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Running Head: Ego depletion and reversal

Ego-depletion in visual perception: Ego depleted viewers experience less ambiguous figure reversal

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Abstract

This study examined the effects of ego depletion on ambiguous figure perception. Adults (*N* = 315) received an ego depletion task and were subsequently tested on their inhibitory control abilities that was indexed by the Stroop task (Experiment 1) and their ability to perceive both interpretations of ambiguous figures that was indexed by reversal (Experiment 2). Ego depletion had a very small effect on reducing inhibitory control (Cohen's d = .15) (Experiment 1). Ego depleted participants had a tendency to take longer to respond in Stroop trials. In Experiment 2, ego depletion had small to medium effects on the experience of reversal. Ego depleted viewers tended to take longer to reverse ambiguous figures (duration to first reversal) when naïve of the ambiguity and experienced less reversal both when naïve and informed of the ambiguity. Together, findings suggest that ego depletion has small effects on inhibitory control and small to medium effects on bottom-up and top-down perceptual processes. The depletion of cognitive resources can reduce our visual perceptual experience.

Keywords: ambiguous figures, reversal, bottom-up processes, top-down processes, ego depletion

Ego depletion in visual perception: Ego depleted viewers experience less ambiguous figure reversal

Research over the past 100 years has used ambiguous figures, pictures with more than one interpretation, to examine the interplay of bottom-up and top-down processing in visual perception (Long & Batterman, 2012; Melcher & Wade, 2006; Ward & Scholl, 2015; Wimmer & Doherty, 2011). Ambiguous figures evoke different interpretations while the physical properties of the stimulus itself remain unchanged. This switching between interpretations is termed “ambiguous figure reversal” (Long & Toppino, 2004). Whilst a plethora of research has demonstrated the interplay of processes allowing reversal, in the current research we addressed how the “depletion” of cognitive resources reduces our visual perceptual experience.

Evidence from different fields has demonstrated that inhibitory processes play a key role in the reversal experience. Developmental research has shown that inhibitory ability allows 4- to 5-year-old children to experience reversal *per se* when informed of the ambiguity (Wimmer & Doherty, 2011). Bilingual children who have superior inhibitory control (Carlson & Meltzoff, 2008) are more likely to reverse ambiguous figures than their monolingual peers (Bialystock & Shapero, 2005; Wimmer & Marx, 2014). In addition to allowing reversal, inhibitory control can also reduce reversal. Adults can voluntarily control the perception of one interpretation when instructed to hold their first interpretation, demonstrating the role of top-down processes in visual perception (Hochberg & Peterson, 1987; Mathes, Strüber, Stadler, & Basar-Eroglu, 2006; Meng & Tong, 2004; Peterson & Gibson, 1991; Slotnik & Yantis, 2005; Suzuki & Peterson, 2000; van Ee, van Dam, & Brouwer, 2005). However, viewers cannot fully control their reversal rate as the instruction to hold one interpretation only leads to a decrease in reversal of between 1/2 and 1/3 over a 3 minute period (Strüber & Stadler, 1999), highlighting the additional role of bottom-up processes in reversal.

The current research investigates the specific role of inhibitory processes in reversal and takes an opposite approach. If inhibitory control allows reversal *per se*, will the depletion of inhibitory processes directly interfere with reversal, thus, reduce it? To investigate the effect of inhibitory depletion on reversal, we use an ego depletion method from Social Psychology. Ego depletion refers to "a temporary reduction in the self's capacity or willingness to engage in volitional action, (including controlling the environment, controlling the self, making choices, and initiating action) caused by prior exercise of volition" (Baumeister, Bratslavsky, Muraven, & Tice, 1998, pp. 1253). The underlying principle of ego depletion is that performance on a task requiring self-control will subsequently lead to a decrease in performance in an unrelated self-control task (Alós-Ferrer, Hügelschäfer, & Li, 2015; Baumeister, et al., 1998; Hagger, Wood, Stiff, & Chatzisarantis, 2010). Specifically, participants who cross off some instances of the letter "e" following complex rules watch a boring movie longer when it requires active quitting (pressing a button) than passive quitting (removing the hand from a button) (Baumeister et al., 1998). Thus, participants' self-control is impaired after monitoring behaviour and overriding a habitual response such as crossing off all instances of the letter "e" (Baumeister et al., 1998).

The ego depletion effect is demonstrated widely across a range of tasks but the underlying mechanisms are not well understood. Ego depletion may reflect a low-level bottom-up process (Baumeister et al., 1998) or a high-level top-down process (Inzlicht, Schmeichel, & Macrae, 2014). The energy model (Baumeister et al., 1998) purports that self-control is a limited resource. In a self-control task energy is consumed and subsequent task performance requiring self-control will be reduced due to limited energy and its conservation, analogous to a tired muscle (Baumeister, 2014). For example, self-control is linked to blood glucose levels and consuming a glucose drink reduces the ego depletion effect (Galliot et al., 2007). In contrast, self-control requirements may subsequently lead to reduced attention to cues that require control and reduced motivation to exert control (Inzlicht, et al., 2014). For example, the ego depletion effect is reduced when participants are motivated to perform a task such as thinking that their participation helps finding Alzheimer's disease treatments (Muraven & Slessareva, 2002). The energy model can account for these findings too; motivation reduces the ego depletion effect because ego depleted participants can still exert conserved self-control if motivated beforehand (Baumeister, 2014). Overall, it is unclear what processes underlie ego depletion *per se*. However, given that ego depletion affects bottom-up processes (Baumeister, 2014) and top-down processes (Inzlicht et al., 2014), it should reduce ambiguous figure reversal involving both processes.

To test whether the depletion of inhibitory control leads to reduced reversal we adapted the well-established ego depletion task (Baumeister et al., 1998) and measured the effect on inhibitory control, indexed by the Stroop task (Stroop, 1935) (Experiment 1) and reversal (Experiment 2). Specifically, it was examined whether ego depletion affects reversal when being naïve of the ambiguity (bottom-up) versus being informed of both interpretations (top-down). If ego depletion reflects a low-level process (Baumeister et al., 1998) then this should lead to reduced reversal under naïve conditions whereas if it reflects a high-level process (Inzlicht et al., 2014) then this should reduce reversal under informed conditions.

Experiment 1: Establishing ego depletion effects on inhibitory control

Here, the effects of ego depletion on inhibitory control were examined. Participants were either ego depleted using a well-established ego depletion task (Baumeister et al., 1998) or not depleted and then subsequently given the Stroop task, indexing inhibitory control.

Method

Participants

Overall 214 adults (165 females) (*M* = 22 years, *SD* = 7 years) recruited via the Plymouth University online participation system participated. They either received course credit or financial reimbursement.

Design

Half of the participants received an ego depletion task (*N* = 113) and the other half an analogous control task (*N* = 101). After that, all participants received a computerized Stroop task. The experiment lasted around 30 minutes.

Materials and Procedure

Participants in the *control condition* received a typewritten sheet of paper containing technical text (a page from a neuroscience article) and were instructed to cross off all instances of the letter "e". Participants in the *ego depletion condition* were additionally told to only cross off an "e" if it is "not adjacent to another vowel and more than one letter away from another vowel" (thus, one would not cross off the "e" in "pear" or "vowel") (Baumeister et al., 1998). Eight example words were provided clarifying the instructions.

After that all participants received a computerized version of the Stroop task on a standard PC (1920 x 1080 resolution), containing 100 word reading-, 100 colour naming-, and 100 interference trials. Each trial type was preceded by 10 practise trials. Trial type order was counterbalanced between participants. Stimuli comprised color words (red, green, blue, yellow) written in red, green, blue, yellow, or black font. Color words were aligned in a 2 by 2 square configuration in the centre of the screen centred by a fixation cross where the mouse was positioned at the start of each trial. The target stimulus appeared below the square configuration and was displayed until participants gave a response via mouse click, followed by the next trial 1000 ms apart. In word reading trials, the target was a color word in black font and participants clicked on the according color patch (e.g., "if the word "BLUE" appears, click on the blue color patch"). In color naming trials, the target was a color patch and participants clicked on the according word (e.g., “if you see a BLUE patch, click on the word “Blue”), In interference trials, the target was a color word and participants clicked on the color the word is written in (e.g., “if you see the word BLUE written in red, click on the word “Red”). In interference trials the color word was *incongruent* with the color the word was written in in most trials (76 trials) mixed with 24 *congruent* trials to increase the interference effect.

Results and Discussion Experiment 1

Accuracy on percentage of Stroop trials was at ceiling (ego depleted: M = 98.34; control: M = 97.89) and therefore no statistical analysis was conducted. Eight participants (3 ego depleted and 5 controls) failed all interference trials and were excluded from analyses. The final analyses include participants who followed the ego depletion instructions, that is, both rules (N = 82) and control instructions (N = 95).

We analysed mean *response time* in the Stroop task using bootstrap resampling to obtain effect sizes. There was barely a response time difference on overall Stroop response time between ego depleted participants (M = 1001 ms) and controls (M = 985ms), Cohen’s d = .095.

However, it was of theoretical interest whether ego depletion would reduce inhibitory control rather than all-across-the-board response time. To isolate the inhibitory component, for each participant, the average of their response time in the two control conditions (word reading and colour naming) was subtracted from their mean response time in interference trials. In this inhibitory mean response time measure, ego depleted participants (M = 233 ms) had a tendency to take longer to respond than control participants (M = 207 ms) Cohen’s d = 0.15. The same findings were obtained when response time in colour naming was used as comparison against the interference trials (interference latency – colour naming latency); ego depleted (M = 234 ms) versus controls (M = 205 ms), Cohen’s d = .18.

Thus, there is a small effect of ego depletion reducing inhibitory control. These findings do not support previous research revealing large ego depletion effects on inhibitory control (Johns et al., 2008). Can this small effect be a result of procedural differences of our Stroop version such as responding via mouse click or implementing the traditional blocked trial version as opposed to the more recently used item-by-item version? This seems unlikely as if anything the blocked version reveals larger inhibitory control effects than the item-by-item version (Ludwig, Borella, Tettamanti, & de Ribaupierre, 2010; Salo, Henik, & Robertson, 2001). Thus, we would have expected to find at least equally large ego depletion effects on Stroop performance in a blocked version as in Johns et al.'s (2008) item-by-item version. Moreover, the Stroop effect is demonstrated widely across different response modalities (e.g., oral versus pressing a keyboard button versus typing in the word). At which stage of the task the Stroop effect emerges, is subject to debate (during encoding or response selection) but evidence rules out that the Stroop effect occurs at response execution (Damian & Freeman, 2007; Gordon & Zbrodoff, 1998). Therefore, it is unlikely that procedural differences in the Stroop version can explain the differences in the magnitude of the ego depletion effect in our study (d = .15) and in Johns et al. (2008) (d = .76).

Experiment 2: The effects of ego depletion on ambiguous figure reversal

Having established a small reduction of inhibitory control with the current ego depletion task, it was examined whether ego depletion reduces reversal (duration to first reversal and number of reversals) when naïve versus informed of ambiguity.

Method

Participants

Overall 101 adults (69 females) (M = 24 years, SD = 11 years) recruited via the Plymouth University online participation system took part and either received course credit or financial reimbursement.

Design

First, participants received the same ego depletion (N = 51) or control task (N = 50) as in Experiment 1 followed by the ambiguous figure (AF) reversal task.

Materials and Procedure

The ego depletion task was the same as in Experiment 1. The AF reversal task was computerized and ran on a standard PC (1920 x 1080 resolution) in Visual Basic.

Ambiguous figure (AF) reversal task. The ambiguous duck/rabbit (11 x 7.5cm) (Jastrow, 1900), man/mouse (8.5 x7.5cm) (Bugelski & Alampay, 1961), mother/face (9 x 10.5 cm) (Fisher, 1967), and cowboy/Indian (10 x 11.5cm) (Botwinick, 1961) were used (Figure 1). Participants sat approximately 1m from the screen.

Before presenting the ambiguous figures, participants received two familiarization trials each lasting 60 seconds. In one trial the image changed physically (a horse morphed into a sheep) whereas in the other no change occurred as the figure was unambiguous (a line drawing of a girl). Participants pressed the space bar whenever they thought that the image changed. The purpose of familiarization was to introduce the concept of change without the concept of ambiguity and to control for false positives (people reporting changes without perceiving them) and false negatives (people perceiving changes without reporting them). Two participants were identified as false positives and their data were removed from further analyses.

After familiarization, in the *naïve phase* participants were presented with the first ambiguous figure and uninformed of the ambiguity and alternative interpretations. Participants were asked what they saw (initial interpretation) (e.g., “a duck”). Then, they indicated their perceptual changes via button press over 60 seconds. The program recorded the dependent variables, i) when the first reversal occurred (duration to first reversal) and ii) how often reversal occurred (reversal rate). This was repeated with the remaining 3 ambiguous figures (man/mouse, cowboy/Indian, face/mother). Ambiguous figures appeared in random order counterbalanced between participants. If participants reversed, then at the end of the *naive phase*, they were asked what the alternative perceived interpretation was, ensuring perception of the alternative interpretation as indicated. Alternative labels were accepted as long as the participant was able to indicate relevant features of his/her stated changed interpretation (e.g., old woman instead of Indian, or woman instead of mother with baby, or man instead of face).

Then, the *informed phase* followed the same procedure, except that first, each figure was disambiguated by adding disambiguating context drawings for each interpretation and each interpretation was labelled (e.g., “This could be a duck, this could be a rabbit.” “You will now be shown the ambiguous image for 60 seconds. Please press the space bar each time you see the image flip between pictures”).

At the end, participants were asked whether they had seen any ambiguous figure before.

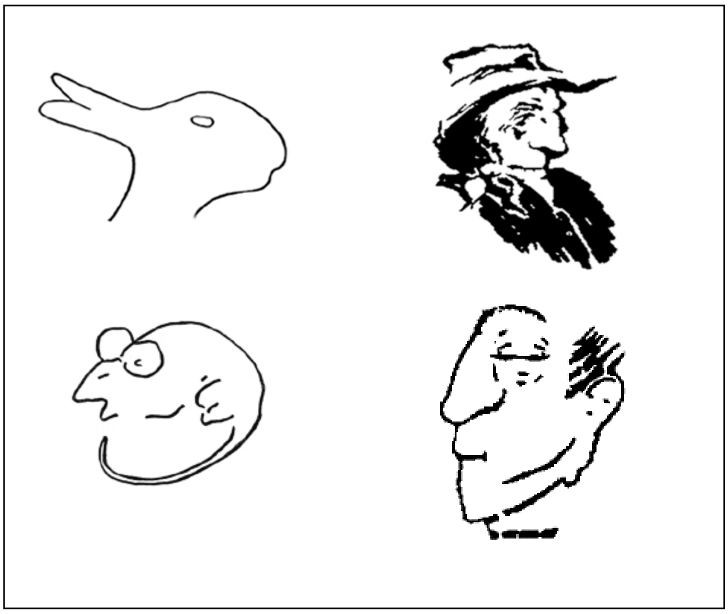

Figure 1. AFs used in Experiment 2 (clockwise from top-left: duck/rabbit, cowboy/Indian, face/mother, man/mouse).

Results and Discussion Experiment 2

Data of 5 outliers (2 standard deviations above the mean) in the number of reversals experienced in the naïve phase were removed from any further analysis.

Prior knowledge of ambiguous figures

Depending on the type of ambiguous figure, there were considerable differences in whether it had been seen before, Friedman-test, $\chi^2(3, 94) = 73.9$, $p < .001$. Specifically, the duck/rabbit was more known (all $z > 5.06$, *ps* < .001) (by 45% of participants) than any other figure which did not differ (all *p*s > .05) (Wilcoxon Signed Ranks) except that the cowboy-Indian was more known than the man-mouse ($p = .04$) (face-woman: 7%, cowboy-Indian: 11%, man-mouse: 4%). Thus, because of high familiarity with the duck-rabbit figure to compare *naïve* and *informed* phases, this figure was removed from any further analyses.

Ambiguous figure reversal

We analysed *mean time in seconds to first reversal* (duration to first reversal) and *mean number of reversals* (reversal rate), using bootstrap resampling to obtain confidence intervals on both the mean values and the effect sizes. Figure 2 shows the means.

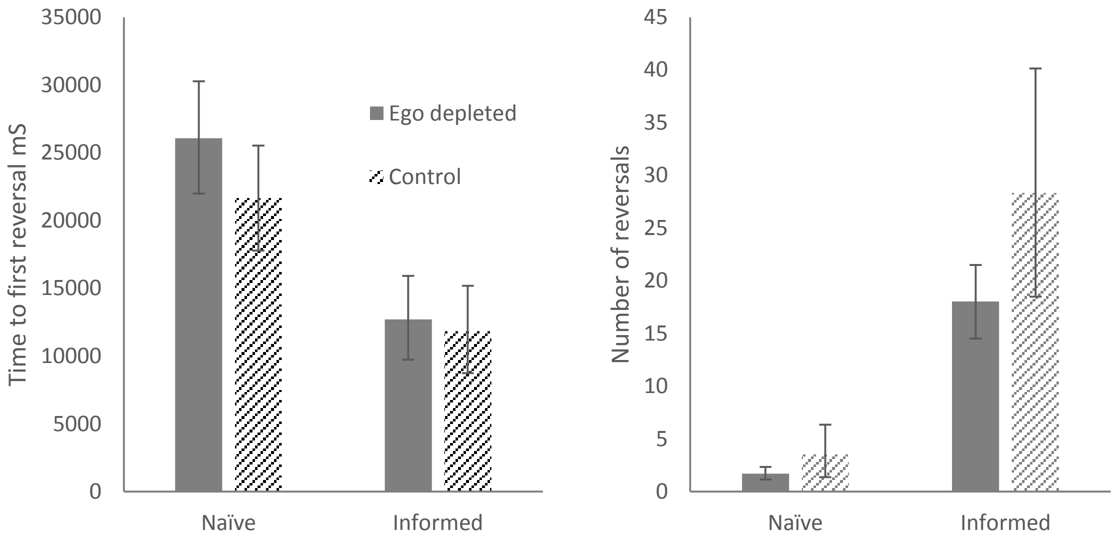

Figure 2. Time to first reversal and number of reversals for Ego depleted and Control participants, when naive and informed about ambiguous figures. Error bars are 95% CI.

The effect of being informed about ambiguity is clear, with a marked decrease in time to first reversal and a large increase in the total number of reversals reported. There is a tendency for ego depleted participants to take longer to report a reversal, and see fewer in total. Figure 3 shows the effect size of the differences between groups in each condition.

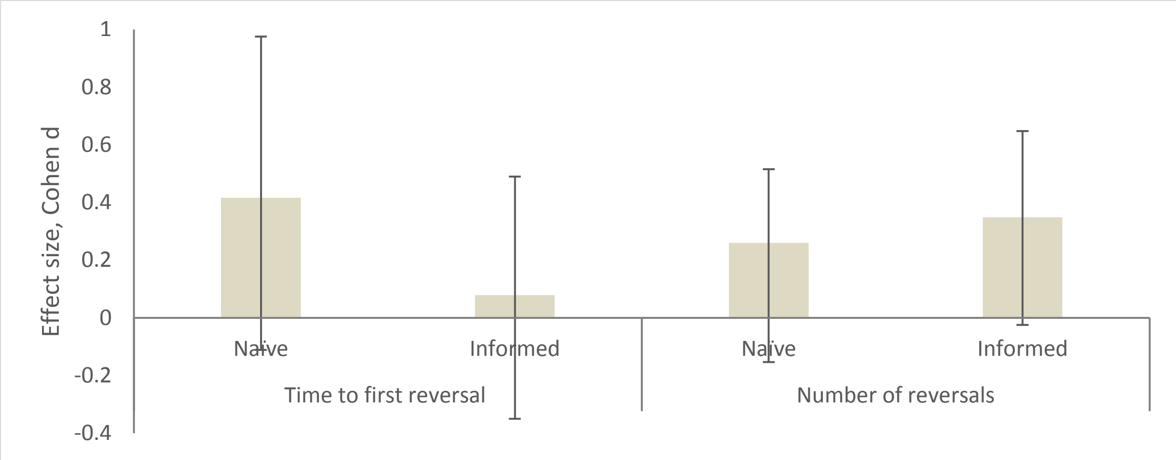

Figure 3. Cohen d effect size for the difference between Ego depleted and Control participants; sign-reversed for number of reversals. Error bars are 95% CI.

The estimate of effect size for time to first reversal is 0.42 in the naïve condition, falling to 0.08 in the informed condition. For number of reversals, the effect size increases from 0.26 when naïve to 0.35 when informed (the direction of the difference is opposite, as shown in Figure 2; reversing the sign of Cohen's d makes Figure 3 clearer. We cannot confidently rule out an effect size of zero in any condition, due to large individual differences between participants. However, the pattern seems clear: while the tendency of ego depleted participants to take longer to see a reversal disappears when they are informed of the ambiguity, they still make fewer reversals overall.

This pattern is consistent with reduced bottom-up processing in ego depleted participants. After ego depletion it takes longer to reverse when uninformed of ambiguity (bottom-up), which disappears when informed (top-down). The addition of this top-down information greatly increases the number of reversals seen, but has much the same effect on both control and ego depleted participants, suggesting both are equally sensitive to top-down processing. Ego depleted participants persist in seeing fewer reversal when informed, consistent with reduced bottom-up processing.

General Discussion

The current aim was to examine whether the depletion of inhibitory control reduces the experience of reversal. Adapting an ego depletion paradigm from Social Psychology (Baumeister et al., 1998), inhibitory control was slightly reduced after ego depletion (Experiment 1) but it is important to stress that the effect is small. In Experiment 2, when ego depleted adults viewed ambiguous figures, they were less likely to reverse ambiguous figures. Thus, in addition to findings demonstrating that inhibitory control allows or stabilises reversal (e.g., Wimmer & Doherty, 2011, Strüber & Stadler, 1999) the current findings reveal that the depletion of inhibitory resources may reduce reversal. Reversal reduction occurred when both being naïve and informed of ambiguity, suggesting ego depletion effects on both bottom-up and top-down processes.

It is unclear what mechanisms underlie ego depletion and there is debate whether ego depletion reflects the depletion of low-level processes (Baumeister et al., 1998) or reduces active motivation and attention to reach a goal or perform a task (Inzlicht et al., 2014). The current findings cannot directly answer this debate and the reduction in reversal rate when informed of ambiguity can be a result of both neural fatigue effects (bottom-up) and lack of motivation to focus on the task (top-down). However, the additional finding that ego depletion increased response time to reverse initially when naïve about the ambiguity is in line with the suggestion that ego depletion particularly reduces bottom-up processing (Baumeister et al., 1998) rather than solely affecting top-down processing (Inzlicht et al., 2014). Thus, overall, a hybrid model of ego depletion involving both bottom-up and top-down processes seems more plausible.

However, the size of the ego depletion effect has recently been put into question in a pre-registered replication study involving 23 laboratories (Hagger & Chatzisarantis, 2016). Effect sizes on response time differences between ego depleted and control participants ranged between Cohen's *d* = -.06 and .36 with 95% confidence interval. Moreover, task performance varied greatly in accuracy both between ego depleted and control participants and across different laboratories (15%-44% of participants performing < 80% correct) (Hagger & Chatzisarantis, 2016). Clearly, this raises the issue of the strength of the ego depletion effect and how minor procedural differences across laboratories, different populations, and variation in task performance affect the overall strength of the effect (Baumeister & Vohs, 2016). Our single lab findings reveal a small ego depletion effect and do not support previous results showing strong effects of ego depletion on inhibitory Stroop performance (Johns et al., 2008). Power analysis (Gpower, Faul, Erdfelder, Lang, & Buchner, 2007) suggests that we had sufficient power (174 participants needed) to detect large sized effects at *d* = .5. In Experiment 2 the ego depletion effect was larger, demonstrating novel effects in visual perception. Thus, the current research supports demonstrations of the effect across a wide domain of tasks (Hagger et al., 2010), but raises the question of the size of the effect.

Furthermore, findings from the ego depletion literature are at odds with the traditional cognitive literature on sequential modulation effects. When a task poses response conflict then inhibitory control performance is enhanced in a second self-control task due to activated cognitive control or priming (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Mayr, Awh, & Laurey, 2003). Specifically, responding to an incongruent Flanker task trial reduces response time on an immediately followed incongruent Number Stroop trial when participants are initially aware of trial difficulty (Fernandez-Duque & Knight, 2008). Crucially, the sequential modulation effect occurs on a trial by trial basis when task type varies across trials as opposed to the sequential task paradigm in ego depletion. Thus, when the cognitive system is put under response conflict across different tasks it can enhance cognitive control across tasks online on a trial by trial basis (cognitive literature on sequential modulation) but not when the task flow is interrupted (ego depletion literature). This difference between online task engagement and task interruption may cause participants to show opposite self-control effects. Future research might want to directly investigate this claim.

Overall, current findings provide novel insights into the functional dependence of inhibitory processes on the disambiguation of visual information under naïve and informed conditions. The depletion of inhibitory control may reduce our visual perceptual experience of reversal.

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