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Learned predictiveness acquired through experience prevails over the influence of conflicting verbal instructions in rapid selective attention

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26 **Abstract**

27 Previous studies have provided evidence that selective attention tends to prioritize the
28 processing of stimuli that are good predictors of upcoming events over nonpredictive stimuli.
29 In the present study we explored whether the mechanism responsible for this effect critically
30 reflects the influence of prior *experience* of predictiveness (history of attentional selection of
31 predictive stimuli), or whether it reflects a more flexible process that can be adapted to new
32 verbally acquired knowledge. Our experiment manipulated participants' experience of the
33 predictiveness of different stimuli over the course of trial-by-trial training; we then provided
34 explicit verbal instructions regarding stimulus predictiveness that were designed to be either
35 consistent or inconsistent with the previously established learned predictiveness. The effects
36 of training and instruction on attention to stimuli were measured using a dot probe task.
37 Results revealed a rapid attentional bias towards stimuli experienced as predictive (versus
38 those experienced as nonpredictive), that was completely unaffected by verbal instructions.
39 This was not due to participants' failure to recall or use instructions appropriately, as revealed
40 by analyses of their learning about stimuli, and their memory for instructions. Overall, these
41 findings suggest that stimuli experienced as predictive through trial-by-trial training produce
42 a relatively inflexible attentional bias based on prior selection history, which is not (always)
43 easily altered through instructions.

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45

46 **Keywords:** Attention, learned predictiveness, experienced predictiveness, spatial cueing,
47 selective attention.

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48 **Introduction**

49 Attention and predictive learning are intimately related in a bidirectional way. On the
50 one hand, we learn more from attended stimuli than from unattended stimuli that are present
51 concurrently in the environment [1-3]: That is, attention influences learning. On the other
52 hand, learning about the *predictiveness* of stimuli has been shown to play an important role in
53 determining how people subsequently allocate attention to those stimuli: That is, learning
54 influences attention. A predictive stimulus is one that is a consistent and reliable indicator of
55 the events that follow it, whether these events refer to presence of an outcome (e.g., electric
56 shock) or its absence (no shock). A nonpredictive cue is one that provides no information
57 regarding the events that follow it (e.g., a stimulus that is sometimes followed by shock, and
58 sometimes by no shock). A wide range of studies has provided evidence consistent with the
59 idea that people tend to allocate more attention to predictive stimuli than nonpredictive
60 stimuli (see, for example, [1, 2, 4-6], for a review, see [7]).

61 Having established a relationship between learned predictiveness and attention, the
62 next step is to determine the nature of the attentional process(es) that underlie this
63 relationship.

64 One possibility is that the effect of predictiveness on attention reflects an effect of
65 *selection history* [8, 9]. On this account, people learn that attending to predictive stimuli is
66 advantageous, since it allows them to make accurate predictions about future events; in
67 contrast, attending to nonpredictive stimuli is less useful since these stimuli do not allow
68 accurate predictions to be made. As a result of this learning, people become more likely to
69 select predictive stimuli than nonpredictive stimuli. Repeated experience of selecting
70 predictive stimuli then induces an attentional bias towards these stimuli, which persists when
71 they are encountered in future.

72 An alternative (though not mutually exclusive) possibility is that attentional biases

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73 towards predictive stimuli reflect the operation of relatively flexible attentional processes that
74 are based on participants' explicit knowledge regarding the current predictive value of
75 stimuli, with this explicit knowledge arising through a process of inferential reasoning [10].

76 The critical difference between these two accounts relates to the information that
77 drives the attentional bias. According to the selection history account, it is participants'
78 *experience* of the different utility of selecting predictive versus nonpredictive stimuli that
79 determines the bias. On the 'flexible processes' account, it is participants' explicit knowledge
80 regarding the predictive status of stimuli that is critical; this explicit knowledge will be
81 influenced by past experience of the consequences of selecting stimuli, but will also be
82 influenced by verbally acquired knowledge independently of direct experience. This
83 distinction thus raises the question: To what extent do effects of predictiveness on attention
84 reflect an influence of experience (i.e., trial-by-trial training) versus an influence of verbal
85 information? Below we review existing evidence on this issue that has produced mixed
86 results, before describing a new experiment that aims to shed light on previous discrepancies.

87 The findings of a study by Mitchell et al. in 2012 [10] show that the allocation of
88 attention to stimuli can be flexibly altered through verbal instructions. In their Experiment 2,
89 participants underwent a first learning phase which established certain stimuli as predictive of
90 the particular outcome that would occur on a trial, while other stimuli did not predict which
91 outcome would occur (i.e., these latter stimuli were nonpredictive). Participants then
92 completed a second learning phase during which all stimuli were paired with new outcomes.
93 Importantly, immediately prior to this second phase, participants received instructions.
94 Participants in the *Continuity* condition were told that those stimuli which had been
95 predictive in Phase 1 would continue to be predictive in Phase 2, and those which had been
96 nonpredictive would continue to be nonpredictive. Participants in the *Change* condition were
97 told that stimuli which had been predictive in Phase 1 would now be nonpredictive, and vice

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98 versa. Mitchell et al. used eye-tracking to monitor overt attention to stimuli during Phase 2, in
99 terms of dwell time – the length of time for which participants looked at each stimulus on
100 each trial. Participants in the Continuity condition recorded longer dwell time on (i.e.,
101 attended more to) stimuli which had previously been predictive in Phase 1 than those which
102 had been nonpredictive. In contrast, participants in the Change condition attended more to
103 stimuli that had been non-predictive in Phase 1 than to stimuli that had been predictive.
104 Judgments about the new stimulus-outcome relationships that were learned during Phase 2
105 also revealed that, in each condition, more was learned about the more-attended stimuli than
106 about the less-attended stimuli.

107 Thus Mitchell et al.'s study [10] demonstrated a flexible influence of verbalisable
108 knowledge on participants' pattern of attention to predictive and nonpredictive stimuli.
109 According to Mitchell et al.'s proposal, learners infer that stimuli that have been predictive of
110 certain outcomes in a previous learning situation are also likely to be predictive of other
111 outcomes in similar learning situations in future. This causal inference then leads learners to
112 pay more attention to such stimuli through cognitive control processes that can be flexibly
113 adapted on the basis of verbal instructions about the current predictive value of stimuli, in the
114 absence of further training (i.e., trial-by-trial experience of predictive relationships). Mitchell
115 et al. argued that their data suggested that attentional processes based on selection history,
116 such as those envisaged by associative learning theories (e.g., [11,12]), were unlikely to play
117 any role in the effect of learned predictiveness on selective attention. This is because such
118 theories would predict the prioritization, during Phase 2, of stimuli that had previously been
119 *experienced* as predictive in Phase 1, regardless of verbal instructions (but see [13, 14], for
120 conflicting evidence – an issue which we take up again in the General Discussion).

121 However, absence of evidence is not evidence of absence. It is possible that learning
122 about predictiveness engages attentional processes based on both explicit knowledge and

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123 selection history, but that the particular measure of attention used by Mitchell et al. (gaze
124 dwell time) was insensitive to the influence of selection history. Previous evidence suggests
125 that effects of selection history are often relatively rapid and inflexible [7, 8]. Hence it
126 remains possible that initial, rapid attentional orienting is influenced primarily by experience
127 of predictiveness (i.e., by selection history), but that this initial experience-driven bias is
128 subsequently overridden by a more flexible attentional control process based on explicit
129 knowledge and reasoning – and it is this latter process that dominates in Mitchell et al.’s
130 dwell time measure. Consistent with this possibility, Mitchell et al.’s dwell time measure
131 summed gaze over a relatively long period (around 1 sec) and hence would be open to
132 influence by relatively slow attentional processes. Moreover, whereas attention and eye
133 movements are generally quite tightly coupled [15], it is possible for rapid shifts of attention
134 to occur *covertly*; that is, in the absence of eye movements. Such covert attentional shifts
135 would not be captured by eye-tracking. Thus it is possible that, even in the Change condition
136 of Mitchell et al.’s study, there may have been a rapid (and possibly covert) attentional bias
137 towards the stimulus that had been predictive during Phase 1, driven by selective history.
138 This rapid bias may then have been followed by a second stage of overt attention to the
139 previously-nonpredictive stimulus in line with verbal instructions that this stimulus would
140 now be predictive, and it is this latter process that would be most evident in the dwell time
141 measure used in this study.

142 In support of this explanation, recent evidence suggests that experienced
143 predictiveness can indeed produce rapid attentional bias. Le Pelley, Vadillo, and Luque in
144 2013 [16] (see also [17]) trained participants on a task in which a pair of stimuli (coloured
145 shapes)—known as a stimulus compound—appeared on each trial, with one stimulus on the
146 left side of the screen, and the other on the right. Participants had to learn to make one of two
147 button-press responses. One of the stimuli presented on each trial predicted the correct

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148 response, while the other was nonpredictive, much as in the study by Mitchell et al. [10].
149 However, in this case attention to the stimuli was measured using a *dot probe task* [18],
150 which is based on the idea that detection of a target will be faster if that target appears in an
151 attended location than in an unattended location.

152 On each trial of the dot probe task in Le Pelley et al.'s study [16], participants were
153 shown (briefly) one of the stimulus compounds that had been experienced during training.
154 After a short stimulus-onset asynchrony (SOA) of 250 ms, a dot (the probe) could appear at
155 the location of one of the two stimuli. Participants were required to respond to the appearance
156 of the probe as quickly as possible. Importantly, across trials of the test phase the probe was
157 equally likely to appear in the location of (that is, be cued by) the stimulus that had been
158 predictive during the training phase as it was to be cued by the nonpredictive stimulus. Hence
159 there was no advantage to be gained in directing attention to either location prior to probe
160 presentation. Indeed, participants were explicitly informed that in order to respond to the
161 probe as quickly as possible, their best strategy was to ignore the initially presented stimuli.

162 Despite this instruction, responses to the probe were significantly faster when it was
163 cued by the predictive stimulus than when it was cued by the nonpredictive stimulus,
164 suggesting that participants had rapidly oriented their attention to the location of the
165 predictive stimulus prior to the appearance of the probe. Notably, Le Pelley et al. [16]
166 demonstrated that providing more time for participants to process the stimuli—by increasing
167 the SOA on dot probe trials to 1000 ms—significantly *weakened* the influence of
168 predictiveness on dot probe responding. Consistent with the argument that we advanced
169 earlier, these findings demonstrate that rapid attentional biases that can be detected at short
170 SOAs might go undetected in tasks that measure the deployment of attention over longer
171 periods of time, including on the timescale of the measure used by Mitchell et al. (~1 sec).

172 In general terms, our hypothesis is that rapid attentional bias towards previously

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173 predictive stimuli is primarily determined by selection history, and relatively immune to the
174 effect of instructions. To test this hypothesis, we conducted an experiment similar to Mitchell
175 et al.'s Experiment 2 [10] but using a dot probe task (with short SOA) to measure rapid—and
176 potentially covert—attention to stimuli. During Phase 1, some stimuli were trained as
177 predictive of the correct categorization responses while others were nonpredictive. During
178 Phase 2, participants learned new categorization responses. Immediately before this second
179 phase, participants received continuity or change instructions regarding which stimuli would
180 be important in determining the correct response in the following phase. A dot probe task was
181 combined with the learning task throughout the experiment, as in Le Pelley et al.'s
182 Experiment 3 [16] (see also [5, 19, 20]). By analyzing response times to the dot probe during
183 Phase 2, we could examine the impact of experienced predictiveness provided through training
184 (in Phase 1) versus instructions on attentional bias. Crucially, in the change condition, we
185 predicted an attentional bias driven by experienced predictiveness within the short SOA
186 condition. In other words, despite the conflict between experienced predictiveness and
187 instructions regarding which stimulus should be prioritised, the former factor would have a
188 greater influence on attentional bias than the latter.

189

190 **Materials and Methods**

191 The design of our study was conceptually similar to that of Mitchell et al. [10] in that
192 it compared the influence of training versus instruction on predictiveness-related attentional
193 biases. Our study departed from the procedure of Mitchell et al. by using a within-subjects
194 manipulation of verbal instructions, in order to increase the sensitivity of the experiment (a
195 similar approach was used in Don & Livesey's, Experiment 3 [13], and in Shone et al.'s
196 Experiment 2 [14]). Accordingly, after Phase 1, participants were informed that four specific
197 stimuli would be the most relevant to learn about during Phase 2. Participants then

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198 experienced different pairs of stimuli in Phase 2. In the *consistent* pair, instructions regarding
 199 relevance were consistent with the predictive or nonpredictive status of stimuli that had been
 200 experienced during Phase 1 training (see Table 1). In contrast, in the *inconsistent pair*,
 201 instructions regarding relevance were inconsistent with the status of stimuli established
 202 during Phase 1. Finally, we also included two pairs of *novel* stimuli in Phase 2 that had not
 203 appeared in Phase 1. One stimulus of each pair was instructed as being relevant in Phase 2,
 204 whereas the other was not. Since these stimuli had not undergone prior training, any
 205 attentional bias revealed in dot probe responding for these novel pairs can only reflect the
 206 influence of instructions (cf. [21]). Observing an attentional bias for novel pairs would also
 207 provide a manipulation check, showing that participants had read, understood, and followed
 208 the instructions regarding relevance prior to Phase 2.

209

210 **Table 1. Design of the experiment**

<u>Phase 1A</u> Categorization only	<u>Phase 1B</u> Categorization & dot-probe	Instructions	<u>Phase 2</u> Categorization & dot-probe	Judgment test	Memory test
$8 \times AC - 1$	$40 \times AC - 1$	“From now on, the only relevant figures to predict the correct category will be A, D, E, and G”	$16 \times \underline{A}C-3$ (consistent)	Associative strength with categories 3 and 4: $\underline{A}?$ $B?$ $C?$ $\underline{D}?$ $\underline{E}?$ $F?$ $\underline{G}?$ $H?$	Was it instructed as relevant?:
$8 \times AD - 1$	$40 \times AD - 1$		$16 \times \underline{B}D-4$ (inconsistent)		
$8 \times BC - 2$	$40 \times BC - 2$		$16 \times \underline{E}F-3$ $16 \times \underline{G}H-4$ (Instructed new)		
$8 \times BD - 2$	$40 \times BD - 2$		$16 \times IJ-3$ $16 \times KL-4$ (fillers)		

211 *Note:* Letters A-L stand for stimuli, and numbers 1-4 stand for response categories. Bold
 212 italic letters denote stimuli that were predictive in Phase 1A and 1B (which we refer to
 213 collectively as Phase 1). Underlined letters denote stimuli that were instructed as relevant
 214 predictors in Phase 2.

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215

216 **Participants and apparatus**

217 A total of 135 students from a Spanish university participated for course credit; 68
218 were randomly assigned to a short SOA group, and the remainder to a long SOA group.
219 Written consent was obtained and the Human Research Ethics Committee of the University
220 of Malaga approved the study. The experiment was carried out in a quiet room with 10
221 semienclosed cubicles each equipped with a standard PC and 38.4 cm monitor. The task was
222 run using the Cogent 2000 toolbox (<http://www.vislab.ucl.ac.uk/Cogent/>) for MATLAB.
223 Participants made all responses with the computer keyboard.

224

225 **Stimuli**

226 Stimuli were the same as those used by Luque et al. (2016), and included eight equal-
227 sized circles (diameter subtending 4.7° visual angle at a viewing distance of ~ 80 cm), with
228 radiating lines of varying thickness (see Fig 1). These figures were filled with different, easily
229 discriminable colours that had similar brightness. The [red, green, blue] values for each
230 colour were light red-brown [190, 86, 78], gold [190, 185, 78], green [93, 191, 77], turquoise
231 [77, 191, 191], purple [132, 71, 255], pink [255, 5, 255], red [208, 0, 0], and grey [150, 150,
232 150]. These stimuli were randomly assigned the roles indicated by letters A-H in Table 1.
233 Additionally, there were four more white outline figures consisting of two identical
234 rectangles, one horizontally and the other vertically oriented, and two identical ellipses, one
235 horizontally and the other vertically oriented. These last figures were used for filler trials, and
236 were assigned roles corresponding to letters I-L in Table 1.

237 These stimuli were presented centrally in white square frames with sides subtending
238 6.4° , which were located on the right and left sides of a small fixation cross that was located
239 in the centre of the screen; the centre-to-centre distance between the two boxes subtended

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240 6.4°. The dot probe was a white square with side length subtending 1.1°. This would appear
241 superimposed centrally on one of the stimuli. The screen background was black.

242

243 **Fig. 1. Stimulus display and timing of events on each training trial of the learning task.**

244

245 **Procedure**

246 The procedure was similar to that described in Le Pelley et al.'s Experiments 2 and 3
247 [16] (see also [5, 19]). Initial instructions (in Spanish) described the categorization task.
248 Participants were told that, on each trial, a pair of stimuli would appear and they should make
249 a categorization response by pressing either the '1' or '2' key with their left hand. Response
250 keys '1' and '2' were randomly assigned the roles of response categories 1 and 2 shown in
251 Table 1 for each participant. They were told they should try to learn the correct response for
252 each pair of stimuli. Participants then underwent a first phase (Phase 1A) of 32 categorization
253 trials. This comprised four eight-trial blocks, with each of the four stimulus pairs shown in
254 Table 1 appearing twice per block in random order; for each stimulus pair, the predictive
255 stimulus appeared once on the left and once on the right. On each trial a fixation cross
256 appeared, followed after 500 ms by the pair of stimuli. After 1 s, a message framed within a
257 central rectangle prompted participants to choose between response keys '1' and '2'.
258 Incorrect responses were followed by the feedback message "Error! The correct response was
259 [1/2]," which remained onscreen for 3 s; no explicit feedback was provided for correct
260 responses.

261 Following Phase 1A, participants received further instructions explaining that on
262 subsequent trials they would complete two tasks: On each trial (a) a pair of stimuli would
263 appear; (b) a small white square (the dot probe) would then appear superimposed on one of
264 these stimuli; (c) participants should press the left or the right arrow with their right hand

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265 depending on whether the square appeared on the left or on the right stimulus, respectively;
266 (d) once they had responded to the square, they should make a categorization response to the
267 stimulus pair using the ‘1’ or ‘2’ keys with their left hand as in the pretraining stage.
268 Participants were told that they should respond to the position of the dot probe as rapidly as
269 possible and that “In order to do so, it is best that you ignore the pair of figures until you have
270 responded to the location of the square” (translated from Spanish).

271 Fig 1 shows the event timing of a standard trial. Each such trial began with
272 presentation of a central fixation cross. After 500 ms the stimulus pair appeared to either side
273 of this cross. After an SOA of either 250 ms or 1,000 ms (depending on the SOA group to
274 which the participant had been allocated), the dot probe appeared superimposed on one of the
275 stimuli. This probe remained until participants made the correct response (left arrow key for a
276 target presented on the left; right arrow key for a target on the right). Immediately on making
277 the correct dot probe response, the probe disappeared and 1 s later the message “1 or 2?”
278 appeared as for Phase 1A. Participants then made a categorization response using the ‘1’ or
279 the ‘2’ keys; feedback was administered as in Phase 1A, and the next trial began after 1 s.

280 Participants completed Phase 1B, which comprised 10 blocks of 16 trials each (see
281 Table 1). Each trial type of Phase 1B appeared four times; once for each combination of cue
282 location (predictive cue on the left or on the right) and dot probe location (on the left or on
283 the right stimulus). Therefore, the dot probe was equally likely to appear on the predictive or
284 on the nonpredictive stimulus. The order of trials within each block was randomized.

285 Following Phase 1B, participants were told that in the next phase (Phase 2) they
286 would learn new relationships between certain stimulus pairs and response categories 3 and 4
287 in a similar way as in Phase 1B. Some stimulus pairs had been presented in Phase 1A and 1B
288 (which we refer to collectively as Phase 1), whereas others included new stimuli (see Table
289 1). Importantly, although all stimuli were in fact equally predictive of the response categories

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290 with which they were paired in Phase 2, participants were told that, from that moment on, the
291 only relevant stimuli that they should use to choose the correct response key were A, D, E,
292 and G. As explained in the Introduction, stimuli in Phase 2 were paired so as to create a
293 consistent pair (AC) in which the instructed-relevant cue (A) had been predictive in Phase 1;
294 an inconsistent pair (BD), in which the instructed-relevant cue (D) had been non-predictive in
295 Phase 1; and two novel pairs (EF and GH), in which neither cue had appeared in Phase 1.
296 Filler trials consisting of pairs IJ and KL were also included to increase the complexity of the
297 learning task. The assumption underlying this procedural measure is that complex
298 environments encourage the use of selective attention in order to focus and simplify
299 information-processing. By increasing memory load in our critical test phase (Phase 2), we
300 therefore hoped that these additional filler trials would provide additional drive for
301 participants to deploy selective processes, e.g., by focusing on the cues mentioned in the
302 verbal instructions. Phase 2 comprised four blocks of 24 trials each. Each of six stimulus
303 pairs appeared four times per block, counterbalancing cue and probe location as in Phase 1B.
304 Response categories 3 and 4 were randomly assigned to response keys '3' and '4' for each
305 participant and independently of the assignment of response categories 1 and 2 to response
306 keys '1' and '2'. Thus, these assignments were uncorrelated across participants.

307 After Phase 2, participants completed a judgment phase in which they rated the extent
308 to which each stimulus was associated with response categories 3 and 4, on a scale from 1
309 ('completely sure that Stimulus X does not predict Response Y') to 7 ('completely sure that
310 Stimulus X predicts Response Y'). Participants rated each stimulus with regard to each of the
311 response categories (3 and 4) in random order.

312 Finally, participants completed a recognition memory test to assess their memory for
313 the instructions regarding which stimuli were relevant and which were not. Again, a rating
314 scale from 1 to 7 was used, with 1 meaning 'completely sure that Stimulus X was not

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315 instructed as relevant', and 7 meaning 'completely sure that Stimulus X was instructed as
316 relevant'. Participants provided ratings for all stimuli in random order.

317

318 **Results**

319 We imposed a selection criterion so as to exclude participants who did not show
320 strong evidence of having learned the correct categorization responses. Specifically, we
321 excluded data from participants who failed to reach a criterion of 80% correct categorization
322 responses in the two last blocks of Phase 1B. This resulted in exclusion of five participants
323 from the short SOA group (final $n = 63$), and eight from the long SOA group (final $n = 59$).

324

325 **Phase 1**

326 Fig 2A shows the mean percentage of correct responses as a function of block and
327 SOA group in Phase 1A (blocks 1-4) and 1B (blocks 5-14). Participants' response accuracy
328 increased over blocks; there was no apparent difference between SOA groups, with both
329 approaching perfect accuracy during the final four blocks. These impressions were confirmed
330 by a 14 (block) \times 2 (SOA group: 250ms vs 1000ms) ANOVA, which yielded a significant
331 main effect of block, $F(13, 1560) = 99.5, p < .001, \eta_p^2 = .45$. Neither the main effect of SOA
332 nor the block \times SOA interaction was significant ($F_s < 0.87$). The same analysis within the
333 last four blocks revealed a marginally significant effect of block, $F(3, 360) = 2.16, p = .093,$
334 $\eta_p^2 = .02$. The main effect of group and the interaction between block and SOA were not
335 significant ($F_s < 0.58$). These statistical analyses yielded almost identical results even when
336 the data from the excluded participants were included.

337 Following the same procedure as in Le Pelley et al. [16], response times (RTs) from
338 the dot probe task were filtered and transformed before the analyses. First, RTs shorter than

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339 150 ms and longer than 1500 ms were excluded, as were RTs from trials in which the first
340 response to the probe was an incorrect response. Then, RTs were log-transformed to better fit
341 a normal distribution. Transformed RTs lying more than 3 SDs from each participant's mean
342 were removed.

343

344 **Fig 2. Summary of results found in Phase 1.** Panel A: Mean percentage of correct
345 categorization responses in Phase 1 as a function of SOA, group, and trial block. Panel B:
346 Mean transformed response times to the dot in Phase 1 as a function of stimulus
347 predictiveness, epoch, and SOA group (the dot probe task started in the fifth block of the
348 learning phase). The intervals in both panels reflect the standard error of the mean.

349

350 Fig 2B shows mean log-transformed RTs as a function of dot probe position and SOA
351 group, averaged over pairs of consecutive blocks (termed *epochs*). Participants in the short
352 SOA group responded faster when the probe appeared on the predictive stimulus than when it
353 appeared on the nonpredictive stimulus. This tendency was greater in late than in early
354 epochs. In contrast, participants in the long SOA group showed similar RTs regardless of the
355 probe's position. A 2 (probe position: Predictive vs nonpredictive stimulus) \times 5 (epoch) \times 2
356 (SOA) ANOVA revealed main effects of probe position, $F(1, 120) = 15.1, p < .001, \eta_p^2 = .11,$
357 and epoch, $F(4, 480) = 19.3, p < .001, \eta_p^2 = .14,$ and a significant probe position \times SOA
358 interaction, $F(1, 120) = 8.27, p = .005, \eta_p^2 = .06$ (F s < 1.5 for all remaining effects, smallest p
359 = .202). A follow-up 2 (probe position) \times 5 (epoch) ANOVA within the 250 ms SOA group
360 yielded significant effects of probe position, $F(1,62) = 19.56, p < .001, \eta_p^2 = .24,$ and epoch,
361 $F(4,248) = 8.98, p < .001, \eta_p^2 = .13,$ and a marginally significant interaction, $F(4, 248) = 2.24,$
362 $p = .066, \eta_p^2 = .04.$ The same analysis within the 1000ms SOA group found only a significant
363 effect of epoch, $F(4, 232) = 11.94, p < .001, \eta_p^2 = .17;$ other F s $< 1.$

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364 The results of the dot probe task essentially replicate Le Pelley et al.'s Experiment 3
365 [16], and indicate that predictive learning tended to produce an attentional bias towards the
366 predictive stimulus. The fact that this bias was found in the 250 ms SOA condition but not in
367 the 1000 ms SOA condition implicates a very rapid and short-lived attentional bias towards
368 predictive stimuli.

369

370 **Phase 2**

371 Fig 3A shows mean log-transformed RTs for 'old' stimuli A-D (i.e., stimuli
372 previously experienced during Phase 1) as a function of experienced predictiveness,
373 instructions, and SOA group, averaged across Phase 2. A 2 (experienced predictiveness:
374 probe appeared on stimulus that had been predictive in Phase 1 vs stimulus that had been
375 nonpredictive) \times 2 (instructions: probe appeared on stimulus that had been instructed as
376 relevant vs noninstructed) \times 2 (SOA) ANOVA yielded a marginally significant effect of
377 experienced predictiveness, $F(1, 120) = 3.17, p = .077, \eta_p^2 = .03$ and a marginal experienced
378 predictiveness \times SOA interaction, $F(1, 120) = 3.37, p = .069, \eta_p^2 = .03$ (other F s < 1.97 ,
379 smallest $p = .184$). This interaction between experienced predictiveness and SOA is
380 consistent with the results from Phase 1 and with Le Pelley et al. [16]. A follow-up 2
381 (experienced predictiveness) \times 2 (instructions) ANOVA within the 250 ms SOA group
382 yielded only a significant effect of experienced predictiveness, $F(1, 62) = 6.61, p = .013, \eta_p^2 =$
383 $.1$ (other F s < 0.15). Similar analysis within the 1000 ms SOA group found no significant
384 effects (F s < 0.5).

385 As expected, the short SOA group showed an attentional bias towards stimuli
386 previously learned to be predictive through trial-by-trial training. Crucially, this effect was
387 not significantly affected by whether these stimuli had been explicitly instructed as relevant
388 or not during Phase 2. In contrast, the long SOA group showed similar RTs regardless of the

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389 experienced predictiveness of stimuli or instructions. The fact that an attentional bias towards
390 predictive stimuli was detected at short SOA but not long SOA is again consistent with the
391 engagement of a fast attentional process that may go undetected if the attentional task does
392 not impose strong enough time constraints.

393

394 **Fig 3. Results from Phase 2.** Panel A: Mean log-transformed response times to the dot when
395 it appeared on stimuli A-D, whose predictiveness had been established through previous
396 experience in Phase 1. Results are displayed as a function of learned predictiveness,
397 instructions regarding stimulus relevance, and SOA group. Panel B: Mean log-transformed
398 response times to the dot when it appeared on new stimuli E-H, which did not form part of
399 previous experience provided through Phase 1. Results are displayed as a function of
400 instructions regarding stimulus relevance and SOA group. In both panels, intervals reflect the
401 standard error of the mean.

402

403 One possible explanation of the failure of instructions to exert any significant effect
404 on the data in Fig 3A is simply that participants did not read, understand, or make use of
405 these instructions during Phase 2. To test this possibility, we analyzed the effects of
406 instructions on RTs for novel stimulus pairs EF and GH. Recall that stimuli E and G were
407 instructed as relevant during Phase 2, while F and H were noninstructed; none of these cues
408 was experienced during Phase 1. Fig 3B shows mean log-transformed RTs during Phase 2.
409 For these novel pairs, participants in the 250ms SOA group responded faster when the probe
410 appeared on instructed stimuli than when it appeared on noninstructed stimuli. Participants in
411 the 1000ms SOA group did not show a clear bias. A 2 (instructions: instructed vs
412 noninstructed) \times 2 (SOA), ANOVA yielded no significant effect (all F s < 2.76, smallest p =
413 .1). However, since our previous analyses suggest that attentional biases in the dot probe task

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414 were confined to the short SOA group, we used a *t*-test to analyze the effect of instructions on
415 RTs within the short SOA group only. This revealed a significant effect of instructions, $t(62)$
416 $= 2.33$, $p = .023$, $\eta^2 = .08$. This confirms that participants *were* effectively following the
417 instructions about stimulus relevance, and that such instructions can produce a rapid
418 attentional bias towards stimuli, at least when such instructions do not conflict with stimulus
419 predictiveness experienced through trial-by-trial training.

420

421 **Ratings of stimulus-outcome relationships**

422 Participants' ratings from the Judgment Test were analyzed to assess the influence of
423 experienced predictiveness and instructions on learning of stimulus–outcome relationships in
424 Phase 2. Following Le Pelley and McLaren [3] (see also [22]), we calculated a rating score
425 for each stimulus by subtracting the rating given to the incorrect response category from the
426 rating given to the correct response category. High, positive values on this scale (maximum =
427 7) indicate strong learning of a correct stimulus–outcome relationship. Table 2 shows mean
428 ratings for each stimulus (ratings for cues E and G, which were equivalent, were combined
429 [denoted E/G]; ditto for cues F and H). The data relating to cues A-D were analyzed with a 2
430 (experienced predictiveness: Predictive vs nonpredictive during Phase 1) \times 2 (instruction) \times 2
431 (SOA) ANOVA. This revealed significant main effects of experienced predictiveness, $F(1,$
432 $120) = 28.3$, $p < .001$, $\eta_p^2 = .19$, and instruction, $F(1, 120) = 6.03$, $p = .015$, $\eta_p^2 = .05$. No other
433 effects were significant (F s < 1.51 , smallest $p = .221$). Both short and long SOA groups
434 learned more during Phase 2 about stimuli that had previously been experienced as predictive
435 than those that had been experienced as nonpredictive. Both groups also learned more about
436 stimuli that had been explicitly instructed as relevant during Phase 2 than those that had not
437 been instructed. This latter finding once again confirms that participants read and made use of
438 the instructions regarding relevance given prior to Phase 2.

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439

440 **Table 2. Mean rating scores and standard deviations of the means (in parentheses) for**

441 **stimulus-outcome relationships learned in Phase 2**

SOA group	Stimulus type					
	Instructed relevant			Noninstructed		
	Predictive (A)	NonPred (D)	New (E/G)	Predictive (B)	NonPred (C)	New (F/H)
250 ms	4.37 (0.42)	2.37 (0.5)	4.25 (0.3)	3.71 (0.45)	2.19 (0.51)	4.12 (0.3)
1000 ms	4.03 (0.44)	2.59 (0.48)	4.37 (0.29)	3.42 (0.5)	0.85 (0.57)	3.86 (0.34)

442

443 Putting together the dot probe results from Phase 2 and participants' ratings for old
 444 stimuli, it seems that past experience with stimuli had an influence on rapid and short-lived
 445 attentional bias towards predictive stimuli, and on how much is learned about such stimuli in
 446 a subsequent phase of learning. Additionally, instructions about stimulus relevance had an
 447 effect on learning, as measured by subjective ratings, but not on rapid and short-lived
 448 attentional capture.

449 Regarding Stimuli E-H, there was a numerical trend towards higher ratings for the
 450 instructed cues than the noninstructed cues, but it did not reach statistical significance. A 2
 451 (instruction) × 2 (SOA group) ANOVA on participants' ratings revealed no significant
 452 effects (all $F_s < 1.55$, smallest $p = .217$). Thus, in this case, instructions exerted an effect on
 453 attentional capture that did not translate into an advantage in terms of stimulus–outcome

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454 learning (as measured by explicit judgments).

455

456 **Recognition ratings**

457 Fig 4 shows participants' mean recognition ratings as a function of instructions, type
458 of stimulus, and SOA group. The different groups of stimuli in the figure correspond to the
459 compounds presented during Phase 2. This highlights the extent to which recognition
460 memory was affected by the congruency between participants' experienced predictiveness,
461 and the instructions they received. A 2 (instructions) \times 3 (stimulus type: AC vs BD vs
462 EF/GH) \times 2 (SOA) ANOVA on participants' recognition ratings revealed significant main
463 effects of instruction, $F(1, 120) = 64.85, p < .001, \eta_p^2 = .35$, and stimulus type, $F(2, 240) =$
464 $11.34, p < .001, \eta_p^2 = .09$, and an instruction \times stimulus type interaction, $F(2, 240) = 8.25, p <$
465 $.001, \eta_p^2 = .06$ (other F s < 2.32 , smallest $p = .101$).

466

467 **Fig 4. Mean recognition ratings.** Mean recognition ratings for stimuli as a function of
468 instructions regarding relevance, and SOA group.

469

470 Overall, recognition ratings were higher for cues that were instructed as relevant than
471 for those that were not instructed, confirming again that participants had read and
472 remembered these instructions. Interestingly, however, the effect of instructions differed as a
473 function of stimulus type: Fig 4 suggests a larger effect of instructions for stimuli belonging
474 to the *consistent pair* (AC) than for the *inconsistent pair* (BD), with an intermediate effect for
475 stimuli belonging to novel pairs (EF and GH). Nevertheless, analysis of simple effects
476 (collapsing across SOA groups) revealed a significant effect of instructions for each type of
477 compound: for AC, $F(1, 121) = 64.04, p < .001, \eta^2 = .35$; for BD: $F(1, 121) = 4.69, p = .037,$
478 $\eta^2 = .04$; and for EF/GH: $F(1, 121) = 42.2, p < .001, \eta^2 = .26$.

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479

480 **Discussion**

481 We examined the influence of both prior training experience (selection history) and
482 verbal instructions on predictiveness-driven attentional biases. To this end, participants
483 experienced differences in the predictiveness of different stimuli over the course of trial-by-
484 trial training in a first learning phase, and, later on, received verbal instructions regarding
485 stimulus relevance for the subsequent learning phase that could be either consistent (AC
486 compound) or inconsistent (BD compound) with experienced stimulus predictiveness. We
487 measured the effects of these manipulations on spatial cueing in the dot probe task following
488 the same procedure as Le Pelley et al.' Experiment 3 [16]. Like Le Pelley et al. [16] (see also
489 [17]), the current experiment found that—with a short stimulus-onset asynchrony (SOA)
490 between the stimuli and the probe—responses to the probe during Phase 2 were faster when
491 its position was cued by stimuli previously experienced as predictive compared with
492 nonpredictive stimuli. This suggests that experienced predictiveness produced an attentional
493 bias towards predictive stimuli. The fact that experienced predictiveness produced a bias in
494 spatial cueing of the probe only at short SOA (250 ms) and not at longer SOA (1000 ms),
495 suggests the operation of a rapid and short-lived attentional process.

496 Most importantly, the rapid attentional bias towards predictive stimuli (observed at
497 short SOA) was not reversed or even significantly altered by conflicting verbal instructions
498 regarding stimulus relevance. This was not due to participants' failure to understand, retrieve,
499 and follow verbal instructions. First, instructions regarding stimulus relevance affected
500 explicit ratings about stimulus-outcome relationships learned in Phase 2. These ratings clearly
501 show that participants tended to learn more about stimuli instructed as relevant (A & D) than
502 noninstructed stimuli (B & C). Second, instructions produced an attentional bias towards new
503 stimuli instructed as relevant (E & G) relative to new stimuli that were noninstructed (F &

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504 H). Finally, memory for instructions was reasonably good as evidenced by participants'
505 higher recognition ratings to stimuli instructed as relevant than noninstructed stimuli.

506 Thus, despite evidence that participants had read, understood, and implemented verbal
507 instructions regarding stimulus relevance, these instructions had no effect on the bias in rapid
508 attentional orienting to stimuli that had previously been *experienced* as predictive, compared
509 to those experienced as nonpredictive. This suggests that trial-by-trial experienced
510 predictiveness (i.e., selection history) drives the development of a rapid and relatively
511 inflexible attentional bias that is somewhat insulated from changes in explicit knowledge
512 about predictive status produced by verbal instructions. Note that we are not claiming here
513 that performance in the dot probe task at short SOA is *generally* immune to verbal
514 instructions. Indeed, our own data suggest this is not the case – for the novel stimuli (that had
515 not been experienced during Phase 1), responses to the dot probe were significantly faster
516 when it was cued by a stimulus that had been instructed as relevant (E/G) than when it was
517 cued by a stimulus that had not been instructed (F/H) (for related findings, see [23, 24]). The
518 novel finding of our data is that the influence of prior experience of predictiveness on rapid
519 attentional bias is sufficiently strong that, given a difference in selection history, no effect of
520 attentional control via instruction is observed.

521 In line with previous evidence [10, 13, 14], we found that participants' learning of
522 stimulus–outcome relationships during Phase 2 was influenced by instructions regarding
523 relevance: Participants learned more, in general, about stimuli instructed as relevant than
524 those that were not instructed. That said, the influence of instructions on learning was
525 relatively slight, and was not sufficient to overcome the influence of experienced
526 predictiveness on learning. That is, we also observed a main effect of experienced
527 predictiveness on participants' judgments of stimulus–outcome relationships, and instructions
528 were not sufficient to reverse the pattern of greater learning about stimuli experienced as

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529 predictive than those experienced as nonpredictive. This is indicated by the finding that
530 stimulus D (experienced as nonpredictive but instructed as relevant) produced weaker
531 judgments than stimulus B (experienced as predictive but not instructed as relevant). Thus
532 while demonstrating an influence of verbal instructions about stimulus relevance on learning,
533 our data fail to replicate Mitchell et al.'s finding of a complete reversal of the effect of
534 experience as a result of instructions [10]. In this respect our data are more similar to
535 subsequent findings that have also failed to replicate this full reversal [13, 14]. Taken
536 together, these findings suggest that both selection history produced via repeated experience
537 with stimuli, and verbalisable knowledge, may contribute to biases in learning towards
538 predictive cues observed in earlier studies (e.g., [2, 3, 25]).

539 It is noteworthy that a significant influence of instructions on stimulus-outcome
540 judgements was observed only for stimuli that had previously been experienced during Phase
541 1 – no significant effect of instructions was seen for novel cues E-H. This pattern was
542 unexpected: One might naturally expect that, in the absence of any other reason to attend to
543 one stimulus or the other, participants would tend towards the stimulus instructed as relevant.
544 It is unclear what to make of this null finding, and we note that there was a numerical trend
545 towards greater learning about the instructed stimulus. One possibility is that the
546 nonsignificant effect may reflect formation of a strong within-compound association between
547 the elements of 'new' compounds EF and GH. For example, F was only ever experienced in
548 compound with E, and hence a relatively strong association may have formed between these
549 stimuli (compared to stimulus A for example, which was sometimes experienced with C and
550 sometimes with D). Suppose that participants followed instructions regarding the relevance of
551 new stimuli to the *outcome*, and learned a stronger stimulus–outcome association for stimulus
552 E than stimulus F. Participants may still show strong responding to stimulus F on test, if
553 presentation of F retrieves the memory of E (via the strong within-compound association),

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554 which in turn retrieves the outcome via the strong E–outcome association. In the absence of
555 further evidence, however, this account is currently speculation.

556 We implemented instructions regarding stimulus relevance by explicitly informing
557 participants which specific stimuli would be relevant during Phase 2 (following a procedure
558 used by Don & Livesey in 2015 [13], and by Shone et al. in 2015 [14]). This differed from
559 the approach used by Mitchell et al. [10], who provided the more general instruction that
560 stimuli which had been predictive during Phase 1 were highly likely (in the Continuity
561 condition) or highly unlikely (in the Change condition) to be predictive during Phase 2. It
562 seems unlikely that this procedural difference was responsible for the persistent, rapid
563 attentional bias towards stimuli experienced as predictive observed in the dot probe task of
564 the current experiment. As Don and Livesey [13] noted, the instructions used by Mitchell et
565 al. [10] might actually result in a rapid attentional bias towards stimuli previously
566 experienced as predictive even in the Change condition, since participants may first need to
567 identify the stimulus that was previously predictive in order to identify the stimulus which
568 was previously nonpredictive (and which should now be attended, according to instructions).
569 In contrast, direct instruction regarding which cues are relevant in Phase 2 does not require
570 that participants first identify the stimulus which used to be predictive in Phase 1. Consistent
571 with this claim, Don and Livesey [13] showed that instructing the relevance of specific
572 stimuli results in, if anything, a *larger* influence of instructions on stimulus–outcome learning
573 than does providing more general instructions regarding continuity/change, as used by
574 Mitchell et al. [10]. This implies that the procedure used in the current experiment should
575 have been at least as sensitive to showing an effect of instructions on attentional orienting as
576 that used by Mitchell et al., if such an effect were to exist.

577 The primary aim of the current experiment was to assess whether—and the extent to
578 which—the influence of experienced predictiveness on attention reflects the operation of

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579 processes based on selection history (modulated by experience) versus explicit knowledge
580 (modulated by experience and verbal instructions). Our data suggest that both play a distinct
581 role. In this final section, we briefly consider the nature of these attentional processes. One
582 interpretation is that the rapid and short-lived influence of selection history reflects a
583 relatively automatic process over which participants have little strategic control (cf. [8, 9,
584 26]). On this account, repeated experience of attentional selection of a particular stimulus
585 produces an automatic and habitual prioritization of that stimulus. In the current dot probe
586 task, the locations of the predictive/nonpredictive stimuli were noninformative with regard to
587 the location in which the probe would appear. Considering this task on its own, then, there
588 was no advantage to be gained in strategically directing attention to either location prior to
589 the onset of the probe – the implication being that the observed attentional bias towards
590 predictive stimuli did not reflect strategic allocation of attention, but rather an involuntary
591 process. The long SOA condition may then have provided sufficient time for a more strategic,
592 top-down attentional process to return attention to the centre of the display.

593 However, an alternative account is possible. Notably, the dot probe task was
594 embedded within predictive learning trials in this experiment, and this overlap in task
595 structures raises questions over the strategies that participants might have used. In particular,
596 while participants were instructed to ignore the stimuli until after they had responded to the
597 dot probe, they may nevertheless have begun a strategic process of identifying the stimuli and
598 preparing a categorization response prior to the onset of the probe. On this account, then, the
599 rapid attentional bias towards predictive stimuli demonstrated in the dot probe task may result
600 from a voluntary process. The absence of a bias at long SOA might then be because 1000ms
601 provided sufficient time for participants to program a categorization response and then return
602 attention to the centre of the display in anticipation of the upcoming dot probe. Additionally
603 the fact that RTs in the short SOA group were longer than in the long SOA group may also be

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604 seen as consistent with the idea that participants spent time preparing for a categorisation
605 response before responding to the dot. According to this, the effect of SOA on RTs may be
606 seen as a typical case of cognitive bottle neck in concurrent multitasking preparations (see
607 [27], for a review on this issue). Note, however, that this effect of SOA on participants' RTs
608 has also been found even when the learning and the dot probe tasks take place in separate
609 trial blocks [16].

610 Thus we have two alternative accounts: One which invokes opposing involuntary and
611 strategic attentional processes, and the other in which allocation of attention is entirely
612 strategic. The current findings do not allow us to decide between these alternatives (though
613 we note that influences of experienced predictiveness on dot probe performance can be
614 observed even when the two tasks are entirely separate, which is harder to reconcile with the
615 wholly-strategic account; see Experiment 2 in [16]). For current purposes this issue is not
616 critical, however: The important finding is that the processes underlying the influence of
617 learned predictiveness on attention show distinct influences of selection history and explicit
618 knowledge. This is true whether we align selection history with involuntary and explicit
619 knowledge with voluntary attention, or whether selection history and explicit knowledge both
620 exert distinct effects on strategic orienting. Having established a distinction here, future
621 studies could further investigate the nature of the underlying cognitive processes.

622

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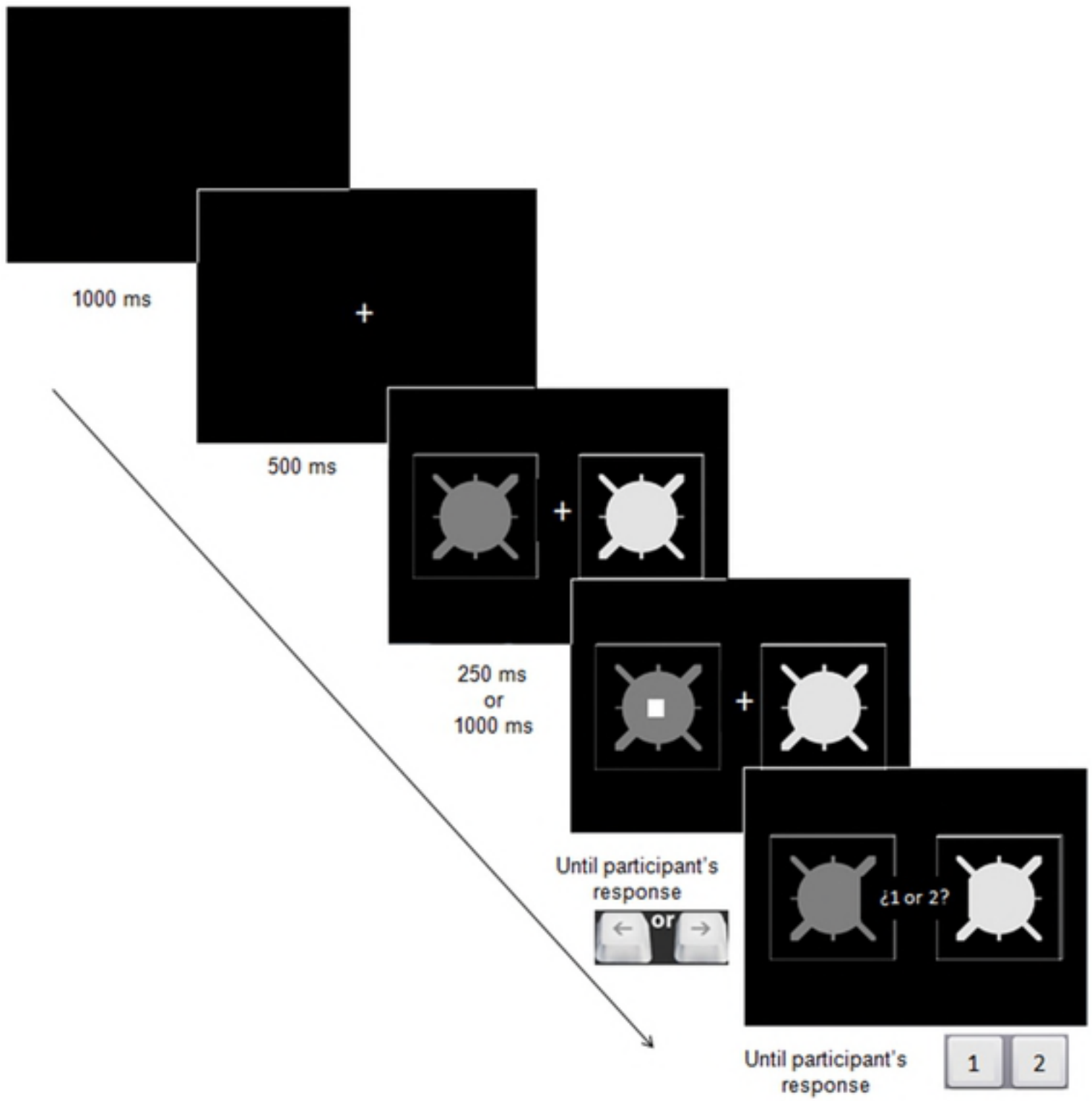
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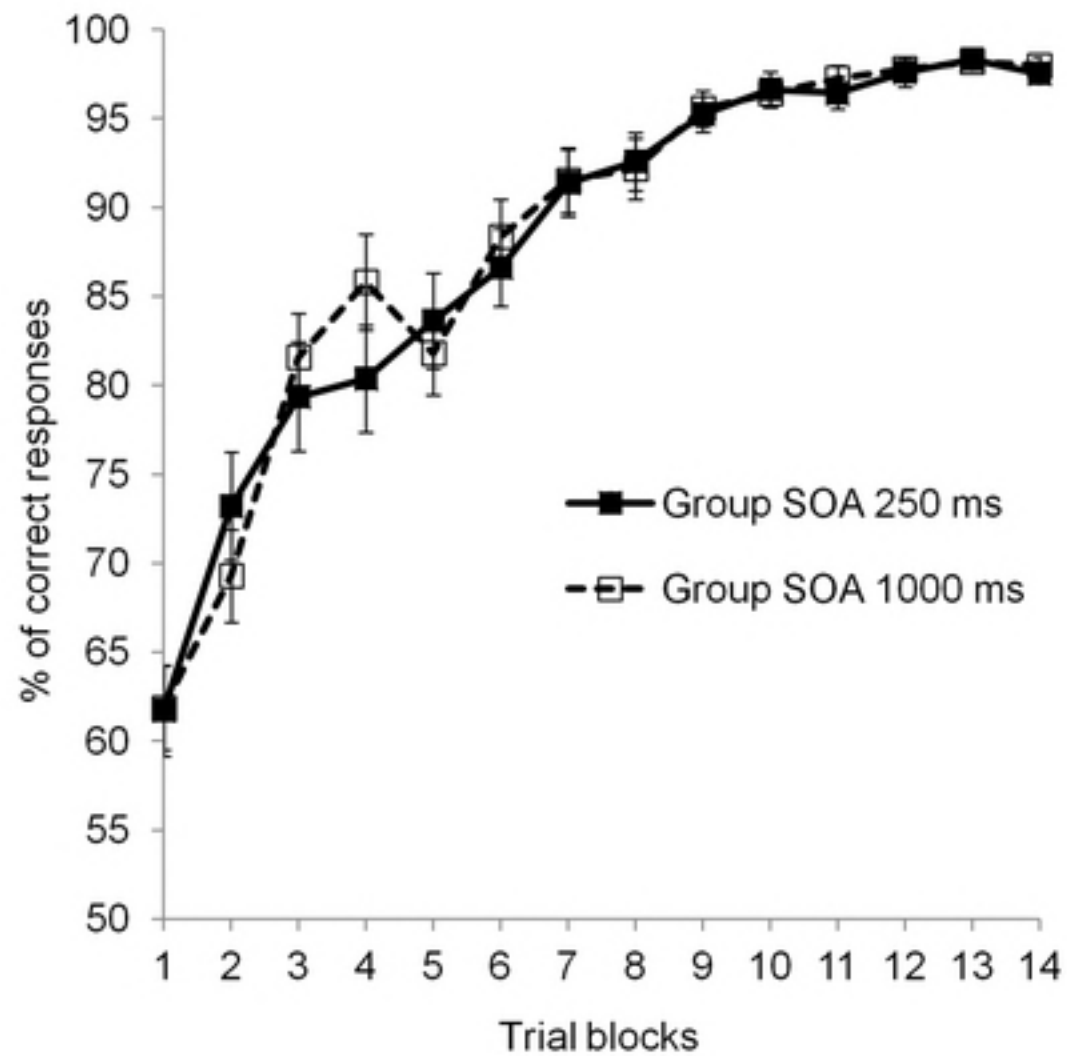
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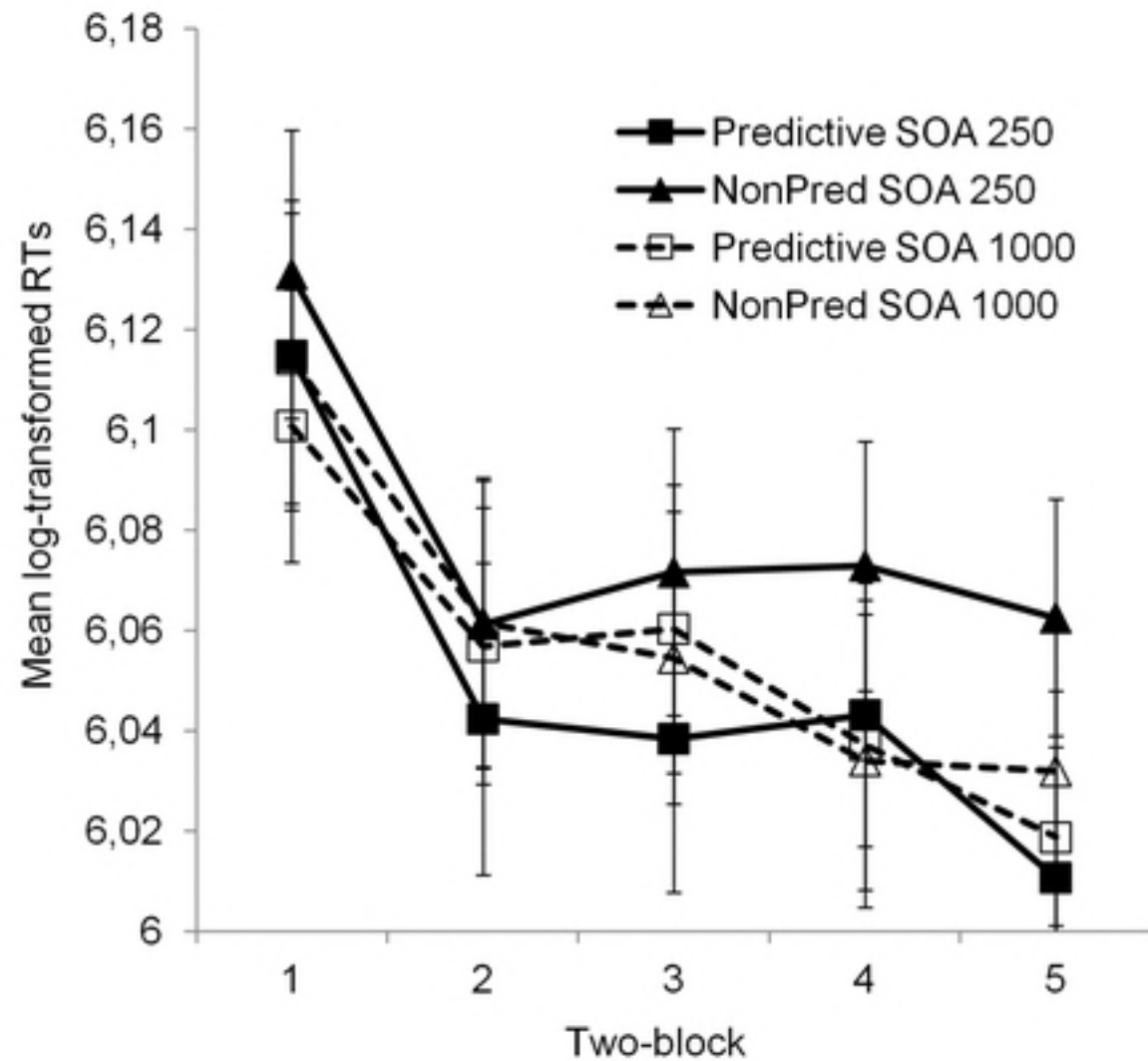
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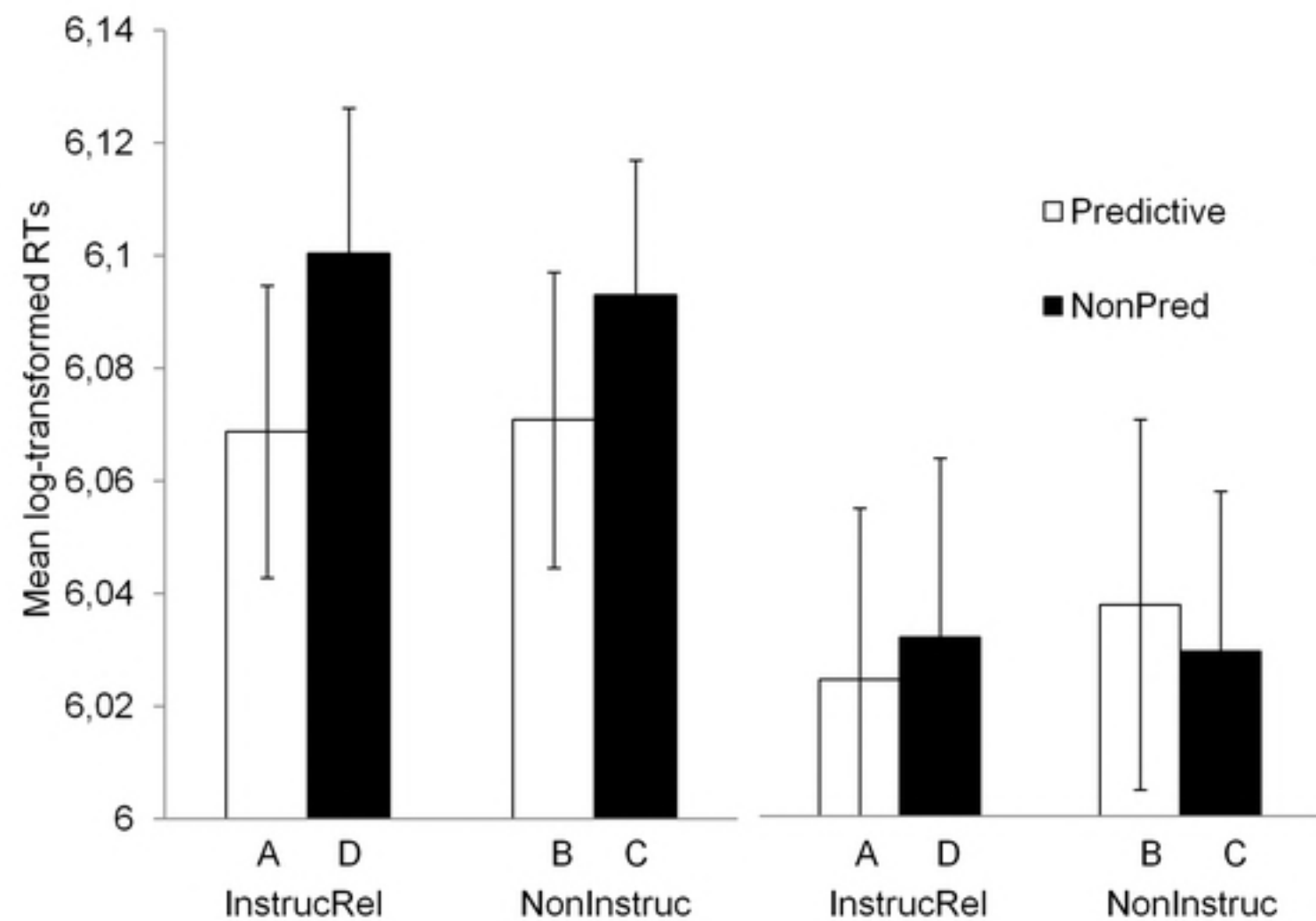
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