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EXOGENOUS ATTENTION AND ITS RELATIONSHIP WITH WORKING MEMORY CONTENTS: NOT ONLY “WHERE?”, BUT ALSO “WHAT?”

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Abstract

Historically, memory and attention have been associated with the past and the future, respectively. However, recent research is moving forward to show that memory fulfills a prospective function, and attention relies heavily on previous experience. In between, working memory (WM) guides flexible and adaptive behavior. Consequently, the present experiment aimed to characterize the relationship between exogenous attention and WM contents by implementing an exogenous retro-cueing paradigm on a task that capitalized on WM. The present research had a two-fold goal: i) to evaluate if cueing effects would not only impact spatial processing but also WM content, and ii) to explore how metacontrol states induced by the manipulation of an intervening event (IE) would modulate these effects. We observed (N=60) that exogenous attention, not only selected space, as it is usually accepted in exogenous attention paradigms, but also, the content associated to that location. Moreover, space selection was modulated by the IE manipulation, which was thought to induce two metacontrol states (persistent vs. flexible). As such, IE manipulation also modulated the participants' performance regarding novel vs. repeated stimulus-response mappings, hinting again 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, metacontrol state, goals, etc.), which are retrieved together once one or more of its elements are encountered. Although introductory, the present experiment opens the door for a new promising line of research.

Introduction

We are constantly surrounded by an infinite number of stimuli of diverse nature that require our attention. Importantly, some stimuli might capture our attention in a quick and involuntary manner (i.e., the claxon of a car alerting a pedestrian that is about to cross a busy road) which is referred to in the literature as exogenous or involuntary attention (Jonides, 1981). On the other hand, we also have the capacity to attend to certain stimuli voluntarily in order to carry out adaptive behaviors. For example, when meeting a friend in the street, you might only focus on the people wearing a yellow t-shirt because your friend previously told you that her clothing would be yellow. This type of attention is called endogenous or voluntary attention (Jonides, 1981; Corbetta, Patel & Shulman, 2008). Intuitively, after reading these examples, one might think that the use of memory is essential for these actions to be performed. However, this relationship between memory and attention has received limited interest in the past. In fact, historically, memory and attention have been associated with the past and the future, respectively, and have been studied as separate constructs. However, as Nobre and Stokes (2020) recently highlight, memory fulfills a prospective function, and attention relies heavily on previous experience. In between, working memory (WM) guides flexible and adaptive behavior, and it refers to the ability to store and manipulate data in an online fashion independently of sensory stimulation (Baddeley, 1992; Souza & Oberauer, 2016).

As such, the interest in studying and conceptualizing the relationship between attention and WM is growing exponentially (Kiyonaga & Egner, 2013; Myers, Stokes & Nobre, 2017; Zokaei et al., 2019; van Ede, 2020; Huynh Cong & Kerzel, 2021). Several of these studies have shown that it is possible to internally and retrospectively guide attention towards WM contents in a top-down fashion (Gunseli, van Moorselaar, Meeter, & Olivers, 2015; Gunseli et al., 2019). In particular, paradigms which implement retro-cues (i.e., cues presented between the offset of a memory array and the onset of a probe) are being recurrently used in this field in order to evaluate how attention can be directed not only to perceptual information, but also to information in WM. In other words, retro-cues have proven to be useful in the selection of content in WM (Souza & Oberauer, 2016; Shepherdson, Oberauer & Souza, 2018; Rerko, Souza & Oberauer, 2014). Although some authors even suggest that the retro-cueing effect can be seen with non-predictive retro-cues (Berryhill et al. 2012), most of the studies in this regard have focused on the effects of endogenous attention in the selection of WM contents (Souza & Oberauer, 2016; Shepherdson, Oberauer & Souza, 2018; Rerko, Souza & Oberauer, 2014; Gunseli, van Moorselaar, Meeter, & Olivers, 2015; Gunseli et al., 2019), while research implementing exogenous retro-cues is scarce (Han & Ku, 2021) and thus our knowledge about the effects of exogenous attention on WM content is limited.

In parallel, research on exogenous attention has tended to focus on the spatial domain, frequently by means of the classical Spatial Orienting Paradigm (Posner, 1980), in which peripheral non-predictive cues are implemented in order to direct attention exogenously to one out of two placeholders located in the left and right sides of a central fixation point, respectively. After the peripheral cue is presented, a target stimulus, which requires a response from the participants, appears on either of the placeholders (Posner, 1980; Chica et al., 2014). Within this paradigm, two main effects tend to be observed: at short stimulus onset asynchronies (SOAs), reaction times (RTs) are usually faster for targets appearing at the same location as the peripheral cue (i.e., cued location) as compared to RTs for targets presented at the opposite location (i.e., uncued location). This effect is interpreted as a facilitation of the target's perceptual processing and is referred to as a Facilitatory effect (Posner, 1980; Lupiáñez, Martín-Arévalo & Chica, 2013); on the other hand, at long SOAs, the opposite pattern of results is observed: RTs are shorter for targets appearing at the uncued location as compared to the cued location (Posner, Choate & Vaughan, 1985). This effect was first reported by Posner and Cohen (1984), and named Inhibition of Return (IOR) by Posner et al., (1985) (Lupiáñez, Martín-Arévalo & Chica, 2013). However, some authors such as Chica and colleagues (2014) highlight the fact that to achieve these two effects, not only SOAs have to be taken into account but also task settings and type of task (e.g. discrimination vs. detection tasks), among other factors. Importantly, until now, works on this paradigm and its associated research have paid little attention to an aspect considered crucial in the interaction of attention and memory: the content of the stimuli presented in the task (Lupiáñez et al., 2013; Martín-Arévalo, Chica & Lupiáñez, 2013, Martín-Arévalo et al., 2021). Therefore, after taking a look at the available evidence on exogenous attention, one could wonder whether content is irrelevant to the mechanisms of exogenous attention. Some authors suggest that this is not the case, by providing evidence that some attentional costs traditionally associated with the limited resources of the visual attentional system, might be, or at least in part, due to a disruption of episodic integration (Spadaro, He, & Milliken, 2012) or by the cost attached to the encoding of the cue (Chen & Wyble, 2018). Moreover, some studies provide evidence for the systematic difference between endogenous and exogenous attention when looking at spatial attentional effects on visuospatial WM (Botta et al., 2010; Botta & Lupiáñez, 2014). Thus, although scarce, these studies already hint at a relation between exogenous attention and WM.

Once exogenous attention and WM are considered as possibly interdependent concepts, a framework to explain that relationship is needed. In this line, the Theory of Event Coding proposed by Hommel (1998; 2019) provides a very interesting approach in which it is established that perception and action are very similar processes that operate under the same codes (Hommel, 2019). Essential to this theory is the concept of "event file" which refers to a "mental representation" in which all the elements related to a specific event are included. According to this framework, event files on visuospatial WM paradigms, contrary to what is considered in traditional exogenous paradigms (Martín-Arévalo, Chica, & Lupiáñez, 2013; Martín-Arévalo et al., 2016; 2021), are not necessarily created with the onset of an exogenous cue, but right when a trial starts. Therefore, in a case where trials start with the encoding of some content (as in retro-cueing paradigms), the event file is considered to contain not only the potential cue, but also the content (e.g. stimulus, response, the laterality of the response, etc.) as well as the metacontrol state adopted when performing the task and the goals of the participant in that moment in time (Hommel, 2019, 2022; Whitehead, Pfeuffer & Egner, 2020; Dignath et al., 2019). Concerning metacontrol states and goal-directed behaviors, it has been theorized that people can approach any given task in a continuum between two modes: one characterized by extreme *persistence* in which there is a strong impact of the current goal and strong mutual competition between alternative decisions; and, the opposite case, where the person can be extremely *flexible* and consequently, the current goals will have a weak impact and poor competition. Importantly these two modes can either facilitate discrimination between alternative events (cognitive/behavioral exploitation) or facilitate integration and cognitive/behavioral exploration, respectively (Hommel, 2019; Dreisbach & Fröber, 2019). This links very well with the idea that a metacontrol state can be induced through experimental manipulations, as has been reported in previous exogenous attention studies. In fact, Martín-Arévalo and colleagues (2021) were able to induce a certain attentional set by manipulating the percentage of trials in which an Intervening Event (IE) - a flash at fixation between cue and target - was present. Specifically, the presence of an IE changed the net cueing effects, by being more positive (or less negative) with IE absent vs. present (i.e., observing more or less facilitation/IOR effect, respectively). That is, the IE affected in a global manner how cue and target were integrated.

The event file conceptualization proposed by Hommel (2019) is key when we implement exogenous cueing because, if this logic is followed, in a task involving holding some content in WM, non-predictive exogenous cues would not only select space, but also, the content associated with that specific location, given that they are both (location and content of the stimulus) part of the same event file, and therefore, retrieved together. This could mean that, by ignoring the role of content, the consequences of exogenous cueing might be, in part, unexplored. For the sake of clarity, let's dive into a more practical example: it is not the same to hear an alerting sound in the middle of a rainforest, where we mostly find animals like tigers and such, than in the proximity of a swamp, which is the habitat of crocodiles. In this case, the event file of "alerting sound" will include not only the sound, but also the place where we locate this sound, as well as the potential cause of the sound (e.g. tiger, if it's rainforest). Essentially, this same event file ("alerting sound") in a different location (e.g. a swamp) will be more likely associated with a different animal (e.g. crocodile) which is usually found in that very specific location. In order to take action and survive in the previously mentioned situation (walking in a rainforest and hearing a noise), the association between the cued location and content is necessary and adaptive because the action to be performed can vary depending on which animal we have to defend ourselves from. This general and broad example suggests the relevance of investigating how exogenous attention relates to memory contents.

Following this reasoning, the present research aimed first, to take a deeper and more exhaustive look into the study of exogenous attention, where cues not only select space but also WM contents. This was achieved by transforming the classic exogenous attentional paradigm into an exogenous retro-cueing paradigm in order to test if a new type of task which implements exogenous attention directed towards WM content is able to shed some light on the matter.

More specifically, our predictions could be divided into two main sets of hypotheses. The first set of hypotheses aimed at testing if the use of an exogenous retro-cueing paradigm leads to the same effects that can be found in the classical exogenous paradigms and to implement the idea of event files in an exogenous cueing WM task. Considering the event file as a representation that contains all the information of the trial, cueing effects can lead to behavioral facilitation under a persistent metacontrol state and, in contrast, reduce the cueing benefit under a flexibility bias (Martín-Arévalo, Chica, & Lupiáñez, 2013; Martín-Arévalo et al., 2016; 2021). This can be achieved by manipulating the presence or absence of an IE as mentioned earlier. We hypothesized that the absence of IE would lead to a persistent metacontrol state (by inducing more positive cueing effects: a facilitatory effect), while the induction of a flexible metacontrol state via the presence of IE might favor top-down segregation (and thus, result in more negative cueing effects or even IOR effect).

Second, in another set of hypotheses, we explored the effect of exogenous attention on WM contents. Specifically, departing from recent theoretical proposals that argue that selective attention does not only “select” but also prioritizes information (Myers et al., 2017), we assessed if exogenous attention modulated WM contents. We did so by testing if WM items associated with exogenously cued locations were accessed faster, compared to objects associated with uncued locations. We further explored the extent to which this effect depended exclusively on WM traces by manipulating the novelty of items: novel (assumed to depend exclusively on WM) vs. repeated items (in which long-term memory traces could support performance as well).

As such, the experiment postulated four main hypotheses. First, we expected mentacontrol states induced by the presence or absence of IEs to modulate the exogenous cueing effect in a task that capitalized on WM processes (Martín-Arévalo et al., 2021; Hommel, 2019). More specifically, RTs in cued trials were expected to be faster than in uncued trials only when the IE was absent (i.e., positive cueing effects: a facilitatory effect). In IE present blocks, we expected either no differences or faster responses for uncued than cued (i.e., more negative cueing effects or even an IOR effect). Second, we expected these same metacontrol states to also modulate the retrieval of novel vs. repeated stimulus-response (S-R) mappings (Dreisbach & Fröber, 2019; Hommel, 2015). More 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. Regarding the effects of exogenous attention on WM content, we expected attention to prioritize the representation of S-R mappings held in memory, indexed by the difference between compatible and incompatible responses (see below, for details) (González-García et al., 2020; Myers, 2017; Hommel, 2019). In particular, we expected larger differences between compatible and incompatible trials in cued compared to uncued trials. Relatedly, we expected the previously mentioned interaction to be modulated by the novelty of stimuli (Whitehead, Pfeuffer & Egner, 2020). Specifically, we expected the cueing x compatibility interaction to be present only, or more strongly, in novel trials, compared to repeated, given that the content component of the event file would be more critical for optimal behavior in the former case.

Methods

Raw data and analysis scripts for this experiment can be found at https://osf.io/5uesb/. The hypotheses and analysis plan were preregistered prior to data collection and can be found at https://aspredicted.org/blind.php?x=F3T_79L.

Participants

Sixty healthy volunteers participated in this experiment, although two of them were excluded from the analyses due to an error rate higher than 40% in regular and catch trials. Thus, the final sample size was 58 (43 female, mean age of 21.6 years, SD=2.79). We determined the sample size based on previous experiments using a similar spatial cueing paradigm (Martín-Arévalo, Chica & Lupiáñez, 2013; Lupiáñez, Martín-Arévalo & Chica, 2013; Martín-Arévalo, Botta, De Haro & Lupiáñez, 2021).

All participants were naïve students from the University of Granada with normal or corrected to normal vision, who gave their written informed consent, and received monetary compensation (5€/0.5 hour). 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).

Apparatus, stimuli and procedure

We conducted the experiment on a computer with an Intel Core i7-3770 CPU @ 3.40GHz x8 processor, connected to a 24 inches Benq XL2411T monitor with a 1920x1080 (16:9) pixel resolution and 350 cd/m² of brightness. 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 x 200 pixels, and the border of the box comprised an extra 10 pixels. The left box was located in the position (x = -250, y = 75) and the right one in (x= 250, y = 75). Inside of each placeholder an image of 200 x 200 pixels appeared. These images of animate (non-human animals) and inanimate (vehicles and instruments) items were compiled from different available databases (Brady et al., 2013, 2008; Brodeur et al., 2014; Griffin et al., 2006; Konkle et al., 2010), creating a pool of 1550 unique pictures (770 animate items, 780 inanimate). To increase perceptual similarity 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 x 175 pixels around the fixation point. Lastly, the target was one of the two images displayed at encoding.

The experiment consisted of a choice-reaction task embedded in an exogenous 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- with a duration of 1000 ms. Participants were instructed and trained to associate the image on the left with a left response and the image on the right with a right response. In 50% of the trials, these mappings (that is, the association of the specific stimulus and the response; S-R) were completely new and appeared only once throughout the experiment ("novel S-Rs"). In the remaining 50% of trials, the exact same S-R mappings appeared and thus we labeled them "repeated S-Rs". Immediately after the encoding screen, the peripheral non-predictive cue was presented for 50 ms in one of the two possible locations with equal probability (50%). This cue was completely non-predictive of which of the two stimuli would be later probed nor of the location of the target, but we expected it to nevertheless capture participants' attention exogenously, selecting both the cued location and the associated S-R. After the peripheral cue had disappeared, a fixation display was presented for 200-300ms. Additionally, in one of the two blocks, an IE would flash for 50 ms on the fixation point. In IE absent blocks, a fixation cross (without flash) was displayed for the same duration to warrant identical cue-target latencies across blocks. Another fixation display was then presented for 200-300ms. Then, a target image was displayed for 1200 ms in one of the two peripheral boxes with equal probability. Participants were instructed to provide the associated response learned at the beginning (encoding) of the trial by pressing the letter "D" (left) or "K" (right) on the keyboard, independently of its present location. This correspondence between the associated response and target location lead to either compatible or incompatible trials (i.e., whether or not the target position was compatible with its associated response).

In 5% of trials, a novel picture was shown as the target. In those cases, which we labeled “catch trials”, they were instructed to press both keys (“D” and “K”) at the same time. These trials were included in order to prevent participants from adopting a strategy 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 white, was 1000-1500ms in duration.

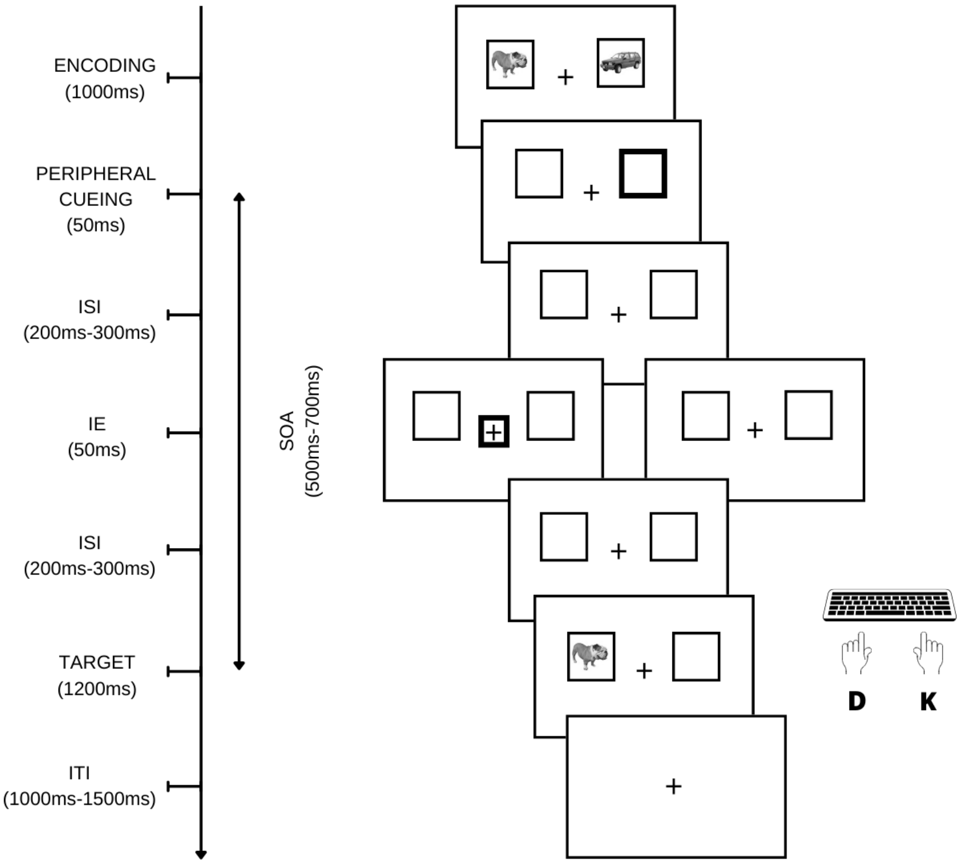

Figure 1.
Sequence of events in a given trial.

Participants completed 2 blocks, 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 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 total duration of the experiment was around 40 minutes.

Design

The experiment consisted of a 2x2x2x2 multifactorial design of four factors in which all variables were manipulated within participants. Two dependent variables were measured: RTs and accuracy, and four independent variables were manipulated throughout the experiment: cueing, novelty and compatibility (manipulated within trials), and IE (manipulated across blocks).

Cueing had two levels (cued vs. uncued location trials); the novelty of the stimuli had two levels as well; that is, S-Rs could be novel or repeated across trials because a pair of images was presented several times in the same location across the experiment Moreover, each trial could be compatible or incompatible, depending on whether or not the target appeared in a location congruent with the response or not; lastly, the IE had also two levels (present vs. absent), but in this case, they were manipulated across blocks (see Martín-Arévalo et al., 2013; 2021), with the order counterbalanced between participants.

Statistical analyses

Following the preregistered plan (https://aspredicted.org/blind.php?x=F3T_79L), to test our hypothesis, we performed a 2x2x2x2 repeated-measures ANOVA on the RTs with the factors defined in the previous section. Accuracy was taken into account to exclude participants with an error rate above 40%. Before performing the ANOVA, trials rejection was conducted by selecting only correct trials, filtering out catch trials, and by eliminating those trials in which the RTs were faster than 200 ms or longer than 1200 ms. All data processing and analyses were carried out with RStudio 2022.02.3 and JASP 0.14.0.0.

Results

Regarding main effects, the ANOVA (see Appendix A. for the full report) provided evidence that novelty had a an effect on RTs [*F*(1,57)=73.672, p<0.001, pes(η^2p)=0.564], with faster responses in repeated (M=594.96, SD=98.45) vs novel (M=630.22, SD=105.60) S-R mappings. Cueing also showed a significant effect [*F*(1,57)=6.57, p<0.013 pes=0.103], with faster responses on cued (M=609.09, SD=104.35) vs. uncued trials (M=616.09, SD=102.73), as well as compatibility [*F*(1,57)=122.418, p<0.001, pes=0.682], with faster responses in compatible (M=578.63, SD=89.20) vs. incompatible trials (M=646.55, SD=105.83). The main effect of IE, on the other hand, was not significant [*F*(1,57)=1.777, p=0.188, pes=0.030].

Regarding our first hypothesis, the ANOVA revealed a significant interaction between IE and cueing [*F*(1,57)=16.927, p<0.001, pes=0.229]. We then performed pairwise comparisons for these two factors. This analysis provided evidence for a significant difference between cued and uncued trials when the IE was absent [*F*(1,57)=-4.23, p=8.34e-05, p.adj=8.34e-05], with faster responses in cued (M=608, SD=104) vs. uncued trials (M=626, SD=101), observing the expected facilitatory effect. However, no statistically significant difference between cued and uncued trials was found when IE was present [*F*(1,57)=1.34, p=1.83e-01, p.adj=1.83e-01], therefore, not observing IOR effect (See Fig. 2).

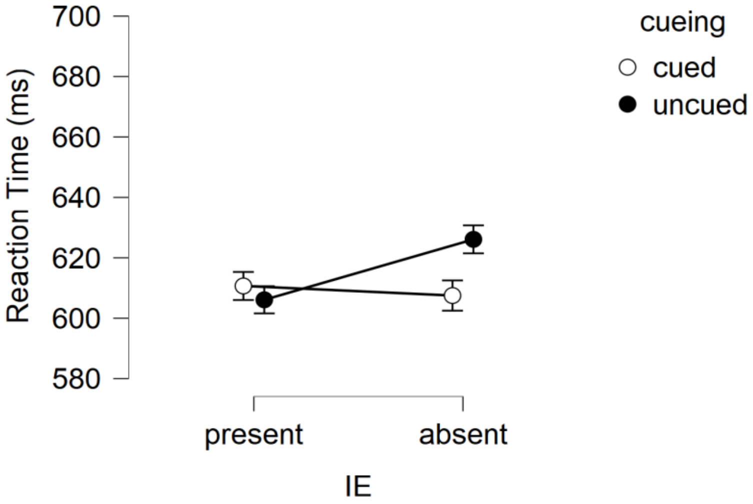

Figure 2.
Effects of the interaction between the presence of an intervening event (IE) and cueing on RTs.
Note. Error bars represent the standard error of the mean.

We also obtained evidence for the second hypothesis, which predicted an interaction between novelty and IE, [*F* (1,57)=5.657, p=0.021, pes=0.090]. More specifically, it was hypothesized that differences between novel and repeated S-Rs would be larger in no-IE than IE blocks. Pairwise comparisons revealed that, in the IE block, the difference between novel vs. repeated S-R mappings was significant [*F*(1,57)=5.97, p=1.61e-07, p.adj=1.61e-07], with faster responses in repeated (M=594, SD=98) vs. novel S-R mappings (M=623, SD=108). The same pattern of faster responses in repeated (M=596, SD=99.1) vs. novel S-R mappings (M=638, SD=103) could be seen, as well, in the IE absent block [*F*(1,57)=7.93, p=8.76e-11, p.adj=8.76e-11]. Importantly, as predicted, this difference between novel and repeated S-R mappings was higher in the IE absent block than in the IE present block (p=8.76e-11<p=1.61e-07) (See Fig. 3).

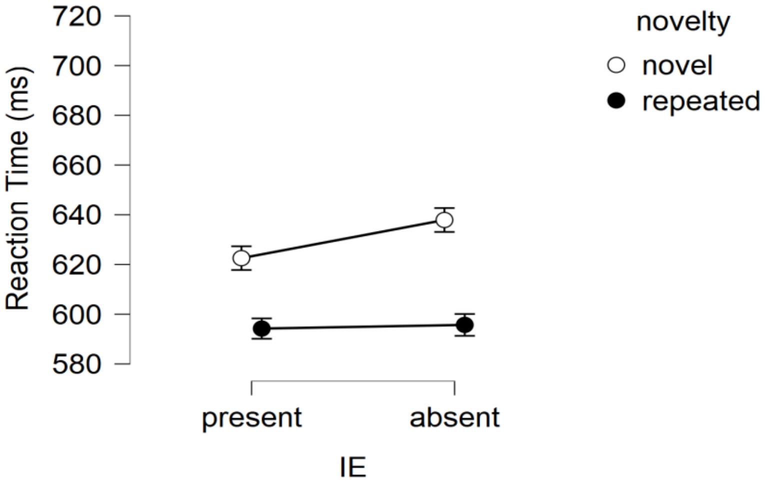

Figure 3.
Effects of the interaction between intervening events (IE) blocks and the novelty of S-R mappings on RTs. Note. Error bars represent standard error of the mean (s.e.m.).

Moreover, the ANOVA also explored our third hypothesis: the interaction between cueing and compatibility, although this effect didn’t turn out as significant, and therefore, we failed to reject the third null hypothesis [*F*(1,57)=3.300, p=0.075, pes=0.055] (See Fig. 4, and *Additional exploratory analyses* for further details).

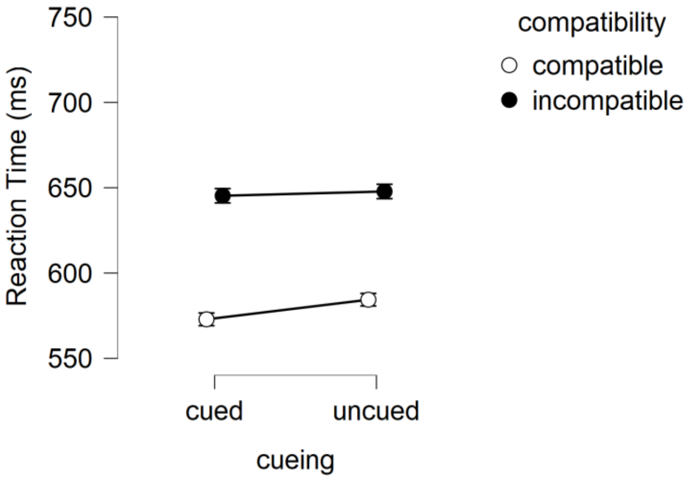

Figure 4.

Effects of cueing and compatibility on RTs. Note. Error bars represent standard error of the mean (s.e.m.).

The last hypothesis predicted a three-way interaction between novelty, cueing, and compatibility, expecting that the cueing and compatibility would only be present, or at least, more strongly, in novel trials compared to repeated trials. This effect was also not significant in the performed analysis [*F*(1,57)=0.075, p=0.786, pes=0.001], hence, we also failed to reject the forth null hypothesis.

Lastly, a non-hypothesized effect came out to be significant: there was an interaction between novelty and compatibility [*F*(1,57)=9.501, p=0.003, pes=0.143]. Both, novel [*F*(1,57)=-10.77, p=2.25e-15, p.adj=2.25e-15] and repeated mappings [*F*(1,57)=-9.56, p=1.89e-13, p.adj=1.89e-13] hosted a significant difference in compatible vs. incompatible trials according to the exploratory pairwise comparisons, with larger difference in RTs between compatible (M=592, SD=88.1) and incompatible trials (M=668, SD=108) in the novel vs repeated mappings [(M=565, SD=88.4) and (M=625, SD=99.1), respectively], (p=2.25e-15<p=1.89e-13) (See Fig.5).

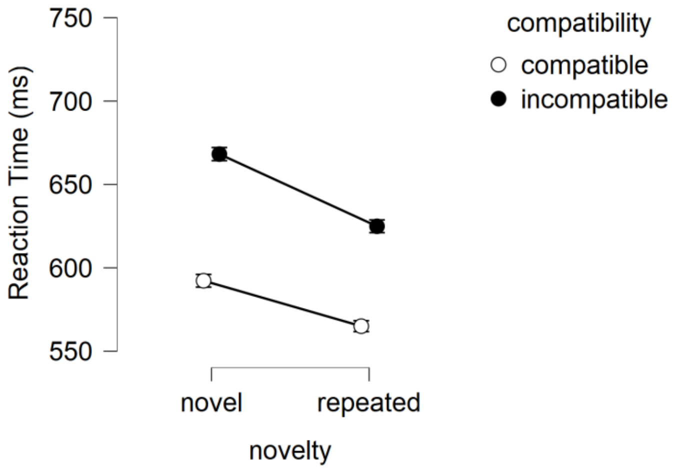

Figure. 5.

Effects of the interaction between novelty and compatibility on RTs.
Note. Error bars represent standard error of the mean (s.e.m.).

Additional exploratory analyses

Exploratory preregistered analyses:

Finally, for exploratory purposes, a repeated measures ANOVA on accuracy scores was performed (according to our preregistered analyses plan: https://aspredicted.org/blind.php?x=F3T_79L; See Appendix A for the full report of the ANOVA). Two main interactions turned out to be statistically significant: on the one hand, there was a significant interaction between IE and cueing [*F*(1,57)=5.072, p=0.028, pes=0.082]. The exploratory pairwise comparisons for this interaction revealed a significant difference between cued and uncued trials when the IE was absent [*F*(1,57)= 2.86, p= 0.006, p.adj= 0.006], with more accurate responses in cued (M=0.94, SD= 0.004) vs. uncued trials (M=0.92, SD=0.005), but no statistically significant difference between cued and uncued trials was found when IE was present [*F*(1,57)= 0.95, p= 0.95, p.adj= 0.95], as it was the case with RTs. On the other hand, the four-way interaction between novelty, intervening, cueing and compatibility also showed significant effects [*F*(1,57)=4.820, p=0.032, pes=0.078]. We didn't further explore this interaction, as we did not have hypotheses on this regard.

Regarding RT results, taking into account that the F value of the cueing x compatibility interaction (related to our third hypothesis) was higher than 1 and that the p value approached significance (*F*(1,57)=3.300, p=0.075), we decided to perform an exploratory Generalized Linear Mixed Model (GLMM) in order to further investigate the relationship between these two factors (See Appendix B for the full GLMM analyses and a detailed justification). Importantly, this finer-grained analysis provided evidence in line with Hypothesis 3, revealing a significant interaction effect between cueing and compatibility [X^2(1,*N*=58)=13.78,*p*=0.0002]. This interaction (see Figure 4) revealed a larger compatibility effect for cued (compatible: M=574, SD=89.9; incompatible: M=645, SD=105) than uncued S-Rs (compatible: M=584, SD=88.3; incompatible: M=648, SD=106), as it was expected.

Additionally, after taking a look and discussing the results of the experiment in depth, we realized that a different interpretation of the results could be that there was a pattern of facilitation from cued-compatible to uncued-incompatible trials, and a pattern of IOR from cued-incompatible to uncued-compatible trials. We then wondered if the compatibility variable was overlooking the effect of the cue on the object. That is, in our task, the cue selected space (left or right placeholder), but by default, it also selected the object that was previously presented in that location (See Appendix C. for an explanatory diagram). Therefore, we thought it might be more appropriate to consider the variable cueing as only "location cueing" and include "object cueing" as a new variable instead of compatibility. In this new "object cueing" variable, a target was considered cued if it matched the object associated to the location where the cue appeared, regardless of response compatibility. In contrast, a target was considered uncued if it did not match the object selected by the cue. As this was not preregistered, we performed a purely exploratory repeated measures ANOVA with these new variables conceptualization. First, there was a significant main effect of location cueing [*F*(1,57)=6.567p=0.013, η2p=0.0682], with faster responses in cued (M=609.09, SD=96.27) vs. uncued trials (M=616.1,SD=95.78). Second, the ANOVA revealed a statistically significant and robust interaction between location cueing and object cueing [*F*(1,57)=122.418, $p<0.001$, η2p=0.0682] (See Appendix C. for full ANOVA report). Crucially, facilitation and IOR effects became evident. Namely, participants were faster for trials in which both the object and the spatial location of the target were cued (M=572.9, SD=89.161) compared to trials in which the location of the target was cued but not the object (M=645.3, SD=103.392) [*F*(1,57)=4.823, $p_{holm}<0.001$]. On the other hand, RTs were slower for trials in which the target object was cued but not the target location (M=647.8, SD=104.420) compared to trials where neither the target object, nor the target location were cued (M=584.4, SD=87.143) [*F*(1,57)=-5.863, $p_{holm}<0.001$] (See Fig. 2. in Appendix C.). Moreover, IE only interacted significantly with location cueing [*F*(1,57)=16.927, $p<0.001$, η2p=0.229]. In IE present trials, responses were slightly faster to targets displayed in uncued locations (M=606.096, SD=98.039) vs. cued locations (M=610.682, SD=97.260) although this difference was not statistically significant [*F*(1,57)=-0.057, $p_{holm}=1.000$]. In IE absent trials, the effect was the opposite, responses were significantly faster in cued (M=607.503, SD=95.263) vs. uncued trials (M=626.102, SD=93.525) [*F*(1,57)=2.997, $p_{holm}=0.020$]. Regarding object cueing, IE didn't significantly interact with this factor [*F*(1,57)=0.104, p=0.749, η2p=0.002]. Finally, the three way interaction of novelty, location cueing and object cueing was also significant [*F*(1,57)= 9.501, p=0.003, η2p=0.143], revealing that the location x object cueing interaction was stronger for novel S-Rs.

Discussion

The present results provide evidence that, besides the initial conception of exogenous attention as a "flashlight" in the spatial domain, exogenous attention seems to interact not only with space but with multiple components of the so-called "event files". Specifically, in a task that capitalized on WM contents, the typical facilitatory effect under relatively short SOAs (500-700ms) was observed, just like in the classical spatial cueing paradigm (Martín-Arévalo, Chica, & Lupiáñez, 2013; Martín-Arévalo et al., 2016; 2021). Moreover, there was an interaction between IE and novelty, suggesting that the hypothesized metacontrol state induced by the IE also interacted with the content maintained in WM. Lastly, we found some preliminary evidence of the effects of exogenous attention on WM contents, suggesting that peripheral non-predictive cues seem to also select and prioritize WM contents.

As expected, the observed facilitatory effect was found in the IE absent block, which was thought to induce a persistent metacontrol state (Martín-Arévalo et al., 2021; Hommel, 2019), and therefore, cognitive and behavioral exploitation, and in turn, faster responses in cued trials. On the other hand, IOR was not seen in this case, which was expected in the IE present block. We predicted IEs to induce a flexible metacontrol state, and therefore, cognitive and behavioral exploration, resulting in faster responses in uncued trials. The absence of this IOR effect can be explained by several factors: first, it is important to take into account the difficulty/demands of the current task, which is more demanding than the classical tasks in which this effect has been seen; secondly, the SOAs have proven to play an important role in the appearance of this effect, while facilitation is associated with short SOAs, IOR tends to appear with longer SOAs (Chica et al., 2014), especially in discrimination tasks (Lupiáñez et al., 1997). Thus, taking these two considerations into account, although we used a SOA (500-700ms) wherein facilitation and IOR was previously observed depending on the presence or absence of an IE, respectively (Martín-Arévalo et al. 2014; 2016), the higher difficulty/demands of the current task as compared to previous discrimination tasks (Martín-Arévalo et al. 2014; 2016), can explain the absence of IOR here, wherein larger SOA could be more appropriate to observe this IOR effect. Given the nature of the task, it is also possible that varying the SOA duration might not suffice to induce IOR and that additional manipulations might be considered. In any case, our results provide evidence that, with an exogenous retro-cueing paradigm that capitalizes on WM contents, cueing effects can be modulated by manipulating the IE.

Similarly, the effect of IE, which was purely spatial and did not carry any associated content, also interacted with WM contents. Under the hypothesized persistent metacontrol state (Hommel, 2019) induced in IE absent blocks, 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. These results provide initial evidence for a relationship between exogenous attention and WM contents supported by event files that contain not only spatial but also all relevant information together: cue, location, content, metacontrol state, goals, etc.

In this regard, we obtained mixed evidence for the hypothesis that cued contents would be accessed faster. The preregistered analysis did not show significant results (p=0.075). However, when the results were analyzed with a more adequate model (GLMM), a significant interaction was found. These results connect again with the concept of event file in which all the elements of the task are included and interconnected within (Hommel, 2019). It is thus conceivable than when a peripheral cue flashes at a particular spatial location, attentional selection does not only concern that spatial location, but all the associated components from the event file. Interestingly, these results hint at a potential prioritization of WM contents selected by exogenous attention. This extends previous findings from the endogenous attention domain (pon aquí las referencia de Myers) and, importantly, suggests that peripheral, non-predictive cues might have a qualitatively similar effect on WM content selection.

In order to further explore the effect of the cue on the object itself, we ran additional exploratory analyses considering location and object cueing separately. Under this new conceptualization of our experimental variables, we obtained an interesting pattern of results in which the responses were the fastest when both location and object were cued or when none of them was cued. In contrast, participants were slower when one out of the elements was not cued. This could again be explained with the concept of event file, given that, in the trials in which both location and object were cued, the response coincided fully with the encoded event file and, therefore, led to a fast response. In the case in which neither the location nor the object were cued, the whole cued event file could be rejected, which would take more time than the previous instance but not too long. Lastly, it could be the case that the cued event file would be partially adequate for the response, which is the occasion of a cued location but not cued object or vice versa. These situations that require to partially update the event file seem to be the costliest ones. This pattern resonates with what is referred to in the literature as *partial repetitions costs*, defined by Hommel (2004) as a result pattern in which repeating some but not all features of an event produces worse performance than repeating all or none of the features. Similar effects have been reported in many other domains, like in priming studies with many different type of tasks (Zehetleitner, Rangelov, & Müller, 2012; Mayr et al., 2011; Sohn & Anderson, 2003). Altogether, our results highlight the ubiquity of event files and suggest that a conceptualization of these as representations that go beyond spatial information will be important to better characterize the relation between WM and exogenous attention.

Importantly, this experiment capitalized in a new task that slightly departs from paradigms traditionally used in the literature, making replication key to ensure that the reported effects are robust. In this regard, we are currently running a second experiment with longer SOAs in order to look for the appropriate metacontrol state under which IOR is observable (https://aspredicted.org/4ps5w.pdf), in which the preliminary pattern of results is very similar, suggesting that we will be able to replicate the results with the full sample. Furthermore, for future studies we think it would be crucial to study in depth the new proposed conceptualization in which we established two new variables, object cueing and location cueing in order to fully understand this relationship. On top of that, we would also be interested in exploring if the novelty of the stimuli, when blocked, might be able to induce metacontrol states just like it was achieved with the IE in this experiment. This could mean that the same metacontrol states can be achieved through different routes, some of which are completely independent from the spatial domain.

Conclusion

Several concluding remarks can be provided. First, these results provide evidence that exogenous attention seems to select and prioritize both space and WM content. This challenges the way in which past research on exogenous attention has been conceptualized and interpreted. In fact, cueing effects can affect the way content is integrated. Moreover, metacontrol states can be induced by task elements like IE and lead to different patterns of results depending on how exploitative or explorative the task setting is. Lastly, event files seem to encompass all relevant elements of the trial and not only space. This association between metacontrol state, cue, target element, location, etc. is meant to facilitate our interaction with the stimuli we encounter in the environment, although it also has its drawbacks, such as situations in which some information might activate the irrelevant event file. Nevertheless, it is essential to mention that this is a growing field in which more empirical research is needed, as well as, theoretical paradigms and interpretations in order to make critical assumptions.

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Appendix A. ANOVAs

Table 1.

Preregistered ANOVA on RTs.

	DFn	DFd	F	p	p<.05>	pes
novelty	1	57	73.672	0.000	*	0.564
intervening	1	57	1.777	0.188		0.030
cueing	1	57	6.567	0.013	*	0.103
compatibility	1	57	122.418	0.000	*	0.682
novelty:intervening	1	57	5.657	0.021	*	0.090
novelty:cueing	1	57	0.376	0.542		0.007
intervening:cueing	1	57	16.927	0.000	*	0.229
novelty:compatibility	1	57	9.501	0.003	*	0.143
intervening:compatibility	1	57	0.064	0.802		0.001
cueing:compatibility	1	57	3.300	0.075		0.055
novelty:intervening:cueing	1	57	0.075	0.786		0.001
novelty:intervening:compatibility	1	57	0.163	0.688		0.003
novelty:cueing:compatibility	1	57	0.047	0.830		0.001
intervening:cueing:compatibility	1	57	0.104	0.749		0.002
novelty:intervening:cueing:compatibility	1	57	1.143	0.290		0.020

Table 2.

Exploratory ANOVA on Accuracy Scores.

	DFn	DFd	F	p	p<.05>	pes
novelty	1	57	21.262	0.000	*	0.272
intervening	1	57	3.718	0.059		0.061
cueing	1	57	3.997	0.050		0.066
compatibility	1	57	35.981	0.000	*	0.387
novelty:intervening	1	57	0.839	0.364		0.015
novelty:cueing	1	57	0.780	0.381		0.014
intervening:cueing	1	57	5.072	0.028	*	0.082
novelty:compatibility	1	57	0.292	0.591		0.005
intervening:compatibility	1	57	0.646	0.425		0.011
cueing:compatibility	1	57	1.308	0.257		0.022
novelty:intervening:cueing	1	57	1.045	0.311		0.018
novelty:intervening:compatibility	1	57	0.195	0.660		0.003
novelty:cueing:compatibility	1	57	0.000	0.991		0.000
intervening:cueing:compatibility	1	57	0.111	0.740		0.002
novelty:intervening:cueing:compatibility	1	57	4.820	0.032	*	0.078

Appendix B. Exploratory GLMM analyses

Generalized Linear Mixed Model (GLMM) - justification and analyses:
Just like in many other psychological investigations, in this experiment, RTs were used as a way to investigate unobservable mental processes, an approach referred to as "mental chronometry" (Posner, 1978). This implies that mental processes take time to complete and that each measured RT reflects a composite of several distinct stages of processing (Lo & Andrews, 2015). However, it is important to highlight that RTs from simple decision tasks have an invariably positively skewed distribution which can be overlooked by traditional ANOVA analyses due to its robustness to violations of normality (Glass et al., 1972; Harwell et al., 1992; Lix et al., 1996). As a consequence, Lo and Andrews (2015) argue that raw RT is the most appropriate metric for the assumptions derived as part of the "mental chronometry approach" because if the data is previously transformed it can behave differently when it is analyzed. These authors highlight the benefits of implementing GLMM because the mathematical and theoretical components of the model are separated and, therefore, GLMM allow researchers to use the dependent variable that is most appropriate to their research question, while simultaneously meeting the mathematical criterion of normalized, homoscedastic residuals in linear regression.

Consequently, two GLMM were carried out, one with RTs and another with the accuracy scores, in order to explore if the obtained results would be finer grained with raw data than with the transformed data included in the ANOVA.

GLMM on RT: to create the GLMM, the four main independent variables (IE, cueing, compatibility and novelty) were computed as fixed factors and two variables were chosen as random factors (trial and subject). The Inverse Gaussian distribution was chosen to best capture the properties of our main dependent variable (RTs) as it can reasonably provide a description of the processes reflected in this variable (Lo & Andrews, 2015). Lastly, the identity link function was implemented because in this experimental paradigm it is assumed that manipulations will directly affect RT rather than some function of it. Table 1. reveals the results from the analysis of deviance of the model on RTs.

The three main interaction effects found with the preregistered ANOVA were also present in this analysis, that is: IE x cueing [X^2(1,N=58)=27.18,p=1.851e-07], IE x novelty [X^2(1,N=58)=16.34,p=5.279e-05] and novelty x compatibility [X^2(1,N=58)=8.03,p=0.0045]. Importantly, the interaction effect hypothesized in the third hypothesis (cueing x compatibility) which was not significant in the previous analysis, did show a significant effect in the analysis of deviance of the GLMM [X^2(1,N=58)=13.78,p=0.0002]. See Tables 2-5 for the specific post-hoc analyses.

Table 1.

Analysis of Deviance of RTs on GLMM (Type III Wald chisquare tests).

	Chisq	Df	Pr(>Chisq)
(Intercept)	20389,6345	1	<2.2e-16***
intervening	18,4962	1	0,00001702***
cueing	14,1591	1	0,000168***
compatibility	925,8007	1	<2,2e-16***
novelty	218,0785	1	<2,2e-16***
intervening:cueing	27,1823	1	1,85E-07***
intervening:compatibility	0,123	1	0,7258472
cueing:compatibility	13,7839	1	0,0002051***
intervening:novelty	16,3453	1	5,28E-05***
cueing:novelty	0,0013	1	0,9712034
compatibility:novelty	8,0334	1	0,0045923**
intervening:cueing:compatibility	3,1222	1	0,0772342*
intervening:cueing:novelty	0,131	1	0,7173842
intervening:compatibility:novelty	0,9079	1	0,3406623
cueing:compatibility:novelty	0,1268	1	0,7217252
intervening:cueing:compatibility:novelty	1,6602	1	0,1975721

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table 2.

Post-hoc comparisons GLMM intervening x cueing.

contrast	estimate	SE	df	z.ratio	p.value	holm	sign
intervening cued – intervening uncued	2,9064	2,792076	Inf	1,040946	0,7253269	0,7253269	NS
(no-intervening cued) - (no-intervening uncued)	-17,96678	2,868453	Inf	-6,263577	2,2565E-09	4,513E-09	***

Table 3.

Post-hoc comparisons cueing x compatibility.

contrast	estimate	SE	df	z.ratio	p.value	holm	sign
cued compatible - uncued compatible	-14,96069019	2,57324	Inf	-5,81394988	3,66E-08	7,31E-08	***
cued compatible - cued incompatible	-68,33844521	2,801682	Inf	-24,391937	0,00E+00	0,00E+00	***
cued compatible - uncued incompatible	-68,43813195	2,812676	Inf	-24,3320356	0,00E+00	0,00E+00	***
uncued compatible - cued incompatible	-53,37775502	2,848257	Inf	-18,7405011	0,00E+00	0,00E+00	***

uncued compatible - uncued incompatible	-53,47744176	2,859361	Inf	-18,702584	0,00E+00	0,00E+00	***
cued incompatible - uncued incompatible	-0,09968674	3,065796	Inf	-0,03251578	1,00E+00	1,00E+00	NS

Table 4.

Post-hoc comparisons intervening x novelty.

contrast	estimate	SE	df	z.ratio	p.value	holm	sign
intervening novel - (no-intervening novel)	-16,6817759	2,954711	Inf	-5,6458225	9,8474E-08	1,96948E-07	***
intervening novel - intervening repeated	21,4722501	2792108	Inf	7,69033524	1,118E-13	4,47198E-13	***
intervening novel - (no-intervening repeated)	20,9785312	2795448	Inf	7,504532	3,96017E-13	1,18805E-12	***
(no-intervening novel) - intervening repeated	38,154026	2859545	Inf	13,3426896	0.00e+00	0.00e+00	***
(no-intervening novel) - (no-intervening repeated)	37,6603072	2,870066	Inf	13,1217545	0.00e+00	0.00e+00	***
intervening repeated - (no-intervening repeated)	-0,4937189	2,694515	Inf	-0,1832311	0,9978181	0,9978181	NS

Table 5.

Post-hoc comparisons compatibility x novelty.

contrast	estimate	SE	df	z.ratio	p.value	holm	sign
novel compatible - repeated compatible	23,8918256	2,575174949	Inf	9,277749	4,2188E-14	4,2188E-14	***
novel compatible - novel incompatible	-66,5824	2,958703	Inf	-22,503911	0,00E+00	0,00E+00	***
novel compatible - repeated incompatible	-31,34166	2,790182	Inf	-11,232839	7,9936E-15	1,5987E-14	***
repeated compatible - novel incompatible	-90,47422	2,871596	Inf	-31,506599	0,00E+00	0,00E+00	***
repeated compatible - repeated incompatible	-55,23349	2,697535	Inf	-20,475541	0,00E+00	0,00E+00	***
novel incompatible - repeated incompatible	35,24073	3,066247	Inf	11,493118	0	0	***

Ultimately, in order to make sure that the model that was created was the fittest, a second GLMM was created with the same fixed factors, distribution and link but with only one random factor (subject). To implement the comparison, an ANOVA between the two models was carried out. The first model significantly outperformed the second model [X^2(1,N=58)=269.6,p<2.2e-16]. See Table 6. for the whole ANOVA table.

Table 6.

ANOVA comparing the two proposed models (glmmRT, glmmRT2).

	npar	AIC	BIC	logLik	deviance	Chisq	Df	Pr(<Chisq)
glmmRT2	18	238080,8	238222	-119022,4	238044,8	NA	NA	NA
glmmRT	19	237813,2	237962,3	-118887,6	237775,2	269,5984	1	1,39E-60

GLMM on Accuracy scores: to create the GLMM, the four main independent variables (IE, cueing, compatibility and novelty) were computed as fixed factors and two variables were chosen as random factors (trial and subject). The binomial distribution was chosen to best capture the properties of our main dependent variable, given that it is based on binary responses. Lastly, the logit link function was implemented because it is commonly used with binomial distributions. Table 7. reveals the results from the analysis of deviance of the model on Accuracy Scores. In this case, regarding the interaction effects, the two same effects that turned out to be significant in the ANOVA, were also statistically significant in this analysis: IE x cueing [X^2(1,N=58)=4.32,p=0.037] and the four way interaction between IE, cueing, compatibility and novelty [X^2(1,N=58)=5.16,p=0.023].

Table 7.

Analysis of Deviance of Accuracy Scores on GLMM (Type III Wald chisquare tests).

	Chisq	Df	Pr(>Chisq)
(Intercept)	924,1619	1	<2,2e-16 ***
intervening	3,5671	1	0,05894
cueing	4,4022	1	0,03589*
compatibility	115,5456	1	<2,2e-16***
novelty	43,8282	1	0,035851*
intervening:cueing	4,3272	1	0,03751*
intervening:compatibility	0,0023	1	0,96206
cueing:compatibility	0,0063	1	0,93688
intervening:novelty	0,2779	1	0,59808

cueing:novelty	3,1095	1	0,07783
compatibility:novelty	0,2091	1	0,6475
intervening:cueing:compatibility	0,0766	1	0,78193
intervening:cueing:novelty	1,6451	1	0,19963
intervening:compatibility:novelty	0,4028	1	0,52565
cueing:compatibility:novelty	2,3527	1	0,12506
intervening:cueing:compatibility:novelty	5,1645	1	0,02305*

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix C. Alternative variable conceptualization

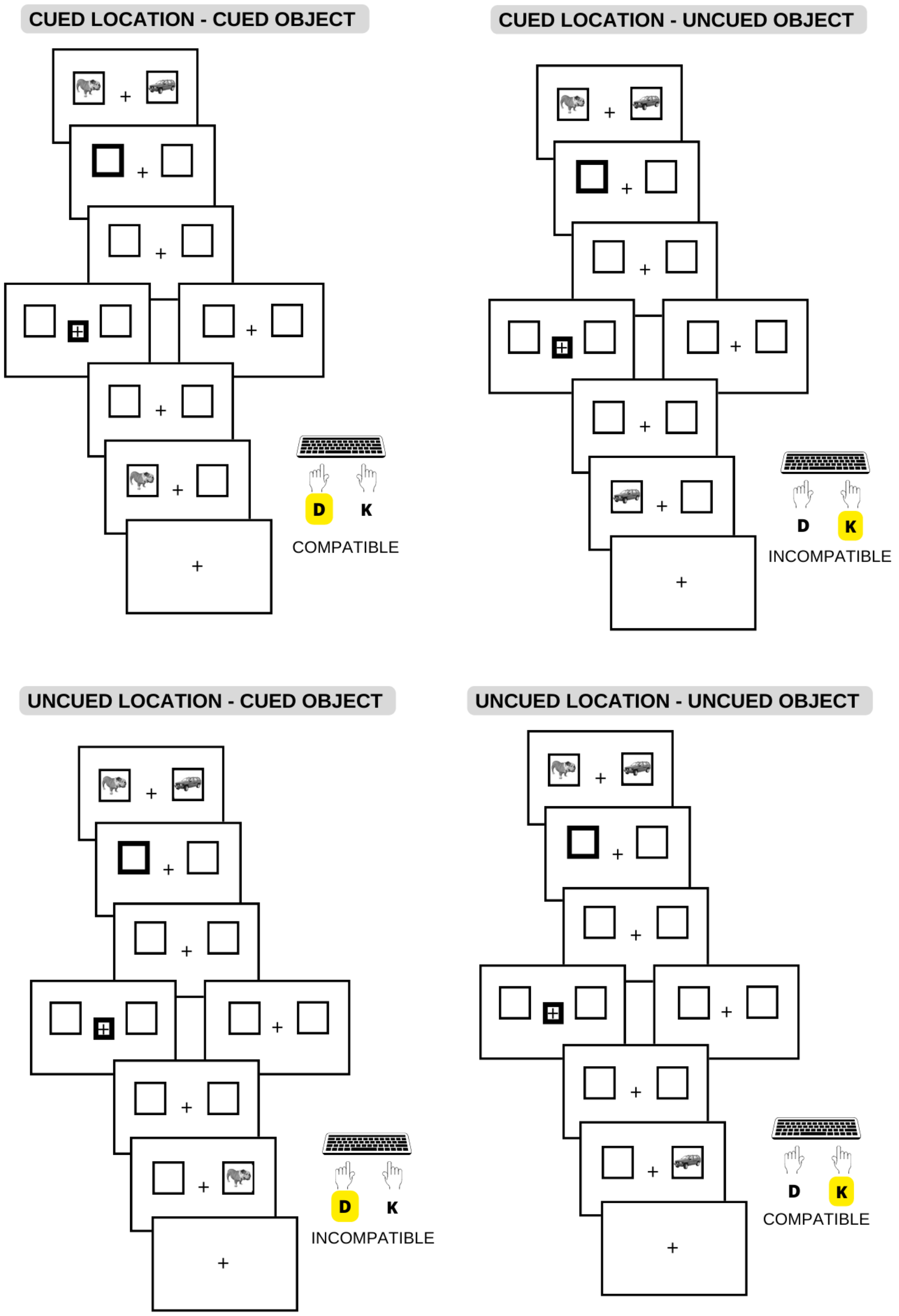

Figure 1.

Diagram of the possible levels of the variables “location cueing” and “object cueing”.

Table 1.

Repeated measures ANOVA with the alternative variable conceptualization.

	Sum of Squares	Df	Mean Square	F	P	η^2_p
novelty	288520.391	1	288520.391	73.672	< .001	0.564
IE	16423.772	1	16423.772	1.777	0.188	0.030
location cueing	11390.252	1	11390.252	6.567	0.013	0.103
object cueing	4682.313	1	4682.313	3.300	0.075	0.055
novelty ∗ IE	11172.806	1	11172.806	5.657	0.021	0.090
novelty ∗ location cueing	394.466	1	394.466	0.376	0.542	0.007
IE ∗ location cueing	31178.244	1	31178.244	16.927	< .001	0.229
novelty ∗ object cueing	41.552	1	41.552	0.047	0.830	8.178e -4
IE ∗ object cueing	108.277	1	108.277	0.104	0.749	0.002
location cueing ∗ object cueing	1.070e +6	1	1.070e +6	122.418	< .001	0.682
novelty ∗ IE ∗ location cueing	67.974	1	67.974	0.075	0.786	0.001
novelty ∗ IE ∗ object cueing	960.888	1	960.888	1.143	0.290	0.020
novelty ∗ location cueing ∗ object cueing	14907.975	1	14907.975	9.501	0.003	0.143
IE ∗ location cueing ∗ object cueing	94.264	1	94.264	0.064	0.802	0.001
novelty ∗ IE ∗ location cueing ∗ object cueing	189.885	1	189.885	0.163	0.688	0.003

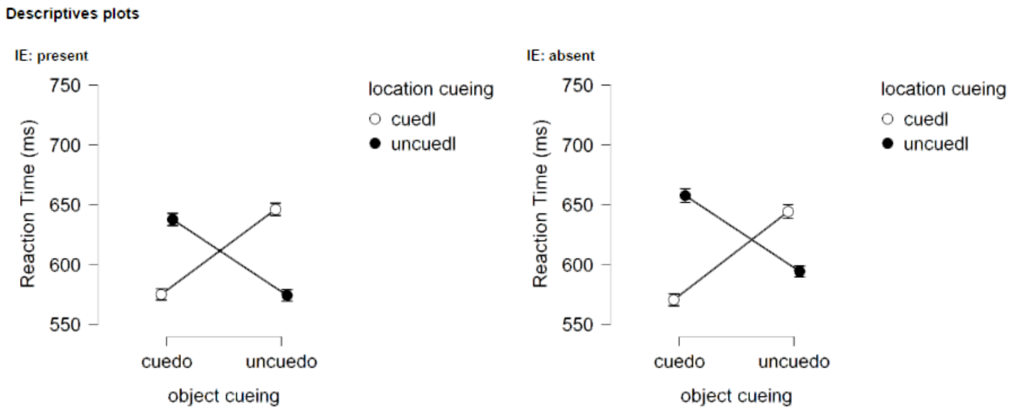

Figure 2.

Interaction effects between “object cueing” and “location cueing” when an intervening event (IE) is present vs. absent.