that an objective comparison of the contribution of congruent and incongruent trials to the typical behavioral pattern is possible. As this study demonstrates, adaptation occurs not only after incongruent trials, i.e. conflict, but also after congruent trials. Therefore, the affective characteristics of the stimuli in an ongoing response conflict paradigm and their relation to behavioral patterns are investigated. To this end, online measurements of the activity of two facial muscles indicating emotional responses are achieved in **Study II** using electromyography. This study shows that indeed, by tendency, incongruent trials elicit rather negative responses and congruent trials elicit positive responses. The strength of muscular activation was furthermore correlated with the strength of behavioral adaptation, pointing towards a process of affectively motivated control adjustments. In **Study III**, a mechanism of contextual rather than sequential control adjustment is the subject of research. Former studies have shown that cognitive control can be flexibly adjusted in a context-specific way depending on perceptual context features, such as stimulus location or social features, such as gender identity of a facial stimulus. The auditory stimuli that were used in the tasks, which are part of Study III, vary in control requirements depending on the voice identity of the speaker. Although context specific control adaptation could not be clearly observed, there are strong hints towards an adaptive mechanism that adjusts attentional control in dependence of the current context. The investigation of an auditory and ecologically graspable context feature like voice identity is relevant and new, and Study III is therefore a door-opener for further scientific investigations.

Results of all three studies corroborate the notion of an affective-motivational mechanism underlying sequential as well as context-specific adaptation of cognitive control. While response conflict is not the only and probably by far not the most frequent event calling for control adaptation, the existing account of conflicts as aversive signals for control adaptation is developed into an account of fluency monitoring. It is supposed that more and less fluent events in our environment cause flexible up- and downregulation along a continuum of control in the service of affect regulation. These are valuable insights insofar that they can be used as a theoretical basis for future experimental research. Potential fields of application like marketing and product development can benefit from and build on the theoretical foundation provided by cognitive psychology that is corroborated and updated here.

PART I

INTRODUCTION

Response conflict and cognitive control

Response conflict

Response conflict is a frequent phenomenon that can occur in various contexts and situations in human daily life. In everyday thinking, a working definition of response conflict covers certain aspects: Response conflict is a situation of certain relevance or affective significance (see Pessoa, 2009) with, a) multiple possible response options of different outcomes (cf. Botvinick et al., 2001), b) certain preferences regarding these response options (e.g. in terms of effort; Hull, 1943; Inzlicht et al., 2018) and outcomes (Botvinick, 2007), and c) a mismatch or cost-benefit tradeoff between the preferred response and the preferred outcome, which harbors a certain unpleasantness (cf. Dreisbach & Fischer, 2016). This rather abstract and general definition becomes more vivid by thinking of an example: The pressing issue of climate change adds the necessary relevance to many situations in daily life for them to arouse response conflicts. Imagine you want to buy apples at the grocery store. In this situation, you can act automatized, grabbing the juicy looking apples packed in four that are presented at the very beginning of the aisle. We can assume that this immediate response would be the most convenient and the least expensive one in terms of effort. Therefore, it might be the preferred response option. The outcome, i.e. the consequences that go with this response (contributing to CO_2 emissions and pollution by consuming imported goods from a southern region and producing plastic waste) might however, not be your preferred outcome. The alternative, more eco-friendly response option would be to walk down the aisle further, read the origin information signs, pick up the local apples one by one and put them in a fruit net. This option might be more costly in terms of effort (and perhaps also time or money), but in this context you will be motivated to make these investments. The alternative response option is therefore the more appropriate one, which is then the option that will likely be carried out eventually.

Although this equation sounds simple, it is not always that clear if and how less desirable automatic response tendencies can be overcome. Of course, in the illustrative shopping example, many factors might additionally influence the response in an actual situation: It has an impact whether there are any alternatives available at all. Other factors, like how much money the person carries with them or whether they are in a hurry or not have to be taken into account and perhaps social factors, like judgment of other customers, or how their family at home might react, may play a role as well. As pointed out before, affective influences may modulate control in one or the other direction. Despite uncertainty and unpredictability in everyday life scenarios, there has been a fair bit of experimental research on response conflict in order to find out how and why response conflict can be overcome. Although this subject of research is apparently accompanied by various sources of noise, general research findings regarding response conflict are quite robust. An action like the one described in the example has to be thought of as a response to stimulus features (i.e. two types of apples) in a certain task (i.e. buying apples) with a certain task rule (e.g. buying local/eco-friendly while ignoring placement and advertisement). This reasoning also applies to situations in which habitual response tendencies have to be overcome: Just think of your overlearned (i.e. preferred) action of looking before crossing a street. When you go to a country with left-hand traffic, the habitual looking pattern (left – right – left) has to be actively reversed (right – left – right) and therefore the preferred action and the preferred outcome of crossing the street safely suddenly no longer match.

It is clear that one response is carried out more easily and rapidly than the other one, but it is less obvious which processes enable the appropriate response to prevail over the automatic one and how action and attention are guided during and after that response. Scientific definitions of response conflict, just like the definition developed above (response and outcome options; preferences; mismatch), contain features like the compatibility between targets and distractors (Gratton et al., 1992) as separate stimulus features activating opposing typical response tendencies (Botvinick et al., 2001). Operationalizations of these situational features are manifold. Therefore, response conflict can be studied well in the lab.

Response conflict paradigms

In order to investigate relevant processes during perception and resolution of response conflicts in the lab, researchers make use of dimensional overlap between stimuli and responses in order to create compatible and incompatible task conditions (Kornblum et al., 1990). The Eriksen Flanker paradigm (cf. Eriksen & Eriksen, 1974), for example, which was initially developed to avoid visual search in a task in which targets had to be identified among noise, has become one of the standard paradigms to investigate response conflict. Typically, the task requires the identification and categorization of a centralized target stimulus that is flanked on two sides by so called distractors. Distractors may either be compatible or incompatible to the target letter (cf. Kornblum et al., 1990). Eriksen and

Eriksen (1974) found out that task-irrelevant noise is processed and impairs correct and fast target identification, varying with the spatial proximity and response compatibility of noise and target. The main finding was that compatible distractors lead to less interference than incompatible distractors. Until Today, this task is frequently used to investigate response conflicts with various types of stimuli among letters and symbols, such as arrows (Bugg, 2008; Mayr et al., 2003; Nieuwenhuis et al., 2006), colors (Cohen & Shoup, 1997; Fritz et al., 2015; Verbruggen et al., 2006) and more complex features like entire words (Kanske & Kotz, 2010; Schmidt & Weissman, 2014).

One study that inspired another paradigm, the typical Simon task, was originally designed to investigate how varying visual angles of stimulus displays and the assigned responses affect reaction time (Simon & Wolf, 1963). The authors found a time reduction of 30 % for an angular rotation of 180°, which is the rotation that is now usually used in these paradigms (i.e. stimulus laterally shifted to the right, manual response laterally shifted to the left). Furthermore, Simon and Rudell (1967) found out that auditory commands to carry out lateralized manual responses led to faster responses in case of spatial compatibility than in the case of spatial incompatibility. The traditional response conflict task that has been used thus far is to respond to a certain stimulus dimension of a lateralized target stimulus with a lateralized response. That is, there is dimensional overlap between the stimulus and the response (Kornblum et al., 1990). If the (irrelevant) position of the stimulus and the position of the response match, we speak of compatible trials. In case of a mismatch, trials are incompatible. Although the location information is uninformative, it seems to be processed either way, just as the distractors in the Eriksen Flanker task. Hitherto, the typical effect of spatial compatibility in terms of the Simon effect with lateralized stimuli and lateralized responses has been tested in various modalities and with different types of stimuli (e.g. tactile: Hasbroucq & Guiard, 1992; for a comprehensive review, see Hommel, 2011).

The most paradigmatic task that is used to investigate response conflicts is the so-called Stroop paradigm. The paradigm originates from a study by Ridley Stroop (1935), who investigated interference of the ink color that words are presented in and their semantic content when reading them out loud vs. when naming their ink color. The main finding was that the semantic content of the words interferes strongly with naming the color they are presented in. This effect is interpreted in terms of the strength of the associations that have been formed between the individual stimulus features and the respective responses. While reading is a much stronger, i.e. the habitual, response when faced with a word, naming colors out loud is a response that is not practiced often. While in the Simon task, for example, there is a conflict between one stimulus dimension and one response dimension, the conflict of the Stroop task lies within the stimulus itself, as there are several opposing stimulus dimensions. This is what makes the Stroop task the most striking example for response conflict investigations in the lab. A situation itself promotes two or more different ways of responding inherently, of which one is more appealing, carried out habitually, or stronger in a different sense, and must be overcome. Until today, it is used in its original and several adapted forms (like face-word Stroop, see e.g. Stenberg et al., 1998; or emotional Stroop, see e.g. Chiew & Braver, 2010; Compton et al., 2003; Isenberg et al., 1999) and is being thoroughly researched.

Response conflict and cognitive control

Cognitive control, also referred to as executive functions, is needed in many situations in human daily life. Executive functions encompass working memory and its updating, inhibitory control and cognitive flexibility or set shifting (Diamond, 2013; Friedman & Miyake, 2017; Miyake & Friedman, 2012). Certain nuances and combinations of these abilities form even more complex skills that modern humans need, such as planning and action control. Cognitive control, as defined in this dissertation, harbors characteristics of inhibitory control, that is the inhibition of an otherwise automatized action or response due to certain task circumstances. The flexible adaptation of cognitive control can additionally be associated with shifting and updating: Depending on current task properties, on the task in general and on its broader context, the beneficial effect of inhibition varies with the varying amount of helpful or harmful task-irrelevant information. One could say that cognitive control is what guides our behavior whenever lower level processes such as reflexes and associations do not suffice, so that we act appropriately in the light of the context and superordinate goals, irrespective of habits and temptations that might counteract these goals.

Many situations in which cognitive control is required afford rather complex actions. Among others, these include situations like multitasking and task switching or planning of future actions and daily life actions and decisions that require a certain degree of willpower. That is, in the case of response conflict our actions require cognitive control. Overlearned, habitual actions can cause conflicts between an automatic, but inappropriate and a more controlled, but correct action. Therefore, cognitive control as a virtually omnipresent process and response conflict as a frequent phenomenon in practical daily life are, justifiably, a central subject of cognitive research. How we flexibly adapt the level of cognitive control after response conflict has been experienced is one of the most interesting questions regarding this topic.

Adaptation to response conflict

The most striking effect of response conflict is, of course, the immediate interference of the conflicting input, may it be distracting flanking information like in the Eriksen-Flanker task, irrelevant but salient location information like in the Simon task or any other irrelevant stimulus component, like the word content in the Stroop task or inappropriate habits in any everyday life example. This interference, termed as Flanker effect, Simon effect, Stroop effect, or just conflict interference, respectively, manifests in increased response times and error rates to conflicting stimuli as compared to stimuli with congruent irrelevant information. Increased response times and errors represent a performance cost that is, of course, sought to be avoided by the organism.

Adaptation to conflict interference is behaviorally observed on several levels. First of all, there is adaptation to conflict in sequences of trials, which allows for facilitated responding to consecutive conflict trials. The so called congruency sequence effect, an apparent behavioral adaptation to the exact sequence of incongruent (i.e. all types of conflicting) and congruent trials after one another, has first been reported by Gratton et al. (1992). They set up the hypothesis that expectancies for compatible and incompatible trials based on previous trials should impact participants' stimulus processing and response behavior. By relying more (after compatible trials) or less (after incompatible trials) on the irrelevant stimulus information, the abovementioned conflict interference effect in errors and response times should be increased or decreased. What they found was exactly what they had expected: The conflict interference effect varied as a function of previous trial congruency: After compatible trials, participants easily solved compatible trials, but showed more interference in case of incompatible trials. After incompatible trials, participants seemingly expected another incompatible trial and hence had less difficulties in solving incompatible trials, but even showed an increase in response time for compatible trials. This effect emerged due to variations in stimulus processing depending on the previous trial type, as is suggested by changes in the lateralized readiness potential (LRP) amplitude (Gratton et al., 1992). While in this original study, the changes in stimulus processing and behavior were investigated using an Eriksen-Flanker paradigm, the effect has by now been replicated for all types of response conflict analogously (e.g. Simon Task, Stürmer et al., 2002; Stroop Task, Kerns et al., 2004). Over the last two decades, it has been extensively researched how exactly our behavior is guided in response conflict situations. Ever since the congruency sequence effect was first reported (Gratton et al., 1992), there has been a discussion on what processes underlie behavioral adaptation. The discussion can be broken down into two different main camps: The associative learning and lower level process theories, and the cognitive control theories that, in line with the reflections on conflict and executive functioning presented here, assume that the conflicting response options motivate adaptations in cognitive control. Although there is ample evidence for an involvement of cognitive control in processes of adaptation to response conflict, both theoretical notions deserve to be given a closer look separately.

Cognitive Control Theories. The neurophysiological basis of all executive functions, and therefore of cognitive control, lies in the prefrontal cortex (PFC). While, of course, also the interconnectedness with other brain areas, e.g. the cingulate cortex, posterior and subcortical regions, plays a role for cognitive control, the PFC can be seen as the central executive that also modulates activation in other brain areas (Stout, 2010). The PFC developed late in human evolution and is also the part of the brain that develops latest within one human life. Compared to other species, the human PFC occupies an overly large part of the cortex. Different prefrontal regions are associated with different specific components of cognitive control (see Goschke, 2017). These neurobiological prerequisites enable complex actions, such as reasoning, planning, and complex social interaction (van Overwalle, 2011) that are unique to humans as compared to non-human animals.

Probably the most influential cognitive control theory of how response conflict guides our behavior is the Conflict Monitoring Theory (CMT) by Botvinick et al. (2001). The CMT offers a knowledgeable view of what response conflict is and how control adjustments develop. As a computational model, it parsimoniously defines response conflict as the simultaneous input of non-corresponding information, equally activating opposing output response tendencies. According to the CMT, this response conflict is registered by a monitoring entity, located in the anterior cingulate cortex (ACC), which is strongly interconnected to the PFC and shows activation as soon as competing response tendencies are activated simultaneously. Imaging studies have shown, that the ACC then signals the need for increased cognitive control by projections to a control unit, located in the PFC (Kerns et al., 2004). Without needing any explicit information on the conflict, the PFC then exerts cognitive control by adjusting the weight of input information. This results in a relatively strengthened focus on task-relevant information in the trial following a response conflict or in conditions where response conflict frequently occurs. In a typical response conflict, e.g. the Stroop conflict, the process would be the following: When a color word (e.g. RED) in a non-corresponding ink color (e.g. blue) is presented, and the instruction is to name out loud the ink color of the word, naming the color (“blue!”) and reading the word (“red!”) would lead to opposing responses. In this incongruent case, the ACC detects response conflict at the output layer and signals the need for adjustment of control at the input layer to the PFC. The weighing of semantic vs. perceptual input and corresponding processes (i.e. reading the color word vs. naming the color) is adjusted and appropriate output, i.e. responding, is possible.

In a modification of the original CMT, Botvinick (2007) specified various affective signals besides conflict that lead to ACC activation and adaptive behavioral changes. In this reconciliation of the specific conflict monitoring account and a more general outcome evaluation account of ACC activation, the author suggests that the ACC responses to various negative stimuli serve as teaching signals which eventually lead to avoidance learning. Response conflicts, performance errors, physical pain, financial loss and negative (social) feedback, among others, promote behavioral patterns and control sets that lead to less negative outcome. In other words, information processing is modified, so that conflicts and other input associated with negative outcome can be responded to in an efficient way. This modification may contain exertion of control and strengthened task-relevant associations in terms of a reallocation of attention towards task-relevant features and/or away from distracting stimuli in the service of an improved cost-benefit balance regarding effort and resources, and performance and outcome (Kool et al., 2017).

Dreisbach and Fischer (2015, 2016) have built on this point of view and on their own research of aversive signals besides response conflict: As they have pointed out, previous research had shown that response conflicts are aversive. Response conflicts can serve as negative primes in the affective evaluation of (subsequent) stimuli (Brouillet et al., 2011; Dreisbach & Fischer, 2012a; Fritz & Dreisbach, 2013; Hatukai & Algom, 2017) and are therefore likely to carry negative affective value. On a related note, van Steenbergen et al. (2009) could show that there is no conflict adaptation in a current trial N, if a positive event (i.e. an unexpected financial reward) occurs between the conflicting foregoing event in trial

N-1 and the current trial N. They supposed that the positive event counteracts the aversive conflict signal, which cancels out the need for control adaptation in order to compensate for the negative affective experience.

Investigations of the signaling function of conflict are also in line with the idea of an aversive conflict signal that initiates adaptation processes. Desender et al. (2014) showed that it is not the actual response conflict but the subjective feeling of (mistakenly) identified conflict that determines behavioral adaptation processes. Although they only investigated conflict identification without any affective judgments, this subjective component already hints towards affective processes fueling adaptation processes. Psychophysiological evidence for this assumption comes from Fröber et al. (2017). They could show that the affective evaluation of a trial influences the subsequently triggered lateralized readiness potential, irrespective of the actual conflict level (i.e. compatible/congruent or incompatible/incongruent trial). The results provide evidence for a role of affect rather than a role of actual response conflict for conflict adaptation.

Adaptation to aversive signals without response conflict has been reported before and is, by now, a robust empirical finding. For example, reduced fluency of processing can serve as an aversive signal that causes sequential behavioral adaptation. Fluency of processing describes the objective or subjective, i.e. felt, ease with which information can be extracted from a stimulus (Winkielman et al., 2003). This can affect the perception, encoding, conceptualization, or retrieval of a stimulus (Reber & Greifeneder, 2017) and is hedonically marked (Forster et al., 2013; Topolinski et al., 2009; Winkielman et al., 2003). Dreisbach and Fischer (2011) were the first to directly and experimentally investigate the assumption that due to the negative affective valence of disfluency there should be sequential adaptation to disfluent stimuli. Instead of conducting a conflict paradigm, their participants had to make magnitude judgments to centrally presented number words that were presented either in black standard font (Arial), or in disfluent gray, scattered or hand-writing style font (Mistral). They found the same behavioral effects of sequential adaptation that are found in conflict tasks.

Taken together, these findings have sparked the thought of control adjustments in response to an affective signal, rather than to response conflict. In line with theoretical amendments to the original CMT, the account of conflicts as aversive signals for control adaptation was introduced (Dreisbach & Fischer, 2012a, 2015, 2016). Dreisbach and Fischer (2016) have revised existing control theories like the outcome evaluation account and added a meaningful motivational context to the concept of response conflict. The aversive signal of conflict is proposed as the driving motivational force of control adaptations. Importantly, the account resolves one central flaw of other theories on sequential (and list-wide or context-specific) control adaptation: Control adaptations as a result of previous conflict and expectancies (cf. Gratton et al., 1992) are not entirely conceivable, because there is no definite knowledge about the congruency level of a certain trial in a sequence or block. In fact, control adaptations may be unnecessary and costly, if an expectedly conflicting trial is in fact not conflicting. The account of conflicts as aversive signals introduces control adaptation as a form of affect regulation, which covers this shortcoming. That is, the change of response strategy (i.e. increasing control and attentional focus on task-relevant stimulus features after conflict detection) reduces the risk of experiencing another aversive event (i.e. errors and difficulties when facing conflict). This account provides a parsimonious yet comprehensive theoretical foundation of control adjustments in response to all kinds of situations that are of a certain relevance and/or affective significance and require a response action. Therefore, it serves as the basis of a broad range of contemporary research and, more specifically, of the research presented in this dissertation.

Associative Learning and Lower Level Process Theories. The congruency sequence effect in a Flanker task that uses stimuli composed of two different letters (e.g. HHSHH) or arrows (e.g. >><>>) and two-choice reactions is not necessarily bound to the presence or absence of response conflicts. As Mayr et al. (2003) have pointed out, response patterns that suggest behavioral adaptation to congruency sequences can sometimes be fully explained by stimulus-specific repetition priming effects. In a task with only two different stimulus features (e.g. > and <), sequences of two consecutive congruent trials (so-called cC sequences) or two consecutive incongruent trials (iI sequences), the stimuli are always full repetitions (e.g. “>>>>>” preceding “>>>>>”) or full switches (e.g. “<<<<<” preceding “>>>>>”). It has been suggested that episodic memory in these trial sequences causes beneficial priming effects insofar that there is a response benefit in terms of extremely fast responses in the full repetition trials (Mayr et al., 2003). Sequences in which the type of congruency changes and an incongruent trial follows a congruent one (cI sequences) or vice versa (iC sequences), however, always harbor partial repetitions. If, for example, an incongruent trial >><>> follows a congruent trial >>>>>, the target changes but the distracting flankers repeat, and if a congruent trial <<<<< follows an incongruent trial

>><>>, the distractors change, but the target repeats.[1] Consequently, these sequences can never benefit form episodic priming in the way cC and iI sequences can, which might explain selectively reduced response times in cC and iI data points. In turn, feature binding may even cause partial repetition costs that impair performance in cI and iC sequences (Hommel, 1998). Similarly, binding processes causing the integration of several stimulus features into so-called event files (Hommel, 2004; Verguts & Notebaert, 2009) may cause effects in paradigms other than the Eriksen Flanker task. Feature pairings that have been responded to in a certain way (e.g. the word BLUE written in red, responded to with the left one of two buttons) may have been formed but become disruptive in the next trial (e.g. when the word blue is written in blue, to which the right one of two buttons is the correct response). The performance costs and benefits described by memory-related processes like binding and priming can indeed produce sequential effects in response conflict paradigms (for an investigation of effects in the third standard paradigm, the Simon task, see (Chen & Melara, 2009). In related accounts, it is sometimes argued that adjustments of control may occur on the basis of these processes due to an interplay of binding and conflict-induced arousal. The arousing conflicts theoretically lead to increased noradrenergic activation which leads to stronger associations and binding (Verguts & Notebaert, 2009).

In addition to sequential adjustments, adaptation to conflict also occurs on a list-wide level, i.e. depending on the overall frequency of conflict in a certain task or list of trials within a task. Interestingly, the hypothesis of Gratton et al. (1992), that the expectancy of conflict guides conflict resolution, was based on earlier research revealing longer-term adaptations to conflict: In a vertical Simon-like task, Logan and Zbrodoff (1979) have manipulated the relative frequency of compatible and incompatible trials and found out that higher proportions of compatible trials led to facilitation of their processing, while lower proportions of compatible trials led to facilitation of processing of incompatible trials. With an 80:20 proportion of compatible to incompatible trials, they found a positive interference effect of spatial compatibility, while with a 20:80 proportion they found a negative interference effect in response times (i.e. slower responses to compatible trials than to incompatible trials). This so-called proportion-congruent (PC) effect (Jacoby et al., 2003) or list-wide adaptation effect (Bugg, Jacoby, & Toth, 2008) has since then been found

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[1] Of course, this example is incomplete and cI trials may also contain a repetition of the target instead of the distractors, and iC sequences may also contain a repetition of the distractors instead of the target.

repeatedly in conflict paradigms. Jacoby et al. (2003) have argued that the PC effect may operate at an item-specific rather than at a general level: While maintaining an overall PC of 50 %, they divided the stimuli they presented into two sets, such that some items were presented mostly congruent and some were mostly incongruent. The results showed that the item type interacted with the congruency effect. The congruency effect in mostly incongruent items was significantly smaller than the congruency effect in mostly congruent items. This finding was at first interpreted as evidence for automatic control processes that operate when being faced with particular stimuli rather than strategic adjustment of effort and control. This notion was later qualified by further examinations that showed that item-specific adjustments can neither explain list-wide effects that transfer to neutral items (i.e. items which are presented with a PC of 50 % within a mostly congruent or a mostly incongruent list), nor can they explain interference that shows in a secondary task, such as a target response to a certain distracting feature (see Bugg, 2012 for a thorough dissociation of item-level and list-level control).

Furthermore, the context in which a stimulus appears can be a cue for control allocations. Crump et al. (2006) modified existing paradigms by uncoupling the PC-manipulation from any stimulus-specific component that could be used to form associations to facilitate responding (e.g. a word in a Stroop task). The PC-manipulation in a Stroop-like prime probe paradigm, in which a colored target-shape (circle or square) followed an irrelevant color-word prime, was tied to the position and/or shape of the target stimulus. The context-specific proportion-congruency (CSPC) effect showed in terms of smaller Stroop-interference effects for targets at the mostly incongruent location/shape, and larger interference for targets at the mostly congruent location/shape. Furthermore, their investigation indicated that some contextual cues are stronger than others: With a redundant context cue, consisting of both shape and location, a CSPC effect was found. When the redundancy was removed and either the position of targets remained the same, but shapes varied, or the shapes remained the same, but position varied, the results were ambiguous insofar that only the location cue led to a CSPC. Nevertheless, the CSPC effect has by now frequently been replicated in various kinds of paradigms and contexts. Contextual cues that have been reported to lead to contextual adaptation of control are for example social categories such as gender or facial expression (Cañadas et al., 2013; Cañadas et al., 2016), conceptual categories (Dreisbach et al., 2019), or even timing components (Wendt & Kiesel, 2011). In line with the account of aversive signals for adaptation, recent research also revealed a context-specific proportion fluency effect (CSPF), that is adaptation to contexts that typically come with higher or lower levels of fluency and, consequently, of higher or lower density of aversive signals (Dreisbach et al., 2018).[2]

Comment on the theoretical debate

In an investigation of cognitive control functioning using simulations, Tomlin et al. (2015) showed that mere automatic processing and responding (i.e. lower level processes) cannot subsist on their own. On the other hand, fully controlled behavior may, by its spread, cause conditions that undermine its further development and therefore cannot subsist either. The authors outline that both, fully automatized and fully controlled ways of behavior come with certain benefits and costs and interact in a manner which causes both to prevail in parallel. Relatedly and to preempt a large part of the discussion about how exactly behavioral adaptation patterns emerge in response conflict paradigms, it has been summed up in the literature before that probably both, episodic priming or associative learning and genuine adaptations in cognitive control, play a part (Egner, 2007; 2017, p. 75; Goschke, 2017, p. 295).

Tying onto the account of aversive signals for control adaptation, it is obvious that emotion and motivation – as the root of volition and action control – go hand in hand. In literature on cognitive control, especially in the context of response conflict, emotion cannot be left unmentioned. It has been stated that cognitive and affective processes are closely intertwined, which renders "their strict separation (…) more semantic than real" (Pessoa, 2017). Pourtois et al. (2020) present a broad range of evidence for the interconnectedness of cognitive control and emotion in processes like error monitoring, conflict processing, task switching, decision making, and the regulation of emotions. Other authors have also pointed out that there are overlaps in terms of neural activation between affect and cognitive control (Botvinick, 2007; Shackman et al., 2011). The functional interplay of cognition and emotion has often been investigated. The logical interconnectedness of emotional input and executive functioning, such as attentional focus when facing threats, has been pointed out

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[2] Some argue that list-wide and context specific adaptation effects are behavioral artefacts caused by task confounds (Schmidt, 2019). Consequently, the CSPC effect is said to be caused by contingencies, i.e. lower level processes, instead of adaptation of cognitive control. As the focus here lies on control theories, this account is not further introduced here.

in early literature (see van Steenbergen, 2015). Pessoa (2009) names shared process capacities of emotional processes and executive functioning and implies that emotion may either enhance or impair behavioral performance depending on how exactly cognitive control is modulated. While affective stimuli and situations can directly influence executive control, affectively driven motivation (e.g. reward sensitivity, avoidance of unpleasant situations) can lead to the exertion of cognitive control in conflicting situations in an indirect way (Pessoa, 2009). Inzlicht et al. (2015) have also outlined that cognitive control is often dependent on emotion and can, more precisely, be understood as an emotional process itself.

Taken together, cognitive control and emotion are connected in a meaningful way and it has been stated that conflict processing lies directly at the intersection between emotion and cognitive control (Inzlicht et al., 2015; Pourtois et al., 2020; see also Dreisbach & Fröber, 2019). Often, situations are perceived as conflicting only by the motivation to act or to not act in a certain way, which in turn is often emotionally motivated (Inzlicht et al., 2015). Therefore, the theoretical account of conflicts and other aversive signals, such as disfluency, as the driving force of control adaptations, is based on a solid theoretical foundation and serves as groundwork for the research that is presented here.

The current state of research

Relevant groundwork on affect and control

As outlined before, van Steenbergen et al. (2009) had found that positive signals in between trials of a conflict paradigm counteract conflict adaptation. Among others, this result informed the theoretical reasoning about conflict adaptation and fits an account of aversive signals for conflict adaptation. However, a systematic attempt to replicate this finding has failed. Dignath et al. (2017) investigated whether the manipulation of affect and arousal in between trials of a conflict paradigm would weaken or strengthen sequential conflict adaptation effects, but did not find evidence for either. While van Steenbergen et al. (2009) showed that the positive affective signal of reward led to diminished conflict adaptation effects, another study (Braem et al., 2012) revealed in contrast, that reward increases conflict adaptation. The explanation for these seemingly contradicting findings is that in the method used by van Steenbergen et al., the unexpected reward acted as a mere induction of positive affect, which reduces proactive control and thus also reduces sequential control adaptation, while performance-contingent reward (as used in Braem et al., 2012) boosted motivation to perform better and thus increased cognitive control (Chiew & Braver, 2011; Dreisbach & Fischer, 2012b; Fröber & Dreisbach, 2014). This deeper understanding of the influence that (positive) affect can have on cognitive control is essential for further research.

The most important groundwork is built on research regarding the signaling function of conflict and other aversive stimuli. Evidence for conflict priming (Brouillet et al., 2011; Dreisbach & Fischer, 2012a; Fritz & Dreisbach, 2013) and fluency adaptation (Dreisbach et al., 2018; Dreisbach et al., 2019; Dreisbach & Fischer, 2011) are findings that have been essential for the development of the account of conflicts as aversive signals (Dreisbach & Fischer, 2015, 2016) and directly endorse theoretical notions that go with it (Dignath et al., 2020).

However, it seems that aversive signals do not always motivate control adaptations, regardless of their source or strength. Fritz et al. (2015) intended to add further aversiveness to some trials of a Flanker and a Stroop interference task. To this end, they presented mini blocks à ten trials of stimuli with unchanged perceptual characteristics and mini blocks of stimuli with reduced fluency of processing, which is assumed to be unpleasant and aversive. Reduced fluency was achieved by lowering the figure-ground contrast. According to the framework of conflicts as aversive signals, they hypothesized that conflict adaptation should be enhanced in the disfluent mini blocks. Instead, they found that conflict adaptation was decreased and even eliminated in disfluent trials and was only present in fluent trials. While the authors discussed demotivating task circumstances by the reduced fluency and resource competition of the affective and cognitive task components as possible explanations for their results, there are hints that in a negative context, the aversive conflict signal might lack saliency. Dreisbach et al. (2018) and Dreisbach et al. (2019) found, in similar experimental approaches, that adaptation effects are more effective and more strongly pronounced in a positive as opposed to a negative context. Dreisbach et al. (2018) used the natural connotation of relative positions (“up” perceived as more positive and “down” perceived as more negative) as affective contexts: They presented the spatially compatible and incompatible stimuli of a Simon task (and fluent and disfluent trials of a number categorization task) either at the upper or the lower half of the screen. They manipulated the relative proportion of compatible trials (or fluent trials, respectively) at a certain location while maintaining the overall proportion of compatibility (fluency). This way, they created a CSPC-manipulation with two oppositely valenced contexts. The result was that the CSPC

(CSPF) effect of enhanced control, as expressed by reduced interference in the mostly incompatible (disfluent) context but larger interference in the mostly compatible (fluent) context, only developed if the mostly incongruent (disfluent) context was the upper (i.e. relatively positive) one. When most conflicting, and therefore aversive, trials were presented in the negative context, they apparently did not trigger any control adaptations. The findings were largely corroborated by Dreisbach et al. (2019), who used inherently positive and negative context categories in order to create a clear context manipulation without the need for obvious location changes. In three experiments using word and picture stimuli, they found that CSPC effects are by tendency stronger in positive high-conflict contexts than in negative high-conflict contexts. The conclusion is that the aversive signal, may it be response conflict or any other aversive signal (e.g. fluency of processing), is more prominent in a positive context than it is in a negative one. The importance of affective signals becomes clear once more. Affect plays an important role in many cognitive processes and it is conceivable that there is more room for adaptations when a clear affective discrepancy between the background and the respective stimuli exists. Although this indeed seems like a robust finding with a plausible theoretical background, some studies have failed to find a modulation of adaptation strength in contexts of different affective valence (Cañadas et al., 2016; Zhang et al., 2019). These results inspire further reasoning about the mechanisms of affective signals guiding cognitive control.

Open questions

In one of the very first studies of response conflict, Eriksen and Eriksen (1974), who actually were interested in effects of noise on visual search, examined the effects of congruent and incongruent noise, and also of neutral noise. Neutral noise, which was neither response congruent nor incongruent with the target stimulus, led to intermediate impairment in target identification. That is, performance regarding target identification was worse in incongruent trials, and it was better in congruent trials. This leads to the assumption that there might be adjustment after the easier, more fluent congruent trials in addition to adjustment after the interfering incongruent trials. The Flanker paradigm as it is used nowadays in countless behavioral experiments in cognitive psychology, only contains congruent and incongruent-noise trials, but lacks a neutral reference. Until now, research on the conflict adaptation effect was, in line with the prevailing theories (cf. Botvinick et al., 2001), mostly focused on the reduction of conflict effects. Although some researchers have included neutral trials in their paradigms, most of them did not have the aim to explicitly gauge the contributions of congruent vs. incongruent noise to sequential adaptation effects. The Flanker task with additional neutral trials has been used as a tool to examine effects of repetition priming (Bugg, 2008; Davelaar & Stevens, 2009) or specific effects of different types of conflict (Verbruggen et al., 2006). The question whether not only incongruent but also congruent trials contribute to sequential adaptation has only been taken up a few times in paradigms like the Stroop (Compton et al., 2012; Lamers & Roelofs, 2011) and the Simon Task (Aisenberg & Henik, 2012). Various alternatives of neutral trials have been tested. By adding neutral trials to a Flanker task and a Stroop task, Lamers and Roelofs (2011) made it possible to compare the extent to which congruent and incongruent events contribute to conflict adaptation effects, respectively. Their results indicated that conflict adaptation is mainly created by relaxation of control after congruent trials, as conflict effects were larger after congruent trials than after neutral or incongruent trials, which did not differ. This finding was replicated by Compton et al. (2012). Their results showed corroborating psychophysiological data of EEG-α-activation, which is an inverted measure of general cerebral activation. The data indicated a more relaxed state after congruent trials. These findings challenge prevailing theories such as the CMT (Botvinick et al., 2001) or the account of conflicts as aversive signals (Dreisbach & Fischer, 2015, 2016), as these accounts lack the explicit statement of compatible noise, causing relaxation of control or facilitation of responses driven by (congruent) task-irrelevant information. Downregulation of control due to detected compatibility signals or positive affective signals might be conceivable, but this has not yet been investigated thoroughly. There are strong hints that, while conflict serves as a negative affective signal, congruency serves as a positive affective signal and causes adaptations of control as well. The first of the three presented studies in the following will therefore aim at answering the question whether congruent trials lead to the subsequent relaxation of cognitive control and attentional focus, just like incongruent, conflicting trials lead to enhancement of control and shielding of attentional focus.

In line with a possible functionality of congruent trials, Study II will examine the affective valence of congruent and incongruent trials in an ongoing conflict paradigm. Studies that examined the subjective perception and/or affective valence of conflict have never actually assessed affective responses using an objective measurement. We cannot know for sure whether there are measurable negative affective responses to conflict trials only, or whether affective responses to congruent trials might even be positive. The one study that has examined the affective evaluation of congruent and incongruent trials on a trial-by trial basis (Fröber et al., 2017) has relied on participants' self-report. Despite the innovative character of a trial-by trial assessment of immediate affective responses, this method is suboptimal insofar that it repeatedly interrupts the task. Furthermore, self-report is not an objective measurement. Although the results point in a clear direction and psychophysiological and behavioral signs of adjustment logically match the self-report data of affect, there is no study so far that provides online measurement of affective responses to the trials within a conflict task and examines the relation of these responses to behavioral adjustment. Therefore, in the second study, online measurements of electromyography (EMG) during a conflict will give insight on subtle changes of affect during task execution. This way, study II answers the questions of the affective valence of different trial types within a conflict paradigm and the relation of this affective valence with subsequent behavioral adaptation.

When it comes to CSPC and CSPF effects, a lot more research has been done on the former than on the latter. This is not surprising considering the theoretical account of conflicts as aversive signals, with which the investigation of control adjustments to disfluency in this context has started, is rather new. Remarkably, different modalities are not investigated often in the CSPC/CSPF literature (but see: Wendt & Kiesel, 2011). While context-specific adjustment of attention and cognitive control is a highly relevant skill for everyday life, the visual modality and visually cued contexts are by far not the only relevant modality. It has been suggested before for sequential adaptation, that processing adjustments may vary in dependence of the task-relevant modalities (Fruchtman-Steinbok et al., 2017). The same might account for contextual adaptation, which renders the investigation of modalities other than the visual one potentially insightful. An investigation of both, CSPC and CSPF effects in different auditory contexts, for example, is still missing. Such an investigation could provide evidence that facilitates further optimization of theoretical frameworks and a better understanding of the general underlying processes and boundary conditions of contextually driven control adjustments to aversive stimuli. In the third study, an investigation of auditory CSPC and CSPF effects is presented, that aims at further examining the scope of contextual control adaptations.

The present research

The goal of the studies presented here was to investigate different affective signals as the origin of cognitive control adaptations. In light of the account of conflicts as aversive signals, which was first outlined by Dreisbach and Fischer (2015, 2016), we systematically investigated the behavioral effects of stimuli that harbor compatible and hence fluent, positive characteristics that facilitate task execution and stimuli with incompatible, conflicting and thus negative characteristics. In **Study I**, we used a Simon paradigm and added neutral trials, without any specific spatial information (i.e. presented centrally, at fixation, in a visual Simon task and binaurally via headphones in an auditory task). This way, we aimed to gauge the influence of adaptations to both incongruent and congruent trials alike. In line with the findings of Lamers and Roelofs (2011) and Compton et al. (2012), we expected a linear trend in terms of a decreasing congruency effect from trials after incongruent, to trials after neutral, to trials after congruent trials.

Furthermore, in **Study II**, the link between objectively measured automatic affective responses and subsequent behavioral adaptation was investigated. By measuring activation from the "frowning" and "smiling" muscles, M. corrugator supercilii and M. zygomaticus major, we assess subtle affective responses (cf. Dimberg, 1990) during an ongoing conflict paradigm. In line with the account of conflicts as aversive signals, the aim was to show that participants elicit negative affective responses to incongruent trials. In addition, we investigated the possibility of a positive signal of congruent trials (see Study I) and we correlated affective signals with behavioral adaptation on subsequent trials in order to gain insight on possible processual relations.

In order to investigate the scope of context-specific control adaptation, we investigated the CSPC and the CSPF effect in the auditory modality. In **Study III**, distinct human voices (female vs. male) served as ecologically relevant contextual cues for the probability of Simon-conflict and were expected to elicit context-specific control adjustments. The generalizability of these effects was tested using frequency-unbiased items within the tasks, which were presented equally, often spatially compatible and incompatible in either of the voices.

PART II

PEER-REVIEWED STUDIES

Study I

It’s more than just conflict: The functional role of congruency in the sequential control adaptation

Anja Berger, Rico Fischer, & Gesine Dreisbach

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Abstract

According to the conflict monitoring theory (CMT), one of the most prominent theories of cognitive control, the exertion of cognitive control is triggered by the detection of conflicting response tendencies in the anterior cingulate cortex (ACC). Recent research has challenged this emphasis of response conflicts and has debated whether in addition to shielding after incongruent trials the relaxation after congruent trials also contributes to the sequential adaptation of control. To investigate the functionality of facilitative congruent trials in sequential adaptation of control, we conducted two experiments using a visual (Experiment 1) and an auditory (Experiment 2, preregistered) Simon task with stimuli presented laterally to the left or right (creating response congruent and incongruent trials) or without any particular spatial information (creating neutral trials). Both experiments showed converging results: in the error and reaction time data, the Simon effect was smaller following incongruent trials, larger following congruent trials, and the Simon effect following neutral trials was in-between. Results thus suggest that sequential control adaptations can originate from two processes: Increased shielding in response to incongruent trials and relaxation in response to congruent trials. Argumentations for a functional role of congruent and incongruent trials in the sequential adaptation of control suggest a more general theory of fluency monitoring instead of mere conflict monitoring. In addition, such extensions of the CMT provide theoretical explanations of how control is ever relaxed in response conflict tasks after being enhanced by conflict in the first place. Last but not least, the results may also be taken as a further hint that congruent stimuli may provide a positive affective signal for control relaxation just it has already been shown for incongruent stimuli as aversive signals for the up-regulation of control (shielding).

KEYWORDS: Cognitive Control, Congruency Sequence Effect, Conflict, aversive signals

Introduction

The conflict monitoring theory (CMT; Botvinick et al., 2001; Botvinick, 2007) is one of the most influential theories of cognitive control. By assuming a monitoring system (presumably located in the anterior cingulate cortex, ACC) that registers competing response tendencies, i.e. conflict, and thus the need for control, it is parsimonious yet exhaustive. Empirical evidence in support of the CMT is provided by congruency sequence effects (CSEs) in various conflict paradigms like Flanker- (Gratton et al., 1992), prime probe- (Desender et al., 2014), Simon- (Stürmer et al., 2002), or Stroop-like tasks (Egner & Hirsch, 2005; Padmala et al., 2011), and also on a neural level (Cole et al., 2009; Kerns et al., 2004). While the original model and most of its derivates emphasize the functional role of the *conflict* signal (incongruent trials) in the conflict-triggered adjustment of control, here we aim to show that sequential control adjustments are not only driven by conflict and subsequently increased shielding, but also by increased relaxation following congruent trials.

In all the above-named paradigms conflict adaptation in terms of reduced interference effects in post-conflict trials have been reported repeatedly.[3] Furthermore, neurophysiological validations of the CMT (Clayson & Larson, 2011; Fischer et al., 2018; Kerns et al., 2004; Larson et al., 2016; Stürmer et al., 2002) were successful. Lateralized readiness potentials differed in size after conflict trials as compared to non-conflict trials (Stürmer et al., 2002). Also, a reduction of the N2 and P3 EEG components after incongruent trials has been reported while N2 amplitudes were especially decreased for more arousing conditions (transcutaneous vagus nerve stimulation, Fischer et al., 2018) and again increased with increasing (RT) on incongruent trials (Clayson & Larson, 2011). Moreover, the ACC activity in trial N-1 correlates with dorsolateral prefrontal cortex activity in trial N (Kerns et al., 2004), confirming the link between conflict detection and subsequent control.

Incongruent stimuli as cause for adaptation are also assumed in the associative learning account by (Verguts & Notebaert, 2009). Here, the detection of a conflict in an incongruent

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[3] We are aware of contrasting views that explain congruency sequence effects by processes of repetition priming and associative learning mechanisms. These processes may very well contribute to sequential adaptation in certain paradigms, yet are not capable of explaining observed patterns entirely (Schmidt & Weissman, 2014). Additionally, hybrid models were suggested in which it was explained that processes using both, concrete and abstract features lead to the effect of conflict adaptation. It is stated that both, feature-integration and cognitive control processes may play an important role (Davelaar & Stevens, 2009; Egner, 2017).

trial by the ACC triggers a phasic release of norepinephrine in the locus coeruleus acting as reinforcement signal and binding glue to enhance the currently active task representation in the dlPFC. They suggest adaptation by binding processes of stimulus features that is enhanced after incongruent stimuli, as they cause autonomic activation. Closely related to this functional role of arousal, emotional features have also been added to the CMT framework: ACC has been found to not only be responsive to conflict but to all kinds of negative signals (Botvinick, 2007), which has been corroborated by diverse studies showing that that response conflicts are registered as aversive events (Damen et al., 2018; Dreisbach & Fischer, 2012a; Fritz & Dreisbach, 2013; Hatukai & Algom, 2017; Schouppe et al., 2015). Theoretically, one may conclude that conflict adaptation may originally be motivated by the *aversive signal* of conflicts (Dreisbach & Fischer, 2015, 2016) and not by the actual conflict itself (Desender et al., 2014).

Despite this discussion of which feature of the conflict signal is responsible for conflict adaptation, there has been consensus ever since that processing the conflict (and/or its affective consequences) represents the event that initiates the recruitment of cognitive control, eventually resulting in the pattern of a CSE. In the original CMT, conflict is measured over the output-layers, meaning that whenever conflicting responses are activated by the input, cognitive control is upregulated (more precisely: the task demand units increase the sensitivity for the task-relevant input and thereby reduce the input of task-irrelevant information). When no conflict is detected over the output-layers, cognitive control is *not* increased or may even be down-regulated. However, in our understanding, CMT remains silent when it comes to the comparison of congruent vs. neutral irrelevant stimulus input. In other words, in both conditions, no conflict is detected such that cognitive control is not increased, but we are not aware of a congruency signal that actually increases the sensitivity for stimulus input, which is irrelevant, yet activates one and the same response tendency as the relevant input does. The idea that congruent trials may trigger relaxation and as a consequence to a stronger impact of the congruent (but irrelevant) stimulus information as compared to neutral trials may not contradict CMT but so far is not made explicit either. Likewise, the adaptation by binding model assumes that incongruent stimuli produce an arousal signal that strengthens currently activated task representations and thereby leads to a stronger focus on task relevant stimuli (Verguts & Notebaert, 2009). Again, the difference between the impact of congruent vs. neutral stimuli may be predicted by the model but is not made explicit. And finally, the same holds true for the conflict-as-aversive-signal account (Dreisbach & Fischer, 2015, 2016) where only conflict stimuli are considered as driving force of the sequential adaptation effect. Taken together, all three accounts put a stronger emphasis on the role of conflicting stimulus information for the dynamic adjustment of cognitive control, whereas the role of congruent stimulus information is not itself taken into account. This makes sense in so far as missing a conflict may have more serious negative consequences than missing congruent information. However, in order to better understand the underlying processes of adaptive action control, it seems important for once to directly investigate the beneficial role of congruent stimulus information beyond the absence of conflict in sequential control adaptation. In fact, there already exist some recent studies that addressed the issue whether not only incongruence but also congruence, as more than just the absence of conflict, might contribute to control adjustments.

Most research to date focuses on the recruitment of cognitive control to flexibly increase processing selectivity (e.g., narrowing of attention). The question of how this up-regulation and increase of cognitive control is regulated into the other direction on the other hand has received only little attention (but see: Damen et al., 2018; Schlaghecken & Martini, 2012). It is conceivable, for example, that the relaxation of control represents a mere passive mechanism, like a rubber band that slacks off in shape once the pressure is released. Alternatively, congruent trials just like incongruent conflict trials might also contain functional information that is utilized, which would lead to a notion of control adaptation by a two-way slider bar rather than by an on/off-button. The notion of congruent trials as triggers for relaxation has been expressed as a sideline in the literature before as part of the CMT (Egner, 2017) but it has been investigated individually in only a handful of studies and rarely been put in the context of the CMT conceptually.

Davelaar and Stevens (2009), for example, added a baseline of neutral (neither congruent nor incongruent) trials to a Flanker task in order to investigate effects of congruent trials and to answer the question whether repetition priming rather than cognitive control might account for congruency sequence effects. Their results suggested a major contribution of repetition priming: They found selective benefits in incongruent trials after incongruent trials, and in congruent trials after congruent trials. But they did not find any differences for congruent trials preceded by incongruent and such preceded by neutral trials. Likewise, incongruent trials preceded by congruent and those preceded by neutral trials did not differ. They concluded that in this task, a mixture of control and lower level processes, referred to as conflict-modulated priming, contribute to the congruency sequence effect. Schlaghecken and Martini (2012) conducted a similar investigation using a cuing-, a priming-, and a

Simon-task. They found that the trial type repetition benefit is specific for congruent-congruent sequences. Additionally, as the benefit was existent in both response repetitions and alternations, they concluded that it’s not due to associative priming. In conclusion, they assume a mechanism that responds to both, presence and absence of conflict, for strategic adjustments.

By adding neutral trials, the amount of conflict interference can not only be measured after congruent and incongruent trials and compared to one another, as in most investigations, but can also be measured after neutral trials (e.g., Davelaar & Stevens, 2009). If sequential control adaptation is driven by both, relaxation (in response to congruent trials) and shielding (in response to incongruent trials), the amount of conflict interference following neutral trials should lie in between that after congruent and that after incongruent trials. Most studies that included neutral trials, however, did not analyze the data according to that exact rationale (e.g. Aisenberg & Henik, 2012; Bugg, 2008; Damen et al., 2018; Davelaar & Stevens, 2009; Desender et al., 2013; Hommel, 1993; Scherbaum et al., 2018; Verguts et al., 2011). For example, Hommel (1993) included neutral trials in an auditory Simon task but sequential effects were not part of his investigations. Scherbaum et al. (2018) used a mouse movement version of the Simon task, but as they focused on the temporal dynamics of mechanisms underlying the specific adaptation to conflict, the relaxation of control following non-conflict congruent trials was not addressed. To the best of our knowledge, there are only two studies – using the Eriksen Flanker and color word Stroop task – that included neutral trials (letters flanked by letters without any association to a possible response, color bars superimposed by a XXXXX-string, words of animals written in color) with the exact purpose of investigating the selective impact of congruent and incongruent trials on sequential control adaptation (Compton et al., 2012; Lamers & Roelofs, 2011). Critically, adaptation effects seemed to be created by increased Stroop interference after congruent rather than decreased Stroop interference after incongruent trials, which never differed significantly from the effect after neutral trials. Furthermore, EEG-α-power was lower following congruent than following neutral trials, but not higher following incongruent than following neutral trials (Compton et al., 2012). Likewise, and as stated above, Schlaghecken and Martini (2012) concluded that the cognitive system adapts not only to conflict but also to its absence. As stated above, these results do not contradict CMT but have not been made explicit either.

In the light of these findings, analogously to adaptation motivated by aversive conflict signals (Dreisbach & Fischer, 2015, 2016), there might be a positive affective quality of congruent trials. In fact, Hatukai and Algom (2017) and Damen et al. (2018) recently showed, that congruent trials do trigger positive evaluation and corresponding affective priming effects (analogously to Fritz & Dreisbach, 2013). From there it seems conceivable that a positive congruency signal might indeed motivate adaptations in terms of relaxation just as the aversive conflict signal presumably triggers adaptation in terms of shielding. Here we will put this idea to an empirical test and ask whether conflict trials as trigger for increased cognitive control are the only source of sequential adaptation effects or whether – in addition – congruent non-conflict trials might serve as trigger for the down-regulation of cognitive control as compared to neutral trials.

While incongruent trials should lead to smaller subsequent conflict interference than that subsequent to neutral trials, congruent trials should lead to higher conflict interference than that after neutral trials. To this end, we chose a number Simon task that has frequently been applied in the research of congruency sequence effects (e.g. Fischer et al., 2008; Fischer et al., 2015; Plessow et al., 2011). The number Simon task allows for a relatively large stimulus set (to control stimulus repetitions) and, most importantly, a straightforward way to create neutral trials (by presenting stimuli at the center of the screen).[4] Hereby, Simon interference was measured as the difference between Simon incongruent trials (e.g., a left hand response is required for a small number presented at the right side) and Simon congruent trials (e.g., a left hand response is required for a small number presented at the left side).

To reiterate, assuming a functional role of non-conflict congruent trials in motivating sequential control adaptations, we expect the size of the conflict measure (i.e., Simon effect) to differ with respect to previous trial history. Considering a neutral condition in the previous trial history enables a more detailed evaluation of the usual pattern of the congruency sequence effect. That is, we expect largest Simon effects following congruent trials and smallest Simon effects following incongruent trials. Most importantly, the Simon effect following neutral trials should lie in between, thus describing a linearly decreasing Simon effect in the order of following congruent, following neutral and following

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[4] Note that the creation of neutral trials can be challenging because the irrelevant feature dimension (e.g., words in the Stroop task, or flanker stimuli in the flanker task) might also have some (unknown) association with the relevant response dimension. For example, Compton et al. (2012) used words depicting animals as a neutral condition without taking into account that animals might be (implicitly) associated with one or the other color. By presenting number stimuli in the center of the screen, the interference-defining attribute of the Simon effect (i.e., spatial overlap between lateral stimulus position and response hand) is eliminated. That is, while the spatial-numerical association (in terms of a mental left-right orientation of number size) is still given, the central presentation ensures that there is no association between the central stimulus position and the lateral response hands.

incongruent trials, respectively. In other words, we expect a significant linear trend from a decreased Simon effect after incongruent to an increased Simon effect after congruent trials, indicating a steady growth of the effect.

Experiment 1

Materials and Methods

Participants

A total of thirty-one undergraduate psychology students (four male, two left-handed) aged *M* = 22.03 (*SD* = 5.92) of the University of Regensburg participated in exchange for partial course credit. All participants signed informed consent and were debriefed after the session.

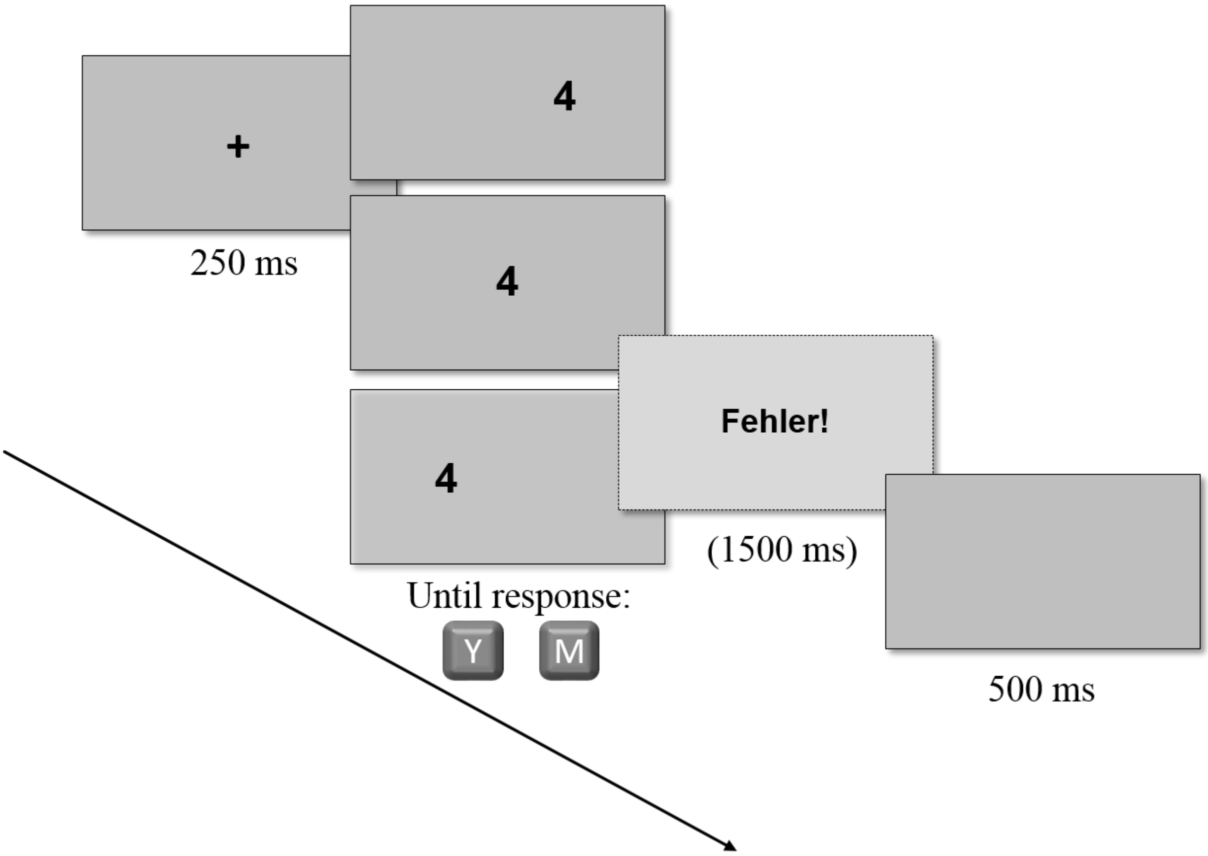
Stimuli and Apparatus

Digits from 1 to 9 without 5 in Arial font (24 pt, black) were used as stimuli for the Simon task. All stimuli were presented on a light grey background. Digits could either be presented in the middle of the screen or presented laterally with a distance of 15 % of the total screen width from the center, resulting in a shift of 4° to the left or right. Congruent trials were formed by digits < 5 on the left or digits > 5 on the right. In incongruent trials, this mapping was reversed. All digits presented in the middle were considered neutral trials. The Y- and M-key of a standard QWERTZ-keyboard were used as left and right response buttons and had to be pressed with the index fingers of both hands. Mapping of keys to magnitude of numbers was kept constant for all participants in order to fit the effect of spatial numerical association of response codes (SNARC, Dehaene et al., 1993). This means, small numbers always required a left hand-response and large numbers required a right hand-response. The experiment was run on two different computers (Dell Optiplex 790, Dell Optiplex 780) and two different CRT screens (EIZO FlexScan F56, EIZO FlexScan F520) using the Software E-Prime 2.0.10.356 (Psychology Software Tools, Sharpsburg, PA, USA).

Procedure

Participants took part individually or in pairs of two in which case they wore headphones for sound protection. The experimenter noted date, time and demographic information of the participants at the beginning of the experiment. Task instructions on the computer screen informed participants about the procedure of the experiment and asked them to respond as fast and as accurate as possible throughout the whole task. Each trial started with a fixation cross presented centrally on the screen for 250 ms and ended with a blank screen shown for 500 ms. In between, the stimulus was presented until the response was made. After correct responses, the blank screen was shown before the next trial started. After incorrect responses, error feedback (”Fehler”, German for “error”) was presented for 1500 ms before the blank screen was shown (see Figure 1). The experiment started with 48 practice trials in which distribution of stimuli and congruency conditions was kept balanced. After the practice block three blocks of 144 trials were presented. In these 144 trials, each of the eight digits was presented at each of the three positions six times, resulting in equally distributed congruent, neutral and incongruent trials. At the end participants received course credit, were thanked and debriefed.

Figure 1. Trial Procedure. The second slide represents examples for an incongruent, neutral or congruent (from top to bottom) trial and the horizontally aligned response keys Y and M on the QWERTZ-keyboard. Feedback was only given for errors. The arrow represents the course of time.



Design

A 3 (Congruency in N: Congruent, neutral, incongruent) × 3 (Congruency in N-1: Congruent, neutral, incongruent) repeated measures design was applied. RTs and error rates served as dependent measures.

Results and Discussion

Preprocessing

The first trial of each test block (0.7 %) and stimulus repetitions (8.5 %) were excluded before analysis of error rates. Prior to RT analyses, errors and post error trials (6.7 %) and all trials in which RTs deviated more than 3 *SD* from the individual mean per subject and condition (1.4 %) were removed as well. Data of one participant whose RT deviated more than 3 *SD* from the overall sample mean (733 ms vs. 489 ms) was excluded from all analyses.

RT data

The 3 (Congruency$_{N}$: congruent, neutral, incongruent) × 3 (Congruency$_{N-1}$: congruent, neutral, incongruent) repeated measures ANOVA yielded a significant main effect of Congruency$_{N}$, $F(2, 58) = 56.76$, $p \leq .001$, $\eta_p^2 = .66$. RTs on incongruent trials were significantly higher than on congruent trials, $F(1, 29) = 83$, $p \leq .001$, $\eta_p^2 = .74$, and neutral trials, $F(1, 29) = 81.25$, $p \leq .001$, $\eta_p^2 = .74$. Furthermore, Congruency$_{N-1}$ was also significant, $F(2, 58) = 7.53$, $p \leq .001$, $\eta_p^2 = .21$. Responses were faster after congruent than after neutral and incongruent trials, but only the difference between responses following congruent vs. incongruent trials was significant, $F(1, 29) = 11.20$, $p \leq .01$, $\eta_p^2 = .28$). Finally, the interaction of Congruency$_{N}$ and Congruency$_{N-1}$ was also significant, $F(4, 116) = 29.80$, $p \leq .001$, $\eta_p^2 = .51$, indicating a linear trend, $F(1, 29) = 62.19$, $p \leq .01$, $\eta_p^2 = .68$. This ANOVA still shows a significant interaction when it is conducted as a 2 × 3 ANOVA, without the – for our research hypothesis irrelevant – neutral trials in trial N, $F(2, 58) = 48.44$, $p \leq .001$, $\eta_p^2 = .63$. Planned comparisons in this ANOVA showed, that the Simon effect was smaller after incongruent than after neutral trials, $F(1, 29) = 45.65$, $p \leq .001$, $\eta_p^2 = .61$, whereas the Simon effect after congruent trials was *larger* than after neutral trials, $F(1, 29) = 19.02$, $p \leq .001$, $\eta_p^2 = .40$ (see Figure 2a).

Error data

The 3 × 3 ANOVA on error data showed a significant effect for Congruency$_N$, $F(2, 58) = 10.85$, $p \leq .001$, $\eta_p^2 = .27$, with significantly increased errors in incongruent compared to congruent, $F(1, 29) = 19.94$, $p \leq .001$, $\eta_p^2 = .41$ and to neutral trials, $F(1, 29) = 9.89$, $p \leq .01$, $\eta_p^2 = .25$. Congruency$_{N-1}$ was not significant, $F(2, 58) < 1$; $p = .66$), but the interaction of previous and current congruency again was, $F(4, 116) = 7.04$, $p \leq .001$, $\eta_p^2 = .20$. Like for the RT data, this interaction was still significant without including the neutral trials in trial N, $F(2, 58) = 8.88$, $p \leq .001$. For errors, the Simon effect decreased after incongruent compared to neutral trials, $F(1, 29) = 8.68$, $p \leq .01$, $\eta_p^2 = .23$, but was not significantly larger after congruent compared to after neutral trials, $F(1, 29) = 0.55$, $p = .46$. The linear trend of the interaction was significant, $F(1, 29) = 14.63$, $p \leq .01$, $\eta_p^2 = .34$ (see Figure 2b).

Figure 2a. The Simon effect in response times (RT) of Experiment 1 as a function of congruency in trial N-1. Error bars represent standard errors.

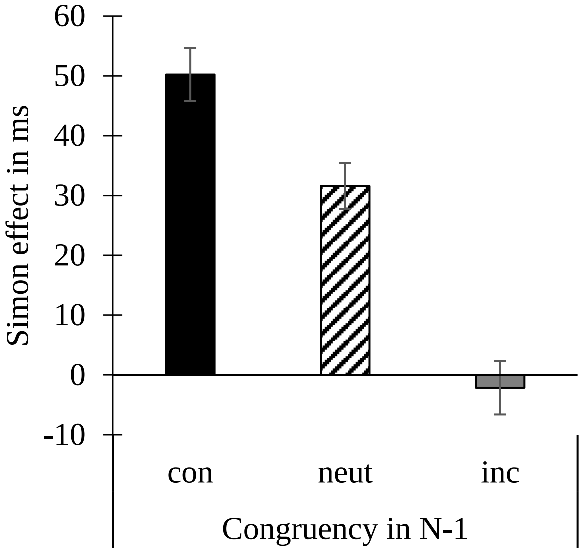
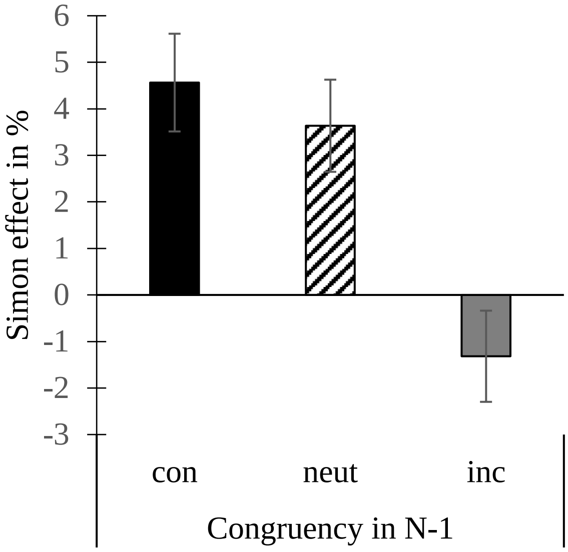


Figure 2b. The Simon effect in error rates (ER) of Experiment 1 as a function of congruency in trial N-1. Error bars represent standard errors.



Experiment 1 was run to gain insight into the role of congruent trials in congruency sequence effects. To this end, a number Simon task with congruent, neutral and incongruent visually presented stimuli was used. Results of RTs and error rates showed an interaction of the previous and current trial type. As predicted, the Simon effect was reduced after incongruent trials *and* increased after congruent trials as compared to neutral trials. This finding adds to prevailing theoretical accounts and fuses together results of different former studies. Whereas some had found evidence for shielding processes in response to incongruent Flanker trials (Wendt et al., 2012), others had presented results pointing to relaxation after congruent Flanker or Stroop trials (Compton et al., 2012; Lamers & Roelofs, 2011). Here, we provide clear evidence that in fact – at least in the number Simon paradigm used here – both processes, shielding in response to incongruent, and relaxation in response to congruent stimuli, are involved in sequential control adaptation.

In the paradigm used here, presenting the neutral condition in the middle of the screen seemed to represent the most accurate neutral condition for our purpose. However, one might still argue that the central location is not entirely neutral, as we did not find any overall performance difference in the RTs and error rates between neutral and congruent trials in N (see). Importantly, however, our results clearly show, that the previous trial type (congruent, neutral, incongruent) in fact determined the degree of subsequent irrelevant information processing (i.e., processing of the irrelevant stimulus location). Compared to neutral, the congruent (irrelevant) stimulus location in trial N-1 led to a stronger processing of the irrelevant stimulus location in trial N, resulting in larger Simon effects following congruent than following neutral trials. Hence, even though overall congruent trials were not faster than neutral trials, they affected the subsequent processing of the irrelevant stimulus location. In order to validate our findings for the number Simon task, we ran Experiment 2.

Experiment 2

In Experiment 2, we intended to replicate the findings using a similar experimental design this time with auditory stimulus presentation. The procedure was preregistered on *As Predicted* (https://aspredicted.org/ck9n4.pdf). In this second experiment, number stimuli appeared as spoken words via headphones and were presented either laterally, only through the left or the right speaker, or binaurally, creating the neutral Simon-condition. This method of creating a neutral reference condition in a Simon task has been applied before (Hommel, 1993)but to our knowledge has never been used to investigate the dynamics of congruency sequence effects. Auditory input is not only an important source of signals for control adaptation, it also provides better prerequisites for creating neutral conditions: Due to the fact that voluntary spatial shifts of attention root in visual spatial representations (Green et al., 2005), spatial direction of attention is easily imaginable for the visual modality, but seems more difficult for the auditory modality. It can therefore be perceived as an even more objective measure. We expect to replicate the results found in Experiment 1: The Simon effect should be largest after congruent, smallest after incongruent trials and it should be in-between after neutral trials.[5] We do not make any predictions about mean error rates or response times in neutral trials N, although in the investigations of Hommel (1993) they lay indeed in between those of congruent and incongruent trials in most conditions. Instead, this time, we restricted our hypotheses and analyses to the Simon effect in N as a function of Congruency in N-1 (congruent, neutral, incongruent). Specifically, we predicted that the Simon effect should be largest after congruent trials, smaller after neutral and smallest after incongruent trials. We thus predict a significant linear trend of a decreasing Simon effects over these conditions.

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[5] We also preregistered a secondary explorative analysis where we aimed to look into the effect of right vs. left responses to congruent vs. incongruent stimuli, which however is unrelated to the main purpose of the research presented here and will therefore not be reported.

Materials and Methods

Participants

As in Experiment 1, thirty-one students (four male) aged *M* = 21.87 (*SD* = 2.74) of the University of Regensburg participated. All participants of Experiment 2 were right-handed as assessed by the Dutch Handedness Questionnaire (van Strien, 1992). They participated in exchange for 3 € or partial course credit, signed informed consent and were debriefed after the session.

Stimuli and Apparatus

German number words (1 to 9 without 5) spoken by a male voice were used as stimuli of the number Simon task. Congruent, incongruent and neutral trials were created following a similar method to the one used by Hommel (1993): Spoken numbers that were presented on the side of the correct response key were congruent trials, and numbers that were presented on the contralateral side of the correct response were incongruent trials. On neutral trials, numbers were presented binaurally. Everything else was kept exactly as in Experiment 1.

Procedure

Task, trial and block procedure mirrored Experiment 1. For instructions, fixation and potential feedback, Experiment 2 also used visual presentation. Whenever the auditory stimulus appeared via headphones, the screen was blank, only showing the light grey background and stayed like this until a response was given.

Design

A 2 (Congruency in N: Congruent, incongruent) × 3 (Congruency in N-1: Congruent, neutral, incongruent) repeated measures design was applied. RTs and error rates served as dependent measures.

Results and Discussion

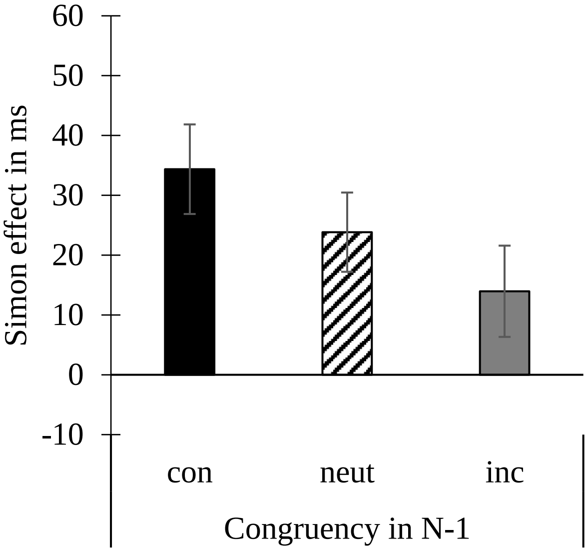
Preprocessing

The first trial of each test block (0.7 %) and stimulus repetitions (8.4 %) were excluded before analysis of error rates. Prior to RT analyses, in addition, errors (2.4 %) and post error trials (2.2 %) and all trials in which RT deviated more than 3 *SD* from the individual mean per subject and condition (1.3 %) were removed as well.

RT data

The 2 × 3 ANOVA revealed a significant main effect of Congruency$_N$, $F(1, 30) = 31.12$, $p \leq .001$, $\eta_p^2 = .51$, typically due to higher RT on incongruent than on congruent trials. There was also a main effect of Congruency$_{N-1}$, $F(2, 60) = 7.5$, $p \leq .001$, $\eta_p^2 = .20$, revealing decreased RTs for trials after congruent as compared to neutral, $F(1, 30) = 9.88$, $p \leq .01$, $\eta_p^2 = .25$, or to incongruent, $F(1, 30) = 14.66$, $p \leq .001$, $\eta_p^2 = .33$, trials. The interaction of Congruency$_N$ × Congruency$_{N-1}$ missed significance ($p = .14$), but a gradually decreasing Simon effect from preceding congruent over neutral to incongruent trials was indicated by the marginally significant linear trend for the interaction, $F(1, 30) = 3.03$, $p =.092$, $\eta_p^2 = .09$ (see Figure 3a).

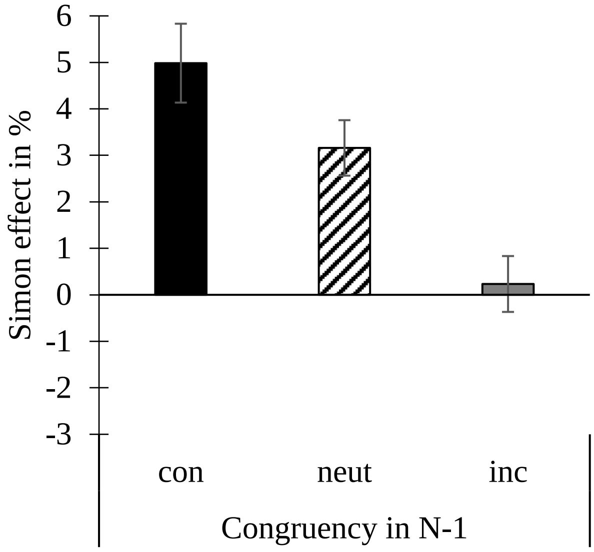
Figure 3a. The Simon effect in response times (RT) of Experiment 2 as a function of congruency in trial N-1. Error bars represent standard errors.



Error data

The analysis of error rates showed a main effect of Congruency$_N$, $F(1, 30) = 39.97$, $p \leq .001$, $\eta_p^2 = .57$, revealing overall better performance on congruent than on incongruent trials. The factor Congruency$_{N-1}$ did not have any significant influence ($F(2, 60) = 1.65$, $p = .20$, $\eta_p^2 = .05$). Importantly, the interaction of Congruency$_N$ × Congruency$_{N-1}$ was significant, $F(2, 60) = 13.47$, $p \leq .001$, $\eta_p^2 = .31$. This interaction suggests a gradually decreasing Simon effect from previous congruent, over neutral to previous incongruent trials with a significant linear trend of $F(1, 30) = 23.16$, $p \leq .001$, $\eta_p^2 = .44$. Figure 3b depicts error data of Experiment 2. A full table of means for RT and error data from both experiments can be found in Table A1 in the Appendix.

Figure 3b. The Simon effect in error rates (ER) of Experiment 2 as a function of congruency in trial N-1. Error bars represent standard errors.



In line with our predictions, the results of Experiment 2 with auditory instead of visual stimulus presentation showed a gradual modulation of the congruency effect depending on the preceding level of congruency. By adding neutral trials as a reference, we found the smallest Simon effect after incongruent, a medium Simon effect after neutral and the largest Simon effect after congruent trials. This effect was significant in the error data and mirrored in the RT data, even though there it missed conventional levels of significance. Taken together, this suggests that not only do incongruent trials trigger shielding to reduce the impact of irrelevant stimulus features, but that congruent trials trigger relaxation thereby increasing the impact of irrelevant stimulus features. Although we had not made any predictions about response times and error rates of neutral trials in N, they lay indeed in between those of congruent and incongruent trials in Experiment 2 (see Appendix, Table A1).

General Discussion

The two experiments presented here addressed the question whether sequential control adaptation in a Simon task is driven solely by the detection of conflict due to simultaneously active and competing response alternatives (i.e., incongruent trials) or whether congruent trials may also contain a functional role beyond the mere absence of conflict.

Results from a visual (Experiment 1) and an auditory (Experiment 2) number Simon task showed converging evidence for both, shielding of attentional focus after incongruent and relaxation after congruent trials. This was indicated by decreased Simon effects after incongruent trials and increased Simon effects after congruent trials as compared to neutral trials without any distracting or beneficial spatial information (i.e. central presentation in Experiment 1, binaural presentation in Experiment 2). Taken together, our results suggest a functional role of congruent trials for sequential control adaptation and thus validate the notion that a possible conflict monitoring unit is apparently also responsive to the absence of conflict and, more precisely, to supporting congruent stimulus (Damen et al., 2018; Schlaghecken & Martini, 2012). The present results add to findings from previous Simon studies including neutral conditions (e.g. Hommel, 1993; Scherbaum et al., 2018). Furthermore, they corroborate recent findings on neutral trials used in other conflict paradigms like the Flanker- or Stroop-task (Compton et al., 2012; Lamers & Roelofs, 2011).

Referring to the introductory metaphor of different control buttons for cognitive control (slider bar, on/off switch), the CMT framework (Botvinick et al., 2001) describes the sequential adaptation as triggered by incongruent trials moving the slider towards shielding. Congruent trials would contribute in terms of a backward movement of the sliderbar thereby increasing the impact of irrelevant distractor information. The Adaptation by Binding account (Verguts & Notebaert, 2009) mainly stresses the role of enhancing (= turning up) connections due to arousing conflict. Likewise, the account of conflicts as aversive signals (Dreisbach & Fischer, 2015, 2016) claims adaptation so far only in response to aversive conflicts. Our finding that congruency effects are larger after congruent than after neutral trials however suggests that facilitative irrelevant information as present in congruent trials may serve as a trigger for control relaxation. This could be amended to persisting theories by specification of how exactly the absence of conflict (and presence of facilitative information) downregulates control (or connection weights). A strong focus on incongruent trials, as suggested by the CMT and many studies created on its basis may, as mentioned by Schlaghecken and Martini (2012), be a biased point of view. Schlaghecken and Martini point out that more weight is added to conflict than to non-conflict congruent trials and one could argue that congruent trials are therefore seen as the standard reference for conflict. However, congruent stimuli are not only non-conflict stimuli, they share *irrelevant* stimulus features that have a *beneficial effect* if they are actually processed. In contrast, neutral stimuli are also non-conflict stimuli, but they don't share any irrelevant stimulus information that is beneficial (or costly). They are (ideally) neutral. As mentioned above, we present evidence for control adjustments to congruent conditions that lead to better performance if irrelevant stimulus information is again beneficial in the subsequent trial (i.e. on congruent trials), and to worse performance if this irrelevant stimulus information is misleading in the subsequent trial (i.e. on incongruent trials). Basically, our critique is that congruent trials are often taken as the (unquestioned) baseline whereas incongruent trials are defined as the only ones that the system monitors for and – after detection – adapts to accordingly. For example, in the CMT, detection of two or more *matching* response tendencies evoked by various stimulus features (e.g., color and word information in the Stroop task, stimulus identity and stimulus location in the Simon task), despite marking absence of conflict, of course, is not a relevant factor for control engagement, but only the detection of mismatch is. Similarly, feature binding accounts presume that the system runs as usual without detection of arousing mismatch. But the detection of shortcuts, and the increased fluency of processing (i.e. congruent conditions) should also act as trigger for learning and therefore strengthen irrelevant connections after these events, in order to establish usage of additional info and save cognitive resources (cf. Whittlesea & Williams, 2000). Again, this idea is already built in the adaptation-by-binding account (Verguts & Notebaert, 2009) but, in our understanding, has not been made explicit. From a motivational point of view, all signals for flexible adjustment of cognitive control and in particular those that call for a relaxation of control should be considered important information. In fact, the conflict monitor might be more adaptive if it monitored more generally for (dis-)fluency in the ongoing processing stream (see also Dreisbach & Fischer, 2011). This is also in accordance with a recent account by Damen et al. (2018) who assume positivity of congruency may either be driven by a "cognitive sense of relief" or by the increased fluency of processing of congruent trials.

With this theoretical extension in mind and in the light of the current findings (see also Compton et al., 2012; Lamers & Roelofs, 2011) we suggest that there is a continuum between relaxation and shielding and that cognitive control can be moved both ways - either towards a more relaxed or more shielded state depending on the immediate trial history.

From this point of view, it becomes clear why we did not necessarily predict significantly different Simon effects when comparing previous congruent and previous incongruent trials with previous neutral trials: Continuously varying strength of cognitive control will not lead to two or three distinct control states (e.g. relaxed, neutral and shielded), but rather to control tendencies, depending on many variables. Theoretically, an even larger number of distinct control states would still imply distinct control states. Our data suggest at least three levels of control. Methodologically, it is therefore hard to falsify a certain number of discrete control states. The nonsignificant differences between these levels in our data however hint at tendencies rather than distinct steps. The fact that there are many variables impacting control exertion and that conflict is not necessarily always to the same extent conflicting (or arousing, or aversive, or disfluent), i.e. the relativity of conflict in the lab and real life situations, are rather suggestive of a continuum. Immediate trial history, saliency of information and task goals all lead to fluctuation in adaptation strength. Potential fluctuations are also determined by the current control default of the agent, depending on traits as well as states (e.g., action- vs. state-orientation, Fischer et al., 2015). This is in line with findings regarding modulation of sequential control adaptation effects by mood induction (Schuch & Koch, 2015; van Steenbergen et al., 2010), acute stress (Plessow et al., 2011) and affective-context manipulation (Fritz & Dreisbach, 2013) and describes sequential control adaptation logically as a form of meta flexibility: Being in an already relaxed state perhaps does not allow for noticeable further relaxation, which leads to measuring weaker effects of control adaptation. Similarly, being encountered with rather aversive quality of many stimuli might raise the threshold for aversive conflict detection and thus prevent adaptation (Dreisbach et al., 2018; Dreisbach et al., 2019). This idea reminds of the notion stated by Damen et al. (2018), that congruency and incongruency both influence affective evaluations and conflict and fluency possibly are the two end points of a gradient line. This and other evidence for the positivity of congruent trials (Hatukai & Algom, 2017) in combination with the present findings hints once more at the very close relation of affect and cognition when it comes to conflict processing. Clearly, future research is needed to further investigate the possible affective valence of congruent stimuli and its function for control adaptations.

Taken together the present findings provide empirical evidence for the assumption of a functional role of congruent trials in the sequential adaptation of cognitive control. In addition to the empirical value it also suggests two important theoretical extensions to influential models. First, a functional role of congruent trials speaks for a fluency/positivity monitoring account and may answer the to date not explicitly asked question of when and why control is relaxed again in response conflict tasks. Second, and in more speculative terms, a functional role of congruent trials contributing to the congruency sequence effect decouples it from the requirement of proper ACC functioning. Evidence for intact conflict-triggered adaptation of cognitive control with lesioned ACC (Fellows & Farah, 2005; Larson et al., 2009; in non-human primates: Cole et al., 2009; but see also: Milham & Banich, 2005) has been a main criticism of the CMT. Detecting increases in fluency (potentially paired with positive motivational consequences) might not depend on ACC functioning and thus be able to produce a sequential control adaptation pattern even with ACC dysfunctions (cf. Krug & Carter, 2010). However, a theoretical extension of classical models to monitoring of (dis)fluency instead of mere conflicts certainly requires further empirical work.

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Declarations of interest: none

Study II

The face of control: Corrugator supercilii tracks aversive conflict signals in the service of adaptive cognitive control

Anja Berger, Vanessa Mitschke, David Dignath, Andreas Eder, & Henk van Steenbergen

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Abstract

Cognitive control is the ability to monitor, evaluate and adapt behavior in the service of long-term goals. Recent theories have proposed that the integral negative emotions elicited by conflict are critical for the adaptive adjustment of cognitive control. However, evidence for the negative valence of conflict in cognitive control tasks mainly comes from behavioral studies that interrupted trial sequences, making it difficult to directly test the link between conflict-induced affect and subsequent increases in cognitive control. In the present study, we therefore use online measures of valence-sensitive electromyography (EMG) of the facial corrugator (frowning) and zygomaticus (smiling) muscles while measuring adaptive cognitive control in a Stroop-like task. In line with the prediction that conflict is aversive, results showed that conflict relative to non conflict trials led to increased activity of the corrugator muscles after correct responses, both in a flanker task (Experiment 1) and in a prime-probe task (Experiment 2). This conflict-induced corrugator activity effect correlated marginally with conflict-driven increases in cognitive control in the next trial in the confound-minimalized task used in Experiment 2. However, in the absence of performance feedback (Experiment 3), no reliable effect of conflict was observed in facial muscle activity despite robust behavioral conflict adaptation. Taken together, our results show that facial EMG can be used as an indirect index of the temporal dynamics of conflict-induced aversive signals and/or effortful processes in particular when performance feedback is presented, providing important new insights into the dynamic affective nature of cognitive control.

Introduction

Cognitive control is the ability to monitor, evaluate and adapt our behavior in accordance with higher-order goals and plans. This ability plays a pivotal role in daily life and has been shown to predict a wide range of outcomes including income, academic performance, and physical and mental health (Ridder et al., 2012). Nevertheless, it still remains elusive what mechanisms drive the adaptive recruitment of cognitive control. According to one influential theory, performance monitoring serves to inform and change cognitive control in an adaptive manner (Botvinick et al., 2001). To specify, this conflict monitory account has proposed that the conflict or incongruence between goal-relevant and -irrelevant information in Stroop-like tasks signals the need for additional cognitive control to prefrontal areas via the anterior cingulate cortex (Kerns et al., 2004). However, more recent work has suggested that conflict-driven increases in cognitive control are not purely driven by cognitive processes but also involve affective processes (Braem et al., 2012; Dreisbach & Fischer, 2015; van Steenbergen et al., 2009). Furthermore, activation patterns associated with cognitive control operations also overlap with neural activation to pain (Kragel et al., 2018; Shackman et al., 2011), anxiety (Cavanagh & Shackman, 2015) and error monitoring (Moser et al., 2013; Riesel, 2019). This work has inspired new theories proposing that negative emotions elicited by conflict trigger the subsequent increases in the recruitment of cognitive control, claiming that cognitive control depends on affective processes (Inzlicht et al., 2015) and/or that the adaptation of control processes reflects an instantiation of affect regulation (Botvinick, 2007; Dignath et al., 2020; Dreisbach & Fischer, 2012a, 2015, 2016; Inzlicht et al., 2015; van Steenbergen, 2015). To date, evidence for the negative valence of conflict in cognitive control tasks mainly comes from behavioral studies showing that conflicting Stroop stimuli are evaluated more negatively than non conflicting stimuli (Morsella et al., 2009), facilitate categorization of negative stimuli relative to positive stimuli (Brouillet et al., 2011; Dreisbach & Fischer, 2012a; Pan et al., 2016) and lead to more negative evaluations of neutral stimuli (Damen et al., 2018; Fritz & Dreisbach, 2013, 2015; Regenberg et al., 2012) and trigger motivational avoidance (Dignath & Eder, 2015). Conflict also modulates reinforcement learning by acting as a signal of costs (Cavanagh et al., 2014) and by providing a reward signal when solved (Schouppe et al., 2015, Exp. 1). Relatedly, inhibition of a dominant response tendency can also trigger stimulus devaluation (Wessel et al., 2014), which corroborates a tight relationship between evaluative and cognitive control processes. Furthermore, studies have shown that affective stimuli can modulate conflict adaptation, providing further evidence for a functional role of affect for control (Kuhbandner & Zehetleitner, 2011; Schuch et al., 2017; Schuch & Koch, 2015; van Steenbergen et al., 2009, 2010, 2015; but see Dignath et al., 2017; Yamaguchi & Nishimura, 2019, Exp. 2 & 3). The functional link between the aversive quality of conflict and subsequent adaptation on the next trial has however only been investigated in paradigms where the original task had to be interrupted by inserting affective ratings in between trials (Fröber et al., 2017). To examine the function of affective responses to conflict and subsequent behavior while not interrupting the task, we here will capitalize on the online recording of physiological measures that index participants' affective state while they perform a typical conflict task.

Physiological measures in previous studies using Stroop-like conflict tasks have already provided evidence that incongruent relative to congruent trials are accompanied by increased pupil dilation (Braem et al., 2015; D'Ascenzo et al., 2016; Diede & Bugg, 2016; Murphy et al., 2017; van Steenbergen & Band, 2013; Wessel et al., 2011), skin conductance response (Kobayashi et al., 2007) and increased heart-rate (Spapé & Ravaja, 2016; Spruit et al., 2018). The abovementioned measures are likely to reflect conflict-modulated processes of attention and arousal rather than a hedonic or valence component. In the present study, we therefore use electromyography (EMG) measurements of the facial corrugator and zygomaticus muscles that produce frowning and smiling expressions, respectively.

Charles Darwin (1872) already noted that people of all cultures frown when they are puzzled, suggesting that effortful processes accompany frowning (see also Rinn, 1984; Shackman et al., 2011). The reduction of effort, by contrast, has been associated with smiling (Oster, 1978). These findings align with the notion that effort is intrinsically aversive (Kool et al., 2010). Recording from surface electrodes over the corrugator and zygomaticus muscles have been shown to be sensitive to cognitive effort (van Boxtel & Jessurun, 1993) and they also track the affective valence of participants' affective state (Lang et al., 1993), although this effect is more pronounced in the corrugator than in the zygomaticus (Larsen et al., 2003). Recent work has also shown that facial EMG is sensitive to affective processes during cognitive tasks. In particular, it has been shown that the corrugator is reliably activated by errors (Dignath et al., 2019; Elkins-Brown et al., 2016; Elkins-Brown et al., 2017; Lindström et al., 2013). The corrugator also responds to low levels of processing fluency, for example if stimuli are difficult to process due to perceptual or conceptual features such as a low figure-ground contrast, short presentation duration, or low semantic coherence (Cannon et al., 2010; Forster et al., 2016; Gerger et al., 2011; Topolinski et al., 2009; Winkielman & Cacioppo, 2001). One study indicated that the corrugator might be sensitive to response conflict, but this effect was only observed for a small subset of trials with very long reaction times (Lindström et al., 2013). An earlier study by Schacht et al. (2010) reported a null finding in a Simon task. To the best of our knowledge, no study has found a modulation of corrugator and zygomaticus activation that would predict conflict-driven adjustments in cognitive control.

The present research tested the idea that, if conflict is aversive and plays a functional role in cognitive control, it should 1) increase corrugator activity (and decrease zygomaticus activity) on incongruent relative to congruent trials, and 2) this effect should predict individuals' behavioral conflict-adaptation effect as indexed by the typical reduction of the congruency effect observed after incongruent versus congruent trials (Egner, 2007; Gratton et al., 1992).

Experiment 1

Method

Participants

The Würzburg team (VM, DD, and AE) planned to collect data from N=60 allowing them to detect correlations of $r >= .4$ between behavior and physiology with a power of 80% and an alpha level of .05. Fifty-nine students of the JMU Würzburg (aged 18 to 43, $M = 25.29$, $SD = 4.89$) participated in the experiment. Eleven of them were male and three participants reported to be left-handed. All of them gave informed consent to participate and were remunerated for their participation after the experiment. One participant had to be excluded from behavioral analyses due to an extremely high error rate (25.08%) compared to the rest of the sample ($M_{sample} = 5.62\%$, $SD = 4.11$). An additional 11 subjects were excluded from the fEMG data analyses due to recording errors or disturbances during the experiment. Finally, we screened the fEMG data for outliers separately for each cell of the factorial design (see below). No extreme outliers (i.e., more than 3 interquartile ranges below/above the 25th/75th percentile) were detected. The final sample for the fEMG analyses comprised $n = 47$ participants.

Procedure

The participants' skin was prepared for EMG measures before 2 (4mm) electrodes above the areas of corrugator supercilii and zygomaticus major and one reference electrode were applied. EMG activity was amplified and recorded using a 16 channel V-Amp system at 1000 Hz (Brain Products, Gilching Germany).

The Flanker task was run using E-Prime 2.0 software (Psychology Software Tools, Sharpsburg, PA, USA) on computers with 1920 x 1200 screens for stimulus presentation. Responses were collected using the D and L keys of a QWERTZ keyboard as left and right response buttons. Participants had to respond to flanker stimuli: Arrays of 5 letters consisting of H and S were presented; the middle letter served as the target stimulus and the flanking letters were distractors. The assignment of the response buttons to the target letters was balanced across subjects. Trials in which target and flanker letters corresponded (HHHHH, SSSSS) were congruent, trials in which they differed (HHSHH, SSHSS) were incongruent. There were 12 practice trials and 8 task blocks with 24 trials each. In each trial, a fixation sign was shown for 750 ms; the distractors without the target letter were presented for 100 ms; then the flanker stimulus was shown until registration of a response. Subjects received performance feedback for incorrect responses (2000 ms, “Falsch!”, German for “wrong!”) and for slow responses exceeding a time limit of 1700 ms (“Zu langsam – reagiere schneller!”, “too slow – respond faster!”). The next trial started after an interval (ITI) of 2,000 ms.

Data preprocessing

For error analyses, the first trial of each block (4.17 %) was discarded. For RT analyses, trials with errors (5.36 %), post error trials (4.86 %) and all trials deviating more than 2.5 SD from the individual cell mean (2.02 %) were additionally removed.

The EMG data were preprocessed with BrainVision Analyzer software (Brain Products Inc., Gilching, Germany). After filtering the data (20 Hz low cutoff filter, 500 Hz high cutoff filter, 50 Hz notch filter) we calculated the Root Mean Square (RMS) over 100-ms time bins locked to the response. Artifacts were detected using a combination of methods (cf. Achaibou et al., 2008; Lindström et al., 2013). Specifically, we removed outliers with a) absolute activity for a given time-bin and/or b) its difference with the following time-bin exceeding 3.5 SDs of its mean value. Mean and SD for these absolute and difference RMS values were calculated separately for each trial across time bins and across trials (for each bin separately). Artefacts were detected for each condition and participant separately in a time window from -300 ms to 1500 ms relative to the registration of the participant’s response. Data were segmented separately for the four different trial sequence conditions provided the response to that trial and to the preceding trial was accurate (congruent – congruent: cC, incongruent – congruent: iC, congruent – incongruent: cI, incongruent – incongruent: iI). The data were baseline corrected by subtracting the mean activity from 200 ms to 100 ms prior to the response from the activity in the rest of the bins (Elkins-Brown et al., 2017). We analyzed fEMG responses in the time window from response execution to 1000 ms past response for ten 100-ms time bins averaged across trials. Average EMG values were then z-transformed for each participant and channel separately across the ten time bins and four conditions. For reasons of completeness, analyses of the raw data (i.e., before z-transformation) are reported in the supplementary information file.

Design and analyses

As we were interested in conflict adaptation, both congruency of the current (congruency$_N$, congruent or incongruent) and of the previous trial (congruency$_{N-1}$, congruent or incongruent) were within subjects-factors in the behavioral analyses. A 2 × 2 repeated measures design was used to analyze the data for the dependent variables mean error rate (ER) and mean response time (RT). The dependent variable in fEMG data was the standardized activation for a certain time bin (1 – 100 ms, 101 – 200 ms, …, 901 – 1000 ms) as a function of congruency$_N$ and congruency$_{N-1}$, resulting in a 2 × 2 × 10 repeated measures analysis of variance (ANOVA). ANOVAs were Greenhouse-Geisser corrected if necessary. In those cases the reported degrees of freedom were rounded. We also computed correlations of behavioral congruency effects (current incongruent minus current congruent; *I* - *C*) and CSEs [congruency effect after congruent minus congruency effect after incongruent trials; *(cI - cC) - (iI - iC)*] and physiological Flanker-effects, i.e. fEMG responses, hypothesizing a positive correlation between these variables. We also report Bayesian t-tests to interpret the null effects in Experiment 3. These tests were run using the JASP software package (JASP Team, 2018) version 0.10.2 using the Oosterwijk prior distribution (t-distribution, centered at 0.35, with a scale of .102 and 3 df) which is representative of the small-to-medium effects typically observed in psychological science (Gronau et al., 2020).

Table 1. Means, standard errors and 95% confidence intervals of response times and error rates of all trial sequences and the respective congruency effects and conflict-adaptation effects for each experiment.

Measure		**Experiment 1 (n =58)**			**Experiment 2 (n = 27)**			**Experiment 3 (n = 38)**		
		M	***SE***	**95% CI**	***M***	***SE***	**95% CI**	***M***	***SE***	**95% CI**
Reaction Time (ms)	cC	381	7	[366, 395]	490	13	[463, 517]	475	10	[455, 495]
	cI	449	9	[431, 467]	581	15	[551, 611]	568	9	[550, 587]
	iC	397	7	[382, 412]	503	13	[476, 529]	488	10	[469, 508]
	iI	448	8	[431, 465]	573	14	[545, 601]	561	10	[541, 580]
	Conflict-adaptation effect	18	4	[9, 25]	20	4	[12, 29]	21	3	[14, 28]
	Congruency effect	59	4	[52, 62]	81	5	[71, 90]	83	4	[75, 90]
	Overall	418	8	[403, 434]	537	13	[509, 564]	523	9	[504, 542]
Error Rate (%)	cC	2.6	0.5	[1.7, 3.6]	5.2	0.8	[3.6, 6.9]	4.2	0.5	[3.1, 5.2]
	cI	8.7	0.9	[6.9, 10.4]	10.4	1.4	[7.6, 13.2]	10.9	1.0	[8.8, 12,9]
	iC	3.2	0.4	[2.3, 4.1]	5.0	0.9	[3.1, 6.8]	4.5	0.7	[3.2, 5.9]
	iI	6.6	0.7	[5.3, 8.0]	9.1	1.2	[6.6, 11.7]	9.2	1.0	[7.1, 11.3]
	Conflict-adaptation effect	2.6	0.9	[0.2, 4.3]	0.9	0.6	[-0.3, 2.3]	2.0	0.8	[0.5, 3.5]
	Congruency Effect	4.7	0.6	[3.2, 5.7]	4.7	0.8	[3.0, 6.3]	5.7	0.6	[4.4, 7.0]
	Overall	5.3	0.4	[4.4, 6.1]	7.4	1.0	[5.4, 9.5]	7.2	0.7	[5.7, 8.7]

Note. cC, cI, cI, and iI indicates the four possible sequences of congruent (c, C) and incongruent (i, I) trials with uppercase letters indicating current and lowercase letters indicating the previous trial type. The conflict-adaptation effect was calculated as follows: (cI-cC)-(iI-iC). The congruency effect was calculated as follows: ((cI+iI)-(cC+iC)/2).

Results

Response times

The 2 × 2 ANOVA revealed a significant main effect of congruency$_N$, $F(1,57) = 226.55$, $p \leq .001$, $\eta_p^2 = .80$, with faster responses in congruent trials (M = 389 ms, SD = 54 ms) compared to incongruent trials (M = 448 ms, SD = 66 ms). The effect of congruency$_{N\text{-}1}$ was also significant, $F(1,57) = 17.41$, $p \leq .001$, $\eta_p^2 = .23$. Responses were slower following incongruent trials (M = 422 ms, SD = 59 ms) relative to congruent (M = 415 ms, SD = 58 ms) trials. The interaction between both factors provided evidence for conflict adaptation [$(RT_{cI} – RT_{cC}) – (RT_{iI} – RT_{iC})$ = 18 ms; see Table 1], $F(1,57) = 16.32$, $p \leq .001$, $\eta_p^2 = .22$.

Error rate

The ANOVA produced a main effect of congruency$_N$, $F(1,57) = 55.55$, $p \leq .001$, $\eta_p^2 = .49$, with higher ERs in incongruent (M = 7.65 %, SD = 4.91 %) than congruent trials (M = 2.92 %, SD = 2.92 %). The main effect of congruency$_{N\text{-}1}$ was not significant, $F(1,57) = 2.264$, $p = .138$, $\eta_p^2 = .04$. However, the interaction between congruency$_N$ and congruency$_{N\text{-}1}$ reached significance, $F(1,57) = 7.43$, $p = .009$, $\eta_p^2 = .12$, confirming adaptation to conflict [$(ER_{cI} – ER_{cC}) – (ER_{iI} – ER_{iC})$ = 2.58 %; see Table 1].

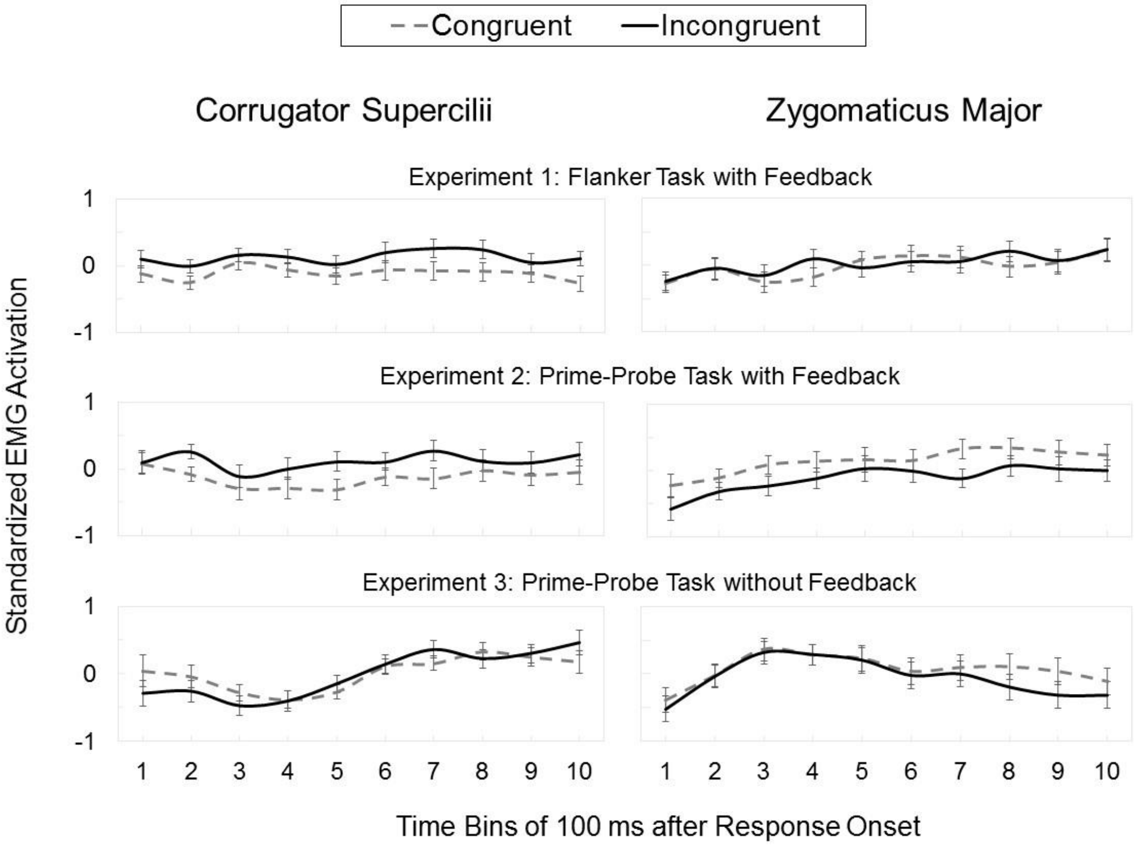
fEMG

Activation of corrugator supercilii was significant for congruency$_N$, $F(1,47) = 7.73$, $p = .008$, $\eta_p^2 = .14$, with stronger muscular activation in incongruent trials (M = 0.12; SE = 0.04; 95% CI [0.03; 0.21]) than in congruent trials (M = -0.12; SE = 0.04; 95% CI [-0.21; -0.03]; congruency effect: M_{CE} = 0.24; SE_{CE} = 0.09; CI [0.07; 0.42]). Figure 1 shows this congruency effect across the ten investigated time bins. No other effects reached significance, all Fs ≤ 0.78, all ps ≥ .577.

An analogous ANOVA for zygomaticus data revealed a significant effect of time bin, $F(1,9) = 4.64$, $p \leq .001$, $\eta_p^2 = .09$. Activation increased over time following a linear trend, $F(1,46) = 11.41$, $p \leq .001$, $\eta_p^2 = .20$. No other effects were significant, all Fs ≤ 1.30, all ps ≥ .250.

The correlational analyses on the relationship between fMEG congruency effect and behavioral CSEs did not produce significant results (-0.6 < rs < -.04, ps ≥ .686).

Figure 1. Grand averages of standardized EMG activation (RMS) of the corrugator and zygomaticus muscles as a function of each time bin and congruency in the three experiments[6]



Note. Error bars represent within-subject standard errors of the grand means

Discussion

Experiment 1 revealed increased corrugator activation in response to incongruent in comparison to congruent trials in a flanker task. The zygomaticus muscle did not show a reliable effect of congruency. Given that the corrugator muscle is responsive to negative emotions (Dimberg, 1990; 1997; 2003), this finding provides the first evidence from a valence-specific physiological measure that conflict during correct trials is aversive (Botvinick, 2007; Dreisbach & Fischer, 2016).

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[6] This figure has been adapted from the original figure in the publication in order to match the style of the other figures presented in this dissertation.

Experiment 2

The two-choice flanker task used in Experiment 1 was not optimal because behavioral CSEs in this task could have been affected by episodic memory processes related to stimulus-response repetitions and feature integration (Davelaar & Stevens, 2009; Hommel, 2004; Mayr et al., 2003; Nieuwenhuis et al., 2006). For example, Mayr, Awh, and Laurey (2003) have proposed that repetition priming during a Flanker task in which there are only two possible target stimuli and responses. All cC and iI sequences contain either complete stimulus repetitions (e.g. HHHHH to HHHHH) or complete switches (e.g. HHSHH to SSHSS), but none of the cI and iC sequences do so (i.e. HHSHH to SSSSS). This provides an explanation of CSEs in terms of episodic memory rather than adaptive control. Even when controlling for this confound, feature integration and contingency learning can still account for (part of) the CSE (for a review see Duthoo et al., 2014).

Given these considerations, it is possible that processes other than adaptive control masked a correlation between conflict-induced corrugator activity and conflict adaption. In Experiment 2, we therefore used a prime-probe task with four responses developed by Schmidt and Weissman (2014) that measures conflict adaptation without feature integration and contingency learning confounds.

Method

Participants

The Leiden team (AB and HvS) planned to collect data from *N* = 30 for Experiment 2 and 3, respectively. The study was planned and conducted in parallel to and independently of the Würzburg team (Experiment 1). Sample sizes were large enough to detect medium-to-large effect sizes ($d_z >= 0.60$) of conflict effects on facial EMG with a power of 80% and an alpha level of .05. Thirty students of Leiden University aged 18 to 27 years (*M* = 22.93, *SD* = 2.38) participated in exchange for 5€ or partial course credit after having signed informed consent. All of them were right-handed and five of them were male. Three subjects had to be excluded from behavioral analyses due to high (> 2.5 *SD*) error rates (> 28.64 % vs. 8.5 % sample mean). Two additional subjects had to be excluded from fEMG analyses due to low EMG activation indicating a loose or broken electrode. Screening the remaining fEMG data for outliers separately for each cell (i.e., more than 3 interquartile ranges below/above the 25th/75th percentile) revealed one outlier. Final sample sizes were *n* = 27 for behavioral and *n* = 24 data sets for psychophysiological analyses.

Stimuli and procedure

The participants' skin was gently cleaned above the left corrugator supercilii (frowning muscle) and left zygomaticus major (smiling muscle) and on the forehead (ground signal) in order to prepare these areas for fEMG signal recording. Five surface Ag/AgCl electrodes filled with electrode gel were applied to these regions. The EMG signal was acquired at 2000 Hz using a BIOPAC MP150 combined with the EMG2-R BioNomadix receiver. Stimulus and response onset markers were conveyed from the E-Prime program via a parallel port and saved into an event marker channel. Data was stored using AcqKnowledge software (BIOPAC Systems Inc., Goleta, CA).

We used a modified version of the Stroop-like conflict task developed by Schmidt and Weissman (2014). Each trial presented a blank screen (1000 ms), a distractor (133 ms), a blank screen (33 ms), a target (133 ms), another blank screen (1383 ms) during which the response was recorded, and a feedback screen (200 ms). The distractor consisted of three identical direction words ('Left', 'Right', 'Up', or 'Down'; 48-point Courier New font) stacked vertically at the center of the display. The target was a single word at the center of the display ('Left, 'Right, 'Up' or 'Down'; 77-point Courier New font). Participants were instructed to identify the target as quickly and as accurately as possible with pressing keys on a computer keyboard. More precisely, participants were to press F (left middle finger), G (left index finger), J (right middle finger), and N (right index finger) in response to 'Left', 'Right', 'Up' or 'Down', respectively. The word 'Error' or 'Too slow' (60-point Courier new font) appeared as feedback after incorrect responses or no response, respectively. The task was presented on a 15-inch monitor (1280 x 1024 px; 60 Hz) using E-Prime version 2.0 software (Psychology Software Tools, Sharpsburg, PA, USA). All stimuli appeared in black on light gray background. Importantly, all odd-numbered trials used a congruent or incongruent pairing of the words Left and Right while even-numbered trials used a congruent or incongruent pairing of the words Up and Down. This procedure ruled out direct or indirect repetitions of particular stimuli and/or responses in two consecutive trials (Schmidt, 2013). Participants performed a single block of 24 practice trials and subsequently eight blocks of 96 test trials (approximately 3 minutes each). Each block was followed by a self-paced break.

Data preprocessing

Like in Experiment 1, the first trial of each block (1.04 %) was discarded for error analysis. For RT analyses, errors (10.05 %), post error trials (8.05 %) and all trials deviating more than 2.5 SD from the individual cell mean (2.11 %) were additionally removed. The processing of fEMG data was done using the same methods as described in Experiment 1.

Results

Response times

The 2 × 2 ANOVA revealed a significant effect of $\text{congruency}_{\text{N}}$, $F(1,26) = 311.43$, $p \leq .001$, $\eta_p^2 = .92$, with higher RTs in incongruent ($M = 577$ ms, $SD = 73$ ms) than congruent ($M = 496$ ms, $SD = 67$ ms) trials. The main effect of $\text{congruency}_{\text{N-1}}$ was not significant, $F(1,26) = 1.04$, $p = .317$, $\eta_p^2 = .04$. The interaction between $\text{congruency}_{\text{N}}$ and $\text{congruency}_{\text{N-1}}$ was significant, $F(1,26) = 26.41$, $p \leq .001$, $\eta_p^2 = .50$, $(RT_{cI} - RT_{cC}) - (RT_{iI} - RT_{iC}) = 20$ ms (see Table 1).

Error rates

The ANOVA produced a significant main effect of $\text{congruency}_{\text{N}}$ (congruent: $M = 5.09$ %, $SD = 4.27$ %; incongruent: $M = 9.76$ %; $SD = 6.62$ %), $F(1,26) = 34.49$, $p \leq .001$, $\eta_p^2 = .57$, and a significant main effect of $\text{congruency}_{\text{N-1}}$ (congruent: $M = 7.80$ %, $SD = 5.27$ %; incongruent: $M = 7.05$ %, $SD = 5.18$ %), $F(1,26) = 6.60$, $p = .016$, $\eta_p^2 = .20$. The interaction was not significant, $F(1,26) = 2.47$, $p = .129$, $\eta_p^2 = .09$.

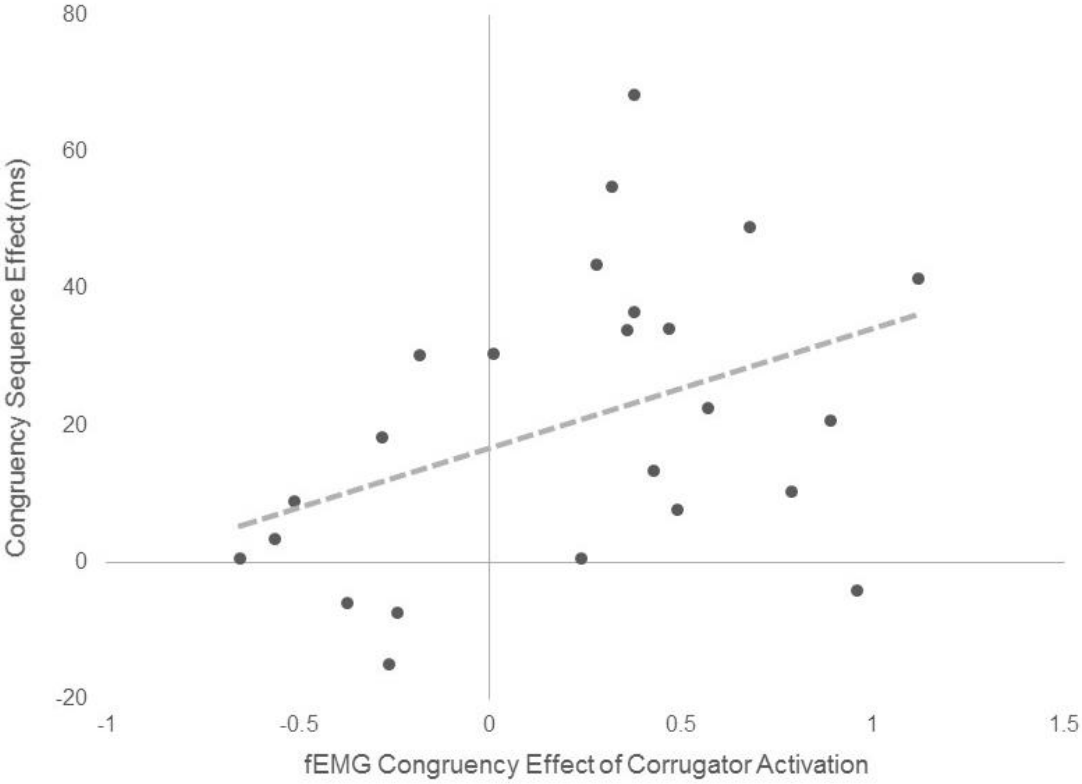
fEMG

The 2 × 2 × 10 ANOVA of corrugator activation revealed a main effect of $\text{congruency}_{\text{N}}$, , $F(1,23) = 4.61$, $p = .043$, $\eta_p^2 = .18$, indicating stronger activation in incongruent trials ($M = 0.111$; $SE = 0.05$; 95% CI [0.004; 0.218]) than in congruent trials ($M = -0.111$; $SE = 0.05$; 95% CI [-0.218; -0.004]); congruency effect: $M_{CE} = 0.22$; $SE_{CE} = 0.10$; CI [0.01; 0.44] see Figure 1). No other effects reached significance, Fs ≤ 2.28, all ps $\geq .144$.

Analyses of the zygomaticus activation showed a main effect of $\text{congruency}_{\text{N}}$, $F(1,23) = 4.42$, $p = .047$, $\eta_p^2 = .16$, with more activation in congruent ($M = 0.13$; $SE = 0.06$; 95% CI [0.002; 0.257]) than in incongruent trials ($M = -0.13$; $SE = 0.06$; 95% CI [-0.257; -0.002]; congruency effect: $M_{CE} = -0.259$; $SE_{CE} = 0.123$; CI [-0.515; -0.004]; see Figure 1). No other effects were significant, all Fs ≤ 1.55, all ps $\geq .225$.

Correlational analyses revealed a marginally significant positive correlation of the congruency effect found in fEMG with the behavioral CSE of RT, $r(22) = .41$, $p = .048$ (see Fig. 2), but no such correlation for the ER measure, $p \geq .52$.

Figure 2. Positive correlation (r = .41) between the effect of conflict on the corrugator muscle (congruency effect) and behavioral conflict adaptation in reaction time[7]



Discussion

Experiment 2 replicated a conflict-induced increase in corrugator activation using a task in which SR congruency levels did not involve systematic repetitions and/or changes of stimulus/response features. Moreover, it also showed that the strength of this signal in the corrugator marginally predicted the strength of behavioral conflict adaptation across individuals (see Fig. 2). This finding provides the first physiological evidence for a functional role of the averseness of conflict, corroborating earlier behavioral evidence using affective manipulations (Fröber et al., 2017; van Steenbergen et al., 2009). This experiment also revealed a reversed conflict effect in the zygomaticus major muscle, although we have

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[7] This figure has been adapted from the original figure in the publication in order to match the style of the other figures presented in this dissertation.

to interpret this effect with caution because we did not observe this effect in Experiment 1 with a larger sample size.

Experiment 3

In Experiment 3 we aimed to examine more closely the processes underlying an enhanced corrugator activation in incongruent trials. Given that Experiment 1 and 2 used error feedback, and conflict trials generally lead to more errors than no-conflict trials, the aversive response to error feedback could have become conditioned to incongruent trial displays, even when the participants responded correctly in these trials. Experiment 3 was the same task as Experiment 2 with the exception that the error feedback in between trials was replaced by a fixation cross.

Method

Participants

Thirty-eight students of Leiden University (3 male), aged 18 to 30 years (*M* = 22.50, *SD* = 2.82) participated for monetary compensation or partial course credit[8]. For fEMG analyses, 10 subjects had to be excluded due to low EMG activation indicating a loose or broken electrode. Finally, we screened the fEMG data for outliers separately for each cell of the factorial design (see below). No extreme outliers (i.e., more than 3 interquartile ranges below/above the 25th/75th percentile) were detected. Thus, the sample size was $n = 38$ for behavioral and $n = 28$ for fEMG analyses.

Stimuli and procedure

Stimuli, design, and procedure were identical with Experiment 2 with the only change that error feedback was replaced by an uninformative fixation cross.

Data preprocessing

Data preprocessing and outlier identification procedures were the same as in the previous experiments (exclusion of first trial in a block, 7.09 % errors, 6.45 % post error trials, 2.26 % responses deviating more than 2.5 SD).

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[8] While collecting data we identified that some data were not recorded correctly due to a broken electrode. We therefore collected data from additional participants to compensate for the dropouts.

Results

Response times

The ANOVA produced a significant main effect of congruency$_N$ (congruent: M = 482 ms, SD = 60 ms; incongruent: M = 565 ms, SD = 57 ms), $F(1,37) = 500.19$, $p \leq .001$, $\eta_p^2 = .93$. The main effect of congruency$_{N-1}$ was not significant, $F(1,37) = 3.37$, $p = .075$, $\eta_p^2 = .08$. The interaction between congruency$_N$ and congruency$_{N-1}$ was significant, $F(1,37) = 37.51$, $p \leq .001$, $\eta_p^2 = .50$, indicating conflict adaptation [$(RT_{cI} – RT_{cC}) – (RT_{iI} – RT_{iC})$ = 21 ms].

Error rates

ER showed a main effect of congruency$_N$, $F(1,37) = 77.44$, $p \leq .001$, $\eta_p^2 = .68$, with more errors in incongruent (M = 10.03 %, SD = 5.96 %) compared to congruent (M = 4.34 %, SD = 3.51 %) trials. There was no effect of Congruency$_{N-1}$, $F(1,37) = 2.91$, $p = .096$, $\eta_p^2 = .07$. The interaction between both factors was significant, $F(1,37) = 6.93$, p = 012, $\eta_p^2 = .16$, showing a CSE [$(ER_{cI} – ER_{cC}) – (ER_{iI} – ER_{iC})$ = 1.97 %; See Table 1].

fEMG

The 2 × 2 × 10 ANOVA of corrugator responses did not show a significant congruency$_N$ effect ($F < 1$, $p = .901$; congruent: M = 0.01; SE = 0.08; 95% CI [-0.15; 0.17]; incongruent: M = -0.01; SE = 0.08; 95% CI [-0.17; -0.15];]; congruency effect: M_{CE} = - 0.02; SE_{CE} = 0.16; CI [-0.34; 0.30]). The effect of congruency$_{N-1}$ was also not significant, $F(1,27) = 3.69$, $p = .065$, $\eta_p^2 = .12$. The main effect of time bin, $F(3,77) = 5.38$, $p = .002$, $\eta_p^2 = .17$, and the interaction Time Bin × Congruency$_N$ were significant, ($F(6,167) = 2.99$, $p = .008$, $\eta_p^2 = .10$). The three-way interaction Congruency$_N$ × Congruency$_{N-1}$ × time bin also reached significance, $F(6,154) = 2.41$, $p = .032$, $\eta_p^2 = .08$. Post hoc comparisons did not reveal stable effects across time bins (effects of congruency$_N$ were not significant at any point in time, no linear trend: $F(1,27) = 0.02$, $p = .901$, $\eta_p^2 = .001$.), see Figure 1. All other effects were not significant, all Fs ≤ 2.89, all ps $\geq .1$.

We performed Bayesian analyses to test whether the data favor the null hypothesis (absence of a congruency effect) over the alternative hypothesis. The evidence supporting the null model was moderate with BF_{01} = 3.39 (Lee & Wagenmakers, 2013). We also compared the magnitudes of the congruency effects observed in Experiments 2 and 3. No significant difference was observed, $t(50) = 1.25$, $p = .22$, BF_{10} = 1.93. The mean difference of the congruency effects was 0.24, 95% CI: [-0.15; 0.63].

Analyses of the zygomaticus data only showed a significant effect of time bin, $F(3,71) = 3.71$, $p = .020$, $\eta_p^2 = .12$, see Figure 1. No other effects reached significance, all Fs ≤ 1.35, all ps $\geq .244$. Correlational analyses did not reveal a significant correlation between the fEMG congruency effect and the RT conflict-adaptation effect, $r(26) = .28$, $p = .146$, and neither for ER, $r(26) =.05$, $p = .794$.

Discussion

The findings of Experiment 3 qualified the findings earlier observed in Experiments 1 and 2. Experiment 3 was identical to Experiment 2 except that we removed performance feedback. There was no evidence that the facial muscles tracked the putative averseness of conflict, neither in the zygomaticus nor in the corrugator. Bayesian analyses indicated that the model specifying no effect on facial activity (H0) is about three times more likely than the alternative model specifying an effect (H1). At the same time, the experiment produced a conflict-adaptation effect of similar magnitude as observed in Experiment 2 (see Table 1). An explanation of the null finding due to weak manipulation of conflict is therefore unlikely. We present a possible explanation for the null finding in the next section.

General discussion

The present study used facial EMG to test the hypothesis that conflict during correct trials in cognitive control tasks is aversive and relates to cognitive control adjustments. Two out of three experiments confirmed the predicted effect, showing increased corrugator activation for conflict relative to no-conflict trials, both in a flanker task (Experiment 1) and a prime-probe task (Experiment 2). These findings show for the first time that the aversive response to conflict is reflected in the facial EMG. The marginally significant between-subject correlation between conflict-induced corrugator activity and conflict adaptation in Experiment 2 provides preliminary evidence that this signal is related to subsequent adjustment of cognitive control, which is in line with the predicted functional role of affective signals in the regulation of cognitive control (Dreisbach & Fischer, 2012b, 2015, 2016; Inzlicht et al., 2015; van Steenbergen et al., 2009; van Steenbergen, 2015). In contrast, conflict did not significantly increase corrugator activity in the absence of performance feedback (Experiment 3), and a Bayesian analysis provided moderate evidence in favor of the null hypothesis in that case.

Our findings are consistent with the notion that conflict in cognitive control tasks is aversive, and the hypothesis that affective processes are functionally related to cognitive control (Dreisbach & Fischer, 2015; Inzlicht et al., 2015, van Steenbergen et al., 2015), as supported by several behavioral findings (van Steenbergen et al., 2009; Dreisbach & Fischer, 2012b; Fritz & Dreisbach, 2013). The high temporal resolution of the EMG measure provides additional insights into the temporal dynamics of this putative affective signal. Firstly, the conflict-driven activation of the corrugator muscle was a response-locked phenomenon that was not visible in stimulus-locked analyses. Secondly, the effect emerged after participants made a response and sustained for the entire 1-second time window following the response. Our findings are consistent with earlier studies (Schacht et al., 2010; Lindström et al., 2013) that have not observed overall conflict-induced facial EMG modulation when focusing on pre-response signals only. However, our findings contrast with traditional measures of neural conflict processes recorded at the scalp which typically precede the response (Cavanagh & Frank, 2014; Larson et al., 2014). Moreover, for conflict trials, we did not observe the typical biphasic response observed for errors, in which the initial aversive facial EMG response is rapidly reversed at the order of half a second later – an effect we have argued to reflect implicit emotion regulation (Dignath et al., 2020). The fact that the sustained post response effect correlates with conflict adaption suggests that conflict - even though successfully resolved – has an aversive after-effect that helps to prepare cognitive control processes in the subsequent trial (cf. Scherbaum et al., 2011).

Given that control adaptation is an effortful process, one could also argue that the corrugator changes in our study reflect the online recruitment of effort (Botvinick, 2007) rather than the negative valence of the uncertainty associated with stimulus and/or response conflict itself (Mushtaq et al., 2011). This account is consistent with recent frameworks that explain cognitive control processes in neuroeconomic terms (Shenhav et al., 2013; Shenhav et al., 2017), and it also fits to previous studies that observed a corrugator increase in conditions that demand effort (Cacioppo et al., 1985; Morree & Marcora, 2010; van Boxtel & Jessurun, 1993). Because effort is typically aversive (Kool et al., 2010), it is impossible to dissociate effort and negative affect in the present task. However, some recent work has highlighted that people in daily life often seek out cognitive challenges (e.g. solving puzzles or doing video games), suggesting that in some situations effort is actually enjoyable (Inzlicht et al., 2018). It is an important topic for future studies to measure activity of facial muscles in these situations, which can answer the question of whether corrugator activity reflects affective valence, a general effort signal that is not sensitive to its value, or a combination of both. We have recently developed a method that allows measuring effort-sensitive cardiac contractility related to task events (Kuipers et al., 2017; Spruit et al., 2018), which provides an additional valuable tool to observe dissociable physiological profiles. In addition to the effect on corrugator, Experiment 2 (but not Experiment 1 and 3) also produced a conflict-driven reduction in the zygomaticus major. Given the supposed role of this muscle in positive affect, one possible interpretation could be that conflict leads to a reduction of positive affect, which has been suggested before by some behavioral studies (Berger et al., 2019; Compton et al., 2012; Damen et al., 2018; Lamers & Roelofs, 2011). However it is difficult to dissociate positive and negative affect in facial EMG, because facial muscles likely track an integrated, bipolar representation of valence, such that corrugator is activated by negative and deactivated by positive stimuli, whereas zygomaticus shows a reversed - although less reliable - pattern (Lang et al., 1993; Larsen et al., 2003) . However, given that the effect was only observed in Experiment 2 (and not in the other two experiments), independent replication of effects in zygomaticus in future studies is warranted.

On a very speculative note, the absence of conflict effects in Experiment 3 might point to the possibility that the presence of performance feedback is an important boundary condition to observe conflict-driven modulation of the corrugator muscle. It should be noted that errors were not punished in the present research – unlike in other experiments where errors sometimes lead to loss of points or feedback is provided by unpleasant auditory or sensory signals (e.g. Lindström et al., 2013; Yang & Pourtois, 2018). Interestingly, the magnitudes of the conflict-adaptation effect in Experiment 3 and Experiment 2 were comparable (see the confidence intervals reported in Table 1), suggesting that conflict adaptation can happen in the absence of aversive signals detectable with EMG. This finding might imply that the aversive response to conflict does not fully mediate the adaptations in cognitive control and that cognitive or lower-level learning processes independently contribute to control adaptations (Verguts & Notebaert, 2009). Alternatively, besides negative valence, differences in conflict-induced arousal (van Steenbergen & Band, 2013) can also contribute to conflict adaptation and it might be speculated that increased arousal is more important than valence when situations demand endogenous cognitive control such as those not supported by feedback cues. At the same time, however, we cannot rule out the possibility that the effects observed in Experiments 1 and 2 reflect a conditioning effect such that errors were paired with aversive feedback leading to increased aversive signaling after error-prone incongruent trials. This interpretation would be widely consistent with error-likelihood accounts of cognitive control that have implied the anterior cingulate cortex in learning prediction to optimize the adaptive recruitment of cognitive control (Brown &

Braver, 2005). Our findings thus raise the possibility that the corrugator muscle might index error-likelihood, in particular in situations where errors are salient. However, it should be also noted that sample size of Experiment 3 was rather small and that a Bayesian test could only provide moderate evidence in favor of the null hypothesis. Most critically, a systematic effect of the presence of feedback was only examined cross-experimentally by comparison Experiments 2 and 3. Therefore, high-powered future studies that manipulate the presence of feedback are required to substantiate these speculations.

Conclusions

To conclude, our study revealed for the first time the temporal dynamics of the aversive quality of conflict in a cognitive control paradigm. Using facial EMG, we showed that conflict is associated with increased activation of the corrugator (frowning) muscle after the response and that the size of this effect predicted the size of conflict-driven control adjustment in the next trial in a confound-minimized paradigm. This effect was only observed in tasks where participants receive feedback on making errors, suggesting that facial EMG is particularly sensitive to situations that make errors salient. Our study highlights the potential of using facial EMG measures to test valence-specific integral emotions in cognitive control tasks and how these might drive adaptations in cognitive control which helps to understand the basic mechanisms underlying adaptive control adaptation (Inzlicht et al., 2015). Applying the method used here might also help to provide insights into the mechanisms underlying disturbed cognitive control, for example in clinical populations (McTeague et al., 2016).

Study III

Challenging voices:
Mixed evidence for context-specific control adjustments in the auditory domain

Anja Berger, Thomas Dolk, Johanna Bogon, & Gesine Dreisbach

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Abstract

The flexible adjustment to changing demands is an astonishing human ability. One related phenomenon is the context specific proportion congruency effect (CSPC). Regarding response conflict, the CSPC refers to reduced response interference in contexts with a high conflict proportion as opposed to contexts with a low conflict proportion.

Derived from previous research showing CSPCs in the visual domain, we here aim to investigate whether human voices (male vs. female) as auditory contexts trigger control adjustments. To this end, we used a numerical judgment task with number words spoken by a male or female voice. We created response conflict by presenting the words either to the left or right ear (Experiment 1) and we created different levels of processing fluency by presenting them clearly or with background noise (Experiment 2). For a given participant, either the female or the male voice was associated with a high proportion of incongruent/disfluent trials and a low proportion of congruent/fluent trials, respectively. Extending previous findings from the visual modality, we found that the frequency of challenging information within one auditory context (i.e. the voice) can lead to typical CSPC patterns. In two further experiments, using frequency biased and unbiased items, we found evidence for the contribution of associative learning. Limitations of context control associations will be discussed.

Keywords: Simon task; Context Specific Proportion Congruency; Perceptual Fluency; Conflict Adaptation

Introduction

The flexible adjustment to changing task demands highlights an outstanding ability of human action control. Adjustments of control may occur dynamically from one trial to the next, like for example in classical interference tasks. In the Eriksen-Flanker, Simon or Stroop paradigm an incongruent stimulus triggers the upregulation of control and, consequently, response interference is reduced in trial n+1 (e.g. Botvinick et al., 2001; Gratton et al., 1992; Kerns et al., 2004; Stürmer et al., 2002, for a review see Egner, 2014). Context-specific, rather than sequential, control adjustments in contrast describe the ability to adapt to specific demands in different contexts (Crump et al., 2006; Dreisbach et al., 2018; Dreisbach et al., 2019; for reviews see Bugg, 2012; Bugg & Crump, 2012). For example, if response incongruent stimuli occur predominantly at one location and congruent stimuli at another, the location associated with mostly incongruent stimuli triggers the upregulation of control. Consequently, response conflict is reduced at this specific location, but not at the other location. Previous research has shown context-specific adjustments to visual contexts such as color, shape, and location of items (for a review see Bugg & Crump, 2012), or even to more complex context-features like faces (Cañadas et al., 2013; Cañadas et al., 2016; Jiménez-Moya et al., 2018). Derived from this research, we here aim to investigate whether human voices (males vs. female) as auditory contexts can also trigger control adjustments.

In the lab, context-specific adjustments are typically investigated using classical interference tasks like the Eriksen-Flanker, Simon or Stroop task (for a review see Bugg & Crump, 2012; for context specific adjustments in task switching and dual tasking see e.g. Crump & Logan, 2010; Fischer et al., 2014; Surrey et al., 2017). In these tasks, a high proportion of incongruent trials (e.g., 80 % incongruent trials) in a given context leads to decreased interference effects in this context whereas a high proportion of congruent trials leads to larger interference effects (e.g., Logan & Zbrodoff, 1979; for a review see Bugg & Crump, 2012).

If, for example, mostly congruent trials are presented at and associated with a location to the right of fixation and mostly incongruent trials, in turn, to the left of fixation, the resulting congruency effect is significantly smaller on the left as compared to the right side (e.g., Corballis & Gratton, 2003). This *context-specific proportion congruency* (CSPC) effect illustrates that the frequency of conflict at a particular location leads to context-specific control associations that supports handling challenging information as illustrated by attenuated interference effects in those contexts (e.g. Corballis & Gratton, 2003; Crump et al., 2006; Dreisbach et al., 2018; Jacoby et al., 2003; van Steenbergen, 2015; Vietze & Wendt, 2009). Meanwhile, there are numerous studies replicating this CSPC for contextual features such as affect, color, face, form, temporal foreperiod, and spatial location (e.g. Bugg et al., 2011; Bugg, Jacoby, & Toth, 2008; Cañadas et al., 2013; Crump et al., 2006; Crump et al., 2017; Crump & Milliken, 2009; Dreisbach et al., 2018; Dreisbach et al., 2019; Heinemann et al., 2009; Lehle & Hübner, 2008; Vietze & Wendt, 2009; Wendt & Kiesel, 2011).

So far, however, CSPC effects have mainly been investigated in the visual modality, and barely in the auditory domain (but see Spapé & Hommel, 2008). Adaptation to our acoustical surroundings seems, however, a quite conceivable and adaptive feature of human action control. Imagine a student during lectures. From previous experiences, they might know that remarks from one fellow student are most often distracting and uninformative whereas the remarks from another fellow student are often helpful and informative. Consequently, voice identity may serve as contextual cue to direct attention towards useful sources and away from distracting sources of auditory information. In fact, there is already some evidence supporting the claim that voice identity can have a modulatory effect on control adjustments. However, so far it is restricted to sequential processing adjustments in a Stroop-like task (Spapé & Hommel, 2008). There, participants had to respond to high- or low-pitched tones by saying “high” or “low,” respectively. Simultaneously, they heard a voice speak the word “high” or “low”, which they had to ignore. In line with previous findings, performance was impaired if the presented word was incongruent with the required response. This Stroop-like effect was reduced after incongruent trials. Interestingly, this sequential modulation only occurred if the voice in the two successive trials was the same, whereas no modulation was obtained whenever the voice changed (Spapé & Hommel, 2008).

In order to extend this finding of sequential control to context specific control adjustments, we aim to investigate whether participants are able to adapt conflict processing in an auditory Simon task with different proportions of congruency to the speaker identity. Voice identity, just like facial expression or gender (Cañadas et al., 2013; Cañadas et al., 2016), is a rather complex feature. In the visual domain, there have been investigations using plain perceptual and abstract features as contextual cues, but also more complex features, which extend the external validity of the findings. A generalization to the auditory domain, especially to human voices, would further increase the relevance of control adjustments in daily life. In our paradigm, we presented number words (one to nine except for five) spoken by a male and a female voice via headphones. The number words were presented monaurally either to the participants' left or right ear and responses to the number magnitude had to be given manually pressing a lateralized button using the left or right index finger. That way stimulus presentation was either response congruent (e.g. < 5 presented to the left ear requiring a left key press) or response incongruent (e.g. > 5 presented to the left ear requiring a right key press; cf. Simon & Rudell, 1967; for an overview, see Lu & Proctor, 1995). Critically, congruent and incongruent trials occurred with equal frequency, while one voice was associated with mostly incongruent trials (MI hereafter) and the other voice was associated with mostly congruent trials (MC hereafter). We predict a CSPC effect in terms of a smaller Simon effect for the mostly incongruent voice and a larger Simon effect for the mostly congruent voice. Statistically we thus predicted an interaction of Congruency (congruent, incongruent) × Conflict Voice (MC, MI).

Experiment 1 – Conflicting Voice

Method

Participants

G*Power 3.1 software (Faul et al., 2009) revealed that a sample size of N = 32 is required to guarantee sufficient statistical power of $1-\beta = .95$ with $\alpha = .05$, and partial $\eta^2 = 0.31$ (Dreisbach et al., 2018; Experiment 1). Based on this analyses, 32 undergraduate students of the University of Regensburg (16 female; 27 right-handed; $M_{\text{age}} = 21.6$, $SD_{\text{age}} = 3.5$, $R_{\text{age}} = 18\text{-}35$ years) participated in the present study. Participants had normal hearing and were naive with respect to the hypothesis of the experiment. All participants signed an informed consent form and were debriefed and rewarded with partial course credit after the session. Data from one participant had to be excluded due to error rates deviating more than 3 *SD*s from the sample mean.

Materials and Procedure

As stimuli, we presented the spoken number words: One, two, three, four, six, seven, eight, and nine, spoken by a single female and a single male speaker at approximately 70 dBA. Participants were instructed to categorize the numbers as smaller or as larger than five. Accordingly, for numbers smaller than five, they pressed the "Y"-key for numbers larger than five, they pressed the "M"-key using a QWERTZ keyboard. This stimulus-response assignment was held constant across participants to avoid any influence of spatial associations with response hands as reflected in the Spatial-Numerical-Associations-of-Response-Codes (SNARC) effect (Dehaene et al., 1993).

These stimuli, pseudo-randomized to avoid any stimulus-repetition, were always presented to the left or the right ear via headphones (Sennheiser HD 201), thus creating an auditory Simon task (cf. Simon and Rudell, 1967; for an overview, see Lu & Proctor, 1995). Congruent trials were those where the stimulated ear (left/right) coincided with the lateral position of the correct response (1, 2, 3, 4 presented to the left ear; 6, 7, 8, 9, presented to the right ear). The other trials were coded as incongruent. For a given participant, one voice was associated with mostly incongruent (*MI*) trials (80% incongruent; 20% congruent) and the other voice was associated with mostly congruent (*MC*) trials (80% congruent; 20% incongruent). This association between voice and proportion congruency was kept constant within a given participant but counterbalanced across participants. Note that the voice varied randomly from trial to trial. Overall, there were 50% congruent and 50% incongruent trials in a given block.

Each trial started with the presentation of a white fixation cross (Courier New, 28 pt) on a black background for 300 ms followed by the imperative stimulus (i.e., spoken number word) to either the left or the right ear. The screen remained black until a response was given or 1300 ms had passed. If the response was correct, the next trial started after an inter-trial interval (ITI) of 550 ms on average. The ITI varied randomly between 100 and 1000 ms in 100 ms steps, in order to prevent rhythmic responding and thus prevent artificially blurred or created (Schmidt, 2016) effects. If the response was wrong or slower than 1300 ms, the German word for wrong (i.e., “falsch”) or too slow (i.e., “zu langsam”) was displayed in red (Courier New, 22 pt) on the screen for 300 ms. In total, the whole experiment consisted of a short block of 20 practice trials and three experimental blocks of 160 trials each.

A 2 (Congruency: congruent, incongruent) × 2 (Conflict Voice: MI, MC) repeated measures design was applied. RTs and errors served as dependent measures.

Results

Reaction times

For statistical analysis, we excluded the first trial of each block, erroneous and post-error trials (together 7.5 %), as well as RTs that exceeded more than 3 *SD*s from the individual cell mean (1.6 %). To investigate as to whether the Simon effect varies as a function of conflict voices associated with different degrees of proportion congruency, the remaining data was submitted to a 2 (Congruency: congruent, incongruent) × 2 (Conflict Voice: MI, MC) ANOVA with repeated measures on both factors.

The respective analysis revealed a significant main effect of Congruency, $F(1,30) = 63.17, p < .001, \eta_p^2 = .68$. Responses were faster for congruent ($M = 566$ ms, 95 % CI [539; 592]) as compared to incongruent trials ($M = 590$ ms, 95 % CI [562; 617])), yielding an average Simon effect of about 24 ms. The main effect of Conflict Voice was not significant, $F(1,30) = 0.24, p = .63, \eta_p^2 = .008$. Most importantly, the Simon effect varied as a function of the Conflict Voice as indicated by a significant interaction of Congruency x Conflict Voice, $F(1,30) = 8.05, p = .008, \eta_p^2 = .21$. The Simon effect was smaller for voices associated with MI trials (18 ms) compared to voices associated with MC trials (31 ms).

Error rates

An analogous ANOVA on errors revealed a significant main effect of Congruency, $F(1,30) = 40.63, p < .001, \eta_p^2 = .58$ (congruent trials: 1.97 %, 95 % CI [1.23; 2.72]; incongruent trials: 4.37 %, 95 % CI [3.41; 5.33]). No other effects or interactions reached significance (all Fs < 1, ps > .71).

Discussion

The present study for the first time hints at context specific control adjustments in the auditory domain. More precisely, voice features that were associated with different levels of proportion congruency modulated the auditory Simon effect. That is, results show a significantly larger Simon effect for voices associated with MI trials as compared to voices associated with MC trials.

This is in line with findings from the visual modality which showed PC-effects in contexts like face or gender identity before (Cañadas et al., 2016; Jiménez-Moya et al., 2018). Just as in the visual modality, the frequency of conflicting information transferred by a particular voice leads to context (here: voice)-control-associations that are retrieved by the respective context (see Gottschalk & Fischer, 2017; for reviews, see Bugg, 2012; Bugg & Crump, 2012). Our results are also in line with findings from Lawo and Koch (2014) who also found a Simon effect in the auditory domain using human voices. More precisely, they also used digits presented by male and female voices dichotically to the left and right ear, with a visual cue announcing which of the two voices (male or female) participants had to attend to in the upcoming trial. Interestingly, while they found robust switch costs (e.g. switch from male to female voice), these switch costs did not interact with the Simon effect (which in fact was identical for voice repetitions and voice switches). Lawo and Koch (2014) consequently concluded that the process of stimulus selection (depending on the voice) can be dissociated from response selection (depending on the spoken number magnitude). In our paradigm, however, participants only had to attend to the stimulus content (and not the voice) in order to accomplish the task. But still, we found evidence that participants were able to use the voice to either retrieve the appropriate control set. Before we further discuss potential underlying mechanisms of the CSPC effect observed here, we first aim to replicate the findings of Experiment 1 with a modified stimulus set.

Voices in our daily environment sometimes may convey conflicting information. But most of the time, voices vary in acoustical quality. We are often confronted with variations in processing fluency and the ease of processing due to background noises or bad phone connections. Furthermore, the theoretical account of conflicts as aversive signals (Dreisbach & Fischer, 2015, 2016) would predict context-specific control adaptations also to different levels of processing fluency just as adaptation to proportion of conflict. This is derived from the well-established finding that (perceptual) fluency of processing is hedonically marked and “high fluency indicates a positive state of affairs, whereas low fluency indicates a negative state of affairs” (Winkielman et al., 2003, p. 203). Correspondingly, from the visual domain, there is already evidence that disfluent stimuli can trigger control adjustments as conflicts do. In fact, there is empirical evidence for a context-specific proportion fluency (CSPF) effect in the visual domain (Dreisbach et al., 2018) as well as sequential processing adjustment (Dreisbach & Fischer, 2011). To investigate whether context dependent control adaptations can also be found for different signal-to noise-ratios in the quality of a particular voice, we manipulated the proportion of Fluency (fluent or disfluent) in Experiment 2.

Experiment 2 – Disfluent Voice

Method

Participants

32 undergraduate students of the University of Regensburg (16 female; 27 right-handed; $M_{\text{age}} = 21.8$, $SD_{\text{age}} = 3.8$, $R_{\text{age}} = 18\text{-}30$ years) participated in the present study. None of them had participated in the first experiment and were naive with respect to the hypothesis of the experiment. All participants signed informed consent and were debriefed and rewarded with partial course credit after the session. Data from one participant had to be excluded due to a mean error rate of more than 3 *SD*s from the sample mean.

Material and Procedure

Task and procedure were the same as in Experiment 1 except for the following changes: Instead of presenting the number words to the left or the right ear as in Experiment 1, they were now presented binaurally and were either presented in clear speech without any background noise or were embedded in so called multi-speaker babble background noise by using Audacity® 2.1.2. (www.audacity.de). More precisely, the original number words spoken by a male or female voice were combined with convolving speech streams of 10 (five female, five male) different speakers (for further detail, see Obermeier et al., 2012) and were windowed with 10 ms linear on- and offset slopes. The signal-to-noise ratio of original number words and multi-speaker babble noise was - 5 dB. For a given participant, one voice (male or female) was associated with mostly disfluent trials (80% disfluent, 20% fluent) and the other voice with mostly fluent trials (80% fluent, 20% disfluent). In this study, word repetitions were possible, but were excluded from further analyses. Instructions, trial and block procedure remained the same as in Experiments 1 and 2. A 2 (Fluency: fluent, disfluent) × 2 (Fluency Voice: Mostly fluent = MF, mostly disfluent = MD) design with repeated measures was applied.

Results

Reaction times

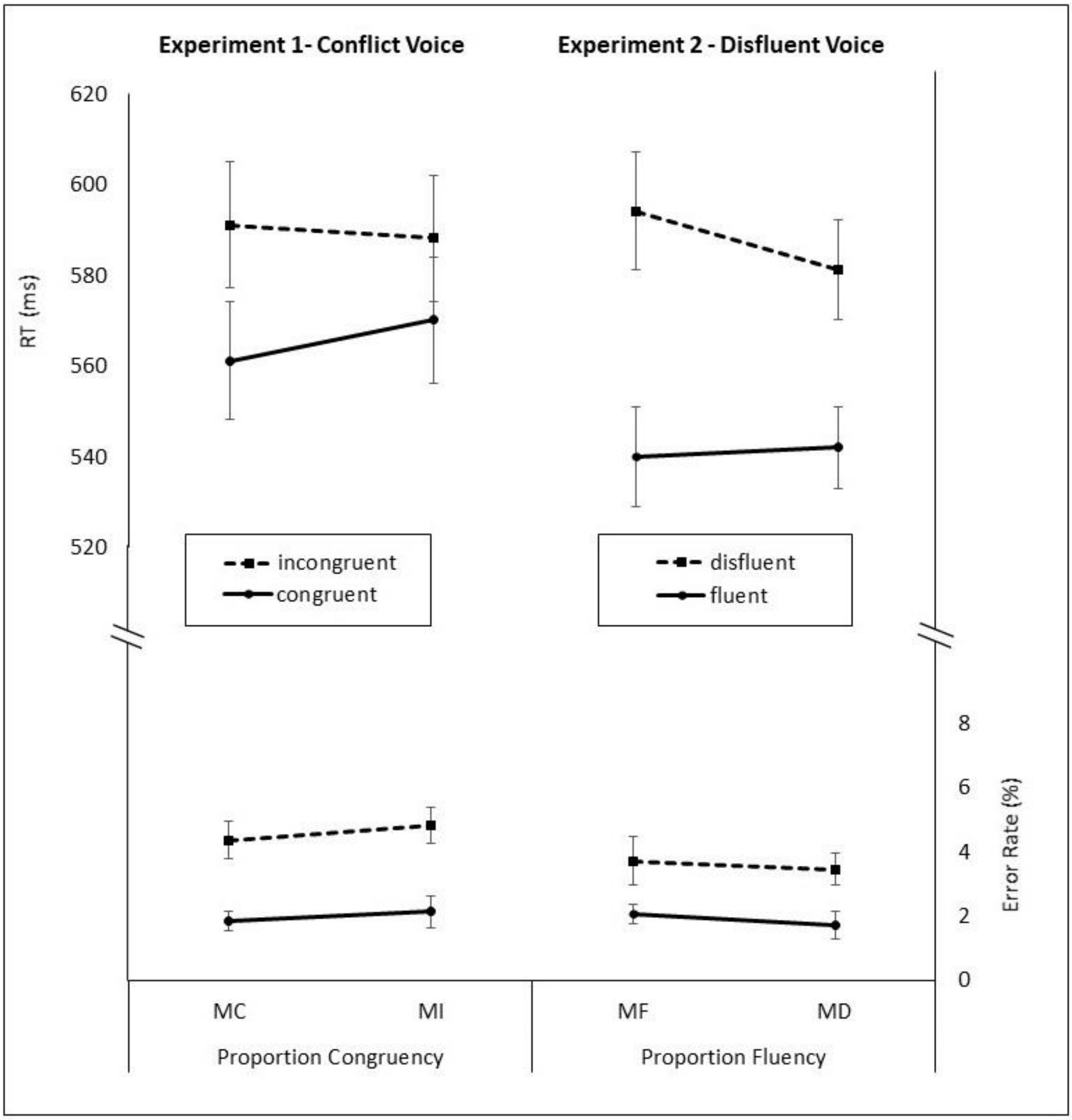
For statistical analysis, we excluded the first trial of a given block, erroneous and post-error trials (together 5.72 %), number repetitions (11.57 %) as well as RTs that exceeded more than 3 *SD*s from the individual cell mean (1.01 %).

A 2 (Fluency: fluent, disfluent) × 2 (Fluency Voice: Mostly fluent, mostly disfluent) ANOVA with repeated measures on both factors revealed a significant main effect of Fluency, $F(1,30) = 92.95$, $p < .001$, $\eta_p^2 = .76$. This shows a processing advantage for fluent ($M = 541$ ms, 95 % CI [522; 560]) as compared to disfluent trials ($M = 587$ ms, 95 % CI [567; 608]), yielding an average fluency effect of about 46 ms. The main effect of Fluency Voice was not significant, $F(1, 30) = 0.39$, p = .54. $\eta_p^2 = .01$. More importantly, however, the Fluency effect varied as a function of the Fluency Voice as indicated by a significant interaction of Fluency x Fluency Voice, $F(1,30) = 4.20$, $p = .049$, $\eta_p^2 = .12$. The Fluency effect was smaller for the mostly disfluent voice (39 ms) compared to the mostly fluent voice (55 ms).

Error rates

An analogous ANOVA on error rates revealed a significant main effect of Fluency, *F*(1,30) = 16.58, $p < .001$, $\eta_p^2 = .36$ (fluent trials: 1.87 %, 95 % CI [1.17; 2.57]; disfluent trials: 3.58 %, 95 % CI [2.44; 4.73]). No other effects or interactions reached significance (all *F*s < 1, *p*s > .39).

Figure 1. Reaction time (ms) and error rate (%) of congruent and incongruent trials in Experiment 1 (left panel) or fluent and disfluent trials in Experiment 2 (right panel) as a function of voice.



Note. mostly congruent/fluent = MC/MF vs. mostly incongruent/disfluent = MI/MD. Error bars represent standard error of the mean.

Discussion

Further extending context specific adaptation in the auditory domain, Experiment 2 revealed control adaptations also for non-conflicting, disfluent stimuli (cf. Dreisbach & Fischer, 2011; Dreisbach et al., 2018). More precisely, manipulation of the fluency of auditory information conveyed by a particular voice led to smaller fluency effects for the voice that spoke mostly disfluently as opposed to another voice that spoke mostly fluently.

So far, we are tempted to argue that the observed context specific adjustments presented can be taken as a sign for control adjustments: Participants learn to associate a certain human voice to the appropriate control set which is then retrieved whenever the respective voice is presented. However, CSPC effects may just as well be the result of stimulus-response learning in the sense that participants learn that a certain stimulus, presented by a certain voice has to be answered with a certain key. If for example the male voice was associated with mostly incongruent/disfluent trials, then the number four, spoken by a male voice will mostly be presented to the response incompatible right side. Participants may thus learn to associate certain stimuli with certain responses. In other words, it is necessary to investigate the underlying mechanisms of the effects observed here. By now, our paradigm may still create effects due to item specific control adaptation, or, more critically, pure contingency learning (cf. Schmidt, 2016, 2019). The CSPC in the visual domain is an effect that can generalize to items that do not follow the proportion congruency manipulation, but appear on the respective context (Bugg et al., 2011; Cañadas et al., 2013; Cañadas et al., 2016; Crump & Milliken, 2009; Jiménez-Moya et al., 2018). In order to investigate whether the voice is a sufficient trigger of control adaptation, we re-ran Experiments 1 and 2, this time including frequency unbiased items. If the effect in the auditory domain results from context specific control adaptations, the CSPC should still be existent for the diagnostic, frequency-unbiased items. Finding the effect for frequency biased items only would suggest that context specific adjustments to vocal stimuli result primarily from associative learning.

Experiment 3

Method

Participants

We collected data of 33 students of the University of Regensburg in order to meet the required sample size of N = 32 (see power analysis in *Method* section of Experiment 1). Normal or corrected hearing and no participation in any of the other experiments presented here were required in order to participate. All participants signed informed consent and were debriefed and rewarded with partial course credit or 4 € after the session. Data from one participant had to be excluded due to a mean error rate deviating more than 3 *SD*s from the sample mean (14.70 % at a sample mean of M_{ER} = 3.97 %, equaling 3.22 *SD*). The final sample was aged M_{age} = 22.47, SD_{age} = 2.91, R_{age} = 18-31 years. 23 participants were female and 30 were right-handed.

Materials and Procedure

The stimuli presented were the same as were used in Experiment 1. The only difference was that the proportion of congruent and incongruent trials per voice did only apply for six of the eight number words. Two number words (four and six, three and seven, two and eight, or one and nine; counterbalanced across participants) were presented equally often congruent and incongruent in both voice contexts (50% congruent, 50% incongruent). These items are coded as unbiased. The procedure of trials and blocks was exactly as described in Experiment 1. Thus, one block consisted of 160 trials of which 120 followed the 80:20/20:80 proportion of congruency and 40 were unbiased (see Table 1).

We conducted a 2 (Congruency: congruent, incongruent) × 2 (Conflict Voice: MC, MI) × 2 (Frequency-biased: biased, unbiased) repeated measures ANOVA. The CSPC is expected to show independently of context bias. That is, we expect an interaction Congruency by Conflict Voice, which is not further modulated by the frequency bias. To avoid the prediction of a null effect, we will also report separate interaction contrasts Congruency × Conflict Voice for biased and unbiased items, respectively.

Table 1. Frequency of trial types.

Experiment	small numbers (1 – 4)				large numbers (6 – 9)			
	congruent/ fluent		incongruent/ disfluent		congruent/ fluent		incongruent/ disfluent	
	MC/ MF voice	MI/ MD voice	MC /MF voice	MI/ MD voice	MC /MF voice	MI/ MD voice	MC /MF voice	MI/ MD voice
Exp. 1	32	8	8	32	32	8	8	32
Exp. 2	32	8	8	32	32	8	8	32
Exp. 3								
biased (3 items)	24	6	6	24	24	6	6	24
unbiased (1 item)	5	5	5	5	5	5	5	5
Exp. 4								
biased (3 items)	24	6	6	24	24	6	6	24
unbiased (1 item)	5	5	5	5	5	5	5	5

Note. All items in Experiments 1 and 2 were frequency-biased items (PC 80/20). In Experiments 3 and 4, PC for biased items was still 80/20 but 50/50 for unbiased items. The overall context-specific PC in Experiments 3 and 4 was therefore weaker with 72.5% / 27.5%.

Results and Discussion

Data Preprocessing

The data of the practice blocks were not included in any analyses. For the analysis of error rates, the first trial of each of the four experimental blocks (0.63 %) and all number repetitions (11.88 %) were excluded. Before RT analysis, errors (3.41 %), post error trials (2.99 %), and all trials with RTs deviating more than ±3 *SD*s from the individual cell mean

(1.25 %) were excluded. This left a total of 87.50 % of all trials for error analysis and 79.84 % for RT analysis.

Reaction Times

The 2 (Congruency: congruent, incongruent) × 2 (Conflict Voice: MC, MI) × 2 (Frequency Bias: biased, unbiased) repeated measures ANOVA brought up a main effect of Congruency, $F(1,31) = 54.14$, $p \leq .001$, $\eta_p^2 = .64$, indicating faster responses to congruent stimuli (598 ms, 95 % CI [572; 624]) than to incongruent stimuli (622 ms, 95 % CI [597; 646]). The critical interaction Congruency × Conflict Voice just missed significance, $F(1, 31) = 3.97$, $p = .055$, $\eta_p^2 = .11$. Participants showed a descriptively smaller congruency effect in response to the conflict voice as compared to the non-conflict voice for both, biased items (19 ms vs. 31 ms) and unbiased items (18 ms vs. 27 ms). This interaction was not further modulated by Frequency Bias ($F < 0.17$, $p = .69$). No other effects were significant, $F\text{s} \leq 0.67$, $p\text{s} \geq .42$. In order to get a more thorough understanding of the data, we looked into the interaction contrasts for biased and unbiased items, separately. It turns out that the CSPC effect was significant for biased items, $F(1,31) = 7.89$, $p = .009$, $\eta_p^2 = .20$, but not for unbiased items ($F(1,31) = 1.04$, $p = .32$, $\eta_p^2 = .03$) All mean values are presented in Table 2.

Error Rates

An analogous 2 (Congruency: congruent, incongruent) × 2 (Conflict Voice: MC, MI) × 2 (Frequency Bias: biased, unbiased) ANOVA on error rates revealed a main effect of Congruency, $F(1,31) = 35.80$, $p < .001$, $\eta_p^2 = .54$, indicating higher error rates on incongruent trials (4.90 %, 95 % CI [3.60; 6.19]) than on congruent trials (2.38 %, 95 % CI [1.56; 3.20]). No other effects were significant, $F\text{s} \leq 0.83$, $p\text{s} \geq .37$. The separate analysis revealed no PC effect for biased items, $F(1,31) = 0.002$, $p = .96$, $\eta_p^2 \leq .001$, nor for unbiased items, $F(1,31) = 0.21$, $p = .65$, $\eta_p^2 = .01$. See Table 2 for an overview of all mean values.

Experiment 3 showed a reliable Simon effect for both item types for both dependent variables. However, the CSPC was, just like in Experiment 1 and 2, only present in RTs. A closer look showed that it was significant only for biased items and was only descriptively observed (but not significant) for unbiased items. RTs thus suggest that associative learning may also have contributed to the effect (cf. Schmidt, 2019). Before further discussing the results, we, analogously, test our findings also for the manipulation of Fluency.

Experiment 4

Method

Participants

Matching the other experiments reported here, a sample size of N = 32 was targeted. 33 students of the University of Regensburg with normal or corrected hearing who were not part of the samples of the other experiments participated in the experiment. All participants signed informed consent and were debriefed and rewarded with partial course credit or 4 € after the session. Data from one participant had to be excluded due to a mean error rate deviating more than 3 *SD*s from the sample mean (18.95 % at a sample mean of M_{ER} = 4.14 %, equaling 3.90 *SD*). The final sample was aged M_{age} = 22.13, SD_{age} = 2.83, R_{age} = 18-31 years. 27 of the participants were female and 30 of them were right-handed.

Materials and Procedure

The stimuli presented were the same as in Experiment 3. The only difference was, that the proportion of fluent to disfluent trials per voice context did only apply for six of the eight number words. Analogously to Experiment 2, two number words (four and six, three and seven, two and eight, or one and nine; counterbalanced across participants) were presented equally often fluently and disfluently in both voice contexts. The procedure of trials and blocks was identical to the other experiments. Like in Experiment 3, one block consisted of 120 biased and 40 unbiased items (See Table 1).

RT and error rates were analyzed in a 2 (Fluency: fluent, disfluent) × 2 (Fluency Voice: MF, MD) × 2 (Frequency Bias: biased, unbiased) repeated measures ANOVA. We expected a two-way interaction of Fluency by Fluency Voice independently of Frequency Bias. To avoid the prediction of a null effect, we will also report the interaction contrasts Fluency by Fluency Voice for biased and unbiased items separately.

Results and Discussion

Data Preprocessing

The data of the practice blocks were not included in any analyses. For the analysis of error rates, the first trial of each of the four experimental blocks (0.63 %) and all number repetitions (11.96 %) were excluded. Before RT analysis, errors (3.75 %), post error trials

(3.29 %), and all trials with RTs deviating more than ±3 *SD*s from the individual cell mean (1.04 %) were excluded. Thus, 87.41 % of all trials were left for error analysis and 79.33 % for RT analysis.

Reaction Times

The 2 (Fluency: fluent, disfluent) × 2 (Fluency Voice: MF, MD) × 2 (Frequency Bias: biased, unbiased) repeated measures ANOVA brought up a main effect of Fluency, $F(1,31) = 114.61$, $p \leq .001$, $\eta_p^2 = .82$, in terms of faster responses to fluent trials (592 ms, 95 % CI [566; 618]) than to disfluent trials (647 ms, 95 % CI [621; 674]).There was no interaction of Fluency by Fluency Voice, $F(1,31) = 0.07$, $p = .79$, $\eta_p^2 = .002$ and no other effects were significant either, all Fs < 1.09, ps > .30. A closer look at the interaction contrasts showed that the CSPF was neither significant for biased items (6 ms; $p = .54$) nor for unbiased items (-2 ms; $p = .84$).

Error Rates

The 2 (Fluency: fluent, disfluent) × 2 (Fluency Voice: MF, MD) × 2 (Frequency Bias: biased, unbiased) repeated measures ANOVA showed a significant main effect of Fluency, $F(1,31) = 15.29$, $p \leq .001$, $\eta_p^2 = .33$, indicating higher error rates on disfluent trials (4.64 %, 95 % CI [3.32; 5.96]) than on fluent trials (2.72 %, 95 % CI [1.87; 3.57]), but no other effects, Fs ≤ 1.44, ps ≥ .24. A look at the interaction contrasts of biased and unbiased items separately showed that the CSPF was neither significant for biased items (-1.08 %; $p = .18$) nor for unbiased items (-0.80 %; $p = .49$). See Table 2 for an overview of all means.

Table 2. Mean RT (error rates) for Experiment 3 and 4.

Exp. 3		**Congruency level**		**Effects**	
		congruent	incongruent	Congruency effect	CSPC
Context Items	MC	594 (2.27)	625 (4.96)	31 (2.69)	12 *
	MI	599 (1.94)	618 (4.59)	19 (2.65)	(0.04)
Unbiased Items	MC	600 (2.56)	627 (5.28)	27 (2.72)	9
	MI	599 (2.73)	617 (4.75)	18 (2.02)	(0.70)

Exp. 4		**Fluency level**		**Effects**	
		fluent	disfluent	Fluency effect	CSPF
Context Items	MF	588 (2.88)	648 (4.30)	60 (1.42)	6
	MD	590 (2.72)	644 (5.22)	54 (2.50)	(-1.08)
Unbiased Items	MF	592 (2.93)	644 (4.41)	52 (1.48)	-2
	MD	599 (2.35)	653 (4.63)	54 (2.28)	(-0.80)

Note. MC = Mostly congruent, MI = Mostly incongruent, F = Mostly fluent, MD = Mostly disfluent, CSPC = Context-specific proportion congruency effect, CSPF: Context-specific proportion Fluency effect. Asterisk denotes significance at the .05 level.

The results show a stable fluency effect but no context specific adaptation effects whatsoever. We can therefore neither conclude that participants identified the voice identity as context cue for the adjustment of cognitive control, nor that any associative learning or binding processes have taken place. This finding contradicts evidence from the visual modality (Dreisbach, Reindl et al., 2018) and is not in line with results of Experiments 1 and 2 presented here.

General Discussion

The experiments presented here were designed to further investigate the role of contextual demands on behavioral adjustments. More precisely, the current study aimed to investigate whether the cognitive system adjusts to voice identity as an auditory context feature signaling a particular kind of demand, i.e., conflict or (dis-)fluency of processing. To this end, we manipulated the contextual control demands by associating one voice (fe-/male) with mostly in/congruent (Experiment 1) or mostly dis/fluent trials (Experiment 2). In order to rule out alternative explanations for the effect, such as contingency learning (cf. Schmidt, 2016), we added frequency-unbiased items in a third (congruency manipulation) and fourth (fluency manipulation) experiment.

For Experiments 1 and 2, our results were as expected: We found a CSPC effect for the spoken number words: Irrespective of the exact nature of the challenge in a particular voice-context (response incongruent or hard to perceive), participants adapted to the particular features of the respective voice resulting in a smaller Simon/Fluency effect for voices associated with mostly incongruent/disfluent trials compared to voices associated with mostly congruent/fluent trials.

Experiment 3 by and large corroborates these findings. In line with previous research on visual stimulus material, we expected that context-unbiased items that appeared in the same task-context would also show context-specific adjustment. Our results show only weak evidence in favor of this assumption. Even though the CSPC effect did not interact with Frequency Bias, a closer inspection of the data showed that the CSPC was significant for frequency-biased, but only descriptively present for unbiased items. This suggests, that the findings from Experiment 1 at least partly emerged due to associative learning.

In Experiment 4, in which we used the same Fluency manipulation as in Experiment 2, we no longer found a CSPC (i.e., CSPF) for neither, biased and unbiased items. This latter result is ambiguous as it may suggest that the effect found in Experiment 2 was a false positive. We, however, favor an alternative explanation: The lack of an effect in biased Items of Experiment 4 may just as well speak against an item-specific explanation in Experiment 2. Note that the fluency manipulation used in Experiments 2 and 4 was different from the conflict manipulation used in Experiments 1 and 3 insofar, that it harbors an additional component of the context-feature. In the conflict experiments (1 and 3), one of the voices (e.g. female) is mostly presented on the response congruent side and one (e.g. male) is mostly presented on the response incongruent side. While the auditory experience of the voice identity features always stays the same (male or female), irrespective of the spatial occurrence, this may not be the case in the fluency manipulation. The voice identity feature (male or female) is distinct from the additional distracting feature (multi-speaker babble), which means that participants would have to learn an additional association between the voice and its background noise. The associative learning between voice identity, stimulus content (i.e. number magnitude), and corresponding response may therefore be facilitated in the conflict experiments as compared to the fluency experiments. The absence of a PC effect for unbiased items in Experiment 3 (conflict) speaks to this interpretation. The absence of a PC effect in both, biased and unbiased items in Experiment 4 (fluency) clearly speaks against associative learning because associative learning should be unaffected by the inclusion of unbiased items. In particular, the results of Experiment 4 do not necessarily rule out context control associations in Experiment 2. The question of whether context-specific control adjustments occur in the auditory domain with voice identities as contextual cues can therefore not be answered unambiguously by the presented research.

There is in fact much evidence in the literature that PC effects can be volatile and depend on the strength of contextual features (cf. Crump et al., 2017). It may be that the context manipulation was weakened by the inclusion of unbiased items and therefore no contextual control adaptation emerged. Although many successful replications and variations of the CSPC exist, there are indications that it underlies strict limitations. Hutcheon and Spieler (2017) have tried to replicate the original findings of Crump and Milliken (2009) who first added unbiased items to their design in order to rule out any lower-level processes in responding as source of the effect. Their results from three experiments did not match the original results: They did not find any CSPC effects neither in the frequency-biased, nor in the unbiased transfer items. They concluded that the context ought to provide meaningful and consistent information on how to organize control and attention levels best and that the addition of unbiased items may add too much ambiguity. In fact, this is an inherent problem of adding unbiased items, which is hard to circumvent. Namely that any inclusion of unbiased items necessarily changes also the reliability of the context. That is, including unbiased items necessarily makes it less worthwhile to adjust to the context. Unless unbiased items are presented so rarely that they do not substantially reduce the informative value of the context. However, this would create problems at the other end, namely the analysis of the few unbiased items. In fact, the descriptively present but non-significant CSPC effect for unbiased items in Experiment 3, which is based on a much smaller subset of trials, supports this argument. In our Experiments 3 and 4, the inclusion of unbiased items has certainly reduced the informational value of the context such that the adaptation to the now less reliable context was weakened (Experiment 3) or even absent (Experiment 4).

Among the abovementioned trial-type frequency per context, this and other methodological factors may be important factors in the occurrence of CSPCs in laboratory designs. It is not uncommon that context-specific adjustments only show in one of two dependent variables. This is another hint at the fragility of the effect and at possible factors of influence that may change it in size or hinder its development, but are not usually controlled or manipulated. Such factors may also lie in subtle differences in composition of the samples or instructions of experiments (cf. Cañadas et al., 2013), even if not manipulated explicitly. With strong differences in cognitive sets between possible underlying contexts, even additional processes such as attentional set-switching or affective context modulations (see Dreisbach et al., 2019) have been reported. In our paradigm, the mere switching between contexts (i.e. voices) does presumably not harbor unwanted confounds, as switching between voices is independent from response congruency effects (cf. Lawo & Koch, 2014). The possible methodological confound of rhythmic responding, that may account for CSPCs in unbiased items (Schmidt, 2016) has been prevented in our tasks by jittered ITIs. Many of these inconsistencies in different methods probably have to be accepted as possible noise in these kinds of investigations. In the light of our and earlier results (cf. Hutcheon & Spieler, 2017; Crump et al., 2017), some methodological recommendations that can minimize a large part of this noise can be inferred. A different type of transfer manipulation, for example, can solve the issue of attenuated context cues. Using unique transfer items in separated blocks or after a certain time of context initiation, for example, might be methods that are more robust. A learning phase can boost the identification of different contexts. Furthermore, salient differences in affective value between contexts and the task properties such as the possibility of rhythmic responding should be prevented (see also Braem et al., 2019, for further recommendations).

The human organism presumably always strives for optimization of behavior upon minimization of resource consumption. When task-relevant and reliable context cues exist, it is supposedly beneficial for the organism to adapt behavior in line with them. When no such overarching cues can be identified, more specific stimulus-response rules may guide behavior in the most beneficial way (cf. Dreisbach, 2012). In this case, associative learning may underlie some ratio of CSPC-like effects reported in the literature.

Conclusion

We cannot draw a clear conclusion in favor of context-driven control in auditory conflict and fluency interference tasks. Our results suggest that both, associative learning and contextual control – as far as a relevant and meaningful context is identified – contribute to the observed adjustments to human voices. The research presented here can only be a first step in this direction. Given the omnipresence and everyday relevance of human voices in different contexts, further research is clearly needed. In particular, investigating processing adjustments in the auditory domain in general and for the context of human voices in particular may be of great interest from a basic as well as applied perspective.

PART III

DISCUSSION

Summary of findings

The three peer-reviewed studies presented in this dissertation investigated how positive and negative affective signals, such as response (in)congruency and (dis)fluency of stimuli lead to adaptations of control and thus guide our behavior. Study I specifically added the positive valence dimension to this investigation, because previous investigations have mainly focused on adaptation to incongruent, aversive stimuli. The introduction of a neutral reference-trial type in addition to congruent and incongruent trials allowed for an analysis of the direction of conflict adaptation. The results from a visual and an auditory Simon task showed that adaptation occurs not only in terms of shielding of attentional focus and enhancement of cognitive control after aversive signals. Dynamic adjustments of control were, in turn, also observed in terms of relaxation of control in response to congruent stimuli, which signal fluency of processing and can therefore be considered a positive signal.

In Study II, objective online measurements of affective responses during three response conflict paradigms were conducted. It was investigated whether evidence for the supposed aversive conflict signal could be demonstrated without explicitly mentioning the possible affective connotation of the different trials by using an objective EMG measurement. We found that indeed conflicts led to negative affective responses even after correct conflict resolution, while congruent trials led to positive affective responses, which is in line with what the results of study I have shown on a behavioral level. The strength of the aversive response in study II even seemed to impact the strength of behavioral adaptation. The affective responses to different trial types were no longer observed, when no performance feedback was given. This is in line with the relevance-component of the working definition of response conflict that was developed in the introduction of this dissertation. It may also indicate that the task required less effortful responses, as results regarding performance were similar but had changed regarding affective markers.

Study III was designed to investigate the scope of cognitive control adaptations to affective signals. In two first experiments, we tested whether adaptation to aversive signals, i.e. Simon conflict and perceptual disfluency, transfers to the context of stimulus presentation in the auditory domain. In order to create ecologically relevant contexts, the contexts were created by two distinct human voices presenting the spoken stimuli. While in one voice, stimuli were presented either mostly spatially compatible with the required response or mostly fluent, i.e. in clear speech without any background noises, the other voice was associated with mostly spatially incompatible auditory information or disfluent, i.e. noisy stimuli accompanied by multi-speaker babble noise in the background. These first two experiments showed a context-specific adjustment of control in terms of reduced interference in contexts (i.e. voices) that were associated with frequent conflicting or disfluent trials, and increased interference of voices that were typically associated with more fluent, non-conflicting trials. In a third and fourth experiment, these investigations were repeated with the addition of so called unbiased-items, i.e. stimuli that occur equally often as compatible/fluent and as incompatible/disfluent trials in both voices, irrespective of the actual association of the voices with frequency of conflict/disfluency. This allowed us to compare biased items to unbiased items and draw conclusions about the transfer of contextual adjustment of control to the whole voice context without any frequency confounds. Results from these additional studies were ambiguous: While the results from the Simon task with unbiased items showed descriptive transfer of adjustment to the context, the results from the fluency task showed no context specific adaptation at all, neither in biased nor in unbiased items. This finding suggests that any behavioral adaptation, whether guided by lower level processes (i.e. in biased items) or top-down control adaptations (i.e. in unbiased items), needs a certain consistency to develop.

Taken together, we have found that human behavior is indeed guided by affective signals such as response conflict, that the strength of adaptation partly depends on the strength of the affective signal (Study II), and that affective signals may be perceived by different modalities (Study I, Study III). One critical new finding is that not only negatively but also positively valenced – e.g. noise-congruent and perceptually fluent – signals contribute to conflict adaptation, supposedly via relaxation of cognitive control (Study I, Study II). The scope of the up- and downregulation of control and any other behavioral adjustments is still not entirely clear. While it seems that adaptation of control is in general transferable to an entire context, like a characteristic auditory component such as a certain voice, it also seems that adaptation of behavior is not always useful (and therefore does not develop) in any case: If context-specific frequencies of aversive and positive signals are not sufficiently distinct and context conditions therefore lack a reliable informational cue for adaptation, typical adaptation effects may not occur (Study III).

Update of theory

Conflicts as aversive signals

While the presented findings do not contradict prevailing theories such as the CMT and its extensions (Botvinick et al., 2001; Botvinick, 2007) or an account of aversive signals for control adaptation (Dignath et al., 2020; Dreisbach & Fischer, 2015, 2016), they do call for amendments to these theories. Cognitive control is not only guided by negative affective processes but also by positive events. The expected value of control theory (EVC; Shenhav et al., 2013) that focuses on dorsal ACC (dACC) functioning has stressed the aspect of positive signals for control adjustments stronger than other theoretical accounts have. As the dACC is responsive to positive outcomes, the EVC suggests that control is not only a tool to avoid negative events but can also be helpful to achieve positive ones. In addition, a cost of control implies that there may also be events in which this cost is too high for control to actually be exerted. Furthermore, it has been suggested before, that human cognitive control follows effort allocation processes as they apply to the labor market (Kool & Botvinick, 2014). If responses to congruent trials are less effortful than the resolution of conflict trials, then it is conceivable that they are less rewarding (see also Schouppe et al., 2015). Therefore, control should indeed be downregulated after congruent trials. Prevailing theories explain the mechanisms of upregulation of control but leave its downregulation unmentioned.

As Study I has shown, conflict interference effects are indeed increased after congruent trials and Study II suggests that this presumably has to do with the affectively positive perception of congruent, fluent trials that support easy and accurate responding. Studies that have not found an effect of affect manipulations on conflict adaptation have often decoupled the aversive feature from the conflict (e.g. by presenting unrelated aversive stimuli in between trials). Perhaps, instead of investigating integral aversive components of task processing, they might have tapped incidental affective states in their experimental approaches (cf. Inzlicht et al., 2015)[9]. While online assessment of affect, like in Fröber et

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[9] Inzlicht et al. (2015) differentiate between integral and incidental affect. The main difference is that incidental affect is decoupled from the task and stimuli while integral affect is elicited by task and/or stimulus components. Incidental affect can have various effects on cognitive control, as it is an extrinsic factor that operates separately. An affective signal elicited by conflict, for example, would be understood as integral affect, having a specific impact on cognitive control. The point that is made here is that manipulations that are

al. (2017) or in the current Study II, investigates the effect of integral emotions on cognitive control, the results of studies that employ affect inductions (e.g. Dignath et al., 2017) likely refer to incidental affect. Incidental affect can have various effects with different outcomes on cognitive control, but integral aversive signals rather consistently signal the need for enhanced cognitive control (Inzlicht et al., 2015). It remains to be clarified in which cases manipulations ensure to impact integral instead of incidental affect. In investigations of context-specific effects of cognitive control, for example, the stimulus and the context both have a certain affective value. Therefore, it can be difficult to specifically manipulate the affective value of the stimulus and the context as part of the stimulus, but not manipulate the participants' mood (that could be categorized as independent from the task). In other words, in some investigations, intended affective stimulus manipulations might have turned out to be mood inductions, if anything, but the affective valence of the stimulus or task itself was not affected. Some manipulations and cues probably work better than others and this tendency may again differ between certain tasks and modalities. It would be conceivable for instance, that relative affective differences between contexts become clearer in the case of facial expressions as contextual cues (Cañadas et al., 2016; Zhang et al., 2019) than in the case of locations marked with relative affective differences (Dreisbach et al., 2018). Although neither affective signal is presented additionally to the stimulus or in between stimuli, but as an inseparable part of it, automatic affective evaluations likely differ. As stated before, this notion is rather speculative and the borderline of integral and incidental affect (i.e. affective value that is seen as part of the stimulus vs. decoupled affective valence) in response conflict tasks remains to be experimentally investigated to add further information to this discussion.

Study III, which investigated context-specific effects, however without the additional affective manipulation of mostly fluent and mostly disfluent context, perhaps also shows differences compared to other studies in terms of affective influence on cognitive control. It has been shown before that interactions of emotion and executive control are partly dependent on sensory modality. Investigations of the visual, auditory, and tactile modality have revealed signs for a stronger interplay of emotion and control in the visual modality than in the auditory or tactile one (Fruchtman-Steinbok et al., 2017).

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intended to elicit integral affect, i.e. to alter control dynamics in a predictable way, may sometimes not be perceived as part of the stimulus or as task-relevant by participants and consequently elicit incidental instead of integral affect, which may operate in a different way or have no impact on control at all.

To conclude, there is no doubt that affective signals guide executive control. In terms of valence, this process is presumably less specific than existing theories have assumed, insofar that not only aversive, but also positive signals modulate control exertion. Even more generally speaking, the perceived processing fluency, which is only hedonically marked as a side-effect, might be the driving force of control adaptations. Fluency can be manipulated by perceptual features such as signal-to-noise ratio (e.g. visual figure-ground contrast or intensity of auditory background noises), by various consistent sources of information (e.g. prime and probe; color and color-word content) or by contextual cues (e.g. of a low effort context, such as a voice or location that signals fluency and/or congruency; or a high effort context, especially when otherwise positively marked and therefore conceptually disfluent by being unexpectedly effortful). The subjectively aversive feeling of disfluency may then signal the need for more cognitive control, and the subjectively positive feeling of fluency may signal the possibility of downregulation of control.

Lower level process accounts

Besides rather complex situations in which executive functions and flexible regulation become necessary in humans, there are also less complex and perhaps less relevant situations to which we apparently adapt. In introductory examples of articles on behavioral adaptation, researchers often describe situations that clearly involve reasoning, at least to a certain degree, while computerized paradigms that are used for research, e.g. the Eriksen Flanker Task, are often easily solved by responding to perceptual features and sometimes by relying on associative processes (see Mayr et al., 2003).

Lower level process accounts often consider affective components (i.e. arousal) to be a part of the process (Verguts & Notebaert, 2009). This reconciles with the findings of Study I, showing that adaptation of control does not only happen in response to aversive signals, but apparently also to positive, fluent signals. The original adaptation by binding theory (Verguts & Notebaert, 2009) focuses on what happens after conflict, and it is conceivable that an arousal-effect would be stronger after conflict than after congruent trials, as negative stimuli are usually more arousing than positive stimuli (Võ et al., 2009). However, the adaptation-by-binding account does not cover the way in which it is decided whether certain stimulus-response associations are strengthened or weakened. Study I showed that, relative to a neutral reference, congruent trials lead to a relaxation of control and broaden attentional focus. This would be equivalent to loosened binding instead of strengthened binding. If affective arousal operates as an enhancing component in the adaptation by binding theory, theoretically, a new homunculus problem is created by the theory, because then some entity would have to decide whether the arousal signal should trigger enhanced or relaxed binding. In conclusion, there is most probably an affect-specific monitoring component (e.g. fluency) which guides adaptation effects, even if they may partly be achieved by repetition binding and associative learning.

In Study I, complete stimulus repetitions were minimized in contrast to other Simon studies due to pseudorandomized stimulus presentation and due to the additional presentation location in both the visual (central presentation) and the auditory (binaural presentation) experiment. Furthermore, number repetitions were excluded to minimize artefacts due to repetition priming in the results. Of course, repetitions of the presentation location in consecutive trials could not fully be ruled out but were, by using three instead of only two opposing presentation locations, minimized. Study II used a paradigm that is completely free of repetition confounds by switching stimulus content and response buttons on every trial. As the data still showed sequential adaptation effects, lower level accounts of repetition priming and contingency learning as the sole explanation of the congruency sequence effect can fully be ruled out (Schmidt & Weissman, 2014). The lack of a CSPC or CSPF effect in unbiased items in Study III, however, is in line with lower level contingency learning accounts. Considering that the CSPF effect was also absent within biased items in the fluency task and that the CSPC effect in the conflict task of Study III was at least descriptively present, a conclusion in favor of lower level processes as the main root of context specific adaptation would also be wrong.

Furthermore, optimization of behavior should, if efficient, not only imply best performance, but the best ratio of performance and effort (with best possible performance and least possible effort). Many cases have been reported in which less controlled but equally successful strategies are applied in human action and decision making (e.g. use of heuristics, Pohl et al., 2013). Consequently, if similar performance in response conflict paradigms can be achieved by relying on lower-level associations, it is no surprise that they are used and favored over more effortful controlled response strategies to a certain degree. As mentioned before, there are cases of easy to solve tasks in which repetition priming and feature binding or associative processes such as contingency learning can operate automatically and save valuable cognitive resources (Mayr et al., 2003). In these cases, lower level processes can even explain behavioral effects entirely and may indeed be the only processes operating. Most tasks and actions in human daily life however contain more complex task components or consequences that are (affectively) relevant. It can therefore be assumed that, whenever possible, associative learning and binding processes are used to guide behavior, but whenever these processes do not suffice, control is flexibly up- and downregulated. This regulation is presumably guided by a kind of fluency monitoring. That is, a certain fluency monitor would indicate whether the organism can rely on associative processing or whether there is the need for more controlled processing. The actual stimulus or task would presumably be what informs about the specific kind of necessary adjustment.

Recent theoretical updates

Hybrid theories of the two major points of view, lower level process theories vs. cognitive control theories, have already been suggested in the past. They combine the notions of control adaptations and of behavioral patterns caused by repetition priming and binding in a fully automatized way. Verguts and Notebaert (2009), for example, have proposed a link between binding processes and cognitive control. They have stated that both processes coexist insofar that in many cases, cognitive control can be understood as the product of Hebbian learning, as arousing conflict stimuli strengthen bindings between neural connections. Although this view allows for continuous updating of association strengths and hence somehow follows the idea of a continuum of control, it differs from what is suggested based on the three studies presented here. According to the suggested Hebbian learning rule, arousal, i.e. conflict, would determine the learning rate (Verguts & Notebaert, 2009). Congruent trials that lack arousal in turn, would in theory be able to weaken associations, but with a much lesser variability in the learning (or here: unlearning) rate, which clearly puts the focus on the upregulation component of control.

Moreover, a recent update of theory takes affective features into account and proposes similarly dynamic interrelations of associations and control. It has been proposed that the current temporal context is bound into an event file as a feature (Egner, 2017). Consequently, a control state that was beneficial in one situation, would also be retrieved in the next situation, possibly accounting for sequential adaptation effects. This framework by Egner (2017) does not contradict a continuum of control or an integration of fluency markers into the event files that, according to it, cause adaptations. Recent research results corroborate the notion of integration of relatively short-term control settings into longer-term contextual control sets in terms of dynamically changing adjustment (Colvett et al., 2020). Adaptive updating of control settings along a continuum of control while considering the current temporal context is therefore conceivable.

Furthermore, a review of the account of aversive signals for control adaptation has been suggested, which is phrased in an equally general manner as the original framework of conflicts as aversive signals. Dignath et al. (2020) have extracted from a broad body of existing literature, that there is a clear link between conflict and negative affect, probably a link between this negative affect and monitoring, and a link between negative affect and increased control. This affect-control link, however, was not supported by studies with additional (phasic) affective manipulations. As mentioned before, these lack of effects may be explained by the nature of these manipulations: Phasic affect induction which is decoupled from the relevant stimulus may result in incidental instead of integral affect (Inzlicht et al., 2015) which possibly is not identified as a signal for control adaptation. As Dignath et al. (2020) explain, one kind of affect induction is attributed to the agent's own action and the other is attributed to external events. The assumption of a fluency monitor might integrate this and other exceptions into the scope of one theory.

Fluency monitoring and a continuum of control

The need for downregulation

By now, it has often been concluded that both, automatic and controlled processing operate conjointly in conflict adaptation processes. There are conditions in which, for example, contingency learning dominates over control allocation (e.g. with only a small stimulus set), but there are also conditions in which adaptation is clearly guided by control (Bugg & Crump, 2012). Tomlin et al. (2015) showed in a simulation that neither mere automatic processing and responding nor entirely controlled modes of processing and action survive in realistic circumstances. They concluded that controlled and automatic behavior will always coexist. The finding of Study I, that control is apparently both up- and downregulated by affective signals, underlines this. As control often operates in a relatively specific way (see Braem et al., 2011), a fully controlled mode could always only provide control over a limited amount of different task dimensions, e.g. whether to focus attention on a central location in a Flanker task, or whether to pay attention to a certain voice or not, given a certain position of an additional visual cue. Control without the necessary specificity would be too energetically costly and is therefore unconceivable in real life conditions. The full spectrum of possible situations in daily life is too complex, as to be fully covered by specific control adjustments without ever drawing on lower level processes. Study III, for example, showed that context-specific adjustments do not develop unless context properties (i.e. contingencies) are sufficiently distinctive and it has been outlined before that an association of the context and the appropriate control set is formed and control is exerted based on that association (Bugg & Crump, 2012). This finding is also in line with what Tomlin et al. (2015) propose: Even with the full capacity to flexibly adjust control to variable conditions, automatic processes will still be beneficial in some cases (see also Goschke, 2017, p. 296).

Regardless of the trigger of control, may it be a previous trial or a certain stimulus feature such as a context, previous theories like the CMT have presented cognitive control as something that is switched on or off (see General Discussion in Study I). Focusing on up- and downregulation along a continuum of control rather than on upregulation alone is a more promising theoretical approach. Furthermore, upregulation of control is not always adaptive or even helpful. The most obvious example in the current context is the deteriorated performance on congruent trials after incongruent trials (i.e., when cognitive control is supposedly enhanced) in conflict paradigms. The shielding of task-irrelevant, but sometimes helpful, information makes responding more difficult in these iC sequences. High levels of cognitive control can also be harmful in other tasks like learning (e.g. of languages), memory, or problem-solving tasks (Amer et al., 2016). In addition, paradox behaviors like in the pre-crastination effect (Rosenbaum et al., 2014), according to which seemingly worsened performance is accepted in order to reduce cognitive effort, lead to facilitated and optimized task completion[10].

A feeling of fluency may serve as a reliable anchor as to when to exert more control and when it is safe or resource-saving to rely on associative learning and binding. When, for example, a task is easy and personal skills are high to begin with, task execution will feel more fluent. With increasing task demands and less confidence in relevant skills, i.e. decreased fluency (Oppenheimer, 2008; Reber & Greifeneder, 2017), the need for a more controlled response mode develops. As many studies have shown, this feeling of fluency

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[10] Although the pre-crastination effect has mostly been researched in physically effortful tasks, see e.g. Rosenbaum et al. (2014) and Fournier et al. (2019), the reduction of cognitive load is also – if not especially so – desirable in cognitive tasks.

implies rather positive affective signals in fluent situations, and negative affective signals in disfluent situations (e.g. Forster et al., 2013; Topolinski et al., 2009).

Overcoming theoretical shortcomings

A lack of modulation of control adaptations in experimental investigations that have used phasic affect induction in between stimuli (cf. Dignath et al., 2020) can theoretically also be explained by a framework of fluency monitoring. An external affective stimulus, e.g. an affective picture that is used for phasic affect induction in between trials (see Dignath et al., 2017) is completely decoupled from task execution. In studies in which a cognitive control modulation by additional affective stimuli was found, the affect eliciting component was either part of the stimulus per se , or was presented as random performance feedback (Fröber & Dreisbach, 2014; van Steenbergen et al., 2009). That way, the affect induction probably is attributed to the agent’s action and is therefore seen as a fluency component of the ongoing task. A decoupled affective stimulus which occurs in between trials, however, might just as well be seen as a different kind of task and as previous research has shown, conflict monitoring and adaptation occur in a task-specific way (e.g. in task switching, Braem et al., 2017). A lack of adaptation in a task with affective manipulations in between stimuli would no longer be surprising if the decoupled affective stimuli are indeed categorized as another type of task. At least, stimulus-decoupled or performance-noncontingent additional affective stimuli seem to have no impact on task-relevant fluency monitoring. It is possible, that an investigation of activation in the right inferior parietal lobe (rIPL) could serve as a test for this hypothesis. Previous research has brought to light, that performance contingency is a crucial factor in the direction of affective control modulations. The rIPL shows activation in response to negative stimuli and deactivation in response to positive stimuli. However, if these stimuli occur performance-noncontingent, i.e. in a random manner and not as a meaningful consequence of participants’ own performance, the activation patterns are reversed (Braem et al., 2013). Thus, the rIPL plays a potentially important role in fluency monitoring. Because it seems to be sensitive to the differentiation of task relevant und task irrelevant affective information, its activation can serve as insightful neural substrate in further research.

Fluency monitoring is supposed to be a relatively unspecific but highly effective tool to detect the need for upregulation or the possibility of downregulation of control due to various information sources. Hence, both the effect of sequential and context-specific control adaptation plus additional modulating effects could be explained within one parsimonious theoretical framework. The beauty of this theoretical notion lies in its capability of taking a number of additional factors into account, which would have to be treated as some kind of “extra” component in other theories. For example, regarding a feature binding account, emotionally relevant stimuli (e.g. conflict-trials containing negative pictures, like in Dreisbach et al., 2019) have different characteristics as non-emotional stimuli (e.g. in a number Simon task). In addition to the arousing response conflict, negative stimulus content should further boost active connections, which is not entirely in line with what has been reported (namely a reduced CSPC in negative contexts, Dreisbach et al., 2019). Similarly, A merely affectively valenced stimulus, which is not contradicting any other active response tendency would not be detected according to the original CMT and would consequently not lead to upregulation of control. An account of fluency monitoring is less specific but more versatile insofar that the same stimulus may be a disfluent one and call for upregulation in one context but be rather fluent and call for no adjustment or for downregulation of control in another. Also, effects of affective context (Dreisbach et al., 2018; Fritz et al., 2015), the participants’ mood (van Steenbergen et al., 2010) or current cognitive focus and load can all be explained by fluency monitoring.

Dreisbach and Fischer (2015) have noted before that “the aversive conflict signal might be a (…) byproduct of the reduced fluency of conflict stimuli” (p. 257). They also present an alternative explanation and introduce the aversive conflict signal as the motivational driving force for conflict adaptation. Perhaps, there has no distinction to be made between these two seemingly alternative notions. Aversive signals of disfluency, with response conflict being the most prototypical example, probably signal the need for control adaptations. The relevance of these affective signals might be detected by the rIPL, that could also play a role in the translation of affective cues into processing adjustments (Braem et al., 2013). In conclusion, I suggest that even if aversive signals only are a byproduct of the stimulus, as soon as they are perceived as an inseparable part of it and cause meaningful changes in integral affect (cf. Inzlicht et al., 2015), control adaptations are indicated that operate in the service of affect regulation, and consequently in the service of optimal task execution (Dreisbach & Fischer, 2016). In addition to the ACC and (dorsolateral) PFC, as suggested by Botvinick et al. (2001), the anterior insular cortex (AIC; see Dreisbach & Fischer, 2015) and rIPL might play an important role in adaptation to conflict and other aversive signals. AIC and ACC are supposedly the structures that register a general need for adaptation, while rIPL and prefrontal structures inform what has to be done, depending on the input stimulus.

Fluency monitoring could therefore be understood as the detection of any input signal that disturbs the fluent, i.e. smooth and effortless task execution. An affective component of this disturbance then leads to appropriate adjustment of cognitive control in order to guarantee the intended performance. Importantly, this is not supposed to be a wide generalization of the account of aversive signals for control adaptation, but rather a small alteration. While response conflict is a specific kind of aversive signal, and also a specific kind of disfluency, all disfluency signals are aversive. By rephrasing and the suggestion of a fluency monitoring entity, the account encompasses particular cases that need an additional element of explanation within the account of aversive signals (e.g. the affective modulation of contexts, Dreisbach et al., 2018; Dreisbach et al., 2019). Simultaneously, it is a weakness of less specific accounts, that they lead to less targeted predictions. Here, as all signals of disfluency are also aversive signals, the slightly more general monitoring does not change the account of aversive signals in its core. This way, the prevailing theory is more thoroughly explored, corroborated and refined, but is not changed.

Outlook

The definition of conflict as it is investigated here and conflict in a general, everyday sense are slightly different. While the response conflict that is researched here is defined as “the simultaneous activation of incompatible representations” (Botvinick et al., 2001, p. 630), conflict in a general sense is defined as “a serious disagreement or argument, typically a protracted one“, “a condition in which a person experiences a clash of opposing wishes or needs“, or “An incompatibility between two or more opinions, principles, or interests” (Lexico, 2020). Although the latter two (opposing wishes; incompatibility between opinions, principles, or interests) come close to how response conflict is illustrated in introductory examples in many research articles, there are often differences in the levels of complexity between experimentally induced conflict and conflict in everyday life.

Deutsch (2019) mentions a micro-, meso- and macro level at which conflict may occur and poses the question whether they can all be seen as one field of research or whether individual theories and methods are needed at each level. The micro level represents conflicts as they are reflected by typical paradigms such as the Stroop-, Simon, and Flanker-task. Approach-Avoidance conflicts and moral conflicts, for example, are represented at the meso level. The most complex field of conflict, including conflicts such as competition, war, and social inequality is introduced as conflict at the macro level (Deutsch, 2019). Conflicts at the meso- and macro level can be considered more complex kinds of conflicts, as they include variables that add uncertainty, may qualify the conflict, or make it vary in its severity across individuals or situations. With the least level of complexity, or in other words, the most compartmentalized and operationalizable kind of conflict, research at the micro level is the most reliable way to investigate conflict and to draw conclusions and make predictions about underlying processes of conflict effects. Theoretically, it remains of course, to be clarified whether the underlying processes of all conflict levels share a mutual core and research results could, consequently, be transferred from research at the micro level to conflicts at the meso- and macro levels.

Cognitive psychology does, self-evidently, not aspire to draw conclusions and make predictions that are applicable to moral conflict and social inequality. It is impossible to model regularities that apply to any conflict situation irrespective of the manifestations of complex variables. Even in the seemingly basic example of buying apples at the supermarket and having to choose between two different types, many variables such as personal attitude, presence and identity of other individuals, advertisement etc. would have to be considered. A universal theory for any conflict situation, including those at the higher levels (Deutsch, 2019), can obviously not exist. However, if there is a mutual theoretical core, cognitive psychology can provide the theoretical foundation for the investigation of processes underlying many pressing issues and modern-day struggles.

With research regarding adaptation to different levels of fluency as aversive signals, the concept of fluency has been moved further into the focus of investigation. Disfluency leads to an aversive signal that can be elicited by stimuli or situations that are not, per se, affectively relevant. It is interesting that fluency has until now mostly been the subject of investigation in fields outside of cognitive psychology, like for example in educational sciences (Reber & Greifeneder, 2017). This could be a hint at what kind of step has to be made by other, more or less related fields in order to make theoretical insight from cognitive conflict research applicable to their issues: By defining what fluent and disfluent conditions in fields like social psychology are (e.g. in- and outgroup in a diverse society, Kozlik & Fischer, 2020), product development and -advertising (e.g. in the field of usability; presenting conceptually fluent symbols like pumpkins in October and snowflakes in December), and even public life (e.g. in governmental decisions about protective measures against the novel coronavirus), these fields could profit from the foundation that has been built by cognitive psychology. Positive and negative reactions and behavioral effects like performance cost or avoidance behavior could possibly be anticipated and the context for best possible adaptations could be created where necessary.

Conclusions

The results of the first study led to the assumption that fluency signals are monitored for just as disfluency signals like response conflict are monitored for. This calls for theoretical amendments to prevailing accounts, that have until now, mostly focused on conflict detection. In Study II, the finding that congruent trials elicit positive affective reactions further corroborated that notion. It was also found that behavioral adjustment correlates with the strength of aversive reactions to incongruent trials, if performance feedback was provided. In Study III, ambiguous evidence for context-specific control adjustments to auditory response incompatibility and disfluency could be found, which cannot be reconciled with existing research in the visual domain.

Existing theories are not fully capable of explaining these results. What is needed is a broader theoretical account that generalizes to many situations and contexts, includes the up- *and* downregulation of cognitive control (Study I), as it is based on affective perception and importance or consequences of the situations in which it is needed (Study II). A framework that can account for irregularities of effects in various contexts (Study III) and yet makes robust predictions is needed. The suggested fluency monitoring for control adaptation includes both response conflict and processing fluency as potential signals for adaptation, just like the framework of conflicts as aversive signals (Dreisbach & Fischer, 2015, 2016) does, but it explicitly includes downregulation of cognitive control whenever it is a resource-saving yet successful task strategy. In addition, it can also account for context effects and affective modulations thereof, like they have been reported in previous research (Dreisbach et al., 2018; Dreisbach et al., 2019; Fritz et al., 2015) and in the current Study III.

The idea of fluency monitoring is less specific than other accounts, yet it encompasses a broader range of research results with less need for explanations of exceptional cases. Future research should aspire to critically test the fluency monitoring account and try to gather more insight of processes regarding adaptation to conflict and other disfluent, aversive signals. Cognitive research can lay the foundation for other research areas and in this way, it can be an enrichment for many areas of modern society.

REFERENCES

Achaibou, A., Pourtois, G., Schwartz, S., & Vuilleumier, P. (2008). Simultaneous recording of EEG and facial muscle reactions during spontaneous emotional mimicry. *Neuropsychologia*, *46*(4), 1104–1113. https://doi.org/10.1016/j.neuropsychologia.2007.10.019

Aisenberg, D., & Henik, A. (2012). Stop being neutral: Simon takes control! *Quarterly Journal of Experimental Psychology (2006)*, *65*(2), 295–304. https://doi.org/10.1080/17470218.2010.507819

Amer, T., Campbell, K. L., & Hasher, L. (2016). Cognitive Control As a Double-Edged Sword. *Trends in Cognitive Sciences*, *20*(12), 905–915. https://doi.org/10.1016/j.tics.2016.10.002

Berger, A., Dolk, T., Bogon, J., & Dreisbach, G. (2020). Challenging voices: Mixed evidence for context-specific control adjustments in the auditory domain. *Quarterly Journal of Experimental Psychology (2006)*, 1747021820921096. https://doi.org/10.1177/1747021820921096

Berger, A., Fischer, R., & Dreisbach, G. (2019). It's more than just conflict: The functional role of congruency in the sequential control adaptation. *Acta Psychologica*, *197*, 64–72. https://doi.org/10.1016/j.actpsy.2019.04.016

Berger, A., Mitschke, V., Dignath, D., Eder, A., & van Steenbergen, H. (2020). The face of control: Corrugator supercilii tracks aversive conflict signals in the service of adaptive cognitive control. *Psychophysiology*, *57*(4), e13524. https://doi.org/10.1111/psyp.13524

Botvinick, M. M. (2007). Conflict monitoring and decision making: Reconciling two perspectives on anterior cingulate function. *Cognitive, Affective & Behavioral Neuroscience*, *7*(4), 356–366. https://doi.org/10.3758/CABN.7.4.356

Botvinick, M. M., Braver, T. S [Todd S.], Barch, D. M., Carter, C. S., & Cohen, J. D [J. D.] (2001). Conflict monitoring and cognitive control. *Psychological Review*, *108*(3), 624–652. https://doi.org/10.1037/0033-295X.108.3.624

Braem, S., Bugg, J. M., Schmidt, J. R., Crump, M. J. C., Weissman, D. H., Notebaert, W., & Egner, T. (2019). Measuring Adaptive Control in Conflict Tasks. *Trends in Cognitive Sciences*, *23*(9), 769–783. https://doi.org/10.1016/j.tics.2019.07.002

Braem, S., Coenen, E., Bombeke, K., van Bochove, M. E., & Notebaert, W. (2015). Open your eyes for prediction errors. *Cognitive, Affective & Behavioral Neuroscience, 15*(2), 374–380. https://doi.org/10.3758/s13415-014-0333-4

Braem, S., King, J. A., Korb, F. M., Krebs, R. M., Notebaert, W., & Egner, T. (2013). Affective modulation of cognitive control is determined by performance-contingency and mediated by ventromedial prefrontal and cingulate cortex. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *33*(43), 16961–16970. https://doi.org/10.1523/JNEUROSCI.1208-13.2013

Braem, S., King, J. A., Korb, F. M., Krebs, R. M., Notebaert, W., & Egner, T. (2017). The Role of Anterior Cingulate Cortex in the Affective Evaluation of Conflict. *Journal of Cognitive Neuroscience*, *29*(1), 137–149. https://doi.org/10.1162/jocn_a_01023

Braem, S., Verguts, T., & Notebaert, W. (2011). Conflict adaptation by means of associative learning. *Journal of Experimental Psychology. Human Perception and Performance*, *37*(5), 1662–1666. https://doi.org/10.1037/a0024385

Braem, S., Verguts, T., Roggeman, C., & Notebaert, W. (2012). Reward modulates adaptations to conflict. *Cognition*, *125*(2), 324–332. https://doi.org/10.1016/j.cognition.2012.07.015

Brouillet, T., Ferrier, L. P., Grosselin, A., & Brouillet, D. (2011). Action compatibility effects are hedonically marked and have incidental consequences on affective judgment. *Emotion (Washington, D.C.), 11*(5), 1202–1205. https://doi.org/10.1037/a0024742

Brown, J. W., & Braver, T. S [Todd S.] (2005). Learned predictions of error likelihood in the anterior cingulate cortex. *Science (New York, N.Y.), 307*(5712), 1118–1121. https://doi.org/10.1126/science.1105783

Bugg, J. M. (2008). Opposing influences on conflict-driven adaptation in the Eriksen flanker task. *Memory & Cognition*, *36*(7), 1217–1227. https://doi.org/10.3758/MC.36.7.1217

Bugg, J. M. (2012). Dissociating Levels of Cognitive Control. *Current Directions in Psychological Science*, *21*(5), 302–309. https://doi.org/10.1177/0963721412453586

Bugg, J. M., & Crump, M. J. C. (2012). In Support of a Distinction between Voluntary and Stimulus-Driven Control: A Review of the Literature on Proportion Congruent Effects. *Frontiers in Psychology, 3,* 367. https://doi.org/10.3389/fpsyg.2012.00367

Bugg, J. M., Jacoby, L. L., & Chanani, S. (2011). Why it is too early to lose control in accounts of item-specific proportion congruency effects. *Journal of Experimental Psychology. Human Perception and Performance*, *37*(3), 844–859. https://doi.org/10.1037/a0019957

Bugg, J. M., Jacoby, L. L., & Toth, J. P. (2008). Multiple levels of control in the Stroop task. *Memory & Cognition*, *36*(8), 1484–1494. https://doi.org/10.3758/MC.36.8.1484

Cacioppo, J. T [J. T.], Petty, R. E., & Morris, K. J. (1985). Semantic, evaluative, and self-referent processing: Memory, cognitive effort, and somatovisceral activity. *Psychophysiology*, *22*(4), 371–384. https://doi.org/10.1111/j.1469-8986.1985.tb01618.x

Cañadas, E., Lupiáñez, J., Kawakami, K., Niedenthal, P. M., & Rodríguez-Bailón, R. (2016). Perceiving emotions: Cueing social categorization processes and attentional control through facial expressions. *Cognition & Emotion*, *30*(6), 1149–1163. https://doi.org/10.1080/02699931.2015.1052781

Cañadas, E., Rodríguez-Bailón, R., Milliken, B., & Lupiáñez, J. (2013). Social categories as a context for the allocation of attentional control. *Journal of Experimental Psychology. General*, *142*(3), 934–943. https://doi.org/10.1037/a0029794

Cannon, P. R., Hayes, A. E., & Tipper, S. P. (2010). Sensorimotor fluency influences affect: Evidence from electromyography. *Cognition & Emotion*, *24*(4), 681–691. https://doi.org/10.1080/02699930902927698

Cavanagh, J. F., & Frank, M. J. (2014). Frontal theta as a mechanism for cognitive control. *Trends in Cognitive Sciences*, *18*(8), 414–421. https://doi.org/10.1016/j.tics.2014.04.012

Cavanagh, J. F., Masters, S. E., Bath, K., & Frank, M. J. (2014). Conflict acts as an implicit cost in reinforcement learning. *Nature Communications*, *5*, 5394. https://doi.org/10.1038/ncomms6394

Cavanagh, J. F., & Shackman, A. J. (2015). Frontal midline theta reflects anxiety and cognitive control: Meta-analytic evidence. *Journal of Physiology, Paris*, *109*(1-3), 3–15. https://doi.org/10.1016/j.jphysparis.2014.04.003

Chen, S., & Melara, R. D. (2009). Sequential effects in the Simon task: Conflict adaptation or feature integration? *Brain Research*, *1297*, 89–100. https://doi.org/10.1016/j.brainres.2009.08.003

Chiew, K. S., & Braver, T. S [Todd S.] (2010). Exploring emotional and cognitive conflict using speeded voluntary facial expressions. *Emotion (Washington, D.C.)*, *10*(6), 842–854. https://doi.org/10.1037/a0019704

Chiew, K. S., & Braver, T. S [Todd S.] (2011). Positive affect versus reward: Emotional and motivational influences on cognitive control. *Frontiers in Psychology*, *2*, 279. https://doi.org/10.3389/fpsyg.2011.00279

Clayson, P. E., & Larson, M. J. (2011). Conflict adaptation and sequential trial effects: Support for the conflict monitoring theory. *Neuropsychologia*, *49*(7), 1953–1961. https://doi.org/10.1016/j.neuropsychologia.2011.03.023

Cohen, A., & Shoup, R. (1997). Perceptual dimensional constraints in response selection processes. *Cognitive Psychology*, *32*(2), 128–181. https://doi.org/10.1006/cogp.1997.0648

Cole, M. W., Yeung, N., Freiwald, W. A., & Botvinick, M. (2009). Cingulate cortex: Diverging data from humans and monkeys. *Trends in Neurosciences*, *32*(11), 566–574. https://doi.org/10.1016/j.tins.2009.07.001

Colvett, J. S., Nobles, L. M., & Bugg, J. M. (2020). The unique effects of relatively recent conflict on cognitive control. *Journal of Experimental Psychology. Human Perception and Performance.* Advance online publication. https://doi.org/10.1037/xhp0000860

Compton, R. J., Banich, M. T., Mohanty, A., Milham, M. P., Herrington, J., Miller, G. A., Scalf, P. E., Webb, A., & Heller, W. (2003). Paying attention to emotion: An fMRI investigation of cognitive and emotional stroop tasks. *Cognitive, Affective & Behavioral Neuroscience*, *3*(2), 81–96. https://doi.org/10.3758/CABN.3.2.81

Compton, R. J., Huber, E., Levinson, A. R., & Zheutlin, A. (2012). Is "conflict adaptation" driven by conflict? Behavioral and EEG evidence for the underappreciated role of congruent trials. *Psychophysiology*, *49*(5), 583–589. https://doi.org/10.1111/j.1469-8986.2012.01354.x

Corballis, P. M., & Gratton, G. (2003). Independent control of processing strategies for different locations in the visual field. *Biological Psychology*, *64*(1-2), 191–209. https://doi.org/10.1016/S0301-0511(03)00109-1

Crump, M. J. C., Brosowsky, N. P., & Milliken, B. (2017). Reproducing the location-based context-specific proportion congruent effect for frequency unbiased items: A reply to Hutcheon and Spieler (2016). *Quarterly Journal of Experimental Psychology (2006)*, *70*(9), 1792–1807. https://doi.org/10.1080/17470218.2016.1206130

Crump, M. J. C., Gong, Z., & Milliken, B. (2006). The context-specific proportion congruent Stroop effect: Location as a contextual cue. *Psychonomic Bulletin & Review*, *13*(2), 316–321. https://doi.org/10.3758/BF03193850

Crump, M. J. C., & Logan, G. D. (2010). Contextual control over task-set retrieval. *Attention, Perception & Psychophysics*, *72*(8), 2047–2053. https://doi.org/10.3758/APP.72.8.2047

Crump, M. J. C., & Milliken, B. (2009). The flexibility of context-specific control: Evidence for context-driven generalization of item-specific control settings. *Quarterly Journal of Experimental Psychology (2006)*, *62*(8), 1523–1532. https://doi.org/10.1080/17470210902752096

Damen, T. G. E., Strick, M., Taris, T. W., & Aarts, H. (2018). When conflict influences liking: The case of the Stroop task. *PloS One*, *13*(7), e0199700. https://doi.org/10.1371/journal.pone.0199700

Darwin, C., Prodger, P., & Ekman, P. (1872). *The expression of the emotions in man and animals: Essay on the history of the illustration / by Philip Prodger* (3rd ed.). Oxford University Press.

D'Ascenzo, S., Iani, C., Guidotti, R., Laeng, B., & Rubichi, S. (2016). Practice-induced and sequential modulations in the Simon task: Evidence from pupil dilation. *International Journal of Psychophysiology : Official Journal of the International Organization of Psychophysiology*, *110*, 187–193. https://doi.org/10.1016/j.ijpsycho.2016.08.002

Davelaar, E. J., & Stevens, J. (2009). Sequential dependencies in the Eriksen flanker task: A direct comparison of two competing accounts. *Psychonomic Bulletin & Review*, *16*(1), 121–126. https://doi.org/10.3758/PBR.16.1.121

Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General*, *122*(3), 371–396. https://doi.org/10.1037//0096-3445.122.3.371

Desender, K., van Lierde, E., & van den Bussche, E. (2013). *Comparing conscious and unconscious conflict adaptation* (Vol. 8). https://doi.org/10.1371/journal.pone.0055976

Desender, K., van Opstal, F., & van den Bussche, E. (2014). Feeling the conflict: The crucial role of conflict experience in adaptation. *Psychological Science*, *25*(3), 675–683. https://doi.org/10.1177/0956797613511468

Deutsch, R. (2019, July 3). *Cognitive Conflicts: Taking a Cognitive Perspective on Social Phenomena: Welcome Note.* European Association of Social Psychology. EASP Meeting, Tübingen, Germany.

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Diede, N. T., & Bugg, J. M. (2016). Spatial proximity as a determinant of context-specific attentional settings. *Attention, Perception & Psychophysics*, *78*(5), 1255–1266. https://doi.org/10.3758/s13414-016-1086-7

Dignath, D., Berger, A., Spruit, I. M., & van Steenbergen, H. (2019). Temporal dynamics of error-related corrugator supercilii and zygomaticus major activity: Evidence for implicit emotion regulation following errors. *International Journal of Psychophysiology : Official Journal of the International Organization of Psychophysiology*, *146*, 208–216. https://doi.org/10.1016/j.ijpsycho.2019.10.003

Dignath, D., & Eder, A. B. (2015). Stimulus conflict triggers behavioral avoidance. *Cognitive, Affective & Behavioral Neuroscience*, *15*(4), 822–836. https://doi.org/10.3758/s13415-015-0355-6

Dignath, D., Eder, A. B., Steinhauser, M., & Kiesel, A. (2020). Conflict monitoring and the affective-signaling hypothesis-An integrative review. *Psychonomic Bulletin & Review*, *27*(2), 193–216. https://doi.org/10.3758/s13423-019-01668-9

Dignath, D., Janczyk, M., & Eder, A. B. (2017). Phasic valence and arousal do not influence post-conflict adjustments in the Simon task. *Acta Psychologica*, *174*, 31–39. https://doi.org/10.1016/j.actpsy.2017.01.004

Dimberg, U. (1990). Facial electromyography and emotional reactions. *Psychophysiology*, *27*(5), 481–494. https://doi.org/10.1111/j.1469-8986.1990.tb01962.x

Dimberg, U., & Karlsson, B. (1997). Facial reactions to different emotionally relevant stimuli. *Scandinavian Journal of Psychology*, *38*(4), 297–303. https://doi.org/10.1111/1467-9450.00039

Dreisbach, G. (2012). Mechanisms of Cognitive Control. *Current Directions in Psychological Science*, *21*(4), 227–231. https://doi.org/10.1177/0963721412449830

Dreisbach, G., & Fischer, R. (2011). If it's hard to read… try harder! Processing fluency as signal for effort adjustments. *Psychological Research*, *75*(5), 376–383. https://doi.org/10.1007/s00426-010-0319-y

Dreisbach, G., & Fischer, R. (2012a). Conflicts as aversive signals. *Brain and Cognition*, *78*(2), 94–98. https://doi.org/10.1016/j.bandc.2011.12.003

Dreisbach, G., & Fischer, R. (2012b). The role of affect and reward in the conflict-triggered adjustment of cognitive control. *Frontiers in Human Neuroscience*, *6*, 342. https://doi.org/10.3389/fnhum.2012.00342

Dreisbach, G., & Fischer, R. (2015). Conflicts as Aversive Signals for Control Adaptation. *Current Directions in Psychological Science*, *24*(4), 255–260. https://doi.org/10.1177/0963721415569569

Dreisbach, G., & Fischer, R. (2016). Conflicts as aversive signals: Motivation for control adaptation in the service of affect regulations. In T. S. Braver (Ed.), *Frontiers of cognitive psychology. Motivation and cognitive control* (pp. 188–2010). Routledge/Taylor & Francis Group.

Dreisbach, G., & Fröber, K. (2019). On How to Be Flexible (or Not): Modulation of the Stability-Flexibility Balance. *Current Directions in Psychological Science*, *28*(1), 3–9. https://doi.org/10.1177/0963721418800030

Dreisbach, G., Fröber, K., Berger, A., & Fischer, R. (2019). Unexpected conflict signals loom larger in a positive context: Evidence from context specific control adjustments. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *45*(8), 1398–1409. https://doi.org/10.1037/xlm0000662

Dreisbach, G., Reindl, A.-L., & Fischer, R. (2018). Conflict and disfluency as aversive signals: Context-specific processing adjustments are modulated by affective location associations. *Psychological Research*, *82*(2), 324–336. https://doi.org/10.1007/s00426-016-0822-x

Duthoo, W., Abrahamse, E. L., Braem, S., Boehler, C. N., & Notebaert, W. (2014). The heterogeneous world of congruency sequence effects: An update. *Frontiers in Psychology*, *5*, 1001. https://doi.org/10.3389/fpsyg.2014.01001

Egner, T. (2007). Congruency sequence effects and cognitive control. *Cognitive, Affective & Behavioral Neuroscience*, *7*(4), 380–390. https://doi.org/10.3758/CABN.7.4.380

Egner, T. (2014). Creatures of habit (and control): A multi-level learning perspective on the modulation of congruency effects. *Frontiers in Psychology*, *5*, 1247. https://doi.org/10.3389/fpsyg.2014.01247

Egner, T. (2017). Conflict Adaptation: Past, Present, and Future of the Congruency Sequence Effect as an Index of Cognitive Control. In T. Egner (Ed.), *The Wiley Handbook of Cognitive Control* (pp. 64–78). Wiley Blackwell.

Egner, T., & Hirsch, J. (2005). Cognitive control mechanisms resolve conflict through cortical amplification of task-relevant information. *Nature Neuroscience*, *8*(12), 1784–1790. https://doi.org/10.1038/nn1594

Elkins-Brown, N., Saunders, B., He, F., & Inzlicht, M. (2017). Stability and reliability of error-related electromyography over the corrugator supercilii with increasing trials. *Psychophysiology*, *54*(10), 1559–1573. https://doi.org/10.1111/psyp.12902

Elkins-Brown, N., Saunders, B., & Inzlicht, M. (2016). Error-related electromyographic activity over the corrugator supercilii is associated with neural performance monitoring. *Psychophysiology*, *53*(2), 159–170. https://doi.org/10.1111/psyp.12556

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics*, *16*(1), 143–149. https://doi.org/10.3758/BF03203267

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, *41*(4), 1149–1160. https://doi.org/10.3758/BRM.41.4.1149

Fellows, L. K., & Farah, M. J. (2005). Is anterior cingulate cortex necessary for cognitive control? *Brain : A Journal of Neurology*, *128*(Pt 4), 788–796. https://doi.org/10.1093/brain/awh405

Fischer, R., Dreisbach, G., & Goschke, T. (2008). Context-sensitive adjustments of cognitive control: Conflict-adaptation effects are modulated by processing demands of the ongoing task. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *34*(3), 712–718. https://doi.org/10.1037/0278-7393.34.3.712

Fischer, R., Gottschalk, C., & Dreisbach, G. (2014). Context-sensitive adjustment of cognitive control in dual-task performance. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *40*(2), 399–416. https://doi.org/10.1037/a0034310

Fischer, R., Plessow, F., Dreisbach, G., & Goschke, T. (2015). Individual Differences in the Context-Dependent Recruitment of Cognitive Control: Evidence From Action Versus State Orientation. *Journal of Personality*, *83*(5), 575–583. https://doi.org/10.1111/jopy.12140

Fischer, R., Ventura-Bort, C., Hamm, A., & Weymar, M. (2018). Transcutaneous vagus nerve stimulation (tVNS) enhances conflict-triggered adjustment of cognitive control. *Cognitive, Affective & Behavioral Neuroscience*, *18*(4), 680–693. https://doi.org/10.3758/s13415-018-0596-2

Forster, M., Leder, H., & Ansorge, U. (2013). It felt fluent, and I liked it: Subjective feeling of fluency rather than objective fluency determines liking. *Emotion (Washington, D.C.)*, *13*(2), 280–289. https://doi.org/10.1037/a0030115

Forster, M., Leder, H., & Ansorge, U. (2016). Exploring the Subjective Feeling of Fluency. *Experimental Psychology*, *63*(1), 45–58. https://doi.org/10.1027/1618-3169/a000311

Fournier, L. R., Coder, E., Kogan, C., Raghunath, N., Taddese, E., & Rosenbaum, D. A. (2019). Which task will we choose first? Precrastination and cognitive load in task ordering. *Attention, Perception & Psychophysics*, *81*(2), 489–503. https://doi.org/10.3758/s13414-018-1633-5

Friedman, N. P., & Miyake, A. (2017). Unity and diversity of executive functions: Individual differences as a window on cognitive structure. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, *86*, 186–204. https://doi.org/10.1016/j.cortex.2016.04.023

Fritz, J., & Dreisbach, G. (2013). Conflicts as aversive signals: Conflict priming increases negative judgments for neutral stimuli. *Cognitive, Affective & Behavioral Neuroscience*, *13*(2), 311–317. https://doi.org/10.3758/s13415-012-0147-1

Fritz, J., & Dreisbach, G. (2015). The time course of the aversive conflict signal. *Experimental Psychology*, *62*(1), 30–39. https://doi.org/10.1027/1618-3169/a000271

Fritz, J., Fischer, R., & Dreisbach, G. (2015). The influence of negative stimulus features on conflict adaption: Evidence from fluency of processing. *Frontiers in Psychology, 6*, 185. https://doi.org/10.3389/fpsyg.2015.00185

Fröber, K., & Dreisbach, G. (2014). The differential influences of positive affect, random reward, and performance-contingent reward on cognitive control. *Cognitive, Affective & Behavioral Neuroscience*, *14*(2), 530–547. https://doi.org/10.3758/s13415-014-0259-x

Fröber, K., Stürmer, B., Frömer, R., & Dreisbach, G. (2017). The role of affective evaluation in conflict adaptation: An LRP study. *Brain and Cognition*, *116*, 9–16. https://doi.org/10.1016/j.bandc.2017.05.003

Fruchtman-Steinbok, T., Salzer, Y., Henik, A., & Cohen, N. (2017). The interaction between emotion and executive control: Comparison between visual, auditory, and tactile modalities. *Quarterly Journal of Experimental Psychology (2006)*, *70*(8), 1661–1674. https://doi.org/10.1080/17470218.2016.1199717

Gerger, G., Leder, H., Tinio, P. P. L., & Schacht, A. (2011). Faces versus patterns: Exploring aesthetic reactions using facial EMG. *Psychology of Aesthetics, Creativity, and the Arts*, *5*(3), 241–250. https://doi.org/10.1037/a0024154

Goschke, T. (2017). Volition und kognitive Kontrolle. In J. Müsseler & M. Rieger (Eds.), *Allgemeine Psychologie* (pp. 251–318). Springer Berlin Heidelberg.

Gottschalk, C., & Fischer, R. (2017). Activation of context-specific attentional control sets by exogenous allocation of visual attention to the context? *Psychological Research*, *81*(2), 378–391. https://doi.org/10.1007/s00426-016-0746-5

Gratton, G., Coles Michael G. H., & Donchin, E. (1992). Optimizing the use of information: strategic control of activation of responses. *Journal of Experimental Psychology*, *121*(4), 480–506.

Green, J. J., Teder-Sälejärvi, W. A., & McDonald, J. J. (2005). Control mechanisms mediating shifts of attention in auditory and visual space: A spatio-temporal ERP analysis. *Experimental Brain Research*, *166*(3-4), 358–369. https://doi.org/10.1007/s00221-005-2377-8

Gronau, Q. F., Ly, A., & Wagenmakers, E.-J. (2020). Informed Bayesian t -Tests. *The American Statistician*, *74*(2), 137–143. https://doi.org/10.1080/00031305.2018.1562983

Hasbroucq, T., & Guiard, Y. (1992). The effects of intensity and irrelevant location of a tactile stimulation in a choice reaction time task. *Neuropsychologia*, *30*(1), 91–94. https://doi.org/10.1016/0028-3932(92)90017-G

Hatukai, T., & Algom, D. (2017). The Stroop incongruity effect: Congruity relationship reaches beyond the Stroop task. *Journal of Experimental Psychology. Human Perception and Performance*, *43*(6), 1098–1114. https://doi.org/10.1037/xhp0000381

Heinemann, A., Kunde, W., & Kiesel, A. (2009). Context-specific prime-congruency effects: On the role of conscious stimulus representations for cognitive control. *Consciousness and Cognition*, *18*(4), 966–976. https://doi.org/10.1016/j.concog.2009.08.009

Hommel, B. (1993). Inverting the Simon effect by intention. *Psychological Research*, *55*(4), 270–279. https://doi.org/10.1007/BF00419687

Hommel, B. (1998). Event Files: Evidence for Automatic Integration of Stimulus-Response Episodes. *Visual Cognition*, *5*(1-2), 183–216. https://doi.org/10.1080/713756773

Hommel, B. (2004). Event files: Feature binding in and across perception and action. *Trends in Cognitive Sciences*, *8*(11), 494–500. https://doi.org/10.1016/j.tics.2004.08.007

Hommel, B. (2011). The Simon effect as tool and heuristic. *Acta Psychologica*, *136*(2), 189–202. https://doi.org/10.1016/j.actpsy.2010.04.011

Hull, C. L. (1943). Principles of behavior: an introduction to behavior theory. In R. M. Elliott (Ed.), *The century psychology series.* Aplleton-Century-Crofts Inc.

Hutcheon, T. G., & Spieler, D. H. (2017). Limits on the generalizability of context-driven control. *Quarterly Journal of Experimental Psychology (2006)*, *70*(7), 1292–1304. https://doi.org/10.1080/17470218.2016.1182193

Inzlicht, M., Bartholow, B. D., & Hirsh, J. B. (2015). Emotional foundations of cognitive control. *Trends in Cognitive Sciences*, *19*(3), 126–132. https://doi.org/10.1016/j.tics.2015.01.004

Inzlicht, M., Shenhav, A., & Olivola, C. Y. (2018). The Effort Paradox: Effort Is Both Costly and Valued. *Trends in Cognitive Sciences*, *22*(4), 337–349. https://doi.org/10.1016/j.tics.2018.01.007

Isenberg, N., Silbersweig, D., Engelien, A., Emmerich, S., Malavade, K., Beattie, B., Leon, A. C., & Stern, E. (1999). Linguistic threat activates the human amygdala. *Proceedings of the National Academy of Sciences of the United States of America*, *96*(18), 10456–10459. https://doi.org/10.1073/pnas.96.18.10456

Jacoby, L. L., Lindsay, D. S., & Hessels, S. (2003). Item-specific control of automatic processes: Stroop process dissociations. *Psychonomic Bulletin & Review*, *10*(3), 638–644. https://doi.org/10.3758/BF03196526

Jiménez-Moya, G., Rodríguez-Bailón, R., & Lupiáñez, J. (2018). The face-specific proportion congruency effect: Social stimuli as contextual cues. *Cognitive Processing*, *19*(4), 537–544. https://doi.org/10.1007/s10339-018-0870-9

Kanske, P., & Kotz, S. A. (2010). Modulation of early conflict processing: N200 responses to emotional words in a flanker task. *Neuropsychologia*, *48*(12), 3661–3664. https://doi.org/10.1016/j.neuropsychologia.2010.07.021

Kerns, J. G., Cohen, J. D [J. D.], MacDonald, A. W., Cho, R. Y., Stenger, V. A., Carter, & C. S. (2004). Anterior cingulate conflict monitoring and adjustments in control. *Science*(5660), 1023–1026.

Kobayashi, N., Yoshino, A., Takahashi, Y., & Nomura, S. (2007). Autonomic arousal in cognitive conflict resolution. *Autonomic Neuroscience : Basic & Clinical*, *132*(1-2), 70–75. https://doi.org/10.1016/j.autneu.2006.09.004

Kool, W., & Botvinick, M. (2014). A labor/leisure tradeoff in cognitive control. *Motivation Science*, *1*(S), 3–18. https://doi.org/10.1037/2333-8113.1.S.3

Kool, W., McGuire, J. T., Rosen, Z. B., & Botvinick, M. M. (2010). Decision making and the avoidance of cognitive demand. *Journal of Experimental Psychology. General*, *139*(4), 665–682. https://doi.org/10.1037/a0020198

Kool, W., Shenhav, A., & Botvinick, M. M. (2017). Cognitive Control as Cost-Benefit Decision Making. In T. Egner (Ed.), *The Wiley Handbook of Cognitive Control* (pp. 167–189). Wiley Blackwell. https://doi.org/10.1002/9781118920497.ch10

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional Overlap: Cognitive Basis for Stimulus-Response Compatibility - A Model and Taxonomy. *Psychological Bulletin*, *92*(2).

Kozlik, J., & Fischer, R. (2020). When a smile is a conflict: Affective mismatch between facial displays and group membership induces conflict and triggers cognitive control.

Journal of Experimental Psychology. Human Perception and Performance, *46*(6), 551–568. https://doi.org/10.1037/xhp0000732

Kragel, P. A., Kano, M., van Oudenhove, L., Ly, H. G., Dupont, P., Rubio, A., Delon-Martin, C., Bonaz, B. L., Manuck, S. B., Gianaros, P. J., Ceko, M., Reynolds Losin, E. A., Woo, C.-W., Nichols, T. E., & Wager, T. D. (2018). Generalizable representations of pain, cognitive control, and negative emotion in medial frontal cortex. *Nature Neuroscience*, *21*(2), 283–289. https://doi.org/10.1038/s41593-017-0051-7

Krug, M. K., & Carter, C. S. (2010). Anterior Cingulate Cortex Contributions to Cognitive and Emotional Processing: A General Purpose Mechanism for Cognitive Control and Self-Control. In R. R. Hassin, K. N. Ochsner, & Y. Trope (Eds.), *Oxford series in social cognition and social neuroscience. Self control in society, mind, and brain* (pp. 3–26). Oxford Univ. Press.

Kuhbandner, C., & Zehetleitner, M. (2011). *Dissociable effects of valence and arousal in adaptive executive control* (Vol. 6). https://doi.org/10.1371/journal.pone.0029287

Kuipers, M., Richter, M., Scheepers, D., Immink, M. A., Sjak-Shie, E., & van Steenbergen, H. (2017). How effortful is cognitive control? Insights from a novel method measuring single-trial evoked beta-adrenergic cardiac reactivity. *International Journal of Psychophysiology : Official Journal of the International Organization of Psychophysiology*, *119*, 87–92. https://doi.org/10.1016/j.ijpsycho.2016.10.007

Lamers, M. J. M., & Roelofs, A. (2011). Attentional control adjustments in Eriksen and Stroop task performance can be independent of response conflict. *Quarterly Journal of Experimental Psychology (2006)*, *64*(6), 1056–1081. https://doi.org/10.1080/17470218.2010.523792

Lang, P. J., Greenwald, M. K., Bradley, M. M., & Hamm, A. (1993). Looking at pictures: Affective, facial, visceral, and behavioral reactions. *Psychophysiology, 30*, 261–273.

Larsen, J. T., Norris, C. J., & Cacioppo, J. T [John T.] (2003). Effects of positive and negative affect on electromyographic activity over zygomaticus major and corrugator supercilii. *Psychophysiology*, *40*(5), 776–785. https://doi.org/10.1111/1469-8986.00078

Larson, M. J., Clayson, P. E., & Clawson, A. (2014). Making sense of all the conflict: A theoretical review and critique of conflict-related ERPs. *International Journal of*

Psychophysiology : Official Journal of the International Organization of Psychophysiology, *93*(3), 283–297. https://doi.org/10.1016/j.ijpsycho.2014.06.007

Larson, M. J., Clayson, P. E., Kirwan, C. B., & Weissman, D. H. (2016). Event-related potential indices of congruency sequence effects without feature integration or contingency learning confounds. *Psychophysiology*, *53*(6), 814–822. https://doi.org/10.1111/psyp.12625

Larson, M. J., Kaufman, D. A. S., & Perlstein, W. M. (2009). Conflict adaptation and cognitive control adjustments following traumatic brain injury. *Journal of the International Neuropsychological Society : JINS*, *15*(6), 927–937. https://doi.org/10.1017/S1355617709990701

Lawo, V., & Koch, I. (2014). Dissociable effects of auditory attention switching and stimulus-response compatibility. *Psychological Research*, *78*(3), 379–386. https://doi.org/10.1007/s00426-014-0545-9

Lehle, C., & Hübner, R. (2008). On-the-fly adaptation of selectivity in the flanker task. *Psychonomic Bulletin & Review*, *15*(4), 814–818. https://doi.org/10.3758/PBR.15.4.814

Lexico. (2020). *Oxford English and Spanish Dictionary, Thesaurus, and Spanish to English Translator*. https://www.lexico.com/en/definition/conflict

Lindström, B. R., Mattsson-Mårn, I. B., Golkar, A., & Olsson, A. (2013). In Your Face: Risk of Punishment Enhances Cognitive Control and Error-Related Activity in the Corrugator Supercilii Muscle. *PloS One*, *8*(6), e65692. https://doi.org/10.1371/journal.pone.0065692

Logan, G. D., & Zbrodoff, N. J. (1979). When it helps to be misled: Facilitative effects of increasing the frequency of conflicting stimuli in a Stroop-like task. *Memory & Cognition*, *7*(3), 166–174. https://doi.org/10.3758/BF03197535

Lu, C. H., & Proctor, R. W. (1995). The influence of irrelevant location information on performance: A review of the Simon and spatial Stroop effects. *Psychonomic Bulletin & Review*, *2*(2), 174–207. https://doi.org/10.3758/BF03210959

Mayr, U., Awh, E., & Laurey, P. (2003). Conflict adaptation effects in the absence of executive control. *Nature Neuroscience*, *6*(5), 450–452. https://doi.org/10.1038/nn1051

McTeague, L. M., Goodkind, M. S., & Etkin, A. (2016). Transdiagnostic impairment of cognitive control in mental illness. *Journal of Psychiatric Research*, *83*, 37–46. https://doi.org/10.1016/j.jpsychires.2016.08.001

Milham, M. P., & Banich, M. T. (2005). Anterior cingulate cortex: An fMRI analysis of conflict specificity and functional differentiation. *Human Brain Mapping*, *25*(3), 328–335. https://doi.org/10.1002/hbm.20110

Miyake, A., & Friedman, N. P. (2012). The Nature and Organization of Individual Differences in Executive Functions: Four General Conclusions. *Current Directions in Psychological Science*, *21*(1), 8–14. https://doi.org/10.1177/0963721411429458

Morree, H. M. de, & Marcora, S. M. (2010). The face of effort: Frowning muscle activity reflects effort during a physical task. *Biological Psychology*, *85*(3), 377–382. https://doi.org/10.1016/j.biopsycho.2010.08.009

Morsella, E., Gray, J. R., Krieger, S. C., & Bargh, J. A. (2009). The essence of conscious conflict: Subjective effects of sustaining incompatible intentions. *Emotion (Washington, D.C.)*, *9*(5), 717–728. https://doi.org/10.1037/a0017121

Moser, J. S., Moran, T. P., Schroder, H. S., Donnellan, M. B., & Yeung, N. (2013). On the relationship between anxiety and error monitoring: A meta-analysis and conceptual framework. *Frontiers in Human Neuroscience*, *7*, 466. https://doi.org/10.3389/fnhum.2013.00466

Murphy, P. R., van Moort, M., Nieuwenhuis, S., & van Moort, M. L. (2017). *Data from: The pupillary orienting response predicts adaptive behavioral adjustment after errors.* https://doi.org/10.5061/DRYAD.MJ0K3

Mushtaq, F., Bland, A. R., & Schaefer, A. (2011). Uncertainty and cognitive control. *Frontiers in Psychology*, *2*, 249. https://doi.org/10.3389/fpsyg.2011.00249

Nieuwenhuis, S., Stins, J. F., Posthuma, D., Polderman, T. J. C., Boomsma, D. I., & Geus, E. J. de (2006). Accounting for sequential trial effects in the flanker task: Conflict adaptation or associative priming? *Memory & Cognition*, *34*(6), 1260–1272. https://doi.org/10.3758/BF03193270

Obermeier, C., Dolk, T., & Gunter, T. C. (2012). The benefit of gestures during communication: Evidence from hearing and hearing-impaired individuals. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, *48*(7), 857–870. https://doi.org/10.1016/j.cortex.2011.02.007

Oppenheimer, D. M. (2008). The secret life of fluency. *Trends in Cognitive Sciences*, *12*(6), 237–241. https://doi.org/10.1016/j.tics.2008.02.014

Oster, H. (1978). Facial Expression and Affect Development. In M. Lewis & L. A. Rosenblum (Eds.), *The Development of Affect* (pp. 43–75). Springer US. https://doi.org/10.1007/978-1-4684-2616-8_3

Padmala, S., Bauer, A., & Pessoa, L. (2011). Negative emotion impairs conflict-driven executive control. *Frontiers in Psychology*, *2*, 192. https://doi.org/10.3389/fpsyg.2011.00192

Pan, F., Shi, L., Lu, Q., Wu, X., Xue, S., & Li, Q. (2016). The negative priming effect in cognitive conflict processing. *Neuroscience Letters*, *628*, 35–39. https://doi.org/10.1016/j.neulet.2016.05.062

Pessoa, L. (2009). How do emotion and motivation direct executive control? *Trends in Cognitive Sciences*, *13*(4), 160–166. https://doi.org/10.1016/j.tics.2009.01.006

Pessoa, L. (2017). A Network Model of the Emotional Brain. *Trends in Cognitive Sciences*, *21*(5), 357–371. https://doi.org/10.1016/j.tics.2017.03.002

Plessow, F., Fischer, R., Kirschbaum, C., & Goschke, T. (2011). Inflexibly focused under stress: Acute psychosocial stress increases shielding of action goals at the expense of reduced cognitive flexibility with increasing time lag to the stressor. *Journal of Cognitive Neuroscience*, *23*(11), 3218–3227. https://doi.org/10.1162/jocn_a_00024

Pohl, R. F., Erdfelder, E., Hilbig, B. E., Liebke, L., & Stahlberg, D. (2013). Effort reduction after self-control depletion: The role of cognitive resources in use of simple heuristics. *Journal of Cognitive Psychology*, *25*(3), 267–276. https://doi.org/10.1080/20445911.2012.758101

Pourtois, G., Braem, S., Notebaert, W., & van Steenbergen, H. (2020). What is cognitive control without affect? *International Journal of Psychophysiology : Official Journal of the International Organization of Psychophysiology*, *153*, 91–94. https://doi.org/10.1016/j.ijpsycho.2020.04.022

Reber, R., & Greifeneder, R. (2017). Processing Fluency in Education: How Metacognitive Feelings Shape Learning, Belief Formation, and Affect. *Educational Psychologist*, *52*(2), 84–103. https://doi.org/10.1080/00461520.2016.1258173

Regenberg, N. F. E., Häfner, M., & Semin, G. R. (2012). The groove move: Action affordances produce fluency and positive affect. *Experimental Psychology*, *59*(1), 30–37. https://doi.org/10.1027/1618-3169/a000122

Ridder, D. T. D. de, Lensvelt-Mulders, G., Finkenauer, C., Stok, F. M., & Baumeister, R. F. (2012). Taking stock of self-control: A meta-analysis of how trait self-control relates to a wide range of behaviors. *Personality and Social Psychology Review : An Official Journal of the Society for Personality and Social Psychology, Inc*, *16*(1), 76–99. https://doi.org/10.1177/1088868311418749

Riesel, A. (2019). The erring brain: Error-related negativity as an endophenotype for OCD-A review and meta-analysis. *Psychophysiology*, *56*(4), e13348. https://doi.org/10.1111/psyp.13348

Rinn, W. E. (1984). The neuropsychology of facial expression: A review of the neurological and psychological mechanisms for producing facial expressions. *Psychological Bulletin*, *95*(1), 52–77. https://doi.org/10.1037/0033-2909.95.1.52

Rosenbaum, D. A., Gong, L., & Potts, C. A. (2014). Pre-crastination: Hastening subgoal completion at the expense of extra physical effort. *Psychological Science*, *25*(7), 1487–1496. https://doi.org/10.1177/0956797614532657

Schacht, A., Dimigen, O., & Sommer, W. (2010). Emotions in cognitive conflicts are not aversive but are task specific. *Cognitive, Affective & Behavioral Neuroscience*, *10*(3), 349–356. https://doi.org/10.3758/CABN.10.3.349

Scherbaum, S., Fischer, R., Dshemuchadse, M., & Goschke, T. (2011). The dynamics of cognitive control: Evidence for within-trial conflict adaptation from frequency-tagged EEG. *Psychophysiology*, *48*(5), 591–600. https://doi.org/10.1111/j.1469-8986.2010.01137.x

Scherbaum, S., Frisch, S., Dshemuchadse, M., Rudolf, M., & Fischer, R. (2018). The test of both worlds: Identifying feature binding and control processes in congruency sequence tasks by means of action dynamics. *Psychological Research*, *82*(2), 337–352. https://doi.org/10.1007/s00426-016-0823-9

Schlaghecken, F., & Martini, P. (2012). Context, not conflict, drives cognitive control. *Journal of Experimental Psychology. Human Perception and Performance*, *38*(2), 272–278. https://doi.org/10.1037/a0025791

Schmidt, J. R. (2013). Questioning conflict adaptation: Proportion congruent and Gratton effects reconsidered. *Psychonomic Bulletin & Review*, *20*(4), 615–630. https://doi.org/10.3758/s13423-012-0373-0

Schmidt, J. R. (2016). Context-Specific Proportion Congruency Effects: An Episodic Learning Account and Computational Model. *Frontiers in Psychology*, *7,* 1806. https://doi.org/10.3389/fpsyg.2016.01806

Schmidt, J. R. (2019). Evidence against conflict monitoring and adaptation: An updated review. *Psychonomic Bulletin & Review*, *26*(3), 753–771. https://doi.org/10.3758/s13423-018-1520-z

Schmidt, J. R., & Weissman, D. H. (2014). Congruency sequence effects without feature integration or contingency learning confounds. *PloS One*, *9*(7), e102337. https://doi.org/10.1371/journal.pone.0102337

Schouppe, N., Braem, S., Houwer, J. de, Silvetti, M., Verguts, T., Ridderinkhof, K. R., & Notebaert, W. (2015). No pain, no gain: The affective valence of congruency conditions changes following a successful response. *Cognitive, Affective & Behavioral Neuroscience*, *15*(1), 251–261. https://doi.org/10.3758/s13415-014-0318-3

Schuch, S., & Koch, I. (2015). Mood states influence cognitive control: The case of conflict adaptation. *Psychological Research*, *79*(5), 759–772. https://doi.org/10.1007/s00426-014-0602-4

Schuch, S., Zweerings, J., Hirsch, P., & Koch, I. (2017). Conflict adaptation in positive and negative mood: Applying a success-failure manipulation. *Acta Psychologica*, *176*, 11–22. https://doi.org/10.1016/j.actpsy.2017.03.005

Shackman, A. J., Salomons, T. V., Slagter, H. A., Fox, A. S., Winter, J. J., & Davidson, R. J. (2011). The integration of negative affect, pain and cognitive control in the cingulate cortex. *Nature Reviews. Neuroscience*, *12*(3), 154–167. https://doi.org/10.1038/nrn2994

Shenhav, A., Botvinick, M. M., & Cohen, J. D [Jonathan D.] (2013). The expected value of control: An integrative theory of anterior cingulate cortex function. *Neuron*, *79*(2), 217–240. https://doi.org/10.1016/j.neuron.2013.07.007

Shenhav, A., Musslick, S., Lieder, F., Kool, W., Griffiths, T. L., Cohen, J. D [Jonathan D.], & Botvinick, M. M. (2017). Toward a Rational and Mechanistic Account of Mental Effort. *Annual Review of Neuroscience*, *40*, 99–124. https://doi.org/10.1146/annurev-neuro-072116-031526

Simon, J. R., & Rudell, A. P. (1967). Auditory S-R compatibility: The effect of an irrelevant cue on information processing. *The Journal of Applied Psychology*, *51*(3), 300–304. https://doi.org/10.1037/h0020586

Simon, J. R., & Wolf, J. D. (1963). Choice reaction time as a function of angular stimulus-response correspondence and age. *Ergonomics, 6*(1), 99–105. https://doi.org/10.1080/00140136308930679

Spapé, M. M., & Hommel, B. (2008). He said, she said: Episodic retrieval induces conflict adaptation in an auditory Stroop task. *Psychonomic Bulletin & Review, 15*(6), 1117–1121. https://doi.org/10.3758/PBR.15.6.1117

Spapé, M. M., & Ravaja, N. (2016). Not My Problem: Vicarious Conflict Adaptation with Human and Virtual Co-actors. *Frontiers in Psychology, 7*, 606. https://doi.org/10.3389/fpsyg.2016.00606

Spruit, I. M., Wilderjans, T. F., & van Steenbergen, H. (2018). Heart work after errors: Behavioral adjustment following error commission involves cardiac effort. *Cognitive, Affective & Behavioral Neuroscience*, *18*(2), 375–388. https://doi.org/10.3758/s13415-018-0576-6

Stenberg, G., Wiking, S., & Dahl, M. (1998). Judging Words at Face Value: Interference in a Word Processing Task Reveals Automatic Processing of Affective Facial Expressions. *Cognition & Emotion, 12*(6), 755–782. https://doi.org/10.1080/026999398379420

Stout, D. (2010). The evolution of cognitive control. *Topics in Cognitive Science*, *2*(4), 614–630. https://doi.org/10.1111/j.1756-8765.2009.01078.x

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*(6), 643–662. https://doi.org/10.1037/h0054651

Stürmer, B., Leuthold, H., Soetens, E., Schröter, H., & Sommer, W. (2002). Control over location-based response activation in the Simon task: Behavioral and electrophysiological evidence. *Journal of Experimental Psychology: Human Perception and Performance, 28*(6), 1345–1363. https://doi.org/10.1037//0096-1523.28.6.1345

Surrey, C., Dreisbach, G., & Fischer, R. (2017). Context-specific adjustment of cognitive control: Transfer of adaptive control sets. *Quarterly Journal of Experimental*

Psychology (2006), *70*(11), 2386–2401. https://doi.org/10.1080/17470218.2016.1239748

Tomlin, D., Rand, D. G., Ludvig, E. A., & Cohen, J. D [Jonathan D.] (2015). The evolution and devolution of cognitive control: The costs of deliberation in a competitive world. *Scientific Reports*, *5*, 11002. https://doi.org/10.1038/srep11002

Topolinski, S., Likowski, K. U., Weyers, P., & Strack, F. (2009). The face of fluency: Semantic coherence automatically elicits a specific pattern of facial muscle reactions. *Cognition & Emotion*, *23*(2), 260–271. https://doi.org/10.1080/02699930801994112

van Boxtel, A., & Jessurun, M. (1993). Amplitude and bilateral coherency of facial and jaw-elevator EMG activity as an index of effort during a two-choice serial reaction task. *Psychophysiology*, *30*(6), 589–604. https://doi.org/10.1111/j.1469-8986.1993.tb02085.x

van Overwalle, F. (2011). A dissociation between social mentalizing and general reasoning. *NeuroImage*, *54*(2), 1589–1599. https://doi.org/10.1016/j.neuroimage.2010.09.043

van Steenbergen, H. (2015). Affective Modulation of Cognitive Control: A Biobehavioral Perspective. In G. Gendolla, M. Tops, & S. Koole (Eds.), *Handbook of Biobehavioral Approaches to Self-Regulation* (pp. 89–107). Springer. https://doi.org/10.1007/978-1-4939-1236-0_7

van Steenbergen, H., & Band, G. P. H. (2013). Pupil dilation in the Simon task as a marker of conflict processing. *Frontiers in Human Neuroscience*, *7*, 215. https://doi.org/10.3389/fnhum.2013.00215

van Steenbergen, H., Band, G. P. H., & Hommel, B. (2009). Reward counteracts conflict adaptation. Evidence for a role of affect in executive control. *Psychological Science*, *20*(12), 1473–1477. https://doi.org/10.1111/j.1467-9280.2009.02470.x

van Steenbergen, H., Band, G. P. H., & Hommel, B. (2010). In the mood for adaptation: How affect regulates conflict-driven control. *Psychological Science*, *21*(11), 1629–1634. https://doi.org/10.1177/0956797610385951

van Steenbergen, H., Band, G. P. H., & Hommel, B. (2015). Does conflict help or hurt cognitive control? Initial evidence for an inverted U-shape relationship between perceived task difficulty and conflict adaptation. *Frontiers in Psychology*, *6*, 974. https://doi.org/10.3389/fpsyg.2015.00974 van Strien, J. W. (1992). Calssificatie van links- en rechtshandige proefpersonen [Classification of left- and right-handed research participants]. *Nederlands Tijdschrift Voor De Psychologie, 47,* 88–92.

Verbruggen, F., Notebaert, W., Liefooghe, B., & Vandierendonck, A. (2006). Stimulus- and response-conflict-induced cognitive control in the flanker task. *Psychonomic Bulletin & Review*, *13*(2), 328–333. https://doi.org/10.3758/BF03193852

Verguts, T., & Notebaert, W. (2009). Adaptation by binding: A learning account of cognitive control. *Trends in Cognitive Sciences, 13*(6), 252–257. https://doi.org/10.1016/j.tics.2009.02.007

Verguts, T., Notebaert, W., Kunde, W., & Wühr, P. (2011). Post-conflict slowing: Cognitive adaptation after conflict processing. *Psychonomic Bulletin & Review, 18*(1), 76–82. https://doi.org/10.3758/s13423-010-0016-2

Vietze, I., & Wendt, M. (2009). Context specificity of conflict frequency-dependent control. *Quarterly Journal of Experimental Psychology (2006), 62*(7), 1391–1400. https://doi.org/10.1080/17470210802426908

Võ, M. L.-H., Conrad, M., Kuchinke, L., Urton, K., Hofmann, M. J., & Jacobs, A. M. (2009). The Berlin Affective Word List Reloaded (BAWL-R). *Behavior Research Methods*, *41*(2), 534–538. https://doi.org/10.3758/BRM.41.2.534

Wendt, M., & Kiesel, A. (2011). Conflict adaptation in time: Foreperiods as contextual cues for attentional adjustment. *Psychonomic Bulletin & Review*, *18*(5), 910–916. https://doi.org/10.3758/s13423-011-0119-4

Wendt, M., Luna-Rodriguez, A., & Jacobsen, T. (2012). Conflict-induced perceptual filtering. *Journal of Experimental Psychology*. *Human Perception and Performance, 38*(3), 675–686. https://doi.org/10.1037/a0025902

Wessel, J. R., Danielmeier, C., & Ullsperger, M. (2011). Error awareness revisited: Accumulation of multimodal evidence from central and autonomic nervous systems. *Journal of Cognitive Neuroscience, 23*(10), 3021–3036. https://doi.org/10.1162/jocn.2011.21635

Wessel, J. R., O'Doherty, J. P., Berkebile, M. M., Linderman, D., & Aron, A. R. (2014). Stimulus devaluation induced by stopping action. *Journal of Experimental Psychology. General, 143*(6), 2316–2329. https://doi.org/10.1037/xge0000022

Whittlesea, B. W. A., & Williams, L. D. (2000). The source of feelings of familiarity: The discrepancy-attribution hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*(3), 547–565. https://doi.org/10.1037//0278-7393.26.3.547

Winkielman, P., & Cacioppo, J. T [John T.] (2001). Mind at ease puts a smile on the face: Psychophysiological evidence that processing facilitation elicits positive affect. *Journal of Personality and Social Psychology*, *81*(6), 989–1000. https://doi.org/10.1037//0022-3514.81.6.989

Winkielman, P., Schwarz, N., Reber, R., & Fazendeiro, T. A. (2003). Affective and Cognitive Consequences of Visual Fluency: When Seeing is Easy on the Mind. In J. Musch & K. C. Klauer (Eds.), *The Psychology of Evaluation: Affective Processes in Cognition and Emotion* (pp. 195–223). Lawrence ERlbaum Asociates Inc.

Yamaguchi, M., & Nishimura, A. (2019). Modulating proactive cognitive control by reward: Differential anticipatory effects of performance-contingent and non-contingent rewards. *Psychological Research*, *83*(2), 258–274. https://doi.org/10.1007/s00426-018-1027-2

Yang, Q., & Pourtois, G. (2018). Conflict-driven adaptive control is enhanced by integral negative emotion on a short time scale. *Cognition & Emotion*, *32*(8), 1637–1653. https://doi.org/10.1080/02699931.2018.1434132

Zhang, J., Kiesel, A., & Dignath, D. (2019). Affective Influence on Context-Specific Proportion Congruent (CSPC) Effect. *Experimental Psychology, 66*(1), 86–97. https://doi.org/10.1027/1618-3169/a000436

APPENDIX

Supplemental Material: Study I

Table A1. *Mean (SE) response times (RT) in ms and error rates (ER) in % as a function of congruency in trial N-1 and in trial N.*

			Congruency in N			
	Congruency in N-1		Congruent	Neutral	Incongruent	Overall
Experiment 1	Congruent	RT	456 (8)	470 (7)	506 (10)	477 (8)
		ER	2.1 (0.5)	3.3 (0.5)	6.7 (1.0)	4.1 (0.5)
	Neutral	RT	471 (8)	466 (7)	502 (8)	479 (8)
		ER	2.2 (0.4)	2.9 (0.5)	5.9 (0.9)	3.7 (0.4)
	Incongruent	RT	491 (9)	479 (8)	488 (8)	486 (1)
		ER	4.4 (0.7)	4.1 (0.7)	3.1 (0.5)	3.9 (0.4)
	Overall	RT	472 (8)	472 (7)	499 (9)	481 (8)
		ER	2.9 (0.4)	3.4 (0.4)	5.2 (0.6)	3.9 (0.4)
Experiment 2	Congruent	RT	604 (17)	632 (12)	638 (15)	625 (16)
		ER	0.8 (0.2)	2.6 (0.5)	5.8 (0.9)	3.1 (0.4)
	Neutral	RT	619 (18)	620 (13)	643 (15)	628 (16)
		ER	1.3 (0.3)	2.5 (0.5)	4.4 (0.4)	2.7 (0.4)
	Incongruent	RT	626 (13)	629 (12)	640 (17)	632 (15)
		ER	2.4 (0.5)	1.9 (0.3)	2.6 (0.7)	2.3 (0.4)
	Overall	RT	616 (16)	627 (16)	640 (15)	627 (15)
		ER	1.5 (0.3)	2.3 (0.3)	4.3 (0.5)	2.7 (0.3)

Supplemental Material: Study II

Methods

Data preprocessing and outlier identification procedures were the same as described in the main text up until the point of z-transformation. The results presented in this section are based on unstandardized data. The unstandardized fEMG data were checked for outliers separately for each cell of the factorial design (see below). In comparison to the data reported in the main text, more participants were identified as outliers (i.e., more than 3 interquartile ranges below/above the 25th/75th percentile in at least one cell) in the unstandardized data sets: Four subjects were excluded in Experiment 1 ($n = 42$), four outliers were excluded in Experiment 2 ($n = 21$) and six outliers were excluded in Experiment 3 ($n = 22$).

Results

Unstandardized fEMG data for all three experiments are presented in Figure S1.

Experiment 1

The 2 × 2 × 10 ANOVA of corrugator activation did not show a significant effect for Congruency$_{\mathrm{N}}$, $F(1,45) = 2.91$, $p = .096$. No other effects reached significance either, all Fs ≤ 0.53, all ps $\geq .47$.

An ANOVA for zygomaticus data revealed a significant effect of time bin, $F(4,169) = 4.73$, $p \leq .001$, $\eta_p^2 = .11$. Activation increased over time following a linear trend, $F(1,40) = 9.75$, $p \leq = .003$, $\eta_p^2 = .20$. No other effects were significant, all Fs ≤ 3.12, all ps $\geq .06$. Results were therefore unchanged to the analysis of unstandardized data.

Experiment 2

The 2 × 2 × 10 ANOVA of corrugator activation revealed a main effect of Congruency$_{\mathrm{N}}$, $F(1,20) = 6.04$, $p = .023$, $\eta_p^2 = .23$, indicating stronger activation in incongruent trials ($M = -0.05$; $SE = 0.10$; 95% CI [-0.27; 0.161]) than in congruent trials ($M = -0.13$; $SE = 0.11$; 95% CI [-0.37; 0.11]; $M_{CE} = 0.07$; $SE = 0.03$; 95% CI [0.01; 0.14]). No other effects reached significance, all Fs ≤ 2.39, all ps $\geq .09$.

Analyses of the zygomaticus activation showed a marginally significant main effect of Congruency$_{\mathrm{N}}$, $F = 4.14$, $p = .06$, $\eta_p^2 = .17$ ($M_{CE} = -0.025$; $SE = 0.012$; 95% CI [-0.051; 0.001]. No other effects were significant, all Fs ≤ 1.63, all ps $\geq .11$.

Experiment 3

The 2 × 2 × 10 ANOVA of corrugator responses did not show a significant Congruency$_N$ effect ($F < 1$, $p = .59$; congruent: $M = -0.09$; $SE = 0.10$; 95% CI [-0.30; 0.11]; incongruent: $M = -0.06$; $SE = 0.13$; 95% CI [-0.32; 0.20]). The effect of Congruency$_{N-1}$ was also not significant, $F < 1.39$, $p = .25$. The main effect of time bin was significant, $F(2,43) = 6.26$, $p = .004$, $\eta_p^2 = .23$, but the interaction time bin × Congruency$_N$ was not, $p = .058$. Neither was the three-way interaction Congruency$_N$ × Congruency$_{N-1}$ × time bin, $p = .219$.

Analyses of the zygomaticus activation showed no significant effects but the effect of time bin, $F(3, 53) = 3.73$, $p = .02$, $\eta_p^2 = .15$.

Figure S1. *Grand averages of unstandardized EMG activation (RMS) in mV of the corrugator and zygomaticus muscles as a function of each time bin and congruency in the three experiments. Shaded areas represent within-subject standard errors.*