Conflict and Curiosity: Evidence Against the Automatic Processing of Task-Irrelevant Distractors

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Observations that people process nominally task-irrelevant information are commonly taken to demonstrate automaticity, an inability to avoid involuntary processing. However, it has been argued that this interpretation rests on an overly narrow view of people's active goals, which are not restricted to the goal reflecting the current task but also comprise other temporary and chronic goals. This suggests that nominally task-irrelevant stimuli are processed because they satisfy other concurrently active goals, such as curiosity: the chronic drive to reduce uncertainty. We tested this possibility in two experiments by comparing standard flanker and Simon tasks with otherwise identical task versions in which the irrelevant stimuli were perfectly predictable. The compatibility effects produced by the irrelevant stimuli were reduced by 50% or more. A third experiment did or did not arouse curiosity in a flanker task by blurring the flankers in some (not analyzed) trials. As predicted, the flanker compatibility effect was increased in the group with occasionally blurred flankers. Taken altogether, these findings suggest that nominally task-irrelevant stimuli are processed not because their processing cannot be prevented but because processing them satisfies curiosity and thus meets a chronic goal of perceivers/actors.

KEYWORDS: attention, action control, interference, curiosity

One of the most widely shared assumptions of psychology is that human behavior emerges from a struggle between intentional (goal-directed, voluntary) and automatic (involuntary, habitual) processes—a theme to which few have contributed as much as the late Robert W. Proctor, whose important and insightful work is commemorated in this special issue. The idea of a struggle between will and habit has motivated numerous dual-route models (e.g., Chaiken & Trope, 1999; Dolan & Dayan, 2013; Hofmann et al., 2009; Kahneman, 2011; Kornblum et al., 1990; Verbruggen et al., 2014). The figure of thought underlying these models has been with us since the beginning of academic psychology (Ach, 1910) and was already manifested in Plato's tripartite concept of the human mind (Plato, 1943). The traditional method to de-

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termine the contribution of automatic processes is to instruct participants to carry out a particular task under conditions that provide both task-relevant and task-irrelevant, often distracting and misleading information and then to assess to what degree the processed information is directly dictated by the task instruction. If evidence for the processing of information that is not strictly task-relevant is found, such as a visual symbol flanking the actual target (Eriksen & Eriksen, 1974) or the location of a stimulus that signals responses by its color (Simon & Berbaum, 1990), it is taken to indicate that the respective information has been processed automatically (i.e., unintentionally), which in turn is taken to imply the partial, temporary, or complete breakdown of cognitive or attentional control.

Dual-route models are widely accepted and dominate the theoretical thinking in many fields investigating interactions between perception and action control (for overviews, see Kornblum et al., 1990; Lu & Proctor, 1995; Shin et al., 2010; Proctor & Vu, 2006). However, Hommel and colleagues have argued that this dual-route view of control may be incorrect and misleading for several reasons (Hommel, 2000, 2019, 2022; Hommel & Wiers, 2017). For our present purposes, one important reason is the unjustified and unrealistic idea that when carrying out psychological experiments, all that human participants have in mind is the goal set by the experimenter. Even though humans can be very efficient in performing entirely arbitrary and meaningless tasks, such as pressing a left or right button in response to the sudden appearance of one or another symbol on a screen, this achievement is unlikely to switch off all of their other current or chronic goals, such as going to the exam after the experiment, having a romantic meeting that evening, seeking sensation, and leading a happy life. Thus, it is possible that processing task-irrelevant information may not be automatic (goal unrelated) but rather reflect the importance of this information for other temporary or chronic goals of the participant. Here, we focus on a chronic goal that humans are particularly likely to bring to any novel situation, task, and stimulus: curiosity.

Curiosity is assumed to reflect "a drive to know" (Berlyne, 1954) or, in more technical terms, to reduce uncertainty (Szumowska & Kruglanski, 2020). It is assumed to be an important driver of cognitive development (Oudeyer & Smith, 2016) and of human cognitive functioning in general (Friston, 2009). The assumption is that novel stimuli create unpleasant internal conflict (Berlyne, 1957) that humans try to reduce by accumulating more information about the stimuli and creating internal representations or models of them to anticipate and predict them better in the future (Berlyne, 1954; Friston, 2009). Accordingly, satisfying curiosity is rewarding (FitzGibbon et al., 2020), so that being curious is rational and in the perceiver/actor's own interest. The degree of curiosity is thus assumed to be a direct function of the uncertainty of the stimulus (Berlyne, 1957). Given that the point of most experimental tasks is to use some degree of uncertainty about task-relevant information, such as the stimulus driving a binary response decision, experiments are likely to trigger a substantial degree of curiosity (Frings et al., 2019). However, it is often not just the task-relevant information that varies in unpredictable ways but also the distractor. We assume that this lack of predictability of the distractor is what makes human participants process the distractor information. If so, one would expect that the effects assumed to provide evidence of automatic distractor processing should be drastically reduced if distractors become predictable.

Effects of predictability as such are not uncommon in research on the impact of distractors on decision making. Numerous findings have shown that manipulating the predictability of stimuli, responses, or stimulus locations, as in Simon tasks, can have a strong impact on the degree to which stimulus- or response-congruent and incongruent distractors speed up or slow down the response to the actually relevant stimulus (e.g., Hommel, 1995a, 1996; Koch, 2007; Wühr & Koch, 2011). This holds for trial-to-trial manipulations, such as priming the stimulus identity, its location, or the response briefly before the stimulus appears, but also for blocked manipulations, where for instance the probability of congruent and incongruent trials was manipulated (e.g., Hommel, 1994; Logan, 1980). However, all these manipulations can be assumed to provide valid information for the agent to adjust or optimize her processing strategies, attentional allocation, and response biases. For instance, reducing uncertainty about the relevant stimulus or response allows the agent to already begin with response selection and to establish a bias toward the

more likely response. Although the concept of curiosity may account for the fact that people are sensitive to informational fluctuation and change in general, it would seem far-fetched to categorize all these adjustments as expressions of curiosity proper. In other words, although manipulating curiosity is likely to involve some sort of variation in predictability, not every predictability manipulation can be assumed to tap into curiosity.

We reasoned that a convincing demonstration that curiosity might play a role would rely on the manipulation of predictability of information that is entirely irrelevant, in the sense that it does not help the agent prepare the processing of any relevant information or initiate response selection already. Accordingly, we restricted our manipulations to the distractors and made sure that these manipulations did not provide information about the relationship between the distractors and the relevant stimuli or responses. Hence, agents had no reason and did not benefit from considering the predictability of the flankers in our study. If they nevertheless do consider this predictability, so we reasoned, this must have been because of some general interest in variability as such: curiosity, that is. We tested this hypothesis by using two well-established tasks, the flanker task (Experiment 1) and the Simon task (Experiment 2). One group of participants performed the tasks with the typical random variation of the irrelevant distractor (flankers and stimulus locations, respectively) and another group with fully predictable distractors. We expected that the flanker and the Simon effect (i.e., worse performance if the target and the distractor signal different responses than if they signal the same response) would be drastically reduced in the predictable-distractor condition.

Theoretically, it would be possible that the effects completely disappear, but previous observations render this possibility unlikely. Flanker effects have been found to be substantially reduced if the distance between flanker and target is increased (e.g., Eriksen & Eriksen, 1974; Hommel, 1995b). Furthermore, the impact of stimulus location on the selection of spatial responses is much less pronounced if the location is associated with the target stimulus rather than with a target-independent sound (Hommel, 1995a; Mewaldt et al., 1980). Both observations suggest that the impact of nominally irrelevant information depends on the degree to which it fits target-related selection criteria, such as the expected location of the target. Given that these criteria reflect the instructed task and thus the intentions of the participant, the parts of the flanker and Simon effects that reflect such an impact of task relevance cannot be considered automatic by definition. However, the available evidence shows that even distractors that do not fit target-related selection criteria can have an impact, which leaves the possibility that another part of the effects indicates truly automatic processing. It is this part that we were interested in and that we tried to eliminate in the first two experiments of the present study.

EXPERIMENT 1

METHOD

Participants

Ninety-six healthy participants (mean age, 32.05 years, range 19–58; 34 women), mostly of European nationality, were recruited via MTurk. They were redirected to the experiment, written with jsPsych 6.1.0 (de Leeuw, 2015). The sample sizes of all three experiments of this study were aimed to at least double our lab standard for robust Simon and flanker effects (i.e., 40 participants), to compensate for possibly greater variability produced by our online method, and all volunteers subscribing to the first wave were accepted.

Stimuli and Procedure

After providing informed consent, each participant took part in a testing session of approximately 15 min, consisting of two blocks. Participants performed a flanker task, in which a target stimulus accompanied by two flanker stimuli on either side of the target was presented on the monitor. The target and flanker letters were either "S" or "H." The instruction was to press the "S" key on the computer keyboard when the target was an "S" and the "H" key when the target was an "H." In 50% of the trials, the target stimulus was the same letter as the flanker stimuli (a compatible trial), and in the other 50% the target was different from the flanker stimuli (an incompatible trial). Each trial started with a blank period of 2,000 ms, followed by the presentation of a fixation point at screen center for 500 ms, another 1,000-ms blank, the presentation of target and flankers at screen center for 150 ms, followed by another blank period of 850 ms or until the response was made.

Design

Predictability varied between groups, and compatibility was manipulated within groups. Participants were equally but randomly divided into two groups. In the random group, the flanker stimuli varied randomly, which was true for both 80-trial blocks. In contrast, flankers were blocked in the blocked group. For 50% of participants in the blocked group, the flankers were always the letter "S" in the first block and the letter "H" in the second block, and the order of flanker letters was reversed for the other 50%. Both groups began with a practice block of 16 trials, and the two 80-trial blocks followed, resulting in a total of 160 experimental trials.

RESULTS

From the total of 96 participants, 82 reached the accuracy criterion of 75%. We then calculated percentages of error (PEs) for the compatible and incompatible condition and mean reaction times (RTs) for the correct responses in these two conditions. Group means were compared via analyses of variance (ANOVAs), with compatibility (compatible vs. incompatible) as the within-participant factor and group (random vs. blocked) as the between-participant factor. Aggregated data used for the analyses are available at https://osf.io/xstv7/?view_only=83415a5e5395479fa298074b971ea758.

In RTs, the main effect of compatibility was significant, $F(1, 80) = 404.73$, $p < .001$, $\eta^2 = .83$, as was the interaction with group, $F(1, 80) = 52.17$, $p < .001$, $\eta^2 = .39$. Figure 1 shows that responses were faster for compatible than for incompatible trials, which was true for both groups, $t(39) = 22.18$, $p < .001$ and $t(41) = 8.27$, $p < .001$, and this compatibility effect was significantly reduced (to about 50%) in the blocked group. PEs showed a comparable pattern, but only the main effect of compatibility was significant, $F(1, 80) = 45.36$, $p < .001$, $\eta^2 = .36$, and the interaction was not, $p = .09$.

EXPERIMENT 2

METHOD

Participants

Eighty-five healthy participants (mean age 25 years, range 18–45; 29 women), mostly of European nationality, were recruited via Prolific (https://www.prolific.co/). They were redirected to the experiment, written with jsPsych 6.1.0 (de Leeuw, 2015) and hosted on Cognition (https://www.cognition.run/).

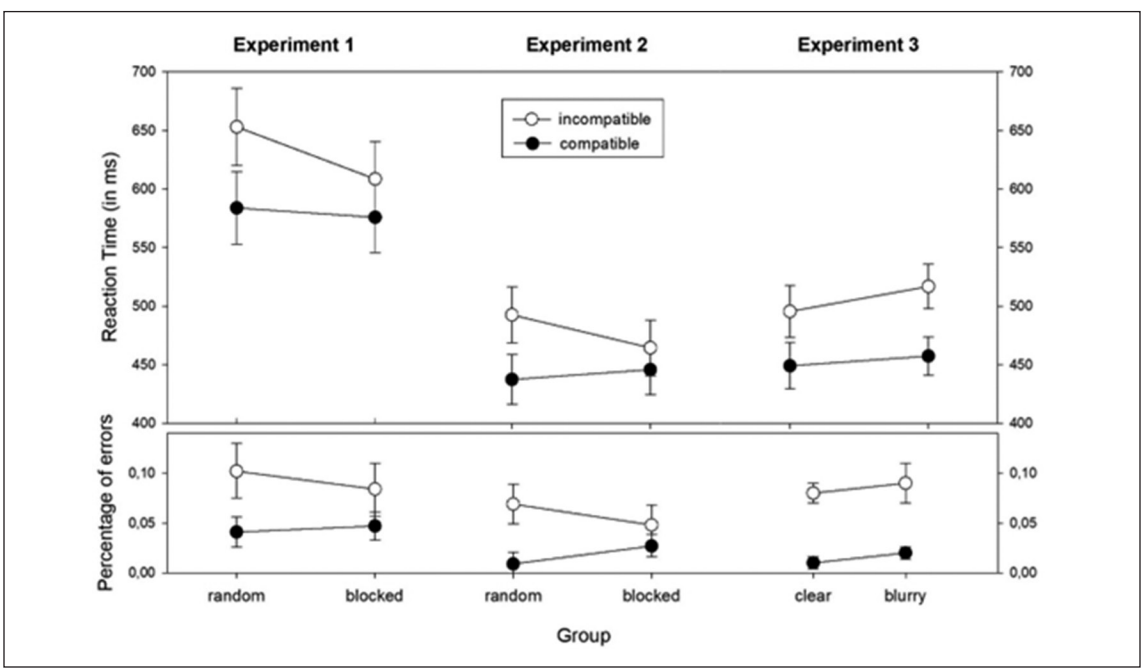

FIGURE 1. Mean reaction times and error percentages as a function of group and compatibility, Experiments 1–3. Error bars show 95% confidence intervals

Design

Predictability varied between groups, and compatibility was manipulated within groups. Participants were equally but randomly divided into two groups. In the random group, the location of the stimulus varied randomly in both 80-trial blocks. In contrast, stimulus location was blocked in the blocked group. For 50% of the participants in the blocked group, the stimulus always appeared on the left side in the first block and on the right side in the second block, and the order of the sides was reversed for the other 50%. Because the stimulus location remained constant in the blocked group, participants might keep their attention on the blocked side, which according to attention-shifting models of the Simon effect would prevent a Simon effect from occurring (Stoffer, 1991). To avoid this possibility, we presented the stimuli on the left or right side of a black frame (Figure 2), which varied randomly on screen (see Hommel, 1993). Both groups began with a practice block of 16 trials, and the two 80-trial blocks followed, resulting in a total of 160 experimental trials.

Stimuli and Procedure

After providing informed consent, each participant took part in a testing session of approximately 15 min, consisting of two blocks. Participants performed a Simon task in which a blue or orange circle appeared on the left or right side of a black frame presented on the computer monitor (see Figure 2). The instruction was to press the right arrow key on the computer keyboard when the orange circle appeared and the left arrow key when the blue circle appeared. In 50% of the trials, the blue circle appeared either on the left side (a compatible trial) or on the right side of the frame (an incompatible trial), and in another 50% of the trials, the orange circle appeared either on the left side (a *n* incompatible trial) or on the right side (a compatible trial). Each trial started with a blank period of 1,000 ms, followed by the presentation of the reference frame for 500 ms in a randomly chosen position (but always inside the screen area), followed by a fixation cross centered on this frame for another 500 ms and the stimulus until the response was made.

RESULTS

From a total of 85 participants, 79 reached the accuracy criterion of 75%. We again calculated PEs for the compatible and incompatible condition and mean RTs for the correct responses in these two conditions. Group means were compared via ANOVAs, with compatibility (compatible vs. incompatible) as the within-participant factor and group (random vs. blocked) as the between-participant factor.

In RTs, the main effect of compatibility was significant, $F(1, 77) = 85.49$, $p < .001$, $\eta^2 = .53$, showing that our setup generated a healthy Simon effect, as was the interaction with group, $F(1, 77) = 21.91$, $p < .001$, $\eta^2 = .22$. Figure 1 shows that responses were faster for compatible than for incompatible trials, which was true for both groups, $t(39) = 8.38$, $p < .001$ and $t(38) = 4.18$, $p < .001$, and this compatibility effect was significantly reduced (to about 50%) in the blocked group. PEs showed a comparable pattern with a significant main effect of compatibility, $F(1, 77) = 57.91$, $p < .001$, $\eta^2 = .43$, and a significant interaction, $F(1, 77) = 17.54$, $p < .001$, $\eta^2 = .19$.

EXPERIMENT 3

The outcomes of Experiments 1 and 2 are consistent with our expectation that the processing of irrelevant information in conflict tasks is not as automatic as dual-route theorizing suggests. However, to obtain our findings, we have changed the structure of the otherwise classic tasks, which might have invited adjustments or strategies that are commonly not used in the more classic task designs. In Experiment 3, we thus sought for converging evidence by using a differ-

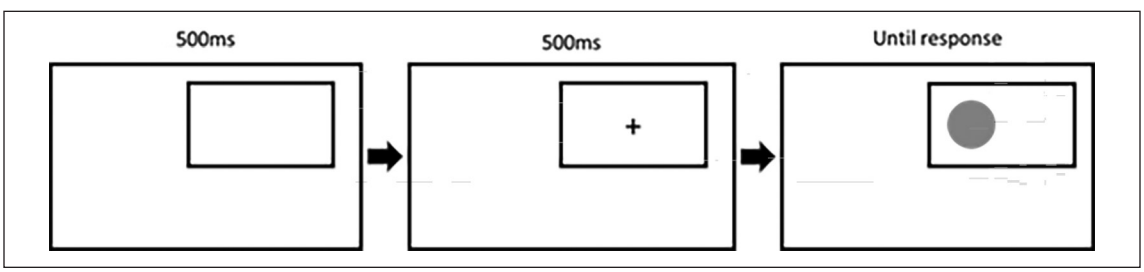

FIGURE 2. Timing and sequence of events, Experiment 2

ent logic. Rather than making flankers less interesting by making them more predictable, as in Experiment 1, we wanted to increase curiosity of participants for flankers. To do so, we borrowed a technique from Jepma et al. (2012), who successfully increased curiosity to stimuli by blurring them. This should increase the perceiver's uncertainty about their identity and thus make processing them intrinsically rewarding. We therefore used the same flanker task as in Experiment 1 but blurred the flankers in 30% of the trials. One group of participants was presented with this version of the task, and another was presented with the standard version including no blurred flankers. We predicted that, in analyses of the unblurred trials, the flanker effect should be more pronounced in the blurry-flankers group than in the clear group.

METHODS

Participants

Eighty healthy participants (mean age 31 years, range 19–50; 37 women), mostly of European nationality, were recruited via Prolific. They were redirected to the experiment, written with jsPsych 7.2 (de Leeuw, 2015) and hosted on the Leiden university server running JATOS (https://www.jatos.org).

Design

Blurring varied between groups, and compatibility was manipulated within groups.

Stimuli and Procedure

After providing informed consent, each participant took part in a testing session of approximately 10 min, consisting of two blocks. Participants performed a flanker task, similar to that of Experiment 1, in which a target stimulus accompanied by two flanker stimuli on either side was presented. The target and flanker letters were either "S" or "H." The instruction was to press the "S" key on the keyboard when the target was "S" and the "H" key when the target was "H." In 50% of the trials, the target stimulus was the same letter as the flanker stimuli (a compatible trial), and in the other 50% the target stimulus was different from the flanker stimuli (an incompatible trial). Unlike in Experiment 1, the distractors were always presented randomly, and thus there was no blocking. Instead, 50% of the participants were randomly assigned to a blurry group, in which 30% of the trials randomly had a Gaussian blur (radius, 11 px) applied to the distractor letters. This made the distractors unrecognizable and has been shown to arouse perceptual curiosity (Jepma et al., 2012). The clear group performed a typical flanker task, in which all distractors were recognizable. Both groups began with a practice block of 16 trials, followed by two 60-trial blocks, resulting in a total of 120 experimental trials. After finishing the flanker task, all participants completed a 10-item version of the perceptual curiosity scale (Collins et al., 2004), as well a 10-item version of the Big Five personality inventory (Rammstedt & John, 2007). These questionnaires were added to assess possible contributions of individual biases. Each trial began with a 600-ms blank period, followed by a 400-ms fixation cross at screen center, a 600-ms blank, and the stimulus with flankers until the response was made.

RESULTS

To render the datasets comparable across groups, we deleted the trials with blurry flankers in the blurry group and randomly deleted the same number of trials in the clear group. This left a total of 80 trials for analysis in both groups. We again calculated PEs for the compatible and incompatible conditions and mean RTs for the correct responses in these two conditions. Group means were compared via ANOVAs, with compatibility (compatible vs. incompatible) as within-participant factor and group (clear vs. blurry) as between-participant factor.

In RTs, the main effect of compatibility was significant, $F(1, 78) = 413.60$, $p < .001$, $\eta^2 = .84$, indicating a sizeable flanker effect, as was the interaction with group, $F(1, 78) = 6.28$, $p = .014$, $\eta^2 = .07$. Figure 1 shows that responses were faster for compatible than for incompatible trials, which was true for both the clear group, $t(39) = 13.03$, $p < .001$, and the blurry group, $t(39) = 15.66$, $p < .001$, but the effect was larger in the blurry group. PEs also showed a significant main effect of compatibility, $F(1, 78) = 88.78$, $p < .001$, $\eta^2 = .53$, but no significant interaction, $F(1, 78) < 1$. None of these effects correlated with any of the personality measures, ps > .05.

Conclusions

The key question of this study is why people process task-irrelevant information, such as flankers in a flanker task or stimulus location in a Simon task. The traditional answer is that participants cannot avoid doing this, because processing this information is "automatic" or "habitual" (e.g., Chaiken & Trope,

1999; Dolan & Dayan, 2013; Hofmann et al., 2009; Kahneman, 2011; Kornblum et al., 1990; Verbruggen et al., 2014). However, one can argue that these accounts provide little more than an abstract redescription (rather than a mechanistic explanation) of the empirical findings (Hommel, 2019, 2020; Hommel & Wiers, 2017) but also that the general assumption of any processing unrelated to the current interests of the agent may be unfounded (Hommel, 2000, 2022; Hommel & Wiers, 2017). As we have explained, all stimulus information suspected to be processed automatically has some direct or indirect relevance to the task, which probably accounts for some of the experimental effects attributed to automaticity; the present study targeted the remaining portion. We argued that attending to task-irrelevant stimuli in tasks considered to involve automatic processing reduces uncertainty. According to Berlyne (1954), this should reduce the cognitive conflict triggered by uncertainty, and according to Friston (2009) this should satisfy our chronic goal to optimize our predictions. Hence, these stimuli might be irrelevant to the current task, but they are relevant for people's chronic curiosity goal, and processing them is intrinsically rewarding (FitzGibbon et al., 2020; Hommel, 2022). If their uncertainty-reducing character makes them relevant for this goal, then making them predictable should reduce the "automaticity" of processing them.

We tested this hypothesis by comparing standard versions of the flanker task and the Simon task, in which the irrelevant stimuli or stimulus features were impossible to predict, with versions of the same tasks, in which these stimuli or stimulus features were completely predictable. Making them predictable reduced their impact on response selection by 50% or more in both RTs and error rates in Experiments 1 and 2. In Experiment 3, increasing uncertainty about the flankers by blurring them in some trials had the expected opposite effect: The impact of flankers was increased. Given that our manipulation had nothing to do with the nominal task relevance of the predictable stimuli, we take that as a contradiction of the automaticity hypothesis. Instead, these findings provide substantial support for our guiding hypothesis that processing the seemingly irrelevant stimuli is due to the match with internal (e.g., chronic) goals other than the current task goal. Hence, what seems like an unfortunate, unintentional limitation of attention actually serves the perceiver/actor's own interests.

One may consider the present findings similar to the Garner interference effect (e.g., Algom & Fitousi, 2016; Garner, 1976; Melara & Algom, 2003). This effect shows that, in the absence of any conceptual overlap between task-relevant and task-irrelevant dimensions, performance is worse with variation on the task-irrelevant dimension (e.g., if participants are to identify the shape of a stimulus when its color varies randomly). On one hand, the situation is rather different from the ones tested in the present study: Conceptual overlap between relevant and irrelevant information did exist in all three of our experiments, and in two of them (Experiments 1 and 3), the variability that we used to attract curiosity did not vary on another dimension than the task-relevant information. On the other hand, one might consider that the explanation for our effects could be related to those applied to the Garner interference effect. For one, it has been argued that introducing irrelevant variation impedes performance by drawing attention away from the task-relevant stimulus dimension (e.g., Sabri et al., 2001). Even though it is not quite clear whether the concept of attention goes anywhere beyond a mere redescription of the actual findings (see Hommel et al., 2019), one could indeed argue that this is exactly what curiosity does: It draws attention to the curiosity-inducing novelty. However, the fact that we found not just a general impairment in the more variable conditions but an impact on congruency effects shows that attracting curiosity goes beyond mere distraction. Rather, curiosity promotes the processing of the content of the attracting stimulus, with all its response-related implications (Sokolov, 1963).

The fact that the flanker and Simon effects were reduced but not eliminated in Experiments 1 and 2 suggests that the uncertainty reduction potency of task-irrelevant stimuli is not the only factor that determines the effect sizes. As explained already, implicit task relevance is likely to play a role: The flankers in a flanker task partially fit the definition of the target (right symbol, wrong location), and the location of the stimuli in a Simon task is important not only for identifying the actual target (because targets are partially defined by their possible locations), but also for discriminating the two possible responses. It is thus possible that flanker and Simon effects consist of a mixture of effects reflecting this implicit task relevance and effects reflecting their ability to satisfy curiosity, which would not leave any room for the assumption

that truly irrelevant information is processed. However, given that interference tasks such as the flanker or Simon task need this implicit task relevance to generate any effect (flankers that are not targets and locations that are task irrelevant or do not match response locations have not been found to have any impact), the exact contribution of these implicit relevance effects is impossible to measure. It is thus theoretically possible that flanker and Simon effects actually consist of three components: the effect of implicit task relevance, the curiosity satisfaction effect, and some residual. The size of this residual remains unknown for the time being, but it is unlikely to be large.

On one hand, one may argue that dual-route models cannot be rejected before having proven the residual to be zero. On the other hand, it is important to emphasize that we tested only one chronic goal and only one aspect of predictability; even if the identity of the flanker is perfectly predictable, its combination with the unpredictable target is not, which leaves additional room for curiosity. In any case, there are reasons to argue that the burden of proof now lies with dual-route models, whose utility critically hinges on the successful demonstration that the residual differs from zero (the only component they can account for). Moreover, the fact that our manipulations were successful in moderating the effect size in flanker and Simon tasks clearly shows that factors other than those considered by the traditional dual-route model are at work. Models considering the possibility of multiple concurrent goals, such as GOALIATH (Hommel, 2022), can easily deal with and systematically predict moderating effects of concurrent goals and task relevance and thus provide an interesting and presumably more realistic alternative to dual-route models. Following GOALIATH, we emphasize that curiosity, which we aimed to manipulate in the present study, is just one of probably many concurrent goals that people bring to the laboratory. Sensitivity to affective stimuli, to humans or other moving agents, as compared with objects, current concerns in the sense of Klinger and Cox (2011), or achievement, affiliation, and power needs (McClelland, 1988), are just some of the factors that are likely to affect which information we process and what we do with it. Finally, we acknowledge that our study dealt with just one of perhaps several types of curiosity. For instance, the Epistemic Curiosity Scale (Litman & Spielberger, 2003) distinguishes between curiosity that involves the desire to obtain new knowledge (I-type) and curiosity that reduces uncertainty (D-type). Although our manipulations arguably targeted the latter, it remains to be seen whether similar effects could be obtained by manipulating the former.

NOTES

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B. Hommel developed the study concept. All authors contributed to the study design. Testing and data collection were programmed by N. Schön and N. Stevenson. B. Hommel performed the data analysis and drafted the manuscript, and N. Schön and N. Stevenson provided critical revisions. All authors approved the final version of the manuscript for submission.

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