

Top-down versus bottom-up: when instructions overcome automatic retrieval

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Abstract Research on human action has extensively covered controlled and automatic processes in the transformation of stimulus information into motor action, and how conflict between both types of processes is solved. However, the question of how automatic stimulus–response (S–R) translation per se depends on top-down control states remains unanswered. The present study addressed this issue by manipulating top-down control state (instructed S–R mapping) and automatic bottom-up processing (retrieval of S–R memory traces) independently from each other. Using a color/shape task-switching paradigm, we compared cross-talk triggered by distractor stimuli, for which the instructed S–R mapping and the S–R associations compiled at the beginning of the experiment matched, with the cross-talk triggered by distractor stimuli, for which (re-)instructed mapping and compiled S–R associations did not match. We show that the latter distractors do not yield any cross-talk in RTs and even reversed cross-talk in error rates, demonstrating that automatic S–R retrieval is modulated by top-down control states.

Introduction

People usually react to the environment in a way that meets their purposes, indicating that stimulus–response (S–R) translation is controlled by the agent’s intentions. However, sometimes people fail to carry out the intended action, performing instead an action they are accustomed to execute. Hence, humans are also liable to automatic processes of S–R translation (cf. Shiffrin & Schneider, 1977).

A key issue in research on human action is the role that controlled and automatic processes play in S–R translation, and how they relate to each other. Research on this topic has focussed on the conflict between the two routes and how controlled processing is ensured during such conflicts (cf. Miller & Cohen, 2001). A number of paradigms have been used in this context, for example, Stroop (MacLeod, 1991), Simon (Lu & Proctor, 1995), flanker (Eriksen & Eriksen, 1974), and task-switching paradigms (Monsell, 2003). This research has yielded the “dual route” account maintaining that motor codes can be activated via two routes: a controlled and an automatic route (e.g., Kornblum, Hasbroucq, & Osman, 1990). According to this view, action control is based on a race between the two routes.

The present study, by contrast, addresses a question that has received comparatively little attention, viz., whether automatic S–R translation (i.e., the transformation of stimulus information into associated response activation) per se depends on top-down control states (for a review of this question see, Hommel, 2000). Hommel argued that distractor stimuli activate motor responses although they are irrelevant on a given trial, only if the distracting information is somehow relevant in the current task context. For example, in the Simon task, the left/right location of the stimulus is only processed if the responses are coded with regard to a spatial dimension (Ansorge & Wühr,

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2004). In the same vein, flanker effects appear only if target and flankers are defined on the same dimension (e.g., color; cf. Cohen & Shoup, 1997). Hence, flanker stimuli may be irrelevant in the current trial in that the correct response does not depend on the flankers; however, in order to be automatically translated into a response, they need to be valid targets which simply appear at the “wrong” location. It seems, thus, that automatic S–R translation itself is heavily dependent on the current top-down control state. However, the precise mechanisms this influence is based on are yet to be discovered.

Note that in everyday life people often switch between different control states. This is mimicked in task-switching paradigms, in which participants typically perform two alternating tasks on the same two-dimensional stimulus set (see Kiesel et al., 2010). The two tasks are usually mapped to the same responses, such that targets are either response congruent or incongruent. For example, if participants switch between a color and a shape task, a congruent target requires the same response for both tasks (e.g., a light blue square in Fig. 1) whereas an incongruent target requires

different responses in both tasks (e.g., a green square). Performance is usually better on congruent than on incongruent trials. This cross-talk demonstrates that the response to the currently invalid distractor stimulus is translated automatically (e.g., Kiesel, Wendt, & Peters, 2007; Meiran, 1996; Meiran & Kessler, 2008; Rogers & Monsell, 1995). If the trial is incongruent, this translation results in conflict and the time it takes to resolve this conflict can be considered a measure of the influence of the automatic S–R translation on performance.

Evidently, in this type of task-switching experiment, top-down control state—i.e., the instructed mapping of the stimuli and the responses (instructed S–R mapping)—and automatic bottom-up processing—i.e., the memory traces accumulating in the course of the experiment that associate stimuli and responses (S–R memory traces)—correspond for both, the currently relevant as well as for the currently irrelevant task. That is, the instruction to press, say, a right key in response to, say, a green stimulus matches the memory traces compiled each time the participant performed a right key press in response to a green stimulus.

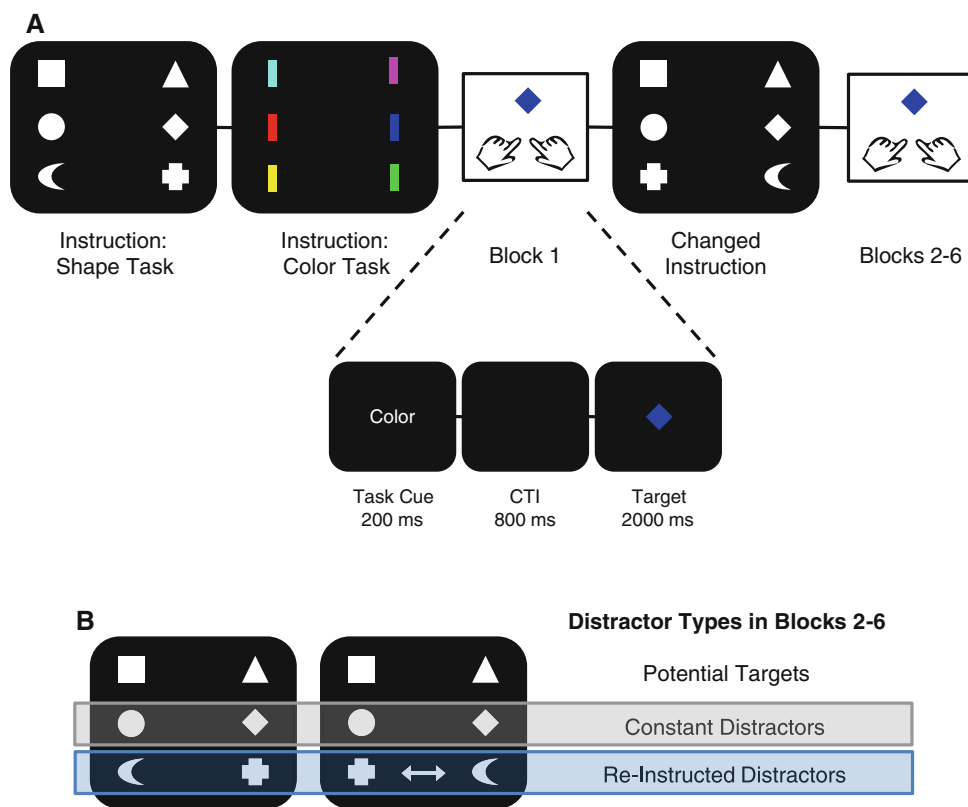


Fig. 1 **a** Block and trial structure of the experiment. Both tasks were instructed separately and practiced in one block of 72 trials. Then, the instructed shape-key mapping changed for two shapes (here: bottom row in the display) and participants used this changed instruction during five further blocks. In these blocks, only two shapes with constant shape-key mapping appeared as targets in the shape task but all possible shapes appeared as distractors in the color task.

CTI = Cue-Target-Interval. **b** The described procedure resulted in three distractor types in Blocks 2–6. *Potential targets* had a constant shape-key mapping and continued to appear as targets in the shape task. *Constant distractors* also had a constant shape-key mapping but appeared only as distractors in the color task. Similarly, *re-instructed distractors* appeared only as distractors in the color task but their mapping was swapped by the re-instruction

The question is whether the congruency effect of a distractor stimulus depends on this correspondence. We tested this question by manipulating top-down control state (instructed S–R mapping) and automatic bottom-up processing (retrieval of S–R memory traces) independently from each other. To do so, we used a task-switching paradigm with arbitrary S–R mappings. Arbitrary S–R couplings lack any compatibility or pre-learned linkage, such that the specific mapping has to be set up by instructions and can be changed during the experiment (cf., Wendt & Kiesel, 2008).

We presented participants with colored shapes and participants switched between categorizing according to the color or according to shape. Crucially, in our paradigm, for some stimuli the top-down task set specifying the S–R translation rule changed in the course of the experiment. These stimuli were re-mapped to new responses. Also, from that point onward, they were not presented as targets anymore, but only as distractor stimuli (*re-instructed distractors*, see Fig. 1). Other stimuli simply ceased to be presented as targets without being re-mapped to new responses (*constant distractors*). The re-instructed distractors are therefore mapped to responses in two ways. First, at the beginning of the experiment, when they were still presented as targets, they acquire associations to certain motor responses and, thus, establish a retrieval-based translation of the given S–R rule (cf., Logan, 1988). In this part of the experiment, the instructed S–R mapping and the S–R associations compiled during the experiment correspond, just as in any other experiment of this kind. More importantly, after the rule change, re-instructed distractors are mapped to one response due to the associations compiled in the first part, but to the alternative response due to the new instructions. As concerns constant distractors, instructions and associations correspond in both parts of the experiment.

The focus of the current experiment was on the part after the rule change during which re-instructed and constant stimuli were presented as distractors only. We compared the cross-talk triggered by constant distractor stimuli, for which the instructed S–R mapping and the S–R associations compiled during the first part matched, with the cross-talk triggered by re-instructed distractor stimuli, for which the (re-)instructed S–R mapping and the S–R associations compiled during the first part did not match.

If automatic S–R translation takes place irrespective of whether or not the corresponding S–R association is consistent with the current top-down S–R mapping, both, constant and re-instructed distractor stimuli should yield the same degree of cross-talk. If, however, automatic S–R translation is modulated by top-down control, cross-talk for re-instructed distractor stimuli should diminish or even

reverse. To take a look ahead to the results, we found constant distractors to yield a large and significant cross-talk effect. Re-instructed distractors, by contrast, did not yield any cross-talk at all in RTs and even reversed cross-talk in errors, demonstrating that automatic S–R retrieval is modulated by top-down control states (see also Colgan, 1970). In the discussion we will outline two possibilities of how precisely this modulation might take place.

Method

Participants, apparatus and stimuli

Eighteen participants (mean age: 23 years) took part in the experiment. Stimuli appeared on a 17" monitor and participants responded with their left and right index fingers. Task cues were the German words for color or shape (displayed in 18 point Arial font). The stimulus set comprised six shapes (circle, square, triangle, diamond, moon, and cross; approximately 3.5 × 3.5 cm) that appeared in one of six colors (red, green, blue, yellow, pink, and turquoise; see Fig. 1), resulting in 36 possible combinations. Shape-key and color-key mappings were randomized across participants; Fig. 1 shows one example of a possible mapping.

Procedure

Participants were first informed about the shape-key mapping. The three shapes requiring the left response were presented on the left side of the monitor while the three shapes requiring the right response were presented on the right side (see Fig. 1 for a possible mapping). The mapping was presented three times with a different top–bottom arrangement of shapes in order to minimize memory effects. The color task was instructed similarly.

The first block consisted of 72 trials, i.e., each color-shape combination appeared once in each task. Trials started with a task cue (200 ms). The target followed after 800 ms and was presented until a reaction was carried out but no longer than 2,000 ms. Wrong reactions triggered an error message (1,000 ms). The next trial started after 1,000 ms.

Importantly, after the first block, the mapping of two shapes was swapped. The new mapping was instructed twice (Fig. 1) and participants were told that the instructions would not change again. The following five blocks also consisted of 72 trials each. In the shape task, all six colors appeared as distractors. Crucially, however, only two shapes (of the four shapes with unchanged mapping) were used as targets, each occurring 18 times. In the color

task, all six colors appeared as targets and all six shapes appeared as distractors. The focus of this study was on the color task conditions that differed with respect to the *shape distractor*. This distractor was either (1) a potential target distractor, i.e., a shape with unchanged mapping that still appeared as target in the shape task, (2) a constant distractor, i.e., a shape with unchanged mapping that did not appear as target in the shape task, or (3) a re-instructed distractor, i.e., a shape with *changed* mapping that did not appear as target in the shape task. In the following, we only report the results for the color task since it allows us to compare the three distractor conditions.

Results

Block 1 data

A 2×3 ANOVA with the factors congruency (congruent vs. incongruent) and distractor type (potential target in Blocks 2–6 vs. constant distractor vs. re-instructed distractor) was run on RTs and error rates. For RT analysis, we excluded the first trial of each block and trials with errors. Participants responded faster in congruent trials (671 ms) than in incongruent trials (720 ms), $F(1,17) = 4.54$, $p = 0.048$, $\eta_p^2 = 0.21$. This congruency effect was not modulated by distractor type and also the main effect of distractor type did not approach significance (both F s < 1). This pattern of results was replicated for the error rates with congruent trials giving rise to fewer errors (9.5 %) than incongruent trials (20.0 %), $F(1,17) = 8.23$, $p = 0.011$, $\eta_p^2 = 0.33$. No other effect was significant (both F s < 1). In summary, a substantial response congruency effect emerged that was identical for all stimuli.

Block 2-6 data

The analysis of the remaining blocks concentrated on the two crucial distractor types in the present context: constant and re-instructed distractors. We computed a $2 \times 2 \times 2$ ANOVA with the factors congruency (congruent vs. incongruent; coded according to the instruction in Block 1), distractor type (constant vs. re-instructed), and task switch (switch vs. repeat). For RT analysis, we excluded the first trial of each block, trials with errors, trials following errors and trials with outliers ($|z_{RT}| > 2.5$).

RT analysis revealed a main effect of congruency, $F(1,17) = 7.18$, $p = 0.016$, $\eta_p^2 = 0.30$, and, crucially, an interaction of congruency and distractor type, $F(1,17) = 5.36$, $p = 0.033$, $\eta_p^2 = 0.24$ (see Fig. 2; Table 1). Constant distractors induced a significant congruency effect (37 ms), $t(17) = 3.75$, $p = 0.002$, $d = 0.88$, whereas re-instructed distractors did not (5 ms), $t(17) = 0.49$, $p = 0.629$, $d = 0.12$. Additionally, participants responded faster in task repetition trials (573 ms) than in switch trials (592 ms), $F(1,17) = 4.95$, $p = 0.040$, $\eta_p^2 = 0.23$. Descriptively, congruency effects were larger in switch trials (32 ms) than in repetition trials (10 ms), but the interaction of task switch and congruency was not significant, $F(1,17) = 2.69$, $p = 0.119$, $\eta_p^2 = 0.14$. No other effect approached significance in the RT analysis (all F s < 1).

The analysis of the error data (Fig. 2) also yielded an interaction of congruency and distractor type, $F(1,17) = 9.39$, $p = 0.007$, $\eta_p^2 = 0.36$. Constant distractors again induced a significant congruency effect (6.3 %), $t(17) = 2.77$, $p = 0.013$, $d = 0.65$, whereas re-instructed distractors induced a reversed congruency effect (−2.9 %), $t(17) = -2.45$, $p = 0.025$, $d = 0.58$. In contrast to RT analysis, the main effect of congruency, $F(1,17) = 2.83$,

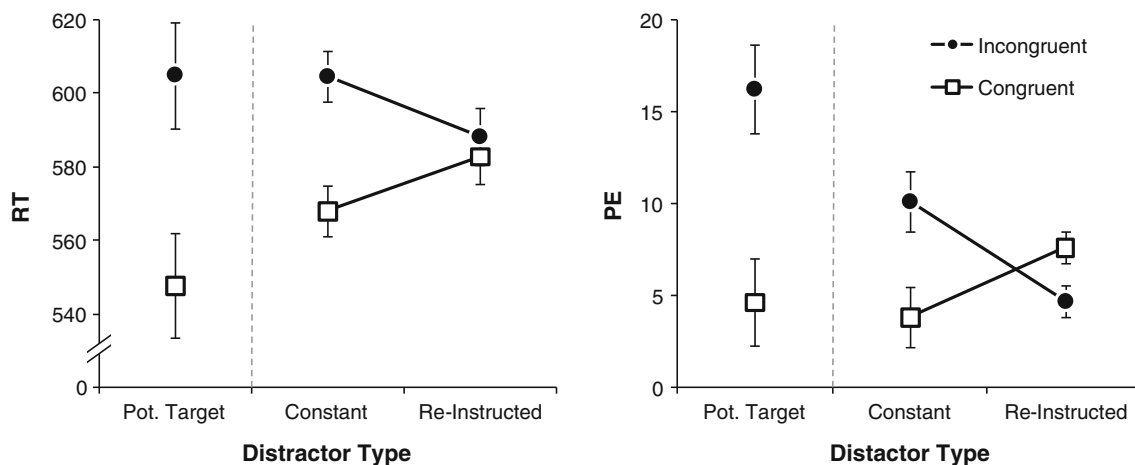


Fig. 2 Mean RTs (*left panel*) and percent errors (PEs; *right panel*) for congruent and incongruent color-shape combinations in the color task after the re-instruction. Congruency is coded according to the

initial instruction in Block 1 and error bars represent within-subjects standard errors that were computed separately for each distractor type

Table 1 Mean RTs and percentage errors (PEs) rates as a function of the three experimental factors (congruency, distractor type, and task switch) in the blocks following the re-instruction

Measure	Congruency	Task repetition			Task switch		
		Distractor type			Distractor type		
		Pot. target	Constant	Re-instructed	Pot. target	Constant	Re-instructed
RT	Incongruent	599	584	574	611	626	602
	Congruent	543	562	576	552	573	590
PE	Incongruent	14.1	7.8	4.8	18.3	12.4	4.5
	Congruent	3.2	3.3	8.0	6.1	4.3	7.2

$p = 0.111$, $\eta_p^2 = 0.14$, and the main effect of task switch, $F(1,17) = 2.61$, $p = 0.125$, $\eta_p^2 = 0.13$, were not significant, just as all remaining effects (all $ps > 0.157$).

Additionally, we performed an exploratory analysis targeting the time course of the effects of the re-instruction. To this end, we considered the impact of time course for the re-instructed distractors. In detail, we split the data of blocks 2–6 in two equally sized halves according to trial number, and ran a $2 \times 2 \times 2$ ANOVA with the factors congruency, task switch, and experimental half for re-instructed distractors. The main effect of experimental half was significant for the RT data, $F(1,17) = 17.93$, $p < 0.001$, $\eta_p^2 = 0.51$, indicating faster responses in the second half (563 ms) than in the first half (608 ms). More importantly, however, there was no main effect of congruency, no interaction of congruency with experimental half and no three-way interaction (all $ps > 0.316$). The analysis of the error data replicated the reversed congruency effect for re-instructed distractors, $F(1,17) = 6.71$, $p = 0.019$, $\eta_p^2 = 0.28$, which did not interact with experimental half ($F < 1$). Furthermore, the main effect of experimental half and the three-way interaction were not significant either ($ps > 0.110$), indicating that the reversed congruency effect was present throughout the experiment.

Discussion

The main results can be summarized as follows: In Block 1, all three distractor types yielded the same amount of cross-talk, indicating that practicing the arbitrary S–R mapping resulted in an efficiently working automatic S–R translation. In Blocks 2–6, although they ceased to appear as targets, constant distractors continued to yield cross-talk. Importantly, re-instructed distractors, which, just as constant distractors, ceased to appear as targets, but which were mapped to new responses, did not yield any cross-talk on RTs and even reversed cross-talk on error rates.

Our findings show that automatic translation of the irrelevant S–R mapping in a task-switching setting is influenced by the top-down control state for this mapping.

This influence might be driven by two different mechanisms. The first one is based on the fact that arbitrary S–R mappings, even if merely instructed, seem to be able to influence behavior, for example, when presented as a distractor (cf. Brass, Wenke, Spengler, & Waszak, 2009; Cohen-Kadosh & Meiran 2007; Kiesel et al., 2007; Liefoghe, Wenke, & De Houwer, 2012; Waszak, Wenke, & Brass, 2008; Wenke & Frensch, 2005; Wenke, Gaschler, & Nattkemper, 2007; cf., Ruge & Wolfensteller, 2010). It is thus possible that, for re-instructed distractors, the mapping learned in Block 1 and the new mapping instructed after Block 1 competed with each other. Accordingly, both effects cancelled each other out for RTs and the new mapping even dominated the learned one in the error data. Future research should manipulate the strength of the learned S–R mapping to investigate whether instructed S–R mappings competing with stronger or weaker learned S–R associations (than in the current study) result in a weaker cancellation or a stronger reversal of the cross-talk (slower RTs for stimuli incongruent with the re-instructed mapping), respectively. Note that we observed this latter pattern of results in the error rates of the present study corroborating this mechanism as an explanation for the current data. It might also be taken to indicate that, in the present study, the re-instructed mapping was even slightly stronger than the learned S–R mapping.

Please note that within this framework we do not claim the translation of an instructed (or re-instructed) S–R mapping to be a resource-consuming, controlled process. Rather a (re-)instructed S–R mapping is an operationalization of top-down control in the sense of a “prepared reflex” (e.g., Hommel, 2000). The term “prepared reflex” has been coined by Woodworth, (1938) who concluded from introspective studies on speeded reactions that once an S–R mapping is established, action execution is “reflex-like” upon presentation of the stimulus. The only controlled process or voluntary act is the preparation of the mapping. However, a (re-)instructed S–R mapping differs from a mapping that has been learned by application, in that its translation is not bolstered by S–R memory traces compiled during each execution of the mapping

(cf., Logan, 1988). The two types of mapping are thus represented in two different formats. One is becoming progressively stronger with increasing number of applications, the other one comes only into being by means of an executive top-down process establishing a potential stimulus–response pairing. Please note that, in the context of this mechanism, we use the term top-down in this particular sense.

However, there is a second mechanism which might at least have contributed to the present results. The pattern of results is likewise in line with the assumption that automatic S–R translation does not always take place, but that the retrieval of S–R associations is constrained such that S–R associations are only retrieved if they concur with the currently valid S–R mapping. In other words, re-mapping the S–R rule might prevent the retrieval of S–R associations that were compiled under the previous mapping and consequently there was no cross-talk based on learned S–R associations. Hence, the results may indicate that S–R memory can be accessed context-dependently, and so aid in bringing not just any knowledge to mind, but knowledge that is relevant to current goals.

Within this line of reasoning, the present findings relate to ideas recently put forward in the domain of item-specific priming. For instance, Waszak, Hommel, and Allport (2003, 2004, 2005; see also Kiesel et al., 2007; Koch & Allport, 2006) showed that it is harder to read the word of a picture-word Stroop stimulus, when the participant previously encountered the same stimulus in the picture-naming task. They suggested that the response that had been associated with the stimulus during previous S–R events is reactivated upon stimulus presentation, slowing down the response. However, experiments by Waszak and Hommel (2007) suggest that the “wrong” S–R event is reactivated only, or to a larger degree, if the “wrong” task remains active across the switch of task and competes with the activations needed for the new task (see also Waszak, 2010). In other words, the “automatic” retrieval of the competing response is preconditioned on the presence of some top-down bias in favour of that stimulus–response association.

Our experiment might be taken to extend this notion. It suggests that intentional control is not only concerned with implementing intended actions in cases of conflicting response tendencies, as proposed many times (e.g., Koechlin, Ody, & Kouneiher, 2003; Braver, Barch, Gray, Molfese, & Snyder, 2001; Braver, Reynolds, & Donaldson, 2003; Kerns et al., 2004; Miller & Cohen, 2001), but that intentions also decide whether automatic S–R associations become manifest in behavior. This type of intentional control warrants what memory access based on mere associative strength cannot assure: that human behavior is fast and flexible at the same time.

As mentioned above, the reversal of the effect in the error rates appears to support the first mechanisms outlined above. However, the two mechanisms are not mutually exclusive. We have two reasons to believe that it is not only the cancellation mechanism that is at work. First, in an experiment using a design very similar to the present study, Waszak et al. (2008) did find RT differences of instructed mappings compared to a neutral condition. However, they did not find differences between instructed distractors that are response congruent versus incongruent with the target. Second, the effect of the constant distractors is quite substantial (37 ms). It seems to us to be unlikely that instructed mappings are able to cancel this effect entirely. In this context, one more observation seems to be noteworthy: the dissociation of RT and error rates in the present study bears some resemblance to the dissociation between RT and error rate task rule congruency effects (TRCE) observed by Meiran and Kessler (2008). These authors put forward the notion that TRCEs for RTs are contingent on the practice-based formation of highly accessible representations in long-term memory. They argue that TRCEs in error data, by contrast, might result from translating a task rule that is independent of practice (see also Meiran & Daichman, 2005). It might be conceivable that RT and error effects in the current study are based to different extents on the two mechanisms in question, with, for example, RT effects being rather based on blocking of accumulated memory traces and error effects being based on the translation of the currently valid mapping.

Currently, we cannot distinguish between the two mechanisms. Interestingly, though, both explanations demonstrate that automatic S–R translation occurs not strictly automatic but that it is modulated by mere instructions, that is, by top-down control states.

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