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Exogenous attention and its relationship with working memory contents: beyond spatial selection

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ABSTRACT

To successfully perform everyday activities, cognitive functions such as working memory (WM) and selective attention are necessary. Specifically, when environmental demands are dynamic, exogenous attention is crucial. However, its ability to select and prioritize not only perceptual spatial locations, but also novel stimulus-response (S-R) bindings held in WM remains largely unexplored. By implementing a retro-cueing paradigm on a task that capitalized on WM, the present experiment's aim was two-fold: i) to evaluate whether exogenous cueing effects would not only impact spatial processing but also WM content, and ii) to explore how meta-control states induced by the manipulation of an intervening event (IE) would modulate these effects. We observed (N = 50) that exogenous attention led to selection of space, as it is usually observed in spatial exogenous attention paradigms, but also the content associated with that location. Moreover, space selection was modulated by the IE manipulation, which was thought to induce two meta-control states (persistent vs. flexible). As such, the presence of the IE also modulated participants' performance regarding novel vs. repeated stimulus-response mappings, again hinting at an important role of content in this task. This pattern of findings fits well with the concept of event file; a mental representation of all relevant components assembled at the beginning of a trial (i.e., cue, target, lateralization, meta-control state, etc.), which are retrieved together once one or more of its elements are encountered. Although preliminary, this evidence of exogenous attentional selection of WM through event file activation paves the way for a promising research line.

1. Introduction

Throughout the day, humans perform a wide variety of activities that, despite their routine-like nature, are far from simple. For example, following a recipe might seem straightforward, but it actually requires a complex sequence of cognitive functions to execute successfully. First, we must voluntarily guide our attention to look for the ingredients in the refrigerator. This is referred to as endogenous/voluntary attention and allows us to select and prioritize relevant information based on goals or preexisting information by biasing sensory recruitment in a top-down/goal-directed manner (Corbetta, Patel, & Shulman, 2008; Jonides, 1981). Additionally, some external stimuli, like the strident sound of the oven timer, will automatically attract our attention. This form of bottom-up attentional selection is known as exogenous/involuntary attention and is essential in our adaptation to environmental demands (Jonides, 1981; Posner & Cohen, 1984). Lastly, to successfully cook the dish, we must maintain in our working memory (WM) the specific actions to be executed and their specific order. This temporal storage of information guides flexible and adaptive behavior by manipulating data in an online fashion (Baddeley, 1992; Souza & Oberauer, 2016).

Hence, given the relevance of these cognitive functions for the execution of most daily activities, they have been the spotlight of several seminal and review papers (see e.g., Awh, Vogel, & Oh, 2006; Baddeley & Hitch, 1974; Oberauer, 2019; Posner, 1980; van Ede & Nobre, 2023; Wolfe, 1994). Particularly, relative to research dedicated to externally directed attention for perception (i.e., looking for the ingredients in the refrigerator or quickly shifting our focus towards the oven in response to the abrupt sound), research on internally directed attention to WM contents is exponentially growing in the recent years (see e.g., Huynh Cong & Kerzel, 2021; Kiyonaga & Egner, 2013; Myers, Stokes, & Nobre,

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2017; van Ede, Board, & Nobre, 2020; Zokaei, Board, Manohar, & Nobre, 2019). Several authors (Gazzaley & Nobre, 2012; Griffin & Nobre, 2003; Gunseli et al., 2019; Gunseli, van Moorselaar, Meeter, & Olivers, 2015; Landman, Spekreijse, & Lamme, 2003; Rerko, Souza, & Oberauer, 2014; Souza, Rerko, & Oberauer, 2014, 2015) have shown that it is possible to guide attention internally and retrospectively towards WM contents in a top-down fashion (i.e., selecting and prioritizing certain steps of the instructions held in WM based on previous goals). Specifically, paradigms that implement retro-cueing (i.e., cues are presented between the offset of memory array and the onset of a probe) have shown effective internal attentional selection of WM contents (Rerko et al., 2014; Shepherdson, Oberauer, & Souza, 2018; Souza & Oberauer, 2016). However, most have focused on endogenous/voluntary attention (Gunseli et al., 2015; Gunseli et al., 2019; Rerko et al., 2014; Shepherdson et al., 2018; Souza & Oberauer, 2016), and, although some authors even suggest that the retro-cueing effect can be observed with bottom-up (although predictive) retro-cues (Berryhill, Richmond, Shay, & Olson, 2012), research implementing pure exogenous/involuntary retro-cues (i.e., automatic spatially driven and non-predictive) remains quite scarce (see Fuentes-Guerra et al., 2025; Han & Ku, 2022; Han, Zhou, Tian, & Ku, 2023).

Parallelly, research on exogenous/involuntary attention has mostly focused on human perception through the spatial domain, by mostly implementing versions of the classical Spatial Orienting Paradigm (Chica, Botta, Lupiáñez, & Bartolomeo, 2012; Chica, Martín-Arévalo, Botta, & Lupiánez, 2014; Posner, 1980). Essentially, two main effects tend to be observed depending on the cue-target onset asynchronies (CTOAs): facilitation (i.e., faster reaction times (RTs) for target at cued as compared to uncued locations) at short CTOAs, and Inhibition of Return (IOR; an attentional cost at previously-cued locations) at longer CTOAs (Lupiáñez, Martín-Arévalo, & Chica, 2013; Posner & Cohen, 1984; Posner, Rafal, Choate, & Vaughan, 1985). However, not only CTOAs must be considered to observe and modulate these effects, but other key factors such as task settings, type of task (e.g., detection vs. discrimination tasks; observing more facilitation in the latter), or the presence of an intervening event (IE; i.e., a flash at fixation between cue and target, which reduces that facilitation and favors the observation of IOR, especially in discrimination tasks; see Chica et al., 2014 for a review). Critically, until now, works on this paradigm (Lupiáñez et al., 2013; Martín-Arévalo, Botta, De Haro, & Lupiáñez, 2021; Martín-Arévalo, Chica, & Lupiáñez, 2013) have paid little attention to the content of the stimuli presented in the task, as a key factor in the interaction between attention and WM. Some authors, however, already hint at a relation between exogenous/involuntary attention and WM contents (Botta, Santangelo, Raffone, Lupiáñez, & Belardinelli, 2010; Botta & Lupiáñez, 2014; Hu & Samuel, 2011; Hu, Samuel, & Chan, 2011; Spadaro, He, & Milliken, 2012; van Ede, Board, & Nobre, 2020; Fuentes-Guerra et al., 2025). For instance, van Ede et al. (2020) showed that involuntary retro-cues (but central and symbolic, with 50 % predictability) led to the selection of WM contents.

Yet, this relationship with purely exogenous retro-cues remains largely unexplored. In other words, it is not fully established whether an abrupt external stimulus, such as the sound and flashing of an oven timer, can not only facilitate perceptual processing of its location (i.e., detecting that the dish is overcooked) but also select and prioritize contents already held in our WM, thereby facilitating their retrieval (i.e., the flash might also bring back a specific step from the instructions that you were not planning to execute). For that matter, in a recent set of experiments (Fuentes-Guerra et al., 2025), we manipulated exogenous cueing, CTOAs and stimulus-response (S-R) associations and we obtained robust evidence that spatially driven exogenous non-predictive retro-cues seem to select and prioritize complex WM contents by showing a facilitation effect. In this line, the Binding and Retrieval in Action Control (BRAC; Frings et al., 2020) provides a common ground for the integration of research on visual search, attentional selection and action control, which fits very well with the cue-target integration theory (Lupiáñez, 2010; Lupiáñez et al., 2013) in explaining such exogenous/involuntary effects. It suggests that features of the stimulus environment, a response in that environment and its subsequent effects are integrated into an "event file": a "mental representation" in which all the elements related to a specific event are included (Theory of Event Coding (TEC); Hommel, 1998, 2019). In this regard, by elements we mean the encoding of some content (as in retro-cueing WM paradigms), the potential exogenous retro-cue, the content itself (e.g., stimulus, response, the laterality of the response, etc.) as well as the meta-control state and goals adopted when performing the specific task at hand (Dignath, Johannsen, Hommel, & Kiesel, 2019; Hommel, 2019, 2022; Whitehead, Pfeuffer, & Egner, 2020).

Concerning meta-control states in particular, it has been theorized that a task can be approached in a continuum between two modes (Hommel, 2019, 2022): one characterized by extreme persistence (with strong impact of the current goal and strong mutual competition between alternative decisions; cognitive/behavioral exploitation); and, the opposite case, where there is extreme flexibility (the current goals have a weak impact and poor competition; cognitive/behavioral exploration) (Dreisbach & Fröber, 2019; Hommel, 2019). In fact, the attentional state with which the person approaches the task, that is, the meta-control state, can be induced through experimental manipulations in spatial exogenous attention. Martín-Arévalo et al. (2021) showed that - by using a classical spatial exogenous cueing paradigm - different attentional sets could be induced by manipulating the percentage of trials in which an IE was present in a discrimination task. Specifically, the presence of an IE in most trials changed the net exogenous effect into less positive/facilitatory (or more negative values/IOR effect) suggesting that the mechanisms underlying the effects of IEs appear to be related to a top-down attentional set instead of a trial-by-trial bottom-up capture effect. That is, the IE affected in a global manner how cue and target were integrated, leading to less integration and consequently, less facilitatory effect (Lupiáñez, 2010; Lupiáñez et al., 2013). In this context, and referring back to the proposed example, it seems intuitive to explore whether metacontrol states also play a role in the attentional selection of WM contents. When following a recipe, these different mindsets can result in either a highly experimental dish that differs significantly from the initial intention or a perfectly by-the-book dish. Namely, in the retro-cueing paradigm, the presentation of an IE, by hindering retro-cue and target integration, could lead to a more explorative meta-control state. Conversely, the absence of IE, through a more straightforward integration of retro-cue and target, could lead to a more exploitative state where goals have a stronger impact. In addition, another key source for this stability-flexibility balance comes from the context of the task itself (Dreisbach & Fröber, 2019). Herein, this balance could be modulated by manipulating the strength of the representations held in WM, with repeated contents being more stable than novel contents (i.e., a novel recipe compared to a recipe you have previously prepared in the past). This, in turn, could also affect cueing effects.

Summarizing, the current preregistered study builds upon recent theoretical proposals about selective attention (Myers et al., 2017; cue-target integration theory in the spatial domain, Lupiáñez, 2010; Lupiáñez et al., 2013), and the BRAC and TEC models (Frings et al., 2020; Hommel, 2019) to investigate how pure exogenous retro-cues; i.e., spatially driven exogenous non-predictive retro-cues, can select both spatial location and WM contents. The main aim is to conceptualize the phenomenon more extensively by exploring how it is modulated by the induced meta-control states (manipulating IEs across blocks) in WM contents (i.e., by presenting novel as compared to repeated content across trials, that have proven to modulate exogenous effects in classical exogenous experiments in the perceptual domain).

Specifically, based on Hommel's proposal of partial repetition costs (Hommel, 2004) - which refers to the cognitive load or processing difficulty experienced when only some elements of a task are repeated as opposed to all elements or none -, we hypothesized that exogenous retro-cues would prioritize both the location and associated object held in

WM, resulting in the fastest RTs when both were retro-cued (i.e., retro-cue in the same location as the target and selected object the same as target -Cued Location, Cued Object-), secondly, when none of them was retro-cued (i.e., retro-cue in the opposite location as the target and selected object different from the target -Uncued Location, Uncued Object-); and last, responses being slowest in the two possible cases when one of them was retro-cued but not the other (i.e., retro-cue in the same location as target and selected object different from the target -Cued Location, Uncued Object;- or retro-cue in the opposite location as the target and selected object same as the target -Uncued Location, Cued Object-) (see Fig. 1).

Secondly, considering the event file as a representation that contains all the information of the trial, pure exogenous effects can lead to behavioral facilitation under a persistent meta-control state and, in contrast, reduce the facilitation/or increase IOR under a flexibility bias (Martín-Arévalo et al., 2013; Martín-Arévalo et al., 2021; Martín-Arévalo, Chica, & Lupiáñez, 2016). We hypothesized that the absence of IE would lead to a persistent meta-control state (by inducing a facilitatory effect), while the induction of a flexible meta-control state via the presence of IE might favor top-down segregation (IOR effect). Specifically, we expected that meta-control states would modulate the effect of exogenous attention on retro-cued locations but not content since the IE was spatial in nature (Hu & Samuel, 2011; Hu et al., 2011).

Additionally, we also hypothesized that the experimentally induced

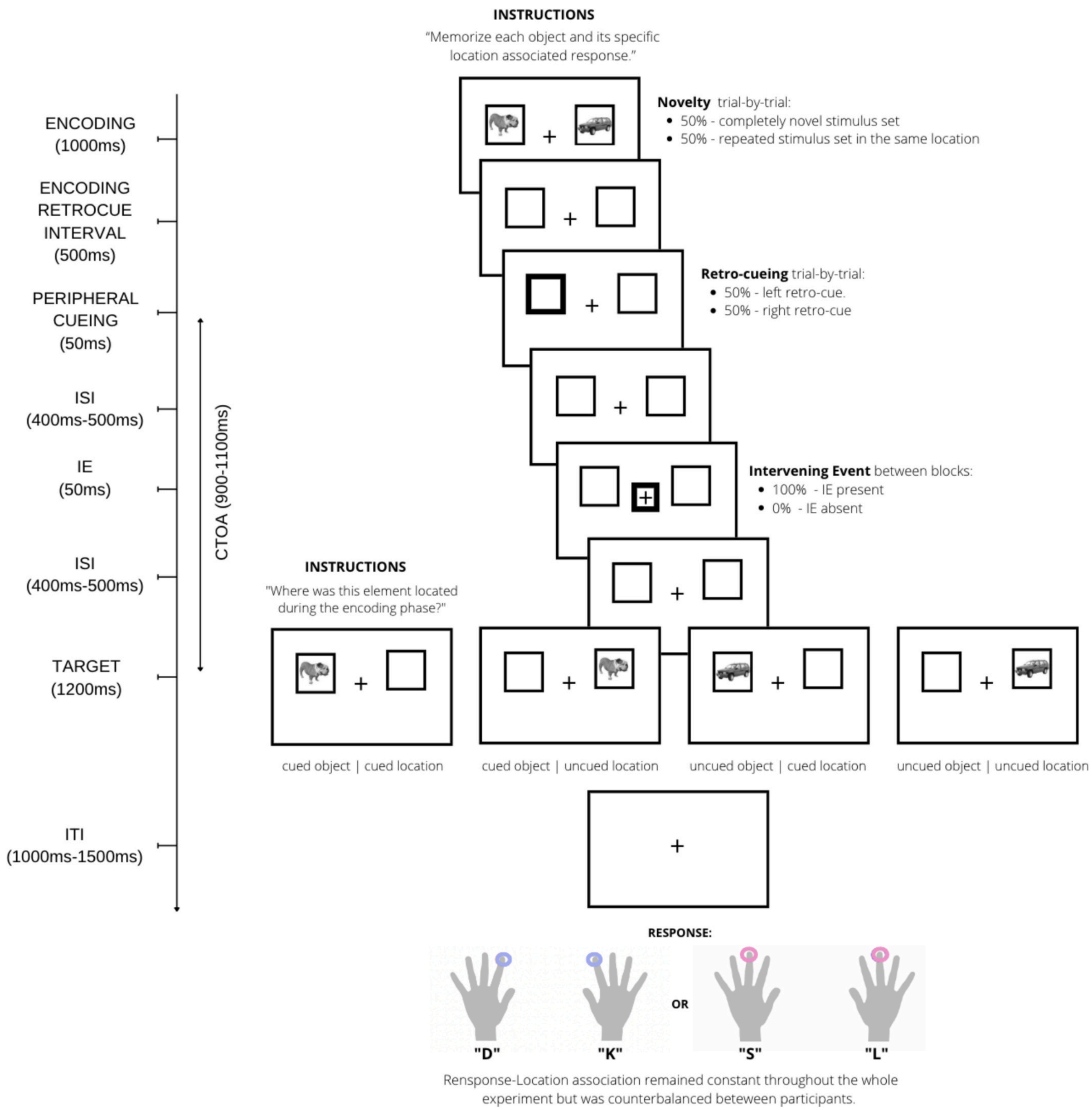

Fig. 1. Sequences of events in each trial.
Note. ISI: inter-stimulus interval. ITI: inter-trial interval. CTOA: cue-target onset asynchrony.

meta-control states would modulate the retrieval of novel (WM) vs. repeated S-R mappings (Dreisbach & Fröber, 2019; Hommel, 2015). Specifically, differences between novel and repeated S-Rs were expected to be larger in no-IEs than IEs blocks, given the increased flexibility in the latter. By lowering the updating threshold in WM (Dreisbach & Fröber, 2019), this induced flexibility could result in more similar RTs in both conditions (novel and repeated) compared to when there is no continuous disruption of information integration, less flexibility and a more goal-directed mindset from which repeated trials should specially benefit.

Lastly, we expected novelty (novel or repeated content across trials) to modulate the strength with which exogenous attention prioritizes both space and content (Whitehead et al., 2020). In this sense, the interaction between the location and object cueing should be larger in novel trials compared to repeated trials since the content component of the event file should be more critical for optimal behavior in the former case (Summerfield & Egner, 2009).

2. Methods

2.1. Data availability

Raw data and analysis scripts for this experiment can be found at (https://osf.io/gz8ja/). The hypotheses and analysis plan were preregistered prior to data collection and can be found at https://aspredicted.org/SQ7_83V.

2.2. Participants

Fifty-seven naïve volunteers participated in this experiment, although seven of them were excluded from the analyses due to an error rate higher than 40 % in regular and catch trials (see preregistration). Thus, the final sample size was 50 (40 females, mean age of 21.1 years, SD = 3.1). We determined the sample size a priori, based on previous experiments using a similar spatial exogenous paradigm (Lupiáñez et al., 2013; Martín-Arévalo et al., 2013; Martín-Arévalo et al., 2021).

Participants were recruited through the experiments' website (https://ugr-cimcyc.sona-systems.com) of the research center where the study took place, the Centro de Investigación Mente, Cerebro y Comportamiento (CIMCYC). The prerequisites for participation in the present study were to be above 18 years old, to have normal or corrected to normal vision and to give a written consent. Moreover, participants were monetarily compensated (5€ per half an hour) after completing their partaking. The experiment was conducted in accordance with the ethical guidelines laid down by the Department of Experimental Psychology, University of Granada, in conformity with the ethical standards of the 1964 Declaration of Helsinki (last update: Brazil, 2013). The experiment was part of a larger research project approved by the University of Granada Ethical Committee (1816/CEIH/2020).

2.3. Apparatus, stimuli, and procedure

We conducted the experiment on a computer with an Intel Core i7-3770 CPU @ 3.40GHz ×8 processor, connected to a 24 inches Benq XL2411T monitor with a 1920 × 1080 (16:9) pixel resolution and 350 cd/m^2 of brightness. Participants sat at a viewing distance of approximately 65 cm. The presentation of stimuli and data acquisition were controlled with PsychoPy 2021.2.3 throughout the whole experiment.

The experimental display consisted in the presentation of two placeholders, one on each side of the fixation point, which was presented right in the middle of the screen (position [relative to the center] of $x = 0$, $y = 0$). Each placeholder box had a size of 200 × 200 pixels, and the border of the box comprised an extra 10 pixels. The left box was in the position ($x = -250$, $y = 75$) and the right one in ($x = 250$, $y = 75$). Inside of each placeholder an image of 200 × 200 pixels appeared at the beginning of each trial. These images of animate (non-human animals) and inanimate (vehicles and instruments) items were compiled from different available databases (Brady, Konkle, Alvarez, & Oliva, 2008, 2013; Brodeur, Guérard, & Bouras, 2014; Griffin, Holub, & Perona, 2022; Konkle, Brady, Alvarez, & Oliva, 2010), creating a pool of 1550 unique pictures (770 animate items, 780 inanimate). To increase perceptual distinctiveness and facilitate recognition, the background was removed from all images, items were centered in the canvas, and images were converted to black and white. Additionally, we created peripheral cues by increasing the outline of one of two placeholder boxes from 10 to 30 pixels. Moreover, the IE was created by presenting a smaller box of 175 × 175 pixels centered around the fixation point.

The experiment consisted of a choice-reaction task embedded in a pure exogenous retro-cueing paradigm. The sequence of events in each trial is illustrated in Fig. 1. Each trial began with the presentation of the encoding display -containing the fixation point, the two placeholders and two images- for a duration of 1000 ms. Participants were instructed to encode (or retrieve, see below) a stimulus-response (S-R) mapping in which they had to associate each stimulus with a specific bimanual response depending on its location on the screen. Specifically, participants were instructed at the beginning of the experimental session to associate stimuli to the left of the fixation point to simultaneous bimanual index finger responses, and stimuli to the right to simultaneous bimanual middle finger responses and to ignore any additional stimuli that could possibly appear between encoding and probe presentation (i.e., the retro-cue and the IE, see below). The location-response contingency was constant during the experiment but counterbalanced across participants. That is, for some participants the objects on the left corresponded to simultaneous index finger responses and the objects on the right to simultaneous middle finger responses throughout the whole experiment, while for others, it was the reverse. Simultaneous bimanual index and middle responses were used to fully orthogonalize the location of the stimulus on the screen with the response location, thereby avoiding the classic Simon effect between the location of the stimuli and the response hand effector (Hommel, 2019). In 50 % of the trials, a completely new pair of images appeared and therefore S-R associations were new ("novel S-Rs"). Novel mappings never repeated and appeared only once throughout the experiment. In the remaining 50 % of trials, the same two images were displayed always in the same position, thus leading to the exact same pair of S-R associations throughout the whole experimental session, which we labeled "repeated S-Rs" in which we expected participants to eventually learn the keys associated with each specific item. Next, an interval, composed by the two empty placeholders and the fixation point, appeared for 500 ms (see Souza & Oberauer, 2016). Immediately after, the peripheral non-predictive retro-cue was presented for 50 ms in one of the two possible locations with equal probability (50 %; i.e., totally unpredictive for both location and object). After the peripheral retro-cue had disappeared, a fixation display was presented for a jittered duration of 400–500 ms. Additionally, in one of the two blocks, an IE would flash for 50 ms on the fixation point. In IE absent blocks, the fixation cross (without flash) was displayed for the same duration to warrant identical retro-cue/target latencies across blocks. Another fixation display was then presented for 400–500 ms. Then, one of the two images (i.e. the target image) was displayed for 1200 ms in one of the two placeholders with equal probability. Participants were instructed to provide the associated simultaneous bimanual response learned at the encoding stage of the trial. Specifically, they had to simultaneously press the "S" and "L" keys on the keyboard with both middle fingers if the target was associated with middle fingers' responses, and "D" and "K" with both index fingers simultaneously if index fingers responses were required. In 5 % of trials, a completely new picture, different from the two displayed in the encoding screen, and never seen before, was shown as the target. In those cases, which we labeled "catch trials", participants were instructed to press the spacebar with their thumbs. These trials were included to prevent participants from adopting strategies to reduce the WM load (e.g., encoding just the left item and then treating the target as a go-no go task). The inter-trial interval, in which the screen remained empty, lasted 1000–1500 ms.

Participants completed 2 blocks (in counterbalanced order across participants), one with IEs (100 % of trials) and one without IEs (0 %), of 168 trials each (160 regular trials, 8 catch ones), for a total of 336 trials. For each cell of the design (see below), participants performed 20 regular trials.

Prior to the main task, participants performed a practice phase with a similar task that did not include retro-cues nor IEs. This practice phase consisted of one block of 16 trials (14 regular and 2 catch), which participants repeated until they achieved an accuracy of at least 85 %. The images used in the practice phase were not used during the main task. The total duration of the experiment was around 40 min.

2.4. Design

The experiment consisted of a 2 × 2 × 2 × 2 full factorial design of four factors in which all variables were counterbalanced within participants: location cueing, object cueing, novelty (all manipulated within trials) and IE (manipulated across blocks) (see Fig. 1).

Location cueing had two levels: *cued location* (the target appeared in the same location as the retro-cue) and *uncued location* (the target appeared in the opposite location of the retro-cue). As such, object cueing also had two levels: *cued object* (the target was the object selected by the retro-cue) and *uncued object* (the target was the object not selected by the retro-cue). Moreover, S-Rs could be novel (for uniquely presented objects) or repeated across trials (for repeated S-R mappings, i.e., for two stimuli which appeared in 50 % of the trials always in the same location). Lastly, the IE could be present or absent, but in this case, it was manipulated across blocks (see Martín-Arévalo et al., 2013, 2021), with the order counterbalanced between participants.

2.5. Statistical analyses

To test our hypothesis, we performed 21 Generalized Linear Mixed Models (GLMM) (see e.g., Lo & Andrews, 2015) with the raw RT data of correct regular trials (catch trials were excluded) that didn't exceed 1200 ms (8.75 % of rejected trials). First, to find the most appropriate random structure, we computed three models. The first model included the random intercept of participant and trial, the second one, the random intercept of participant and, the last one, the random intercept of trial.[2] Once we compared these models by performing an ANOVA, the model with both the random intercept of participant and trial had the smallest AIC and BIC (AIC = 18,976.2, BIC = 187,120.4), and therefore, it was chosen as the model with the most suited random structure. Consequently, we modeled the fixed effects of the model by comparing the model which included the most complex interaction among independent variables to its subsequent one, and so on. After carrying out 18 additional models, we identified the best fixed structure (see Zuur, Ieno, Walker, Saveliev, & Smith, 2009). The selected model included the random intercept of both participant and trial as random structure and for the fixed structure the model comprised an interaction between location cueing and object cueing, an interaction between IE and location cueing, and last, an interaction between IE and novelty. Within this model, we performed an analysis of deviance on RT. All data processing and analyses were carried out with RStudio 2022.02.3 and JASP 0.14.0.0. B. We also performed some exploratory analyses regarding accuracy scores (see https://osf.io/gz8ja/) and catch trials. Accuracy was considered to exclude participants with an error rate above 40 % on regular and/or catch trials. Lastly, p-values in post-hoc comparisons were corrected with the Holm-Bonferroni method.

3. Results

The analysis of deviance within the selected GLMM revealed a significant main effect of IE [X^2(1,N = 50) = 11.51, p < .001, η^2 = 0.19], with faster responses when IE was present (M = 684 ms, SD = 99 ms) vs. when it was absent (M = 703 ms, SD = 104 ms); Location Cueing [Xˆ2(1, N = 50) = 64.56, p < .001, η^2 = 0.57], with faster responses in cued location (M = 690 ms; SD = 102 ms) vs. uncued location trials (M = 697, SD = 102); Object Cueing [X^2(1,N = 50) = 136.96, p < .001, η^2 = 0.74], with faster responses in cued object (M = 688 ms; SD = 97 ms) compared to uncued object (M = 694 ms; SD = 97 ms); and Novelty [X^2(1,N = 50) = 131.70, p < .001, η^2 = 0.73], with faster responses for repeated (M = 670 ms; SD = 95 ms) vs. novel S-R mappings (M = 717 ms; SD = 103 ms). See Table 1 for descriptive statistics.

Regarding the first preregistered hypothesis (https://aspredicted.org/eg7tc.pdf), where we expected pure exogenous retro-cues to modulate not only spatial representation but also the content held in working memory (WM), there was a significant interaction between Location Cueing and Object Cueing [X^2(1,N = 50) = 224.32, p < .001, η^2 = 0.82], with faster RTs when the retro-cue selected both the target's location and the object (M = 672 ms; SD = 102 ms); next, when the retro-cue didn't select any of them (M = 683 ms; SD = 102 ms); on the third place, when the retro-cue selected the location but not the object (M = 709 ms; SD = 94 ms); and lastly, when it selected the object but not the location (M = 712 ms; SD = 93 ms). Crucially, pairwise comparisons revealed a significant distinction between those trials in which the retro-cue selected both the location and the object, in comparison to when it didn't select either [X^2(1,N = 50) = −9.34, p = .024, η^2 = 0.14] (see Fig. 2).

We also obtained evidence for the second hypothesis, which predicted an interaction between Location Cueing and IE [X^2(1,N = 50) = 13.29, p < .001, η^2 = 0.21]. In this line, the pairwise comparisons revealed a significant difference between cued location trials (M = 695 ms; SD = 99 ms) vs. uncued location trials (M = 711 ms; SD = 99) when IE was absent [X^2(1,N = 50) = −14.71, p < .001, η^2 = 0.26]. In contrast, when IE was present, there were no statistically significant differences between cued and uncued location trials [X^2(1,N = 50) = 3.16, p = .789, η^2 = 0.02] (see Fig. 3). Lastly, the interaction of IE and Object Cueing was not part of the selected model and therefore, it was not further tested.

As to the third hypothesis, where we expected the metacontrol states (absent/present IE) to modulate the novel vs. repeated S-R mappings, there was also a statistically significant interaction between Novelty and IE [X^2(1,N = 50) = 6.89, p < .001, η^2 = 0.12]. Pairwise comparisons

Table 1
Descriptive statistics on RTs (ms).

Location cueing	Object cueing	Intervening event	Novelty	Mean	SD
Cued location	Cued object	Present	Novel	686.2	106.1
			Repeated	646	91.5
		Absent	Novel	697.3	104.3
			Repeated	656.7	104.2
	Uncued object	Present	Novel	720.7	98.1
			Repeated	689.3	88.9
		Absent	Novel	746.8	100.7
			Repeated	680.2	88.3
Uncued location	Cued object	Present	Novel	723.2	102.8
			Repeated	675.3	86.2
		Absent	Novel	747.5	93.6
			Repeated	700.6	89.9
	Uncued object	Present	Novel	690.4	101.9
			Repeated	643.8	92.4
		Absent	Novel	726.4	105.7
			Repeated	669.6	107.2

Note. SD: Standard Deviation.

[2] Given the complexity of the experimental design, random slopes were not included since convergence issues were raised. Nevertheless, a classical ANOVA (see https://osf.io/gz8ja/) was carried out and the pattern of results mainly mimicked the one reported below in the Results section.

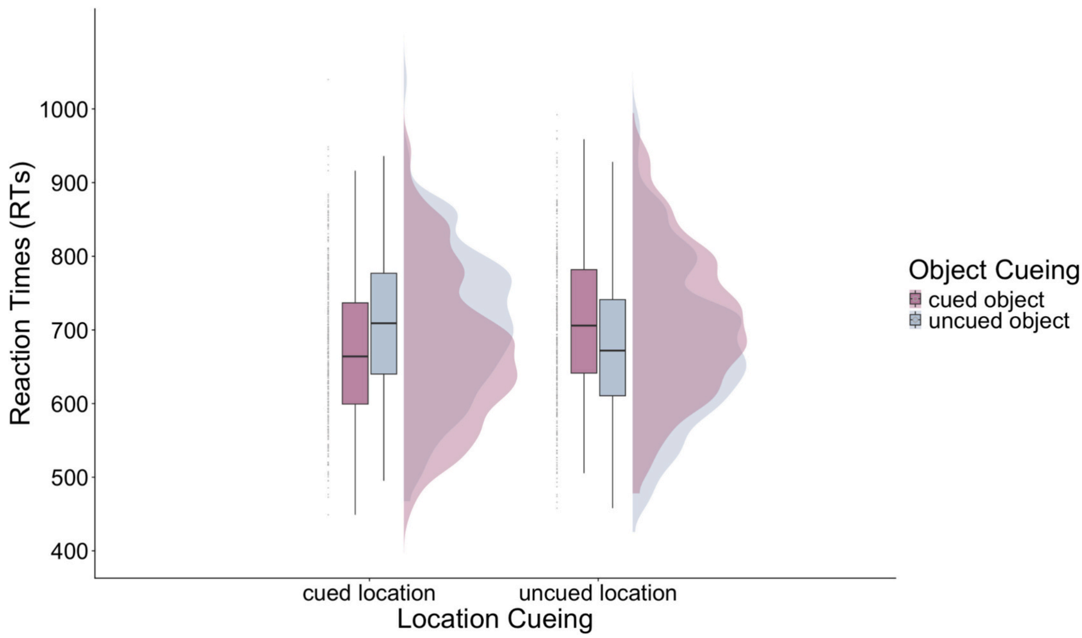

Fig. 2. Effects of the interaction of Location Cueing and Object Cueing on RTs.
Note. The maximum and minimum Reaction Times' (RTs) values are represented in the whiskers of the box plots. The Interquartile range (IQR) is displayed in the boxes by portraying the lower quartile, median and upper quartile. The half-violin plots represent the distribution of RTs across conditions.

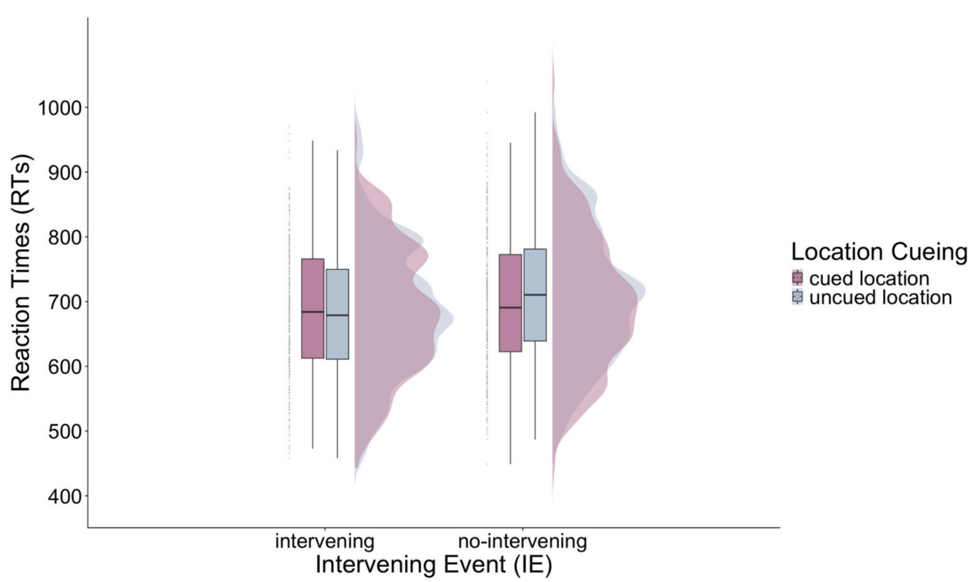

Fig. 3. Effects of the interaction of Intervening Event and Location Cueing on RTs.
Note. The maximum and minimum Reaction Times' (RTs) values are represented in the whiskers of the box plots. The Interquartile range (IQR) is displayed in the boxes by portraying the lower quartile, median and upper quartile. The half-violin plots represent the distribution of RTs across conditions.

revealed that although the difference between novel vs. repeated S-R mappings was significant for both the IE present [$X^2(1,N = 50) = 39.2$, $p < .001$, $\eta^2 = 0.72$] and IE absent condition [$X^2(1,N = 50) = 52.1$, $p < .001$, $\eta^2 = 0.81$], the difference (41 ms) was reduced in the IE present block, with faster responses in repeated ($M = 664$, $SD = 90$) vs. novel S-R mappings ($M = 705$, $SD = 102$), compared to the IE absent block (53 ms), which also led to faster responses in repeated ($M = 677$, $SD = 97$) vs. novel S-R mappings ($M = 730$, $SD = 101$) (see Fig. 4). A direct comparison of the Novelty effect between the two conditions (absent/present IE) confirmed that this difference was statistically significant ($z = 2.67$, $p = .007$).

The last hypothesis predicted a three-way interaction between Location Cueing, Object Cueing and Novelty. Nevertheless, this effect was not part of the selected model, so it was not further tested.

4. Discussion

These results suggest that pure exogenous attention selects and prioritizes different contents included in an event file held in WM. In particular, it reveals that exogenous cues can equally select two of the main components of event files: location and object. This is evidenced by the significant difference between those trials in which the retro-cue selected both, the location and the object, compared to when it only selected the location; as well as the contrast between trials where the

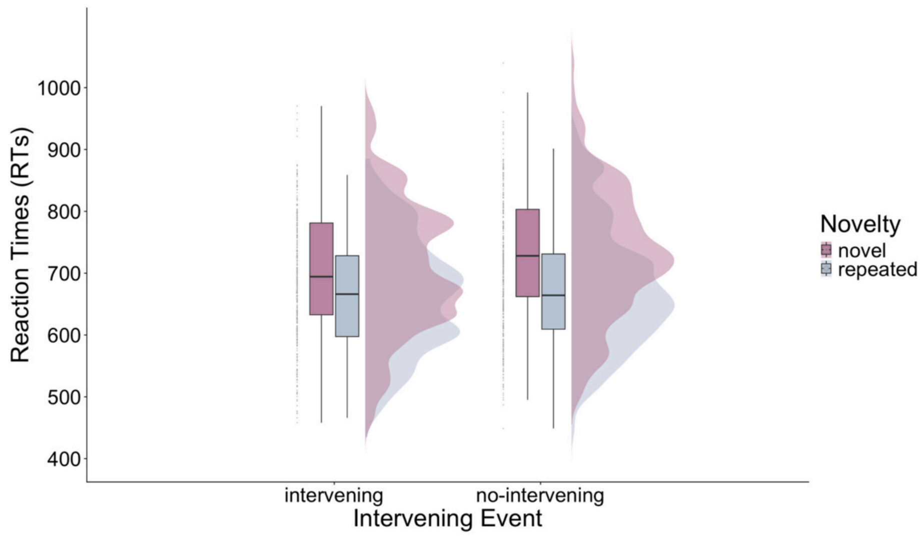

Fig. 4. Effects of the interaction of Intervening Event and novelty on RTs.
Note. The maximum and minimum Reaction Times' (RTs) values are represented in the whiskers of the box plots. The Interquartile range (IQR) is displayed in the boxes by portraying the lower quartile, median and upper quartile. The half-violin plots represent the distribution of RTs across conditions.

retro-cue selected both the object and location, and those where it did not select either. Additionally, these results also align with BRAC and TEC models (Frings et al., 2020; Hommel, 2019), and with the *partial repetition costs* hypothesis (Hommel, 2004): full repetitions of the encoded event file (Cued Location and Cued Object trials or Uncued Location and Uncued Object trials), led to faster responses, wherein participants had to accept or just reject the event file. However, in partial repetitions (Cued Location and Uncued Object trials or Uncued Location and Cued Object trials), participants had to partially update the event files leading to longer responses. This outcome presents critical implications for the understanding on how attentional selection interacts with WM contents since it suggests that all the different features presented on each trial are encoded and retrieved as whole, and this can be triggered automatically by retro-cueing one of its dimensions (space/location), although this default activation can lead to slower RTs when there is some conflicting information. Similar effects have been reported in many other domains, like in priming studies with different types of tasks (Mayr, Buchner, Möller, & Hauke, 2011; Sohn & Anderson, 2003; Zehetleitner, Rangelov, & Müller, 2012). In summary, this research shows that a perceptual non-predictive flash retrieved content that was previously associated with the location where it occurred (i.e., the flash coming from the oven timer could potentially bring back certain recipe instructions that we were not planning on executing, which could ultimately affect our final behavior).

In contrast, it could be argued that the pattern of results observed in the current study could be based on encoding-probe congruency rather than being a retro-cueing effect. That is, the fact that the encoded stimuli could be repeated at the same location from encoding to probe could facilitate its retrieval. Nevertheless, this explanation does not account for the statistically significant difference in RTs between those trials in which the cue selected both location and object, in comparison to those in which it didn't select either. According to the encoding-probe congruency interpretation participants should be equally fast in these two conditions since there is a full repetition of object and location from encoding to probe. However, this is certainly not the case. Participants were significantly faster for Cued Location and Cued Object trials than for Uncued Location and Uncued Object trials, which suggests that the retro-cue prioritized the selected content. Additionally, this aligns with recent evidence where this encoding-probe spatial congruency was eliminated by centralizing the probe, obtaining robust evidence for a pure exogenous retro-cueing effect, (Fuentes-Guerra et al., 2025). However, whether this retro-cueing effect is based on a benefit from cued trials and/or a cost from uncued trials cannot be disentangled here since neutral retro-cues were not included. The inclusion of neutral retro-cues should be considered in future experiments to clearly distinguish between these two possibilities. Moreover, while this experiment provided evidence that event files encompass the different features encountered within a certain trial, the different weights associated with each feature extend its scope. However, recent evidence suggests that some features might be more accessible than others (Fuentes-Guerra et al., 2025). The mechanisms through which exogenous attention selects and prioritizes complex WM contents depend, at least in part, on the hierarchical relevance of the dimensions that have been encoded. In this context, and considering the long trajectory of exogenous attention being associated with the spatial dimension in the perceptual domain (Hu & Samuel, 2011; Hu et al., 2011; Lupiáñez et al., 2013; Martín-Arévalo et al., 2013; Posner & Cohen, 1984; Posner et al., 1985), for pure exogenous attentional selection (characterized by its automaticity) of WM contents, space also seems to be a more accessible feature compared to others (e.g., color)(Fuentes-Guerra et al., 2025).

Furthermore, following the idea of event file, in which the different elements of the trial are interrelated, as expected, IE interacted with Location Cueing. More specifically, in a task that capitalized on WM contents, a significant facilitatory effect was observed, just like in the classical spatial exogenous paradigm especially when using discrimination tasks (Martín-Arévalo et al., 2013; Martín-Arévalo et al., 2016, 2021). In the IE absent block, we observed a significant facilitation effect, which aligns with a persistent meta-control state (Hommel, 2019; Martín-Arévalo et al., 2021), and thus cognitive, and behavioral exploitation, which in turn led to faster responses in cued trials. On the other hand, the expected IOR on the IE present block was not present, although no significant facilitation was observed (i.e., we observed, as alternatively expected, less positive/facilitatory effect). We predicted IEs to induce a flexible meta-control state, and therefore, cognitive, and behavioral exploration, resulting in faster responses in uncued trials. The obtained results - in terms of facilitation (significant in the IE absent and non-significant in the IE present trials, but no IOR) - may be explained by the difficulty/demands of the current task (Chica et al., 2014), which are higher than those in the classical exogenous spatial tasks in which this effect has been seen, and wherein longer facilitation effects are usually observed (Lupiáñez et al., 1997; Martín-Arévalo et al., 2013; Martín-Arévalo et al., 2016).

Alternatively, if IOR is the result of a detection cost (Lupiáñez et al., 2013), which is specially apparent when the spatial selection benefits are eliminated by the IE, no detection cost would be present in this task as both the cued and the uncued objects and location are already detected and encoded into WM. Future research should investigate whether IOR also operates in the reactivation or retrieval of WM representations, or just in the detection of perceptual representations for their encoding into WM.

As it was also hypothesized, IE interacted with Location Cueing but not with Object Cueing. This may be explained by the fact that the implemented IE was purely spatial and consequently, it already shared a dimension with that type of cueing. In fact, location has proven to be a critical dimension when considering exogenous attentional modulation (Hu & Samuel, 2011; Hu et al., 2011). Nevertheless, this remains as an open question that could be tested with a content related IE (Law, Pratt, & Abrams, 1995).

Conversely, as also expected, the effect of IE did interact with WM contents. Under the hypothesized persistent meta-control state (Hommel, 2019), the difference between novel and repeated trials was larger as compared to blocks with IE (where behavioral flexibility, in which there is a weaker influence of the goal, was expected). In IE present trials, in contrast, a more explorative state could support better performance in novel trials (Dreisbach & Fröber, 2019). These results imply that the metacontrol state with which participants approach the task doesn't only affect the impact of the exogenous retro-cue on their performance, but also, the ease with which they are able to discriminate between novel and more declarative/long term memory (LTM) contents, which can also, in turn, be part of that explorative or exploitative mindset, respectively. In this context, regarding novel (WM) and repeated trials, it could be argued that the WM demands of the task in both conditions might be altered as the repeated stimuli could be well-stored in LTM. Nevertheless, even if this was the case, we argue that when the stimuli were repeated, the task should still engage WM mechanisms (Ranganath & D'Esposito, 2001) through active maintenance and manipulation of that information trial-by-trial (Jonides et al., 2008), since the participants did not know in advance the exact type of trial (novel or repeated) that could be presented. In summary, the system dynamically manages the complexity of event files based on situational demands. While the Theory of Event Coding (Hommel, 2019) does not explicitly state hard limits on what an event file can contain, it suggests that the handling of event files is influenced by cognitive control processes, which likely impose practical constraints. Hence, depending on the demands of the task, participants might be more conservative and focus on their goals without paying that much attention to additional upcoming information (rejecting the entrance of additional elements to the event file), or in contrast, they might be more flexible and adapt to upcoming events (by dropping, adding and updating different elements of the event file). By establishing a balance between stability-flexibility based on the context (Dreisbach & Fröber, 2019) humans might handle these computational constraints.

Last, we hypothesized that Novelty would modulate the strength with which exogenous attention prioritizes both space and content, based on Whitehead et al. (2020), who found reduced task-switching costs for probes whose primes were task switches as opposed to repeat trials. Nevertheless, this effect was not present in our results. One possible explanation is that, in this task, several factors that could induce cognitive and behavioral exploration/exploitation were included (Novelty and IE), hence, the modulatory effect of Novelty and its supposed induced flexibility, might be hindered under the complexity of the design and the variability within so many interactions. Future research could address this issue by evaluating the effects of Novelty on exogenous attention in isolation, avoiding the inclusion of additional factors. This would allow testing whether novelty exerts a modulatory effect in the absence of other overarching influences.

5. Conclusion

Exogenous attention selected and prioritized both space and associated WM contents, challenging previous conceptualizations. Additionally, pure exogenous effects have proven to influence content integration. In fact, task elements like IE can induce meta-control states, leading to varied results based on task settings. Therefore, it seems that event files encompass trial elements beyond space, facilitating stimulus interaction but may activate irrelevant information, and that these elements can be prioritized within WM via purely exogenous cues.

CRediT authorship contribution statement

Águeda Fuentes-Guerra Toral: Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Fabiano Botta:** Writing – review & editing, Validation, Supervision, Conceptualization. **Juan Lupiáñez:** Writing – review & editing, Validation, Supervision, Conceptualization. **Carlos González-García:** Writing – review & editing, Validation, Supervision, Software, Resources, Methodology, Funding acquisition, Conceptualization. **Elisa Martín-Arévalo:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Funding acquisition, Conceptualization.

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Consent for publication

Informed consent was obtained from all individual participants included in the study.

Code availability

The codes for the task design and statistical analyses are available at (https://osf.io/gz8ja/?view_only=2bd63bc8915e402a8749057149a0e45d).

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used COPILOT to correct English grammar. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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Declaration of competing interest

The authors declare no competing interests.

Data availability

The data and materials for all experiments are available at (https://osf.io/gz8ja/?view_only=2bd63bc8915e402a8749057149a0e45d) and the experiment was preregistered (https://aspredicted.org/SQ7_83V).

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