# Exploring the impact of cognitive conflict on subsequent cognitive processes

Marta La Pietra[1]& Manuela Ruzzoli[1,2]

1. Basque Center on Cognition Brain and Language (BCBL), Donostia/San Sebastián, Spain
2. Ikerbasque, Basque Foundation for Science, Bilbao, Spain

**Corresponding author**: Manuela Ruzzoli (m.ruzzoli@bcbl.eu)

Basque Center on Cognition Brain and Language (BCBL)
Mikeletegi Pasealekua, 69, 20009 Donostia, Spain

**Keywords**: cognitive conflict, conflict resolution, Stroop task.

**Acknowledgement**: This research is supported through project SweetC (PID2020-114717RA-I00 /AEI/ 10.13039/501100011033) funded by the Ministerio de Ciencia e Innovación (MICIIN) and the Agencia Estatal de Investigación (AEI), and by the Basque Government through the BERC 2022-2025 program and by the Spanish State Research Agency through BCBL Severo Ochoa excellence accreditation CEX2020-001010-S. MR is supported by Ministerio de Ciencia e Innovación (MICIIN) and the Agencia Estatal de Investigación (AEI) under the Ramón y Cajal program (RYC2019-027538-I/0.13039/ 501100011033), and the Basque Foundation for Science (Ikerbasque). MLP is supported by the grant ref. PRE2021-097880 and the project PID2020-114717 funded by MCIN/AEI/10.13039/501100011033 and the FSE+.

**Conflict of interest**: The authors declare no conflict of interest.

**Supplementary Materials** can be found at this link.

# Abstract

Cognitive conflict is an effective trigger for control, flexible behaviour, and adaptation. It is considered effortful, detrimental to performance and affectively aversive. However, converging evidence also indicates that, when successfully resolved, cognitive conflict has positive consequences. Prior research has shown that conflicting stimuli can be rewarding, attract attention and improve memory performance. In this registered report, our goal is to examine if instances of cognitive conflict can positively impact subsequent cognitive processes and, therefore, human behaviour, contesting the assumption that conflict is inherently aversive and exclusively detrimental. To achieve this, we designed three independent experiments to investigate behavioural changes on subsequent tasks after congruent and incongruent Stroop items. If, as we hypothesise, performance after incongruent Stroop trials is better than after congruent trials, we will interpret it as a generalization of the evidence that cognitive conflict can benefit human behaviour on functions other than conflict adaptation.

# 1. Introduction

Cognitive conflict is a multifaceted phenomenon described as a mismatch between stimulus and simultaneously activated responses (Berlyne, 1960; Harmon-Jones et al., 2009; Jones et al., 2002; Shenhav & Botvinick, 2015) or as an information gap (Berlyne, 1960). It can arise when novel/unexpected/dissonant events (Berlyne, 1957; Gruber & Ranganath, 2019; Harmon-Jones et al., 2009) or low-frequency stimuli are detected (Braver et al., 2001) or from a mismatch between expected outcomes and actual results (Silvetti et al., 2018). It encompasses violations of expectations (Chetverikov & Kristjánsson, 2016; Cheung et al., 2019; Gruber & Ranganath, 2019), uncertainty (Berlyne, 1957; see also Brandstätter & Herrmann, 2016), surprise (Noordewier & Breugelmans, 2013), errors (Stürmer et al., 2011), and interference in decision-making that guides learning strategies (Abrahamse et al., 2016; Botvinick, 2007).

Cognitive conflict is an effective trigger for cognitive control functions, flexible behaviour and adaptation (Botvinick, 2007; Botvinick et al., 2001). However, it is considered effortful, detrimental to performance and aversive (Bouzidi & Gendolla, 2022; Dignath et al., 2020; Dreisbach & Fischer, 2012, 2015; Fritz & Dreisbach, 2013; Inzlicht et al., 2015; van der Wel & van Steenbergen, 2018; Vassena et al., 2017). Its detection is indeed associated with negative affective states (Yang et al., 2019; Yang & Pourtois, 2018), such as frustration, feelings of worry, anxiety, caution, and avoidance (Botvinick, 2007; Inzlicht et al., 2015). At the anatomical level, the Anterior Cingulate Cortex (ACC), a key brain structure for conflict monitoring and resolution (Botvinick & Cohen, 2014; Kerns et al., 2004; Shenhav et al., 2013; Yeung, 2014), also appears to integrate information related to pain and negative affect (Shackman et al., 2011; Vogt, 2005). According to the *affective-signalling hypothesis* (Dignath et al., 2020), conflict elicits a negative affective response, detected by the ACC, which triggers control strategies to attenuate the conflict’s subsequent impact on performance and reduce aversive reactions (see also Botvinick, 2007; Dreisbach & Fischer, 2015; Fröber et al., 2017; Harmon-Jones et al., 2010; Harmon-Jones et al., 2009; Inzlicht et al., 2015; van Steenbergen et al., 2012; Yang et al., 2019; Yang & Pourtois, 2018). In a key study supporting this perspective, Dreisbach & Fischer (2012) asked participants to classify as positive or negative the emotional valence of a word presented after a congruent or incongruent Stroop trial (MacLeod, 1991; Stroop, 1935). Their findings showed that target words with a negative valence were evaluated faster after incongruent than after congruent Stroop trials, and were interpreted as suggesting that incongruency in the Stroop task held a negative valence (see also Fritz & Dreisbach, 2013; Pan et al., 2016). Similarly, *cognitive dissonance theory* (Festinger, 1957) posits that the interference between discrepant cognitions and effective actions provokes a negative affective state (Harmon-Jones et al., 2010; Harmon-Jones et al., 2009; Harmon-Jones & Mills, 2019).

To date, cognitive control theories (Botvinick, 2007; Dignath et al., 2020; Dreisbach & Fischer, 2012; Inzlicht et al., 2015; van Steenbergen et al., 2012; Yang et al., 2019; Yang & Pourtois, 2018), models of cognitive dissonance (Harmon-Jones et al., 2010; Harmon-Jones et al., 2009), and computational models of ACC functions (Vassena et al., 2017) assign a negative value to conflict. Previous research (van Steenbergen et al., 2012; Yang et al., 2019; Yang & Pourtois, 2018) found that negative affect facilitates conflict adaptation, which was interpreted as evidence for the negative nature of cognitive conflict (but see Fröber et al., 2017). However, although effortful, cognitive conflict also leads to positive consequences. Indeed, conflict detection and resolution trigger adaptive adjustments in the brain and behaviour, which are ultimately beneficial. Conflict adaptation is the most emblematic example. Also known as the congruency sequence effect (Gratton et al., 1992), it refers to the improvement in performance when two conflicting events are presented one after the other beyond the low-level stimulus and/or response repetitions in the trial sequence (Braem et al., 2014; Duthoo et al., 2014; Egner, 2007). Conflict adaptation provides key evidence that conflict can positively influence performance, at least in the case of repetitive exposure to it.

Previous studies showed that successful conflict resolution in a Stroop task – in contrast to passive viewing, as in Dreisbach & Fischer (2012) – facilitated positive affective reactions (Ivanchei et al., 2021; Schouppe et al., 2015). This result nicely fits the *Reward Value and Prediction Model* (RVPM) by Silvetti and colleagues (2011), which explicitly predicts that conflict resolution could lead to positive reactions. Similarly, although cognitive dissonance can generate a negative affective state, it ultimately has a positive effect: It motivates people to reduce the discrepancy, thus catalysing self-regulation (Harmon-Jones et al., 2010; Harmon-Jones et al., 2009; Harmon-Jones & Mills, 2019). Hence, despite evidence demonstrating the positive consequences of resolving cognitive conflict, the prevailing perspective still regards it as inherently negative and aversive, overlooking the possibility for conflict to also possess a positive nature.

Crucially, if one considers conflict from a broader viewpoint that goes beyond the conflict adaptation framework, the potentially positive essence of cognitive conflict emerges. For instance, within the *Predictive Coding* framework, Clark (2018) has suggested that surprising/unpredictable events – thus, conflict – may be positively interpreted as opportunities for exploration. Clark’s (2018) argument is reminiscent of Berlyne (1957, 1960), who believed that a moderate level of conflict could stimulate curiosity and act as a reward. Although Berlyne’s idea influenced later works (Botvinick & Cohen, 2014; Gruber & Ranganath, 2019; Huskey et al., 2018; Inzlicht et al., 2018), it has received little experimental support. To the best of our knowledge, only Meyer et al.

(1991) have specifically investigated the effects of conflict on subsequent behavioural performance outside the conflict adaptation framework, by testing how surprise affects attention and memory. They found that a surprising trial delayed response times to a target's relevant information but improved the recall of a distractor, which was attributed to the involuntary automatic focusing of attention.

Interestingly, it has been shown that surprise and uncertainty largely contribute to enjoyment, engagement and hedonic pleasure in music (Cheung et al., 2019; Salimpoor et al., 2015; Stark et al., 2018; Zatorrea & Salimpoor, 2013), poetic language (Bolognesi et al., 2022a; Ching, 1975; Gibbs & Kearney, 1994; La Pietra & Masini, 2020; Teng & Sun, 2002), surrealistic visual art (Phillips & McQuarrie, 2004) and advertising (Alden et al., 2000; Ruzzoli et al., 2021), wherein familiar but semantically distant items can be juxtaposed or intermixed to convey a message beyond the individual constitutive elements. Also, Ruzzoli and colleagues (2020) showed that conflicting (e.g., surrealistic and incongruent) images elicited a pattern of brain activity (i.e., increased oscillatory theta power at frontal-medial electrodes) akin to the characteristic brain response elicited by typical conflict tasks (e.g., Eriksen & Eriksen, 1974; Simon, 1969; Stroop, 1935) and had a positive impact on memory compared to visually similar control images with no conflicting elements.

It is undeniable that cognitive conflict demands effortful control (Bouzidi & Gendolla, 2022; Dignath et al., 2020; Dreisbach & Fischer, 2012, 2015; Fritz & Dreisbach, 2013; Inzlicht et al., 2015; van der Wel & van Steenbergen, 2018; Vassena et al., 2017). However, albeit costly, effort can be stimulating, rewarding and sought-after (Inzlicht et al., 2018; Wu et al., 2022).

Therefore, conflict is negative and aversive, it can be detrimental to performance but, at the same time, can also positively impact cognition and behaviour. We believe a shift in perspective is essential to challenge the currently predominant view, which mostly considers cognitive conflict as an aversive state with negative consequences (Botvinick, 2007; Botvinick et al., 2001; Dignath et al., 2020; Dreisbach & Fischer, 2012, 2015; Fritz & Dreisbach, 2013; Harmon-Jones et al., 2010; Inzlicht et al., 2015; Kerns et al., 2004; Shackman et al., 2011; Shenhav et al., 2013; van der Wel & van Steenbergen, 2018; Vassena et al., 2017; Yeung, 2014) or, if a positive consequence of conflict is contemplated, it is exclusively in the context of conflict adaptation (Fröber et al., 2017; van Steenbergen et al., 2012; Yang et al., 2019; Yang & Pourtois, 2018). By investigating and generalizing the beneficial consequences that cognitive conflict can engender on cognitive processes not directly related to conflict, such as speeded reactions, perceptual discrimination, and memory, we challenge the assumption of its inherently negative nature and propose that cognitive conflict, having positive consequences, might be positive itself.

### 1.1. Current research

Inspired by Berlyne (1957, 1960), who suggested that there should be a moderate level of cognitive conflict which serves as a reward, as opposed to extreme (low/high) levels which are aversive, and that, if conflict is resolved successfully, this moderate level would be sought after rather than avoided, we aim to explore how *instances of cognitive conflict can positively impact human behaviour, contesting the assumption that conflict is inherently and solely detrimental*.

To test our hypothesis that cognitive conflict has positive effects on cognitive processes and, therefore, behaviour, we designed three experiments to investigate how responses to a conflict task, i.e., the Stroop (MacLeod, 1991; Stroop, 1935), impact subsequent cognitive functions in a speeded detection task (experiment 1), a Go/No-Go task (experiment 2), and an implicit memory task (experiment 3). We hypothesise that incongruent Stroop trials prompt better performance on the subsequent tasks than congruent trials.

Crucially, our focus is on identifying any behavioural benefits resulting from successfully resolving cognitive conflict, as opposed to previous research that primarily focused on examining the emotional and affective impact of cognitive conflict (Dreisbach & Fischer, 2012, 2015; Fritz & Dreisbach, 2013; Pourtois et al., 2020; Schouppe et al., 2015) or the adaptation to conflict (Braem et al., 2014, 2019; Gratton et al., 1992; van Steenbergen et al., 2012; Yang et al., 2019; Yang & Pourtois, 2018). If conflict resolution positively impacts behaviour, this would constitute strong evidence that the effects of conflict on cognition – and, perhaps, to an extent, conflict itself – can be positive.

### 1.2. Implications

Our research aims to challenge the body of research which considers cognitive conflict as inherently negative (Botvinick, 2007; Botvinick et al., 2001; Dignath et al., 2020; Dreisbach & Fischer, 2012, 2015; Fritz & Dreisbach, 2013; Inzlicht et al., 2015; Shackman et al., 2011). Instead, we will directly address the opposite and under-explored perspective: Cognitive conflict positively influences cognition and performance.

Demonstrating that cognitive conflict can have positive effects on cognition and behaviour holds significant implications. It would indeed challenge several previous theoretical perspectives which explicitly label cognitive conflict as negative in its essence (Botvinick, 2007; Botvinick et al., 2001; Bouzidi & Gendolla, 2022; Dignath et al., 2020; Dreisbach & Fischer, 2012, 2015; Fritz & Dreisbach, 2013; Inzlicht et al., 2015; Kerns et al., 2004; Shackman et al., 2011; Shenhav et al., 2013; van der Wel & van Steenbergen, 2018; Vassena et al., 2017; Yeung, 2014), with the repercussion of oftentimes considering it as something to be avoided (Botvinick, 2007; Inzlicht et al., 2015). Instead, we intend to emphasize and contribute to the perspectives that deem cognitive conflict as an incentive to stimulate curiosity and resolve an information gap (Berlyne, 1960; Clark, 2018; FitzGibbon et al., 2020; Gruber & Ranganath, 2019), promote learning (Engel, 2011; Hsee & Ruan, 2016; Van de Cruys et al., 2021), enhance motivation (Chiew & Braver, 2011; Yee & Braver, 2018), well-being and cognitive reserve (Gajewski et al., 2020; McGraw & Warren, 2010), with concrete real-life applications in art, music and language (Alden et al., 2000; Bolognesi et al., 2022b; Cheung et al., 2019; Clark, 2018; FitzGibbon et al., 2020; Gibbs & Kearney, 1994; Gratton et al., 1992; Gruber & Ranganath, 2019; Inzlicht et al., 2018; McGraw & Warren, 2010; Ruzzoli et al., 2020, 2021; Salimpoor et al., 2015; Stark et al., 2018; Teng & Sun, 2002; Zatorrea & Salimpoor, 2013).

The brain responds strongly to incongruency, even when it is predictable or after extensive training (MacLeod, 1991). Demonstrating that cognitive conflict can have positive effects on behaviour and cognition would accredit its stimulating nature to influence – or even provoke – a cascade of processing in the brain and contribute to building an overarching account of the role of cognitive conflict for information processing, attention bias (Pool et al., 2016), learning (Gruber & Ranganath, 2019; Press et al., 2020), and inferences (Van de Cruys et al., 2021). Finally, it is worth noting that investigating whether or not the down-regulation of conflict on behaviour is mediated by affect or emotion (see Fröber et al., 2017) is beyond the scope of the present registered report, in which we do not modulate nor collect information about affect.

# 2. Methods

## 2.1. Participants

Participants are recruited through the BCBL *Participa* database (https://www.bcbl.eu/participa/), a repository that gathers information regarding volunteers, previously assessed, cognitively and linguistically, who want to participate in an experiment at the BCBL. We aim to recruit young adults (18-35 years old, balanced gender, both left and right-handed), native Spanish speakers with normal or corrected-to-normal vision. They must show no history of psychiatric or neurological conditions. Further general exclusion criteria are colour blindness and non-corrected visual impairments.

Participants are divided into three groups, depending on the secondary task they perform. We aim to achieve a final sample of 52 participants in each group (see section 4. *Estimation of the sample size*).

## 2.2. General procedure

In three independent experiments, congruent, incongruent, and neutral Stroop trials are used to influence secondary task performance. Secondary tasks are a speeded detection task (experiment 1), a Go/No-Go task (experiment 2), and an implicit memory task (experiment 3). These secondary tasks investigate the effects of conflict on diverse cognitive domains, i.e., speeded motor reactions, inhibitory mechanisms, and memory processes, which might be differentially affected by cognitive conflict (see Meyer et al., 1991; Schacht et al., 2010).

The procedure in each task is identical (Fig. 1): First, participants familiarise themselves with the Stoop task by performing two 36-trial blocks, which serve as a baseline. Next, participants perform a 24-trial block of the secondary task baseline, followed by a 36-trial block of the primary Stroop task intermixed with the secondary task (dual-task practice). Participants can repeat the dual-task practice up to three times if performance meets the exclusion criteria (Table 1), after which they are excluded from participation.

Following the dual-task practice phase, the test phase includes 10 blocks of a 36-trial Stroop task intermixed with the secondary task (dual-task test), separated by self-paced breaks. In the case of experiment 3, the test phase consists of 7 blocks of 36 dual-task trials (memory encoding) and two additional 40-trial blocks (implicit memory test).

Participants receive feedback after their responses in the practice/baseline phases, but not in the test phase. Specifically, the fixation cross turns red or green for incorrect and correct responses, respectively. Instructions are presented on the screen at the beginning of each phase and verbally by the experimenter. After the baseline and practice phases, the experimenter checks the participants' performance to ensure it is within the inclusion criteria (Table 1). Participants proceed with the experiment only if: (1) their overall accuracy in the Stroop task is at least 80%, and (2) the sum of too-slow (1500 ms) or too-fast (50 ms) responses is below 10% of the total trials. Only in the Stroop baseline, participants must also show a Stroop effect (RTs to incongruent trials > RT to congruent trials), which we will use to ensure that only participants sensitive to the Stroop task manipulation will enter the final dataset. If a participant does not meet any of these inclusion criteria, they are excluded from the study without completing the entire experiment.

The experiments are programmed in MATLAB, version R2021b, using custom-made code adopting the PsychToolbox-3.0.10 extension (Brainard, 1997; Kleiner et al., 2007). The research received approval from the Basque Center on Cognition, Brain and

Language (BCBL)'s Ethics and Scientific Committee. All participants sign informed consent before taking part in the experiment and receive monetary compensation (8€/hour).

## 2.3. The Stroop primary task

Stimuli are the Spanish colour words ROJO, VERDE, AZUL, and AMARILLO (i.e., red, green, blue, and yellow), presented in uppercase in the middle of the screen (Arial font, size 35), in one of the respective colours. The RGB values for the colours are 190,0,0 (red); 0,176,0 (green); 20,40,250 (blue); and 250,250,0 (yellow).

On each trial, participants are required to indicate the colour of the word, ignoring its meaning. The word meaning and colour are either congruent (i.e., the word colour and meaning match, e.g., AZUL in blue) or incongruent (i.e., the word and meaning mismatch, e.g., AZUL in red). A neutral stimulus (i.e., XXXXX, printed in one of the four above-mentioned colours) is randomly intermixed with the (in)congruent trials. We created four lists of 36 trials in which congruent, incongruent, and neutral (12 trials/each) trials are counterbalanced and intermixed. No stimulus and/or correct response repetition is present in the N-1 trial sequence, thus avoiding low-level stimulus-response priming effects (Braem et al., 2019). Note that 36 is the minimum number of the Stroop trials, resulting from the combination of 5 words x 4 colours x 3 conditions (congruent/incongruent/neutral). Each participant sees one list only. The lists are counterbalanced across participants. On each block, the list presentation starts from a random number, preserving the trial sequence, but avoiding learning the first or last elements of the list.

Participants sit comfortably in front of a computer screen (refresh rate: 60 Hz, at 60 cm) in a soundproof experimental cabin. Each block starts once participants press the space bar after reading the instructions. A black fixation cross appears in the middle of the screen for 500 ms against a uniform grey background screen colour (RGB: 128,128,128). Subsequently, a coloured word (target) replaces the fixation cross and remains on the screen until response or for 1000 ms. If no response is provided, the stimulus is replaced by another fixation cross that stays onscreen until participants respond. Participants are instructed to provide quick and accurate responses using the index and middle fingers of each hand by pressing one of the four response keys. Specifically, keys Z, X, N and M correspond to correct responses for blue, red, green, and yellow. They are marked with coloured stickers to facilitate the response mapping. The inter-trial interval lasts between 1000 - 2000 ms from the response. If participants erroneously press an invalid key on the keyboard (i.e., the space bar), a warning message appears on the screen for 3000 ms to ensure participants' fingers are placed on the correct keys.

## 2.4. The secondary tasks

### *2.4.1. Speeded detection task (experiment 1)*

A speeded detection task tests the consequence of (in)congruent Stroop trials on simple reaction times and alertness. The observation of interest pertains to whether incongruency differently affects visual-motor reactions compared to congruent trials.

One fully visible black and white sinusoidal grating appears at the centre of the screen for 500 ms (Michelson contrast = 0.5, noise level of -20 dB, spatial frequency of 0.025 cycles per degree, embedded in Gaussian white noise with an SD = 20º visual degrees, amplitude 18 dB). Grating orientation can be clockwise (20°) or anticlockwise (340°) from the vertical midline, randomly changing across trials. Although it is unnecessary for this task, we use two orientations to avoid reactions being triggered by a specific visual configuration.

During the dual-task practice and test phases, the speeded detection task is intermixed with the Stroop task. A sinusoidal grating is presented for 500 ms, between 1000 - 2000 ms after the central fixation cross, randomly appearing after 66.67% of the Stroop trials, i.e., 22.22% after (in)congruent and neutral trials. Therefore, we will collect 240 responses to the detection task after (in)congruent and neutral trials in experiment 1.

Participants must press the space bar on the keyboard as soon as they detect the grating. A response is always required. The next trial follows a jittered interval of 1000 - 2000 ms. If no grating occurs, the next Stroop trial follows the previous after a jittered interval of 1000 - 2000 ms.

### *2.4.2. Go/No-Go task (experiment 2)*

A Go/No-Go task tests the consequence of cognitive conflict on response inhibition. The observation of interest pertains to whether (in)congruency selectively affects motor inhibition instead of response speed as in experiment 1.

One fully visible sinusoidal grating appears at the centre of the screen for 500 ms, and 1000 ms (jittered 0-1000 ms) after the Stroop trial response. The grating has identical features to the one used in the speeded detection task described above, the only difference being that the grating orientation functions as a Go/No-Go signal (i.e., 20° or 340º oriented, counterbalanced across participants).

Participants must press the space bar as fast as possible when a Go stimulus occurs and inhibit their response if a No-Go-oriented stimulus occurs. After each Stroop trial, a Go/No-Go stimulus always appears. Go-stimuli occur 66.67% of the time, 22.22% after each (in)congruent/neutral Stroop trial, and No-Go stimuli the remaining 33.33%. The unequal distribution between Go and No-Go trials serves to amplify the inhibitory processing in the No-Go responses. In total, we will collect 240 responses (Go-trials) after (in)congruent trials in experiment 2. If no response to the Go trials is provided after 2000 ms, the next trial follows a jittered interval of 1000 - 2000 ms.

### *2.4.3. Implicit memory task (experiment 3)*

An implicit memory task tests the consequence of cognitive conflict on implicit memory. The observation of interest pertains to whether incongruency affects implicit memory retrieval compared to congruent trials.

Black and white pictures were extracted from the Multilingual Picture (MultiPic) databank (Duñabeitia et al., 2018, 2022), initially created and tested for picture-naming tasks in Spanish. We selected the variables: 1) Name of the drawing; 2) Most frequently reported name for the pictures; 3) Mean rating of visual complexity. Subsequently, we extracted from the Spanish lexeme database EsPal (Duchon et al., 2013) each word's frequency value (i.e., *log_cnt*, the recommended word frequency value for matching words), the numbers of letters, and the *familiarity* and *imageability* ratings.

From the initial database, we selected those images for which the name ranges from 4 to 8 letters, the same as the length ranges of the Stroop word stimuli. We excluded items for which frequency, familiarity or imageability values were not provided. Each picture was manually assigned to two categories, i.e., artificial/non-living (e.g., objects like chairs, watches, scissors, benches, cars) or natural/living (e.g., animals, human beings, body parts, fruits, vegetables, and natural places). Each category comprises 168 items plus 24 additional images exclusively for use in the practice phase. Then, we created an artificial index by summing the frequency, familiarity, and imageability ratings for each picture, which ranged from 10.84 to 18.47 (Median = 15.70). This way, we intended to balance the image’s features that might facilitate future recalling in the implicit memory test. The pictures were further divided into four sub-groups (84 elements each), balancing the two categories (artificial/non-living vs. natural/living) and the artificial index median value (additional sub-groups are created for the practice trials, 12 elements each). The list of pictures’ labels and subgroup subdivisions is available in the Supplementary material.

In the memory encoding phase, after a jittered interval of 1000 - 2000 ms from a Stroop trial response, in 66.67% of the cases (22.22% after incongruent, congruent, and neutral trials), an image is presented on the screen for 2000 ms. Participants are asked to categorise the pictures as belonging to the natural/living or the artificial/non-living category only after it disappears. To avoid response preparation and disengagement from picture observation, the position of the response labels varies randomly on each trial. Participants must press either the C or B keys on the keyboard, depending on the response prompt onscreen. Please note that we are not interested in the semantic categorisation response. This task is introduced only to ensure that participants pay attention to the images for the subsequent implicit memory test. However, if accuracy on this task is below 70%, the participant is excluded from further testing (Table 1), supposing that the participant is not paying attention to the instructions and the images.

After completing the semantic categorisation task during the memory encoding phase and filling in some personality questionnaires (see below, section 2.5) - thus, after 40 minutes, approximately - participants are required to perform an impromptu implicit memory test. In the implicit memory test, two images of the same (artificial/non-living vs. natural/living) category, one seen, and one not seen during the experiment, are presented side by side on the screen for two 40-trial blocks. Participants are asked to identify the image seen during the previous encoding phase by pressing either the C or the B key, depending on the position (left/right) of the seen image. The position of the target image varies randomly on each trial. The ITI interval is jittered between 1000 and 2000 ms. We aim to collect 168 responses for the memory encoding phase and 80 for the implicit memory phase.

### 2.5. Questionnaires

Although we do not have clear hypotheses and predictions related to personality traits, we collect data using three paper-and-pencil questionnaires to consider the possible influence of personality traits on the impact of cognitive conflict on performance. The questionnaires are the Need for Cognition (Cacioppo et al., 1984), which assesses individual tendencies to enjoy effortful cognitive activities, such as completing puzzles and solving complex problems; the Barrat Impulsiveness Scale (BIS-11) (Martínez-Loredo et al., 2015; Patton et al., 1995; Stanford et al., 2009), which assesses the construct of impulsiveness in one's behaviour and personality; the Boredom Proneness Scale (Struk et al., 2017), which measures the individual propensity to experience boredom in daily life.

## 3. Hypotheses

The present investigation aims to test the hypothesis that cognitive conflict can impact ensuing cognitive processing. To test this overarching hypothesis, we focus on differences in performance after congruent and incongruent Stroop trials in three independent tasks.

We assess three hypotheses: (1) The *null hypothesis (H0)* posits no significant effects in the secondary tasks, irrespective of whether the preceding Stroop trial is congruent or incongruent. Conversely, (2) the *first alternative hypothesis* (*H1),* or *beneficial* *hypothesis*, states that instances of cognitive conflict, i.e., incongruent Stroop trials, benefit subsequent performance. We also consider (3) the *opposing alternative hypothesis (H2)*, or *detrimental hypothesis*, which suggests that instances of conflict hinder subsequent performance.

Importantly, regardless of the direction of the results, the present registered report should be informative. If our main hypothesis H1 is disconfirmed, the planned design and analysis pipeline can still test the opposite hypothesis that conflict detection - and resolution - have no, or negative, effects on behaviour.

## 4. Estimation of the sample size

We employ a two-tailed paired t-test to test whether cognitive conflict impacts subsequent cognitive processes compared to no-conflict trials, i.e., whether the mean difference between RTs after incongruent and RTs congruent Stroop trials is statistically different than zero.

We estimated the sample size needed to test our main hypotheses from the previous literature. Specifically, we considered four published experiments and the effect sizes reported (3 from Schouppe and colleagues, 2015, 1 from Dreisbach & Fischer, 2012; Table 2), in which the Stroop or the Flanker tasks were used as primes for target valence judgments. Although, in the present study, we assess the influence of Stroop (in)congruency on secondary task performance - instead of emotional ratings as in the experiments mentioned above -, we considered those datasets valuable to estimate the impact of (in)congruency on subsequent cognitive processes (see Table 2).

To control for biases in the previous literature (Brysbaert, 2019; Simonsohn, 2015), we adopted a conservative approach, calculated 33% of the effect sizes reported in the original studies, and then took the average of those values, obtaining an effect size equal to Cohen’s *dz* = 0.51. We estimated, through G*Power, v. 3.1.9.4 (Faul et al., 2007), that to replicate an effect - if it exists - considering an effect size equal to Cohen’s *dz* = 0.51, with 95% power, and $p < 0.05$, we would need 52 participants (see also below, section 6 and Table 2).

As a sanity check, we plan to verify the presence of a Stroop effect in the test phase, thereby ensuring the effectiveness of our manipulation of cognitive control processes. To check whether the estimated sample size (N = 52) is appropriate for detecting the desired effect - if present -, we carried out a statistical power estimation for detecting the Stroop effect through the RStudio package conflictPower (Crump & Brosowsky, 2019; version 0.1.1). This analysis was based on unpublished data (La Pietra et al., n.d.), collected from 78 participants performing an online version of a 4-colour Stroop task, closely resembling the one used in this study. Each participant contributed to the final dataset with a minimum of 30 trials per block, up to a maximum of 10 blocks. Each block comprised 15 congruent and 15 incongruent trials, with no neutral condition. Our preliminary steps for the statistical power estimation included computing the parameters of the ex-Gaussian RTs distributions for congruent (mu = 667.9, sigma = 185.8, tau = 144.2) and incongruent (mu = 790.3, sigma = 214, tau = 204.6) trials. Subsequently, we used the *c_power* function, which employs Monte-Carlo simulation (N = 100), to estimate the statistical power for detecting a conflict effect. This analysis yielded a 100% power to detect a Stroop effect of at least 10 ms with the selected group of 52 participants performing 12 (in)congruent trials ($p < 0.05$).

## 5. Data analysis

All data are analysed through MATLAB, R2021b and plotted through custom-made Python 3.8.8 (Van Rossum & Drake, 2009) codes, using seaborn (Waskom, 2021) and

Matplotlib (Ari & Ustazhanov, 2014; Barrett et al., 2005) packages in the Spyder 4.2.5 anaconda3 environment (Raybaut, 2009).

In all the experiments, only correct trials in both primary Stroop and secondary tasks (in Exp. 1 and 2) are analysed. The first trials of each block for the Stroop task are discarded. Responses above 1500 ms or below 50 ms are discarded.

The independent variables are (in)congruent trials in the Stroop task at the test phase. The dependent variable is the RT in the secondary task at the test phase after congruent and incongruent Stroop trials for experiments 1 and 2. In experiment 3, the dependent variable is the number of items correctly reported as seen in the encoding phase after congruent and incongruent Stroop trials.

At the group level, we test the beneficial hypothesis H1, asserting that instances of cognitive conflict benefit subsequent performance compared to congruent trials, and the detrimental hypothesis (H2), asserting that instances of cognitive conflict hinder subsequent performance compared to congruent trials, while contrasting it with the null hypothesis (H0), asserting that instances of cognitive conflict have no effect on subsequent performance compared to congruent trials, through a two-tailed paired t-test ($p < 0.05$) (see section 6).

Note that the neutral condition is not included in the main critical analyses. Yet, it might be employed in subsequent exploratory analyses to establish the directionality of the effect - if present - and further discriminate between the influence of both congruent and incongruent trials (vs. neutral) on subsequent performance. Please also note that, although we collect information about accuracy and RTs, our hypotheses mainly focus on RTs because we expect accuracy at the secondary tasks to be at ceiling. Overall accuracy at the Stroop task in the test phase will be used to establish the inclusion of participants in the final dataset (Table 1).

In addition, to confirm the effective manipulation of cognitive conflict in the dual-task test, we use a paired one-tailed t-test ($p < 0.05$) to compare the group mean RTs on incongruent trials with the group mean RTs on congruent trials.

Item values from the Need for Cognition, BIS-11 and BPS questionnaires are scored according to Cacioppo et al. (1984), Patton et al. (1995), and Struk et al. (2017). We do not have any specific hypotheses regarding the questionnaire data, which are collected to gather information regarding personality traits to better formulate specific hypotheses in the future. Collecting this information could lead to additional insights concerning the correlation between cognitive control abilities at an individual level and personality traits. Therefore, we do not pre-register the analysis of the questionnaire data, leaving it open to exploration.

## 6. Expected results

First, we expect the presence of the Stroop effect in the test phase (incongruent group mean RTs > congruent group mean RTs), which would confirm an effective cognitive conflict manipulation in our task.

Our general expectation based on H1 is that performance in a secondary task after incongruent Stroop trials is better than after congruent ones. The null hypothesis significance test yields the following possible outcomes:

i. The mean difference between the RTs after incongruent and the RTs after congruent Stroop trials (mean difference ± 95% confidence interval) is statistically smaller than zero (left-tailed, $p < 0.05$). We could reject the H0 and accept the beneficial hypothesis H1.

ii. The mean difference between the RTs after incongruent and the RTs after congruent Stroop trials (mean difference ± 95% confidence interval) is statistically larger than zero (right-tailed, $p < 0.05$). We could reject the H0 and accept the detrimental hypothesis H2.

iii. The mean difference between the RTs after incongruent and the RTs after congruent Stroop trials (mean difference ± 95% confidence interval) is not statistically different than zero ($p > 0.05$). We could not reject the H0 that cognitive conflict does not impact subsequent cognitive processes.

Evidence that H1 can be accepted (case i. above) would confirm that instances of cognitive conflict induce behavioural benefits in subsequent performance. Conversely, if we find evidence in favour of the opposing hypothesis H2 (case ii. above), it would suggest that performance in the second task following incongruent trials is worse than after congruent trials. In this scenario, we would conclude that cognitive conflict has a detrimental effect on subsequent performance. Such a finding would align with the conventional perspective, which posits that cognitive conflict is costly and aversive (Botvinick et al., 2001; Dignath et al., 2020; Dreisbach & Fischer, 2012, 2015; Inzlicht et al., 2015). Otherwise, if the mean difference between the paired observations is not statistically different than zero (case iii.), this finding would suggest that cognitive conflict does not significantly affect subsequent cognitive processes.

For each of the three distinct tasks, namely, the speeded detection, the Go/No-Go, and the implicit memory task, the evidence in support of H0, H1, or H2 will be interpreted separately. Data will also be interpreted across tasks in the direction of generalizability of the effect (i.e., more than one task allows conclusions) or specificity of the effect (i.e., just one task allows conclusions) of incongruence in subsequent cognitive processes and task performance.

## References

Abrahamse, E., Braem, S., Notebaert, W., & Verguts, T. (2016). Grounding cognitive control in associative learning. *Psychological Bulletin*, *142*(7), 693–728. https://doi.org/10.1037/bul0000047

Alden, D. L., Mukherjee, A., & Hoyer, W. D. (2000). The Effects of Incongruity, Surprise and Positive Moderators on Perceived Humor in Television Advertising. *Journal of Advertising*, *29*(2), 1–15. https://doi.org/10.1080/00913367.2000.10673605

Ari, N., & Ustazhanov, M. (2014). Matplotlib in python. *2014 11th International Conference on Electronics, Computer and Computation (ICECCO)*, 1–6. https://doi.org/10.1109/ICECCO.2014.6997585

Barrett, P., Hunter, J., Miller, J. T., Hsu, J.-C., & Greenfield, P. (2005). Matplotlib – A Portable Python Plotting Package. *ASP Conference Series*, *347*, 5.

Berlyne, D. E. (1957). Uncertainty and Conflict: A Point of Contact between Information-theory and Behavior-theory Concepts. *The Psychological Review*, *64*(6), 329–339.

Berlyne, D. E. (1960). *Conflict, Arousal, and Curiosity*. McGraw-Hill.

Bolognesi, M., Combei, C. R., La Pietra, M., & Masini, F. (2022a). What makes an awfully good oxymoron? *Figurative Thought and Language: Dynamicity, Schematicity and Variation in Figurative Thought and Language—Book of Abstracts.*

Bolognesi, M., Combei, C. R., La Pietra, M., & Masini, F. (2022b). What makes an awfully good oxymoron? In *Figurative Thought and Language: Dynamicity, Schematicity and Variation in Figurative Thought and Language—Book of Abstacts*.

Botvinick, M. M. (2007). Conflict monitoring and decision making: Reconciling two perspectives on anterior cingulate function. *Cognit., Affect. and Behav. Neurosc.*, *7*(4), 356–366. https://doi.org/10.3758/CABN.7.4.356

Botvinick, M. M., Carter, C. S., Braver, T. S., Barch, D. M., & Cohen, J. D. (2001). Conflict Monitoring and Cognitive Control. *Psychological Review*, *108*(3), 624–652.

Botvinick, M. M., & Cohen, J. D. (2014). The computational and neural basis of cognitive control: Charted territory and new frontiers. *Cognitive Science*, *38*(6), 1249–1285. https://doi.org/10.1111/cogs.12126

Bouzidi, Y. S., & Gendolla, G. H. E. (2022). Is cognitive conflict really effortful? Conflict priming and shielding effects on cardiac response. *Psychophysiology*. https://doi.org/10.1111/psyp.14169

Braem, S., Abrahamse, E. L., Duthoo, W., & Notebaert, W. (2014). What determines the specificity of conflict adaptation? A review, critical analysis, and proposed synthesis. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.01134

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

Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision*, *10*(4), 433–436. https://doi.org/10.1163/156856897X00357

Brandstätter, V., & Herrmann, M. (2016). Goal disengagement in emerging adulthood: The adaptive potential of action crises. *International Journal of Behavioral Development*, *40*(2), 117–125. https://doi.org/10.1177/0165025415597550

Braver, T. S., M, B. D., Gray, J. R., Molfese, D. L., & Snyder, A. (2001). Anterior Cingulate Cortex and Response Conflict: Effects of Frequency, Inhibition and Errors. *Cerebral Cortex*, 825–836.

Brysbaert, M. (2019). How Many Participants Do We Have to Include in Properly Powered Experiments? A Tutorial of Power Analysis with Reference Tables. *Journal of Cognition*, *2*(1), 16. https://doi.org/10.5334/joc.72

Cacioppo, J. T., Petty, R. E., & Feng Kao, C. (1984). The Efficient Assessment of Need for Cognition. *Journal of Personality Assessment*, *48*(3), 306–307. https://doi.org/10.1207/s15327752jpa4803_13

Chetverikov, A., & Kristjánsson, Á. (2016). On the joys of perceiving: Affect as feedback for perceptual predictions. *Acta Psychologica, 169,* 1–10. https://doi.org/10.1016/j.actpsy.2016.05.005

Cheung, V. K. M., Harrison, P. M. C., Meyer, L., Pearce, M. T., Haynes, J. D., & Koelsch, S. (2019). Uncertainty and Surprise Jointly Predict Musical Pleasure and Amygdala, Hippocampus, and Auditory Cortex Activity. *Current Biology*, *29*(23), 4084-4092.e4. https://doi.org/10.1016/j.cub.2019.09.067

Chiew, K. S., & Braver, T. S. (2011). Positive Affect Versus Reward: Emotional and Motivational Influences on Cognitive Control. *Frontiers in Psychology*, *2*. https://doi.org/10.3389/fpsyg.2011.00279

Ching, M. K. L. (1975). *A Linguistic Analysis of Compact Verbal Paradox in Literature: A Semantic Interpretation of the Oxymoron* [Doctoral Dissertation].

Clark, A. (2018). A nice surprise? Predictive processing and the active pursuit of novelty. *Phenomenology and the Cognitive Sciences*, *17*(3), 521–534. https://doi.org/10.1007/s11097-017-9525-z

Crump, M. J. C., & Brosowsky, N. P. (2019). *conflictPower: Simulation based power analysis for adaptive control designs. R package version 0.1.0*. https://www.crumplab.com/conflictPower/

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

Dreisbach, G., & Fischer, R. (2012). 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. (2015). Conflicts as Aversive Signals for Control Adaptation. *CurrDirectPsycholSci*, *24*(4), 255–260. https://doi.org/10.1177/0963721415569569

Duchon, A., Perea, M., Sebastián-Gallés, N., Martí, A., & Carreiras, M. (2013). EsPal: One-stop shopping for Spanish word properties. *Behavior Research Methods*, *45*(4), 1246–1258. https://doi.org/10.3758/s13428-013-0326-1

Duñabeitia, J. A., Baciero, A., Antoniou, K., Antoniou, M., Ataman, E., Baus, C., Ben-Shachar, M., Çağlar, O. C., Chromý, J., Comesaña, M., Filip, M., Đurđević, D. F., Dowens, M. G., Hatzidaki, A., Januška, J., Jusoh, Z., Kanj, R., Kim, S. Y., Kırkıcı, B., … Pliatsikas, C. (2022). The Multilingual Picture Database. *Scientific Data*, *9*(1), 431. https://doi.org/10.1038/s41597-022-01552-7

Duñabeitia, J. A., Crepaldi, D., Meyer, A. S., New, B., Pliatsikas, C., Smolka, E., & Brysbaert, M. (2018). MultiPic: A standardized set of 750 drawings with norms for six European languages. *Quarterly Journal of Experimental Psychology*, *71*(4), 808–816. https://doi.org/10.1080/17470218.2017.1310261

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*. 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

Engel, S. (2011). Children's Need to Know: Curiosity in Schools. *Harvard Educational Review*, *81*(4), 625–645. https://doi.org/10.17763/haer.81.4.h054131316473115

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., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Festinger, L. (1957). *A theory of cognitive dissonance*. Stanford University Press.

FitzGibbon, L., Lau, J. K. L., & Murayama, K. (2020). The seductive lure of curiosity: Information as a motivationally salient reward. *Current Opinion in Behavioral Sciences*, *35*, 21–27. https://doi.org/10.1016/j.cobeha.2020.05.014

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

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

Gajewski, P. D., Falkenstein, M., Thönes, S., & Wascher, E. (2020). Stroop task performance across the lifespan: High cognitive reserve in older age is associated with enhanced proactive and reactive interference control. *NeuroImage*, *207*, 116430. https://doi.org/10.1016/j.neuroimage.2019.116430

Gibbs, R. W., & Kearney, L. R. (1994). When parting is such sweet sorrow: The comprehension and appreciation of oxymora. *Journal of Psycholinguistic Research*, *23*(1), 75–89. https://doi.org/10.1007/BF02143177

Gratton, G., Coles, M. G. H., & Donchin, E. (1992). Optimizing the Use of Information: Strategic Control of Activation of Responses. *Journal of Experimental Psychology: General*, *121*(4), 480–506.

Gruber, M. J., & Ranganath, C. (2019). How Curiosity Enhances Hippocampus-Dependent Memory: The Prediction, Appraisal, Curiosity, and Exploration (PACE) Framework. *Trends in Cognitive Sciences*, *23*(12), 1014–1025. https://doi.org/10.1016/j.tics.2019.10.003

Harmon-Jones, E., Amodio, D. M., & Harmon-Jones, C. (2009). Action-Based Model of Dissonance: A Review, Integration, and Expansion of Conceptions of Cognitive Conflict. In *Advances in Experimental Social Psychology* (Vol. 41, pp. 119–166). Elsevier. https://doi.org/10.1016/S0065-2601(08)00403-6

Harmon-Jones, E., Amodio, D. M., & Harmon-Jones, C. (2010). Action-Based Model of Dissonance: On Cognitive Conflict and Attitude Change. In J. P. Forgas, J. Cooper, & W. D. Crano (Eds.), *The Psychology of Attitudes and Attitude Change* (pp. 163–181).

Harmon-Jones, E., & Mills, J. (2019). An introduction to cognitive dissonance theory and an overview of current perspectives on the theory. In E. Harmon-Jones (Ed.), *Cognitive dissonance: Reexamining a pivotal theory in psychology (2nd ed.).* (pp. 3–24). American Psychological Association. https://doi.org/10.1037/0000135-001

Hsee, C. K., & Ruan, B. (2016). The Pandora Effect: The Power and Peril of Curiosity. *Psychological Science*, *27*(5), 659–666. https://doi.org/10.1177/0956797616631733

Huskey, R., Craighead, B., Miller, M. B., & Weber, R. (2018). Does intrinsic reward motivate cognitive control? A naturalistic-fMRI study based on the synchronization theory of flow. *Cognitive, Affective, & Behavioral Neuroscience*, *18*(5), 902–924. https://doi.org/10.3758/s13415-018-0612-6

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

Ivanchei, I. I., Braem, S., Vermeylen, L., & Notebaert, W. (2021). Correct responses alleviate the negative evaluation of conflict. *Quarterly Journal of Experimental Psychology*, *74*(6), 1083–1095.

Jones, A. D., Cho, R. Y., Nystrom, L. E., Cohen, J. D., & Braver, T. S. (2002). A Computational Model of Anterior Cingulate Function in Speeded Response Tasks: Effects of frequency, sequence and conflict. *Cognitive, Affect & Behavioral Neuroscience*, *2*(4), 300–317.

Kerns, J. G., Cohen, J. D., MacDonald, A. W., Cho, R. Y., Stenger, V. A., & Carter, C. S. (2004). Anterior Cingulate Conflict Monitoring and Adjustments in Control. *Science*, *303*(5660), 1023–1026. https://doi.org/10.1126/science.1089910

Kleiner, M., Brainard, D. H., & Pelli, D. (2007). *What's new in Psychtoolbox-3?* 89.

La Pietra, M., & Masini, F. (2020). Oxymorons: A preliminary corpus investigation. *Proceedings of the Second Workshop on Figurative Language Processing*, 176–185. https://doi.org/10.18653/v1/2020.figlang-1.24

La Pietra, M., Vives, M.-L., Molinaro, N., & Ruzzoli, M. (n.d.). *Exploring people's preferences towards cognitive conflict*. OSF.

MacLeod, C. M. (1991). Half a Century of Research on the Stroop Effect: An Integrative Review. *Psychological Bulletin*, *109*(2), 163–203.

Martínez-Loredo, V., Fernández-Hermida, J. R., Fernández-Artamendi, S., Carballo, J. L., & García-Rodríguez, O. (2015). Spanish adaptation and validation of the Barratt Impulsiveness Scale for early adolescents (BIS-11-A). *International Journal of Clinical and Health Psychology*, *15*(3), 274–282. https://doi.org/10.1016/j.ijchp.2015.07.002

McGraw, A. P., & Warren, C. (2010). Benign Violations: Making Immoral Behavior Funny. *Psychological Science*, *21*(8), 1141–1149. https://doi.org/10.1177/0956797610376073

Meyer, W.-U., Niepel, M., Rudolph, U., & Schützwohl, A. (1991). An experimental analysis of surprise. *Cognition & Emotion*, *5*(4), 295–311. https://doi.org/10.1080/02699939108411042

Noordewier, M. K., & Breugelmans, S. M. (2013). On the valence of surprise. *Cognition & Emotion*, *27*(7), 1326–1334. https://doi.org/10.1080/02699931.2013.777660

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

Patton, J. H., Stanford, M. S., & Barratt, E. S. (1995). Factor structure of the barratt impulsiveness scale. *Journal of Clinical Psychology*, *51*(6), 768–774. https://doi.org/10.1002/1097-4679(199511)51:6<768::AID-JCLP2270510607>3.0.CO;2-1

Phillips, B. J., & McQuarrie, E. F. (2004). Beyond visual metaphor: A new typology of visual rhetoric in advertising. *Marketing Theory*, *4*(1–2), 113–136. https://doi.org/10.1177/1470593104044089

Pool, E., Brosch, T., Delplanque, S., & Sander, D. (2016). Attentional bias for positive emotional stimuli: A meta-analytic investigation. *Psychological Bulletin*, *142*(1), 79–106. https://doi.org/10.1037/bul0000026

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

Press, C., Kok, P., & Yon, D. (2020). The Perceptual Prediction Paradox. *Trends in Cognitive Sciences*, *24*(1), 13–24. https://doi.org/10.1016/j.tics.2019.11.003

Raybaut, P. (2009). *Spyder-documentation* [Computer software]. Available Online at: Pythonhosted.org

Ruzzoli, M., McGuinness, A., Fernández, L. M., & Soto-Faraco, S. (2020). From cognitive control to visual incongruity: Conflict detection in surrealistic images. *PLoS ONE*, *15*(6). https://doi.org/10.1371/journal.pone.0224053

Ruzzoli, M., McGuinness, A., Morís Fernández, L., & Soto-Faraco, S. (2021). What happens to the brain when we view surrealistic advertising images? In *Neuromarketing Yearbook 2021* (pp. 24–25). Neuromarketing Science &

Business Association (NMSBA). https://nmsba.com/neuromarketing/books/neuromarketing-yearbook-2021

Salimpoor, V. N., Zald, D. H., Zatorre, R. J., Dagher, A., & McIntosh, A. R. (2015). Predictions and the brain: How musical sounds become rewarding. *Trends in Cognitive Sciences*, *19*(2), 86–91. https://doi.org/10.1016/j.tics.2014.12.001

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

Schouppe, N., Braem, S., De Houwer, J., 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

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. (2015). Uncovering a Missing Link in Anterior Cingulate Research. *Neuron*, *85*(3), 455–457. https://doi.org/10.1016/j.neuron.2015.01.020

Shenhav, A., Botvinick, M. M., & Cohen, J. 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

Silvetti, M., Seurinck, R., & Verguts, T. (2011). Value and Prediction Error in Medial Frontal Cortex: Integrating the Single-Unit and Systems Levels of Analysis. *Frontiers in Human Neuroscience*, *5*. https://doi.org/10.3389/fnhum.2011.00075

Silvetti, M., Vassena, E., Abrahamse, E., & Verguts, T. (2018). Dorsal anterior cingulate-brainstem ensemble as a reinforcement meta-learner. *PLOS Computational Biology*, *14*(8), e1006370. https://doi.org/10.1371/journal.pcbi.1006370

Simon, J. R. (1969). Reactions toward the source of stimulation. *Journal of Experimental Psychology*, *81*(1), 174–176.

Simonsohn, U. (2015). Small Telescopes: Detectability and the Evaluation of Replication Results. *Psychological Science*, *26*(5), 559–569. https://doi.org/10.1177/0956797614567341

Stanford, M. S., Mathias, C. W., Dougherty, D. M., Lake, S. L., Anderson, N. E., & Patton, J. H. (2009). Fifty years of the Barratt Impulsiveness Scale: An update and review. *Personality and Individual Differences*, *47*(5), 385–395. https://doi.org/10.1016/j.paid.2009.04.008

Stark, E. A., Vuust, P., & Kringelbach, M. L. (2018). Music, dance, and other art forms: New insights into the links between hedonia (pleasure) and eudaimonia (well-being). In *Progress in Brain Research* (Vol. 237, pp. 129–152). Elsevier. https://doi.org/10.1016/bs.pbr.2018.03.019

Stroop, J. R. (1935). Studies Of Interference In Serial Verbal Reactions. *Journal of Experimental Psychology*, *XVIII*(6), 643–662.

Struk, A. A., Carriere, J. S. A., Cheyne, J. A., & Danckert, J. (2017). A Short Boredom Proneness Scale: Development and Psychometric Properties. *Assessment*, *24*(3), 346–359. https://doi.org/10.1177/1073191115609996

Stürmer, B., Nigbur, R., Schacht, A., & Sommer, W. (2011). Reward and punishment effects on error processing and conflict control. *Frontiers in Psychology*, *2*. https://doi.org/10.3389/fpsyg.2011.00335

Teng, N. Y., & Sun, S. (2002). Grouping, Simile, and Oxymoron in Pictures: A Design-Based Cognitive Approach. *Metaphor and Symbol*, *17*(4), 295–316. https://doi.org/10.1207/S15327868MS1704_3

Van de Cruys, S., Bervoets, J., & Moors, A. (2021). *Preferences need inferences: Learning, valuation, and curiosity in aesthetic experience* [Preprint]. PsyArXiv. https://doi.org/10.31234/osf.io/zh6nt

van der Wel, P., & van Steenbergen, H. (2018). Pupil dilation as an index of effort in cognitive control tasks: A review. *Psychonomic Bulletin & Review*, *25*(6), 2005–2015. https://doi.org/10.3758/s13423-018-1432-y

Van Rossum, G., & Drake, F. L. (2009). *Python 3 Reference Manual*. [Computer software].

van Steenbergen, H., Band, G. P. H., & Hommel, B. (2012). Reward valence modulates conflict-driven attentional adaptation: Electrophysiological evidence. *Biological Psychology*, *90*(3), 234–241. https://doi.org/10.1016/j.biopsycho.2012.03.018

Vassena, E., Holroyd, C. B., & Alexander, W. H. (2017). Computational models of anterior cingulate cortex: At the crossroads between prediction and effort. *Frontiers in Neuroscience*, *11*, 1–9. https://doi.org/10.3389/fnins.2017.00316

Vogt, B. A. (2005). Pain and emotion interactions in subregions of the cingulate gyrus. *Nature Reviews Neuroscience*, *6*(7), 533–544. https://doi.org/10.1038/nrn1704

Waskom, M. (2021). seaborn: Statistical data visualization. *Journal of Open Source Software*, *6*(60), 3021. https://doi.org/10.21105/joss.03021

Wu, R., Ferguson, A. M., & Inzlicht, M. (2022). Do humans prefer cognitive effort over doing nothing? *Journal of Experimental Psychology: General*.

Yang, Q., Paul, K., & Pourtois, G. (2019). Defensive motivation increases conflict adaptation through local changes in cognitive control: Evidence from ERPs and mid-frontal theta. *Biological Psychology*, *148*, 107738. https://doi.org/10.1016/j.biopsycho.2019.107738

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

Yee, D. M., & Braver, T. S. (2018). Interactions of motivation and cognitive control. *Current Opinion in Behavioral Sciences*, *19*, 83–90. https://doi.org/10.1016/j.cobeha.2017.11.009

Yeung, N. (2014). Conflict Monitoring and Cognitive Control. In K. N. Ochsner & S. M. Kosslyn (Eds.), *The Oxford Handbook of Cognitive Neuroscience. Volume 2: The Cutting Edges.* (pp. 275–299). Oxford University Press.

Zatorrea, R. J., & Salimpoor, V. N. (2013). From perception to pleasure: Music and its neural substrates. *Proceedings of the National Academy of Sciences of the United*

*States of America*, *110*(SUPPL2), 10430–10437. https://doi.org/10.1073/pnas.1301228110

# Figures and Tables

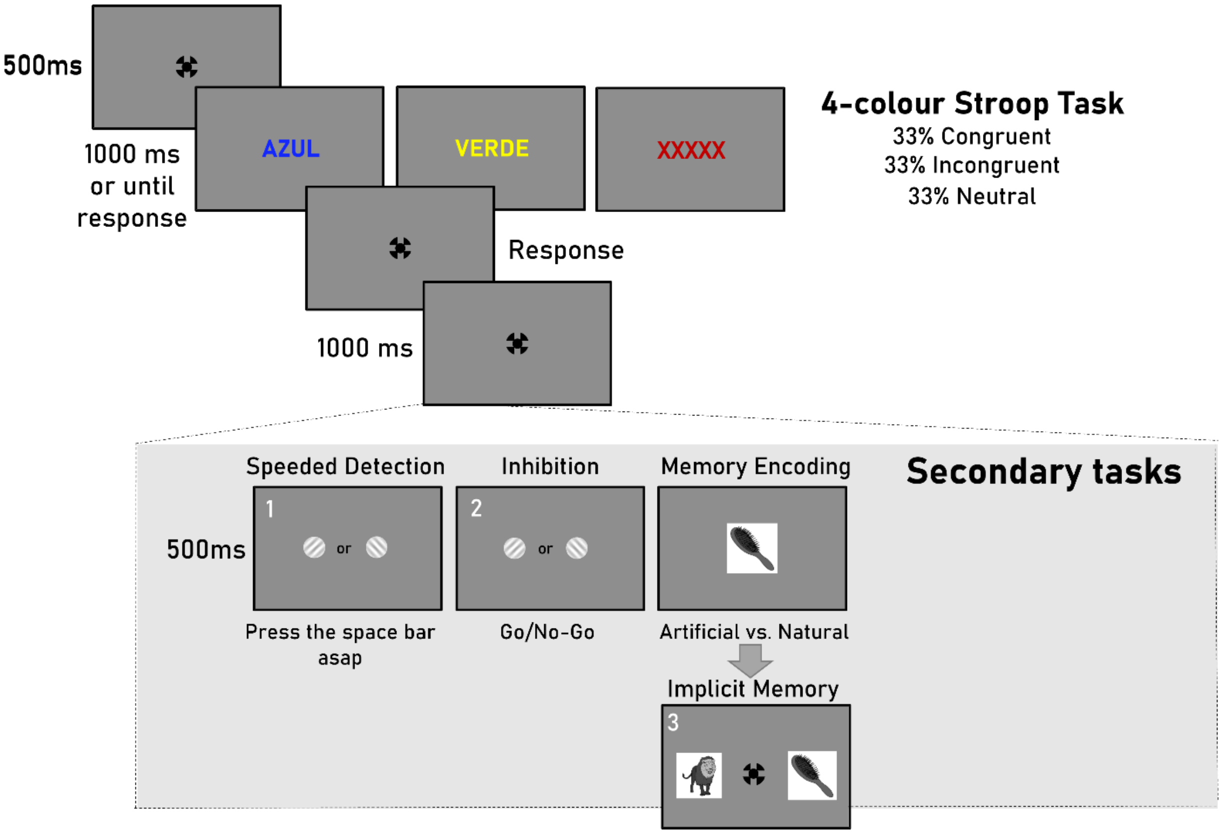

**Fig. 1.** Schematic representation of the paradigm used in three separate experiments. A 4-colour Stoop task is used as the primary task. There is an equal probability of congruent, incongruent, and neutral trials (33%). The secondary tasks target different cognitive functions: (1) alertness, (2) inhibition, and (3) implicit memory. In experiment 3, only the memory encoding phase is intermixed with the Stroop trials. The implicit memory test happens approximately 40 minutes after the encoding phase.

**Table 1. Experiment flow and exclusion criteria.** In each experiment, the experimental flow is identical. The four experimental phases, the total number of trials for all tasks, and the exclusion criteria are listed. Exp = experiment. Experiment 1 is a speeded detection task. Experiment 2 is a Go/No-Go task. Experiment 3 is an implicit memory task.

| **Phases of the experiment** | **Number of trials** | **Exclusion criteria** |
|---|---|---|
| Baseline<br>*Stroop task* | 72 | • Accuracy < 80%<br>• N. (RTs > 1500 ms + < 50 ms) > 10% of total N. of trials<br>• No Stroop effect (difference between incongruent and congruent RTs ≤ 0) |
| Baseline<br>*Secondary task* | 24 | • N. (RTs > 1500 ms + < 50 ms) > 10% of total N. of trials [All Exp]<br>• Missed responses in Go trials > 20% [Exp 2]<br>• False alarms > 20% [Exp 2]<br>• Accuracy < 70% [Exp 3] |
| Practice<br>*Dual-task*<br>(max. 3 repetitions) | 36 | • N. (RTs > 1500 ms + < 50 ms) > 10% of total N. of trials [All Exp]<br>• Accuracy < 80% [Stroop trials]<br>• Accuracy < 70% [Exp 3] |
| Test<br>*Dual-task* | 360 [Exp 1, 2]<br>252 [Exp 3 Encoding] + 80 [Exp 3 Implicit Memory] | • N. (RTs > 1500 ms + < 50 ms) > 10% of total N. of trials [All Exp]<br>• Accuracy < 80% [Stroop trials] |

**Table 2.** Estimation of the effect size from previous literature and sample size for our experiments.

| **Reference** | **Experiment design** | **Statistics in the original study** | **1/3 of the reported effect size (ηp2)** |
|---|---|---|---|
| Schouppe et al. 2015, Exp. 1 | FLANKER Task: 2 × 2 repeated-measures ANOVA with prime congruency (congruent vs. incongruent) and target valence (positive vs. negative) as within-subjects factors. | F(1, 19) = 4.52, p < 0.05, ηp2 = 0.19 | 0.063 |
| Schouppe et al. 2015, Exp. 2A | FLANKER Task: 2 × 2 × 2 repeated-measures ANOVA with prime congruency (congruent vs. incongruent), target valence (positive vs. negative), and prime RT (50 % fastest vs. 50% slowest prime responses; based on a median split on prime RTs for each congruency condition separately) as within-subjects factors. | F(1, 19) = 5.1, p < 0.05, ηp2 = 0.21 | 0.069 |
| Schouppe et al. 2015, Exp. 2B | STROOP Task: 3 × 2 × 2 repeated-measures ANOVA with prime congruency (3 levels), target valence (positive vs. negative), and prime RT (50 % slowest vs. 50 % fastest) as within-subjects factors. | F(2, 62) = 3.3, p < 0.05, ηp2 = 0.10 | 0.033 |
| Dreisbach & Fisher 2012 | STROOP Task: 2 (Prime Congruency: congruent vs. incongruent) x 2(Target Valence: positive vs. negative) x 2 (Target type: picture vs. word) mixed factors design was applied. Prime congruency and valence were repeated measures. The target type was manipulated between participants. | F(1,28) = 10.79, p < 0.01, ηp2 = 0.25 | 0.083 |
| | | Mean Eta Square | **0.06** |
| | | Conversion to Cohen's dz | **0.51** |
| | | Estimated sample size | **52** |

**Table 3.** Summary of the design and analysis pipeline.

| **Question** | **Hypotheses** | **Outcome Measures** | **Sampling Plan**<br>**(N, power analyses)** | **Sanity checks** | **Analysis Plan** | **Interpretation given to different outcomes for each of the three tasks separately** |
|---|---|---|---|---|---|---|
| Can cognitive conflict affect subsequent cognitive processes? | **H1, the beneficial hypothesis**<br>Performance in the secondary tasks after incongruent Stroop trials is better than after congruent trials. | Reaction time (ms) for experiments 1 and 2, memory performance (accuracy) for experiment 3. | **N = 52** participants in each experiment (see Table 2 and Section 4 for a detailed description of the sampling plan).<br>Sample size estimated from previous literature: Cohen's *dz* = 0.51<br>Power = 95%<br>α = 0.05 | Two 36-trial blocks of the Stroop task serve as a baseline and inclusion criteria for the presence of the Stroop effect.<br>RTs (ms) incongruent vs. RTs congruent trials in the main dual-task test Stroop trials (paired one-tailed t-test, p<0.05). | Null hypothesis significance test (NHST) through a two-tailed paired t-test; Cohen's dz = 0.51; p < 0.05 | ***Sanity Check***<br>The presence of a group-level Stroop effect in the main dual-task test serves as a confirmation of the successful manipulation of cognitive control processes within our experimental setup. This validation justifies the testing of our primary hypotheses, as without this confirmation, such testing would lack significance. |
|  | **H0, the null hypothesis**<br>Performance in the secondary tasks after incongruent Stroop trials is not statistically different than performance after congruent trials. |  |  |  |  | ***Case 1***<br>The results of the NHST show that the mean difference between the RTs after (in)congruent Stroop trials is significantly faster than zero.<br>H1 is supported as instances of cognitive conflict are associated with subsequent behavioural benefits. |
|  |  |  |  |  |  | ***Case 2*** |

| | | | | | | |
|---|---|---|---|---|---|---|
| | **H2, the detrimental hypothesis**<br>Performance in the secondary tasks after incongruent Stroop trials is worse than after congruent trials. | | | | | The results of the NHST show that the mean difference between the RTs after (in)congruent Stroop trials is not significantly different than zero.<br>H0 cannot be rejected as no reasonable effect of cognitive conflict is found on subsequent performance. |
| | | | | | | ***Case 3***<br>The results of the NHST show that the mean difference between the RTs after (in)congruent Stroop trials is significantly larger than zero.<br>H2 is supported as instances of cognitive conflict are detrimental to subsequent performance. |