

RUNNING HEAD: Gaze dynamics of feature-based inhibition

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Gaze dynamics of feature-based distractor inhibition under the prior-knowledge and expectation

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11 **Abstract**

12 Prior information about distractor facilitates selective attention to task-relevant items and
13 helps the optimization of oculomotor planning. Particularly, feature-based attentional
14 inhibition could be benefited from the pre-knowledge of critical features of the distractors. In
15 the present study, we capitalized on gaze-position decoding to examine the dynamics of
16 attentional deployment in a feature-based attentional task that involved two groups of dots
17 (target/distractor dots) moving toward different directions. Specifically, this measurement
18 revealed how pre-knowledge of the target's or distractor's direction modulated real-time
19 feature-based attentional bias. In Experiment 1, participants were provided with target cues
20 indicating the moving direction of target dots. The results showed that participants were biased
21 towards the cued direction and tracked the target dots throughout the task period. In Experiment
22 2 and Experiment 3, participants were provided with cues that informed the moving direction
23 of distractor dots. The results showed that participants would continuously monitor the
24 distractor's direction when the distractor cue varied on a trial-by-trial basis (Experiment 2).
25 However, when the to-be-ignored distractor direction remained constant (Experiment 3),
26 participants would strategically bias their attention to the distractor's direction before the cue
27 onset and reduce the cost of re-deployment of attention between trials. These results suggest
28 that monitoring the distractor's feature is a prerequisite for feature-based attentional inhibition
29 and this process is facilitated by the predictability of the distractor's feature.

30 **Keywords: feature-based attention, suppression, expectation, decoding.**

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32 **Introduction**

33 To process the rich and fast-changing visual input, human needs to efficiently assign the
34 limited attentional resource to task-relevant stimuli. Target cues have been proven to be
35 beneficial in promoting target selection (Posner, 1980; Vickery, King, & Jiang, 2005; Wolfe,
36 1994). However, whether prior knowledge of distractors (i.e., distractor cues) can help us to
37 avoid unnecessary attention allocation to task-irrelevant information and facilitate performance
38 is still an issue under debate. Divergent findings have been reported regarding whether
39 distractor cues can accelerate search efficiency (Arita, Carlisle, & Woodman, 2012; Beck &
40 Hollingworth, 2015; Becker, Hemsteger, & Peltier, 2015; Olivers, 2009; Soto, Heinke,
41 Humphreys, & Blanco, 2005; Geoffrey F Woodman & Luck, 2007). Among the studies that
42 showed behavioral promotions, the emergence of suppression benefits seemed to be dependent
43 on multiple factors (Conci, Deichsel, Müller, & Töllner, 2019; Han & Kim, 2009; Stilwell &
44 Vecera, 2019; Tanda & Kawahara, 2019; Töllner, Conci, & Müller, 2015), especially the
45 constancy of distractor cues across trials so as to form expectations (Cunningham & Egeth,
46 2016; Gaspelin, Leonard, & Luck, 2015; Gaspelin & Luck, 2018a; Vatterott & Vecera, 2012;
47 Wen, Hou, & Li, 2018, for reviews, see Gaspelin & Luck, 2018b, 2019; Noonan, Crittenden,
48 Jensen, & Stokes, 2018; van Moorselaar & Slagter, 2020).

49 Despite the increasing number of studies on whether the distractors can be efficiently
50 inhibited, the question of how do we filter out them remains untangled. Researchers have
51 proposed two possible mechanisms: proactive vs. reactive suppression (Geng, 2014)
52 Supporting evidence has been observed for both mechanisms. Some studies found that
53 rejection templates would be created based on the foreknowledge of distractors and proactively
54 guide our attention away from matched stimuli (Woodman, Carlisle, & Reinhart, 2013;
55 Woodman & Luck, 2007). For example, a salient color-singleton distractor can be proactively
56 inhibited and letters inside of the singleton distractor were less likely to be reported (Gaspelin

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57 et al., 2015). Moreover, an eye-tracking study showed that fewer gazes were directed to the
58 color-singleton distractor than other search items (an oculomotor suppression effect) and this
59 occurred even when the eye movements were initiated relatively quick, indicating that salient
60 items can be proactively suppressed (Gaspelin, Leonard, & Luck, 2017). Event-related-
61 potential (ERP) evidence demonstrated that salient distractors evoked the Pd component to
62 intervene in the automatic capture (Gaspar & McDonald, 2014; Sawaki & Luck, 2011). Hence,
63 the *signal suppression hypothesis* suggested that the suppression of the salient item occurs
64 before the initial capture (Gaspelin & Luck, 2018b; Sawaki & Luck, 2011).

65 On the contrary, some researchers contended that distractor suppression is a reactive
66 process and suppression cannot occur unless the distractor has been attended to. For instance,
67 Moher and Egeth (2012) provided distractor cues before the search array and participants were
68 slower in the negative-cue condition than in the neutral condition. By manipulating the stimulus
69 onset asynchrony (SOA), they found the trend of avoidance in long SOA trials. Hence, they
70 proposed the *search and destroy* process where attention is biased toward matched distractors
71 and then rejected given sufficient time. This reactive inhibition hypothesis echoed the literature
72 that proposed the mechanism of rapid disengagement (Awh, Belopolsky, & Theeuwes, 2012;
73 Theeuwes, 2010). Liesefeld and colleagues (2017) further examined the temporal dynamics
74 of Pd and N2pc evoked by the distractor and target to demonstrate the disengagement from the
75 misallocated attention to the salient distractor and re-direction of attention to the target.

76 Critically, the majority of the existing studies changed the distractor feature from trial to
77 trial, which hampered the establishment of stable inhibition templates through learning. Recent
78 findings seemed to reach the consensus that the ability to inhibit distractors can be learned
79 (Gaspelin & Luck, 2019; Geng, Won, & Carlisle, 2019) when the distractor feature remained
80 constant or when the distractor locations were statistically manipulated (Wang & Theeuwes,
81 2018). Under such arrangements, the initial capture would disappear and the rejection benefit

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82 would emerge gradually along with blocks (Cunningham & Egeth, 2016; Stilwell & Vecera,
83 2019; Vatterott & Vecera, 2012).

84 Most of the above-mentioned studies used a visual search paradigm where items were
85 spatially separated. Although the participants were informed of the distractor feature using the
86 distractor cue, they would transform the feature cue into a spatial filter so as to suppress the
87 matched items. One dominant discrepancy between feature-based attention and spatial
88 attention is that feature-based attention does not rely on specific locations. Thus, common
89 oculomotor events, such as fixation, dwell time and first saccades, which are location-based,
90 are not effective indicators of attentional allocation for features that are spatially inseparable.
91 To unequivocally reveal how distractor inhibition evolves over the course of a trial, we need a
92 finer-scale measurement that can provide continuous information about attentional deployment
93 at a millisecond level.

94 In the present study, we aimed to investigate the role of prior information in feature-based
95 attentional inhibition. To avoid the confounding factors that are related to spatial attention, we
96 used moving dots stimuli that were intermingled and spatially inseparable. Participants were
97 asked to fixate at the center of the stimuli and their eye positions were recorded during the task.
98 In the task, participants were instructed to detect speed change in one of the two moving
99 directions. Previous literature has suggested that small fixational gaze shifts could reflect
100 covert attention to external stimuli (Engbert & Kliegl, 2003; Hafed & Clark, 2002) or internal
101 attentional selection inside working memory (van Ede, Chekroud, & Nobre, 2019). These
102 attributes make small gaze shift an ideal measurement of attention for the stimuli and task used
103 in the present study. Specifically, we examined the gaze positions using a decoding approach
104 to inform the temporal dynamics of attentional deployment when participants received target
105 cues (Experiment 1), distractor cues (Experiment 2), and repeated distractor cues (Experiment
106 3).

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107 **Experiment 1**

108 **Participants**

109 Eighteen participants were recruited in Experiment 1 and were paid for their participation.

110 All participants (including those in Experiments 2 and 3) had a normal or corrected-to-normal
111 vision and had no history of psychiatric or neurological disorders. They (including participants
112 in Experiments 2 and 3) provided written informed consent prior to the experiment.

113 One participant's eye data was missing due to technical failure. One participant showed
114 extremely bad performance (detection sensitivity was more than 1.5 SD below the mean and
115 response time was 3 SD beyond the mean). These two participants were excluded from the
116 analysis. The final sample consisted of sixteen participants (mean age = 21.3, range from 19 to
117 26, 5 males, all right-handed). The study was approved by the local ethics committee at Peking
118 University.

119 **Method**

120 The stimuli were presented using MATLAB (Mathworks, Natick, MA, USA) with
121 Psychtoolbox3 extensions (Brainard, 1997) and were displayed on a LED monitor (refresh rate:
122 100Hz, resolution: 2560×1440) with a viewing distance about 80 cm. As shown in Fig. 1A,
123 each trial began with a cue indicating the moving direction of the target dots. The cue was
124 presented for 0.3s. During the delay period, a set of dots ($N = 260$, $0.12^\circ \times 0.12^\circ$, speed = 3
125 deg/s, lifetime = 0.1s) appeared in an aperture (outer circle diameter = 20° , inner circle diameter
126 = 8°) centered at the fixation cross (0.4°) and moved randomly for 0.6s. Once the grey fixation
127 cross changed into green, the dots started to move coherently (coherence level = 0.8) toward
128 two different directions. Dots in the target direction (target dots, $N = 130$) would move toward
129 the cued direction while the distractor dots would move toward another direction. The
130 directions were randomly and independently selected from eight direction bins which covered
131 the whole circle. It was possible that the moving directions of target dots and distractor dots

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132 belonged to the same direction bin but the minimal difference must be above 15°. In half of the
133 trials, the speed of the target dots would increase (two times upon the speed) and the increment
134 lasted for 0.3s. The speed-up might start at any time from 0.3~1.3s after the onset of the central
135 green fixation. Participants were asked to detect the speed-up and respond whenever it
136 happened. The moving dots disappeared immediately after the response. For the no-change
137 trials, coherent moving would be displayed for 1.5s. Participants completed 16 blocks of 80
138 trials and they received feedback about their performance at the end of each block.

139 Eyelink 1000 Plus (SR Research) was used to record the binocular movements with a
140 sample rate of 500Hz. At the beginning of each block, the eye tracker was calibrated using a
141 five-point calibration procedure. Participants were asked to fixate at the central fixation cross
142 and avoid tracking the moving dots during the whole experiment. Their heads were stabilized
143 using a chin-rest.

144 **Data analysis**

145 *Behavior.* To compute the detection sensitivity (d'), we took trials in which responses
146 were later than the speed change onset as hit. Standard corrections were performed to deal with
147 hit rate of 1 or false alarm rate of 0 (Macmillan & Kaplan, 1985). Reaction time was measured
148 as the time between the speed change onset and the response. Mean RT was obtained from hit
149 trials.

150 *Decoding.* We carried out the decoding analysis using the correct-rejection trials. Eye
151 blinks were spline-interpolated (van Ede et al., 2019). Given that the gaze position of the left
152 and right eye should be highly correlated, we averaged the binocular data and obtained the two-
153 dimensional data representing the raw horizontal and vertical gaze positions. We epoched the
154 continuous data -0.3~2.4s time-locked to the cue onset and baseline-corrected to the mean of -
155 0.3~0s before cue onset. Finally, we smoothed the time-series data using a Gaussian kernel
156 (standard deviation = 4ms). Decoding was performed on each time point based on the

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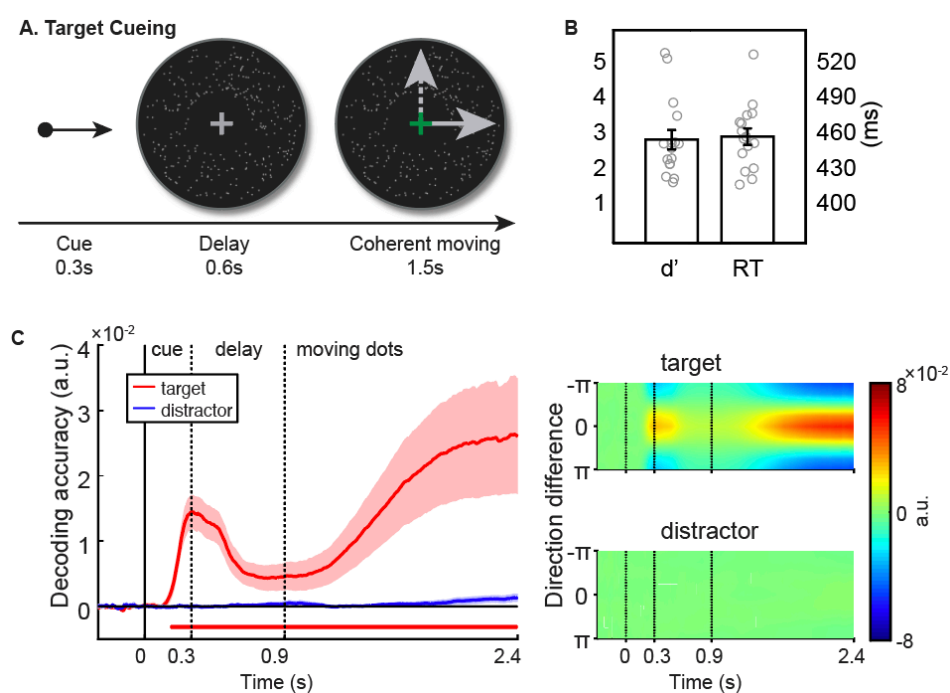
157 Mahalanobis distance in a leave-one-out manner. Trials were randomly partitioned into 7
158 training-folds and 1 test-fold. To create an unbiased training set, the number of trials from each
159 direction bin was equalized by subsampling. The subsampled trials of each direction bin were
160 averaged and convolved with a half cosine basis set raised to the 7th power. The covariance
161 matrix was estimated based on the convolved training set. The Mahalanobis distances were
162 computed between each trial of the test set and the averaged basis-weighted training set. After
163 obtaining the Mahalanobis distances, we mean-centered them across the eight directions. The
164 distances to the eight directions were regarded as the ‘tuning curve’. By computing the cosine
165 vector mean of the tuning curve, we obtained the ‘decoding accuracy’, where a more positive
166 value suggests a higher pattern similarity between similar directions than between dissimilar
167 directions (Wolff, Jochim, Akyürek, & Stokes, 2017). This process was repeated for 1000 times.
168 The averaged results for each trial was used for the statistical test. The significance of decoding
169 was assessed by comparing whether the decoding accuracy was different from zero. Cluster-
170 based permutation was performed on the decoding accuracy time-series over participants
171 ($\alpha = 0.05$, cluster-based nonparametric $\alpha = 0.05$, cluster statistic = sum, two-tail,
172 permutation times = 10000, Maris & Oostenveld, 2007).

173 **Results**

174 As shown in Fig.1B, the speed-change detection performance was good when the target
175 cue was presented ($d' = 2.9 \pm 1.1$, $RT = 460 \pm 28$ ms). There was a trend of gaze shift towards
176 the cued direction after the cue onset, during the delay and coherent moving period (see the
177 gaze heatmap in Supplementary Fig. 1). To reveal the temporal characteristics of the feature-
178 based gaze bias, we performed the Mahalanobis decoding on the gaze position data.
179 Participants’ attention was biased toward the cued direction and this bias lasted during the
180 entire delay period and further increased once the coherent moving started (Fig1.C, clustered
181 $p < .001$, $0.164 \sim 2.4$ s). By contrast, little information about the distractor dots was obtained

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182 from the gaze data. These results were in agreement with the gaze heatmap which together
183 suggested that gaze decoding can reveal the bias in attentional selection in the current
184 feature-based task. Therefore, we examined the ocular dynamics under feature-based
185 attentional inhibition with gaze decoding in Experiment 2.
186



187 **Figure 1. Task and results of Experiment 1.** (A) Task. The cue indicated the moving direction
188 of the target dots. All dots moved randomly during the delay. Participants need to detect the
189 speed change of target dots during the coherent moving period. The solid/dashed arrow
190 represents the moving direction of the target/distractor dots which were plotted for illustrations.
191 (B) Behavioral performance. Error bars represented standard errors of the mean. Each circle
192 dot represented one participant. (C) Direction decoding using gaze positions. The left panel
193 was the time series of decoding accuracy. Shaded errorbar was the standard deviation of mean
194 derived from 5,000 bootstrapped samples. Solid lines below the x-axis are the cluster-permuted
195 significant time intervals. The right panel was the tuning curve of the averaged eight directions
196 for the target and distractor direction at each timepoint. The tuning curve was the mean-
197 centered and sign-reversed Mahalanobis distance between patterns to all moving directions.

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198 **Experiment 2**

199 **Participants**

200 According to an estimation from G-power (Faul, Erdfelder, Lang, & Buchner, 2007),
201 twenty-seven participants were supposed to be collected assuming a medium effect size ($d =$
202 0.5) and a high statistic power (80%) for a one-tail paired sample T-Test ($\alpha = 0.05$). We
203 tested twenty-seven participants in total and two participants were excluded as their
204 performances were outliers to the sample (their d' and RT were more than 2.5 SD beyond the
205 mean). Twenty-five participants were included for the analysis (mean age = 21.7, range from
206 18 to 26, 8 males, all right-handed).

207 **Method**

208 The general procedures were similar between Experiment 1 and Experiment 2. There were
209 two conditions in Experiment 2. In the distractor-cueing condition, the cue indicated the
210 moving direction of distractor dots. In the neutral condition, the cue was uninformative as
211 neither the target dots nor the distractor dots would move towards the cued direction (see Fig.
212 2A). Since participants had no idea which group of dots would have the speed change in the
213 neutral condition, they should attend both directions equally. Each condition had eight blocks
214 of eighty trials and the blocks of the two conditions were randomly interleaved. Participants
215 were informed of the cueing condition at the beginning of each block. There was a quiz at the
216 end of the block asking participants to report which cueing condition they had performed. The
217 overall accuracy was 97.5% suggesting that participants were aware of the cueing condition
218 for each block.

219 **Data analysis**

220 To examine whether distractor-cueing would benefit participants' behavioral performance,
221 the non-parametric permutation test (iteration = 100000) was performed on d' and the averaged
222 RTs of the two conditions. Direction decoding in the distractor cueing condition was similar to

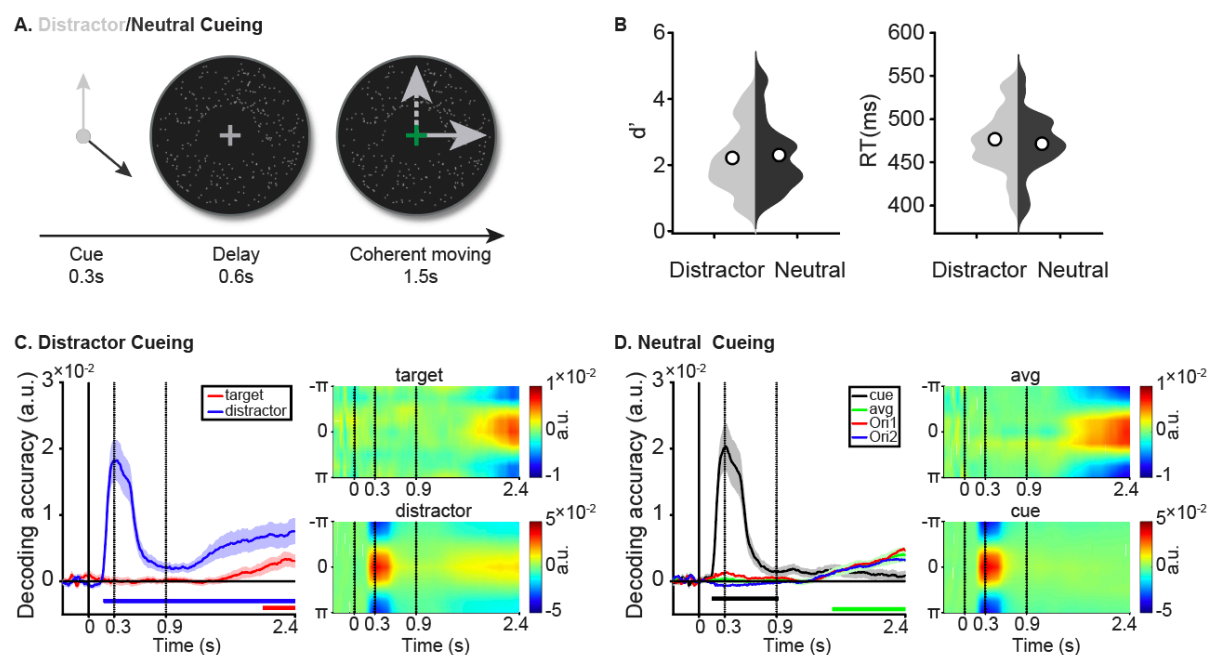
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223 what we performed in Experiment 1. Because we had fewer trials for each direction bin, we
224 partitioned the data into six-folds for the leave-one-out cross-validation. As for the decoding
225 in neutral cueing condition, we arbitrarily labeled one direction as “ori1” and the other as “ori2”
226 in each trial and performed decoding separately so that the decoding performance between the
227 distractor and neutral condition would not be affected by the amount of trials. However, the
228 statistical test was performed on the averaged decoding accuracy of the two directions.

229 **Results**

230 There was no significant difference between distractor-cueing and neutral cueing
231 conditions in the detection sensitivity ($M_{\text{dis}} = 2.2 \pm 1.0$, $M_{\text{neu}} = 2.3 \pm 1.0$, $t(24) = -1.066$, $p = .759$,
232 Cohen’s $d = .062$) or RT ($M_{\text{dis}} = 477 \pm 35\text{ms}$, $M_{\text{neu}} = 471 \pm 36\text{ms}$, $t(24) = 1.735$, $p = .611$, Cohen’s
233 $d = .102$). However, participants demonstrated distinct ocular dynamics under these two
234 conditions. In the distractor-cueing condition, participants’ attention was biased by the
235 distractor cue as informed by the decoding accuracy and the bias remained even after the
236 coherent moving onset (Fig. 2C, blue curve, 0.17~2.4s, $p < .001$). In contrast, the target
237 information gradually emerged until the late period of the coherent moving stage (Fig. 2C, red
238 curve, 2.024~2.4s, $p = .034$). In the neutral cueing condition, although there was an initial bias
239 cause by the uninformative cue (Fig. 2D, black curve, 0.15~0.926s, $p = .002$), participants
240 disengaged from that direction and started to accumulate evidence for speed change at the two
241 possible directions (Fig. 2D, green curve, 1.536~2.4s, $p = .004$).

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242

243 **Figure 2. Task and results of Experiment 2.** (A) Task. The cue in the distractor cueing

244 condition (light arrow) indicated moving direction of the distractor dots, whereas neither the

245 moving direction of the target dot nor the distractor dots will be informed by the cue (dark

246 arrow) in the neutral condition (i.e., uninformative cue). (B) Behavioral performance of the

247 two cueing conditions. Circles were the mean of all participants. (C) The direction decoding of

248 distractor cueing condition. Solid lines below the x-axis are the cluster-permuted significant

249 time intervals. (D) The direction decoding of neutral cueing condition. The green curve (avg)

250 was the average of the red (ori1) and the blue curve (ori2).

251

252

Experiment 3

253 Previous literature has suggested that distractor inhibition can be learned with extended

254 practice. Suppression benefit would be found if the distractor feature remains the same

255 throughout the experiment (Cunningham & Egeth, 2016; Moher, Lakshmanan, Egeth, & Ewen,

256 2014). In Experiment 3, we planned to investigate how the consistency of the distractor features

257 affected the gaze dynamics.

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258 **Participants**

259 According to G-power (Faul et al., 2007), twenty-three participants were supposed to be
260 collected to ensure a medium effect size ($f = 0.25$) and a high statistic power (85%) for a
261 repeated one-factor ANOVA ($\alpha = 0.05$). Twenty-three participants (mean age = 21.9, range
262 from 18 to 26, 12 males, all right-handed) were recruited for the experiment.

263 **Method**

264 Participants in Experiment 3 only completed the distractor cueing condition. However,
265 instead of changing the distractor-cue every trial, we presented the same distractor cue across
266 five consecutive trials. Target dots might change their moving directions in each trial.
267 Participants performed 16 blocks and each block contained 80 trials.

268 **Data analysis**

269 Repeated ANOVAs were performed on the d' and RT to examine the behavioral
270 difference across five repetitions. We first performed the decoding analysis on each repetition.
271 The baseline correction was performed on each repetition separately to the mean of the pre-
272 stimulus interval (-0.3~0s) of the repetition. Because we had fewer trials for each direction bin,
273 the data was partitioned into five folds for the leave-one-out cross-validation. To reveal how
274 expectations of the distractor direction modulated gazes, we performed the cross-repetition
275 decoding. Five consecutive trials were baseline corrected to -0.3~0s of the first trial. Trials at
276 each repetition were partitioned into five folds. We took the four folds of trials from each
277 repetition to train a common classifier and then tested the remaining one-fold of trials from
278 each repetition. This process was iterated for 1000 times.

279 To examine how repetition changed the decoding accuracy of target and distractor
280 directions, we drew a best-fit line to account for the trend of mean decoding accuracies across
281 five repetitions for each participant. Populations' best-fit line slopes were tested against 0 using

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282 one-sample t-test (two-tailed, $\alpha = .05$). A significant positive/negative t-value indicated
283 that the decoding accuracy increased/decreased along with each repetition.

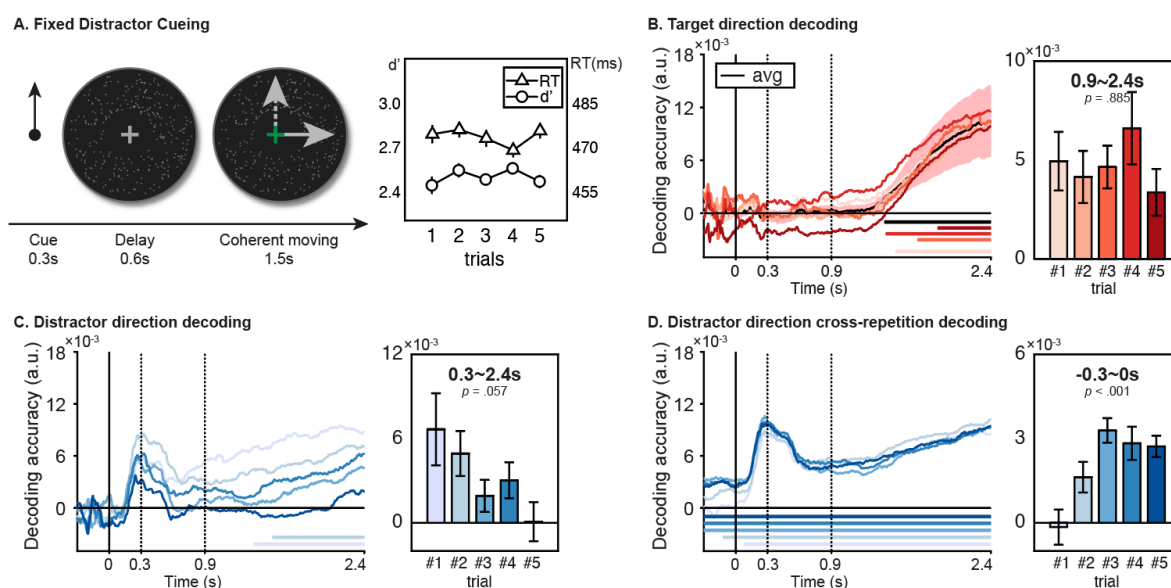
284 **Results**

285 There were no significant differences among the five consecutive trials on d' ($F(4,88)$
286 $=0.914$, $p = .460$, $\eta_p^2 = .040$) or RT ($F(4,88) = 0.861$, $p = .491$, $\eta_p^2 = .038$). We speculated that
287 the lack of the expected suppression benefits might be due to the relatively fewer repetitions in
288 the current study compared with previous literature (e.g., Cunningham & Egeth, 2016; van
289 Moorselaar & Slagter, 2019; Vatterott & Vecera, 2012; Wen et al., 2018).

290 Next, we investigated how repetitions of the distractor cue modulated the information
291 about the target and distractor contained in the gaze positions. In terms of the averaged target
292 direction decoding accuracy during the coherent moving stage, slopes of the best-fit lines were
293 not statistically different from 0 (Fig.3B, $t(22) = -0.15$, $p = .885$, $CI_{95} = [-.0011, .0009]$).
294 However, slopes of the best-fit lines for the decoding accuracy of distractor direction were
295 marginally significant negative (Fig. 3C, $t(22) = -2.01$, $p = .057$, $CI_{95} = [-.0031, 0]$). Moreover,
296 the averaged decoding accuracy between 0.3 to 2.4s of the fifth trial was smaller than the first
297 trial ($t(44) = 2.097$, $p = .021$, one-tailed, $\alpha = .05$).

298 To demonstrated how the participants prepared the distractor inhibition under a predictive
299 context, the cross-repetition decoding was conducted. The decoding accuracy of the pre-
300 stimulus interval increased along with the repetition (Fig.3D, $t(22) = 3.56$, $p < .001$, $CI_{95} =$
301 $[.0003, .0011]$). The reconstruction of the distractor direction in the fifth trial was larger than
302 the first trial ($t(44) = 3.009$, $p = .002$, one-tailed, $\alpha = .05$). This result suggested that, as the
303 number of repetitions of the distractor cue increased, participants shifted their attention to the
304 fixed distractor direction in advance before the start of the trials.

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305

306 **Figure 3. Task and results of Experiment 3.** (A) Task and behavioral results. The cue
 307 indicated the moving direction of the distractor dots which remained unchanged in five
 308 consecutive trials. The dashed arrow in the coherent moving stage represented the moving
 309 direction of distractor dots while the solid arrow represented the target direction. The right
 310 panel showed the performance for speed-up detection. The errorbar represented the between-
 311 subject standard error. (B) Decoding of target direction for each trial repetition. The black
 312 curve is the averaged decoding accuracy across five repetitions. The solid lines below the x-
 313 axis indicate significant temporal clusters (trial 1, 1.506~2.4s, $p = .007$; trial 3, 1.712~2.4s, p
 314 = .014; trial 4, 1.412~2.4s, $p = .009$; trial 5, 1.906~2.4s, $p = .035$; average, 1.398~2.4s, p
 315 = .003). The right panel is the averaged decoding accuracy during the coherent moving stage
 316 (0.9~2.4s). Error bars represent within-subject standard errors. (C) Decoding of distractor
 317 direction for each trial repetition. Solid lines at the bottom represent the time intervals of
 318 significant clusters (trial 1, 1.344~2.4s, $p = .012$; trial 2, 1.52~2.4s, $p = .024$). The right panel
 319 shows the averaged decoding accuracy of distractor direction within the time window
 320 0.3~2.4s. The p -value suggested that the population's slopes of the best-fit line were
 321 marginally significant negative. (D) Cross-repetition decoding the distractor direction. (trial

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322 1, 0.058~2.4s, $p < .001$; trial 2 -0.12~2.4s, $p = .003$; trial 3~5, -0.3~2.4s, $p < .001$). The right
323 panel is the averaged decoding accuracy of the pre-stimulus interval (-0.3~0s). The p -value
324 suggested that the population's slopes of the best-fit line were significantly positive. See
325 Supplementary Fig. S2-S4 for detailed decoding results at each repetition.

326

327

Discussion

328 Distractor inhibition is challenging and context-dependent. Mixed results have been
329 reported concerning whether distractors matched with the distractor cue could be efficiently
330 suppressed. The current study investigated small gaze shifts in feature-based attentional control
331 that could benefit from the inhibition of distractors in various cueing contingences and
332 predictive contexts. Experiment 1 demonstrated that attention was biased toward the moving
333 direction of the target dots and this bias could be quantitatively measured through the decoding
334 of gaze positions. In Experiment 2, participants were cued to the distractor's moving direction
335 and the results showed that participants' attention was biased toward the cued distractor
336 direction, as evidenced by decoded information from gaze positions. After being repeatedly
337 cued to the same distractor direction in Experiment 3, participants strategically shifted their
338 attention towards that direction preceding the cue onset and gradually suppress further bias
339 towards the distractor's direction during the coherent moving stage.

340 In Experiment 2 where the distractor's direction alternated on a trial-by-trial basis,
341 participants' attention was biased by the distractor cue and this bias lingered throughout the
342 delay and coherent moving period. The sustained distractor information decoded from the gaze
343 positions during the coherent moving stage suggested that distractor dots were still being
344 attended and monitored. By contrast, cue-induced bias was quickly overcome in the neutral
345 condition. Beck and colleagues (2018) examined the eye movement under the distractor cueing
346 condition using a visual search task. They found that the first eye movement was

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347 biased towards the items that matched the to-be-ignored color cue but subsequent fixations
348 were biased away from them. They further argued that configure an online feature-based
349 negative template in a trial-by-trial manner is almost impossible and behavioral benefits of
350 distractor cues emerge on condition that the later avoidance offsets the cost of early capture.
351 Instead of measuring conventional ocular events (e.g., fixation and saccade), we performed
352 direction decoding on the gaze positions to reveal the dynamics of feature-based distractor
353 processing. Our results did not show the *later avoidance* as reported in Beck et al (2018) or the
354 destroy component of the *search and destroy* process that was proposed by Moher and Egeth
355 (2012). We conjectured that this discrepancy might be related to stimuli property and paradigm
356 setting used in the present study. In a visual search task (Beck et al., 2018; Moher & Egeth,
357 2012), disengagement from the distractor location is the prerequisite to identify the target if the
358 distractor captures attention. However, in the speed detection task used in the present study,
359 the spatially intermingled moving dots of the target and distractor directions induced
360 interference that was unlikely to be resolved by redirecting spatial attention. This interference
361 occurred throughout the coherent moving stage, suggesting that sustained inhibition of the
362 distractor direction could benefit the speed change detection in the target direction. Indeed, it
363 has been suggested that distractors cannot be ignored before being selected in visual search
364 (Donohue, Bartsch, Heinze, Schoenfeld, & Hopf, 2018). The decoding results in the distractor
365 cueing condition demonstrated that monitoring the distractor direction while attending to the
366 target direction serves as a means to reduce the between-direction interference.

367 In Experiment 3, when the distractor cue repeated in consecutive trials, the gaze dynamics
368 manifested a functional dissociation at different stages. During the preparation, participants
369 showed increased attention bias toward the distractor direction along with each repetition.
370 Previous work showed that expectations could pre-activate the stimulus template (Blom,
371 Feuerriegel, Johnson, Bode, & Hogendoorn, 2020; Kok, Mostert, & de Lange, 2017). Our

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372 results resonated with these findings and indicated that expectations could modulate gaze
373 positions even before the trial started (see Fig. 3D). As a result of this strategical gaze-related
374 attention shift, trial-wise re-deployment of attention to the distractor direction was not
375 necessary as evidenced by the systematically deteriorated decoding performance during the
376 coherent moving stage (see Fig. 3C). In van Moorselaar and Slagter (2019), they presented the
377 distractor at the same place across trials to induce expectations about the upcoming distractor
378 location. Their results suggested that expectations modulated distractor processing in a reactive
379 manner as reflected by the smaller Pd component evoked by the distractor and lower decoding
380 accuracy of the distractor location in the forth repeated trial relative to the initial trial. Indeed,
381 we also found reduced reactive distractor inhibition as the repetition increased. Given the fixed
382 distractor cue across consecutive five trials, our participants learned to shift their attention to
383 the distractor's direction proceeding the trial onset so as to avoid reactive processing of the
384 distractor. Yet, they could still monitor the distractor with minimal attentional resources after
385 stimulus onset. Taken together, the results of Experiment 3 suggested that predictive context
386 facilitates distractor inhibition by strategically maintaining early attentional bias and reducing
387 later switch costs for the monitoring process.

388 Instead of defining ocular events, we capitalized on the raw gaze positions to explore the
389 real-time attentional bias in the present study. Because the participants were instructed to fixate
390 at the central fixation cross and try to avoid tracking of the moving dots, the recorded data is
391 treated as fixational eye movements. The fixational eye movement can be categorized as slow
392 drift, microtremor, and microsaccades (Alexander & Martinez-Conde, 2019; Martinez-Conde,
393 Macknik, & Hubel, 2004; Rucci & Poletti, 2015). The microsaccade has been regarded as an
394 overt measure of covert attention while the slow drift is often assumed to random motions of
395 the eye attempting to maintain visual fixations. However, one recent study suggested that the
396 slow drift manifested stimulus-driven modulation in speed and direction (Malevich, Buonocore,

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397 & Hafed, 2020) and the changes in drift were behavior-relevant (Intoy & Rucci, 2020). We did
398 not distinguish these two ocular events and performed direction decoding using the raw gaze
399 data. This approach has been adopted by a recent study that showed that small gaze bias can
400 reflect internal attention shifts in working memory (van Ede et al., 2019). Our results further
401 demonstrate that the processes of feature-based attentional selection and inhibition could also
402 be read-out from these small gaze shifts.

403 To conclude, we performed gaze decoding to reveal the dynamic process of feature-based
404 attentional control. In the target cueing condition, tracking of the target direction was dominant
405 and preserved to the end of the trial, whereas little information about the distractor could be
406 read-out from the gaze positions. In the distractor cueing condition, distractor inhibition
407 required constant monitoring of its direction, and this process was modulated by expectation.
408 Expectations would promote distractor inhibition by biasing the gaze-related attention to the
409 distractor's direction in the preparatory stage and decreasing the cost of re-deployment of
410 attention for distractor monitoring.

411

412 **Author Contributions**

413 Wen Wen (Wen) developed the study concept and experimental design. Testing and data
414 collection were performed by Wen and Yangming Zhang (Zhang). Wen performed the data
415 analysis and interpretation under the supervision of Sheng Li (Li). Wen drafted the
416 manuscript, and Li provided critical revisions. All authors approved the final version of the
417 manuscript for submission.

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