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2 The selection balance: contrasting value, proximity and priming in a  
3 multitarget foraging task  
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### Abstract

A critical question in visual foraging concerns the mechanisms driving the next target selection. Observers first identify a set of candidate targets, and then select the best option among these candidates. Recent evidence suggests that target selection relies on internal biases towards proximity (nearest target from the last selection), priming (target from the same category as the last selection) and value (target associated with high value). Here, we tested the role of eye movements in target selection, and notably whether disabling eye movements during target selection could affect search strategy. We asked observers to perform four foraging tasks differing by selection modality and target value. During gaze foraging, participants had to accurately fixate the targets to select them and could not anticipate the next selection with their eyes, while during mouse foraging they selected the targets with mouse clicks and were free to move their eyes. We moreover manipulated both target value and proximity. Our results revealed notable individual differences in search strategy, confirming the existence of internal biases towards value, proximity and priming. Critically, there were no differences in search strategy between mouse and gaze foraging, suggesting that disabling eye movements during target selection did not affect foraging behaviour. These results importantly suggest that overt orienting is not necessary for target selection. This study provides fundamental information for theoretical conceptions of attentional selection, and emphasizes the importance of covert attention for target selection during visual foraging.

Keywords: Foraging, Visual search, Visual attention, Eye movements, Target selection

## 52 **1. Introduction**

53 While a large amount of research has been devoted to how humans visually search for targets in their  
54 environment, this research has for the most part involved search for one unique target among several  
55 distractors (Hulleman & Olivers, 2017; Treisman & Gelade, 1980; Wolfe, 2010; Wolfe & Horowitz,  
56 2017). Recently, multi-target displays have been used to assess orienting in the visual field (e.g., Cain  
57 et al., 2012; Fougne et al., 2015; Hills et al., 2013; Wolfe, 2013; Wolfe et al., 2016), and the results  
58 have raised a number of challenges for theories of visual attention (Á. Kristjánsson et al., 2014; T.  
59 Kristjánsson et al., 2018, 2020; Tagu & Kristjánsson, 2020), calling for further characterization of visual  
60 foraging under different conditions.

61

62 One critical question in visual foraging concerns the factors driving the next target selection. This is  
63 likely to require two steps: identifying a set of candidate targets for the next selection, and then  
64 selecting the best option among these candidates (Wolfe et al., 2018, 2019). In a recent study, Wolfe  
65 et al. (2018) investigated which factors determine the second step, the selection of the best candidate,  
66 and examined whether the value assigned to different target types and the prevalence of target types  
67 could affect foraging behaviour. This is an important issue as our interactions with the world often  
68 involve targets of different value (e.g., coins in a purse, our favourite candies in a full bowl). In their  
69 foraging task, each stimulus was associated with a different number of points and participants were  
70 asked to earn a pre-specified number of points as quickly as possible. The prevalence of the targets  
71 was manipulated as well, so that in one of the conditions the most valuable targets were the rarest in  
72 the display. Observers could move to another stimulus display whenever they wanted, and the authors  
73 were interested in the time at which observers chose to move to the next display and in the identity  
74 of the targets that they had left behind. Wolfe et al. (2018) showed that when the most valuable  
75 targets were fewer on screen, some observers chose to only pursue rare but valuable targets and to  
76 move to the next display as soon as these targets had been erased, while others chose to continue  
77 foraging for other more common but less valuable targets before moving to the next display. But in

78 other conditions where all targets had the same value, observers either prioritized targets from the  
79 most prevalent category in the display or the targets closest to the previous selection. Note that the  
80 influence of target prevalence on search performance has also been found in single-target visual search  
81 (Wolfe & Van Wert, 2010). These results led Wolfe et al. (2018) to the conclusion that three main forces  
82 determine the next target selection: *target value*, *spatial proximity* to the previous selection, and  
83 *priming* of the previous target features. In other words, these three forces compete with one another,  
84 and depending on the conditions and on the individual's internal biases, the "winner" of the  
85 competition is the target selected next.

86

87 Recent evidence has identified several factors that could bias the competition in favour of value,  
88 proximity or priming. For example, Á. Kristjánsson et al. (2014) showed that during feature-based  
89 foraging, observers tend to locate the nearest target from the previous selection and frequently switch  
90 between target types for consecutive selections, while during conjunction foraging, they tend to focus  
91 on a single target type until the entire category is exhausted. In other words, this study revealed that  
92 task difficulty (or target crypticity) is an important factor for determining the next target selection,  
93 easy feature-based foraging favouring proximity to the previous target and difficult conjunction-based  
94 foraging favouring the primed features of the previous target. Later studies have identified other  
95 factors that play a role in determining the next target selection. Selection modality seems to be an  
96 important factor, as foraging with a computer mouse or with an infrared hand tracker made  
97 participants more likely to switch between target categories, favouring proximity, compared with  
98 foraging with fingers on a touchscreen (Thornton et al., 2019) or with eye gaze on a gaze-contingent  
99 display (Tagu & Kristjánsson, 2020) where participants tended to select items from the same category  
100 as on previous selections, favouring priming. Importantly, these different selection modalities are  
101 associated with different temporal dynamics, that may have contributed to the observed results. For  
102 example, the inter-target time, which corresponds to the time that has elapsed between two

103 successive target selections, is much lower during finger foraging (about 360 ms<sup>1</sup> in Á. Kristjánsson et  
104 al., 2014) than during mouse foraging (about 580 ms<sup>1</sup> in Tagu & Kristjánsson, 2020). Increased time  
105 between target selections may allow participants to switch more easily between target categories,  
106 prioritising proximity over priming. Thornton et al. (2020) directly tested this potential influence of  
107 time constraints upon foraging strategy by asking participants to synchronise their foraging speed with  
108 an auditory metronome signal and by manipulating the tempo of this signal. Their results clearly  
109 showed that with slow tempo, participants located the nearest targets and prioritised proximity, but  
110 that with increasing tempo, they were more likely to select items from the same category as previous  
111 selections and to prioritise priming. Importantly, this was found both during feature-based and  
112 conjunction-based foraging, suggesting that task difficulty and time constraints are two different  
113 factors that play a role in determining the next target selection. Although time constraints seem to be  
114 important, they cannot, on their own, explain the differences in foraging strategies between the  
115 different selection modalities. Indeed, the results of Tagu & Kristjánsson (2020) showed that observers  
116 were more likely to prioritize primed targets during gaze foraging, while the long inter-target times  
117 (about 685 ms<sup>1</sup> in Tagu & Kristjánsson, 2020) suggest that they should have prioritized proximity. At  
118 this point, it is therefore important to note that during gaze foraging participants are forced to be  
119 careful with their eye movements and fixations, to prevent accidental distractor selections, which is  
120 not the case during mouse or finger foraging. Hence, selecting targets with eye gaze may also affect  
121 visual exploration and oculomotor dynamics, and consequently the first step of the target selection  
122 process: the identification of the potential candidates for the next selection. We will revisit this issue  
123 since we will compare mouse and gaze foraging in this study.

124

125 Although past studies have identified conditions that would tilt the selection balance in favour of value,  
126 proximity or priming, all the studies mentioned above have also revealed large individual differences,

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<sup>1</sup> All inter-target times here are extracted from previous research using a feature-based foraging task with 40 targets and 40 distractors, from 2 target types and two distractor types.

127 suggesting that individuals have by-default internal biases towards value, proximity and priming, and  
128 are differentially sensitive to the effects of task difficulty, selection modality or time constraints. As an  
129 example, in Á. Kristjánsson et al. (2014) and later studies (Jóhannesson et al., 2017; Tagu &  
130 Kristjánsson, 2020; Thornton et al., 2019, 2020) the differences in search strategy between feature-  
131 based and conjunction-based foraging were consistently found for most participants, but about one  
132 third of the participants – the so-called “super foragers” – systematically located the nearest target  
133 and frequently switched between target categories, even during difficult conjunction-based foraging.  
134 The mechanisms that differentiate these super foragers from other participants are however not fully  
135 understood. Jóhannesson et al. (2017) tested, for example, whether super foragers might have better  
136 executive functions, but their results did not reveal any differences in attentional or working memory  
137 capacity between normal and super foragers. Another possibility is that super foragers could show  
138 very strong internal biases towards proximity, that could override any influence of other factors  
139 favouring priming. Consistent with this assumption, observers can switch between conjunction targets  
140 when explicitly asked to do so (Wolfe et al., 2019), or when task demands require it (T. Kristjánsson et  
141 al., 2018), but only a few individuals (i.e., the “super foragers”) spontaneously adopt this strategy.  
142 Similarly, in Wolfe et al. (2018), although the manipulation of target value strongly influenced the  
143 foraging patterns, there were clear individual differences. Some observers only selected the high-value  
144 targets, while others still selected some of the low-value targets before moving to a new display. Once  
145 again, these individual differences suggest that the former show a much stronger internal bias toward  
146 value than the latter. Nevertheless, it seems that these internal biases towards value, proximity and  
147 priming are intrinsically linked to the conditions and the task: by using three different visual search  
148 tasks (including single-target and multi-target visual search tasks), Clarke et al. (2020) have recently  
149 shown that individual differences in foraging strategy and performance were stable over repetitions  
150 of the same task, but that observers’ strategies in one task were not predictive of their behaviour in  
151 other tasks. It is therefore possible that internal biases towards value, proximity and priming are task  
152 dependent.

153

154 Here, our aim is to contribute to this growing field of research and to the identification of the factors  
155 tilting the selection balance in favour of value, proximity or priming when determining which target to  
156 select next during visual foraging. Critically, we note that past research has largely focused on the  
157 second step of the target selection process, namely the selection of the best candidate for the next  
158 target selection, but that little is known about the mechanisms involved in the first step, the  
159 identification of a set of candidates (Wolfe et al., 2018). In the current study, we therefore investigated  
160 the mechanisms underlying target identification, notably by examining the potential involvement of  
161 eye movements during target selection. Current theories of visual orienting indicate that the  
162 identification process could either be achieved with overt shifts of attention and involve eye  
163 movements, or could be achieved with covert shifts of attention, not accompanied by eye movements  
164 (Posner & Cohen, 1980; see also Hunt & Kingstone, 2003). Although there is a large literature on eye  
165 movement behaviour during single-target visual search (for a review, see Eckstein, 2011), oculomotor  
166 dynamics during visual foraging are far less well known (Kosovicheva et al., 2020; Tagu & Kristjánsson,  
167 2020). Recently, Tagu & Kristjánsson (2020) examined the influence of task difficulty and effector type  
168 on oculomotor dynamics during foraging, and showed that feature-based foraging is associated with  
169 higher fixation duration and smaller saccade amplitude than conjunction-based foraging, suggesting  
170 that easy search is associated with visual exploration in a *focal* mode while difficult search is associated  
171 with exploration in an *ambient* mode (Goldberg & Kotval, 1999; Krejtz et al., 2016; Over et al., 2007;  
172 Unema et al., 2005; Velichkovsky et al., 2002). Importantly, these effects of task difficulty on  
173 oculomotor dynamics were accompanied by effects on foraging strategy (e.g., the order of target  
174 selections) and foraging dynamics (e.g., inter-target times), and were found both when observers  
175 selected targets with a computer mouse and with eye gaze (Tagu & Kristjánsson, 2020). In other words,  
176 although there are some differences, foraging behaviour does not seem to vary much between mouse-  
177 and gaze foraging in terms of foraging strategy, foraging dynamics or oculomotor dynamics. Critically,  
178 as discussed above, during gaze foraging the target selection process is intrinsically linked to where

179 participants look, and consequently, to eye movements. If participants do not covertly select a visual  
180 target prior to the eye movement, they are likely to select a distractor. Hence, similar foraging  
181 behaviour during mouse foraging (where participants are free to use overt orienting) and during gaze  
182 foraging (where covert orienting is much more probable) suggests that the identification of the set of  
183 candidates for the next target selection is achieved through covert orienting. Note however that the  
184 effect of task difficulty (feature-based versus conjunction-based foraging) has proven to be large and  
185 robust and may have overridden the potential effects of effector type on foraging behaviour (Tagu &  
186 Kristjánsson, 2020). Moreover, although the study of Tagu & Kristjánsson (2020) has cast light on how  
187 the selection balance between proximity and priming could influence oculomotor dynamics, the  
188 authors did not manipulate target value.

189

190 Here, for the first time, we used a feature-based foraging task to investigate the role of eye movements  
191 in target selection during visual foraging. More precisely, we examined how favouring overt orienting  
192 (in a mouse foraging task) or covert orienting (in a gaze foraging task) influences the competition  
193 between target value, proximity and priming, and therefore affects foraging strategy. In light of  
194 previous studies, we hypothesized that target value and proximity manipulations should strongly affect  
195 foraging behaviour (Wolfe et al., 2018), but that the results should not vary much between mouse-  
196 and gaze foraging tasks (Tagu & Kristjánsson, 2020), suggesting that eye movements play only a small  
197 role in target selection. Moreover, we expected to observe individual differences in foraging strategy,  
198 with considerable variation in the effects of target value and proximity across individuals, suggesting  
199 the presence of internal biases that guide target selection.

200

## 201 **2. Methods**

### 202 **2.1. Participants**

203 Twenty-four participants aged from 21 to 48 years (mean age = 28.6, SD = 6.4) were recruited from the  
204 Icelandic community. Fourteen were females, 21 were right-handed (self-reported) and 12 were right-



205 eye-dominant (hole-in-card test, Durand & Gould, 1910). Prior to their inclusion in the study, all  
206 participants received clear explanations about the procedure and gave their written informed consent.  
207 The study was completed in accordance with the requirements of the Icelandic bioethics committee  
208 and conformed with the ethical guidelines set out in the 1964 Declaration of Helsinki and its later  
209 amendments.

210

211 The sample size ( $n = 24$ ) was determined prior to data collection and was based on recent studies with  
212 similar procedures where within-subject differences in foraging behaviour have been successfully  
213 measured (e.g.,  $n = 16$  in Á. Kristjánsson et al., 2014;  $n = 21$  in Kristjánsson and Kristjánsson, 2018;  $n =$   
214  $24$  in Tagu & Kristjánsson, 2020;  $n = 12$  in Wolfe et al., 2018). Following data collection, we verified  
215 that this sample size would provide sufficient power to detect the main effects of block type, spatial  
216 organization and effector type, and the 2 (block type: value, no value) by 2 (spatial organization:  
217 random, patches) interaction, by conducting a power analysis using the “`ss.power.wa.general()`”  
218 function of the “Bias and Uncertainty Corrected Sample Size” (BUCSS) R package (Anderson et al.,  
219 2017). This function uses the F-value and sample size from a previous study to generate the necessary  
220 sample size needed to achieve the desired level of statistical power in the current study, for any type  
221 of effect using a within-subject ANOVA involving any number of factors. Here, we chose the previous  
222 study from our group (Tagu and Kristjánsson, 2020) that most closely resembles the current design.  
223 That study involved a 2 (block type: feature, conjunction) by 2 (effector type: mouse, gaze) repeated-  
224 measures analysis of variance conducted on a set of dependent variables, including the number of runs  
225 and inter-target times. Along with the sample size and alpha parameters from Tagu and Kristjánsson  
226 (2020), we used the F-values of the reported main effects of block type on the number of runs ( $F[1,23]$   
227  $= 93.1, p < .001, \eta_p^2 = .80$ ) and of effector type on inter-target times ( $F[1,23] = 31.8, p < .001, \eta_p^2 = .58$ )  
228 as inputs for the BUCSS `ss.power.wa.general()` function. We used the by-default settings of assumed  
229 alpha (.05), level of assurance (.8) and desired power (.8). The analysis yielded a minimum sample size  
230 of 12. Because our study involves a more complex design (2 x 2 x 2 within-subject design) than the 2 x

231 2 within-subject design of Tagu and Kristjánsson (2020), the doubled sample size ( $n = 24$ ), should  
232 ensure that our study reaches the desired statistical power.

233

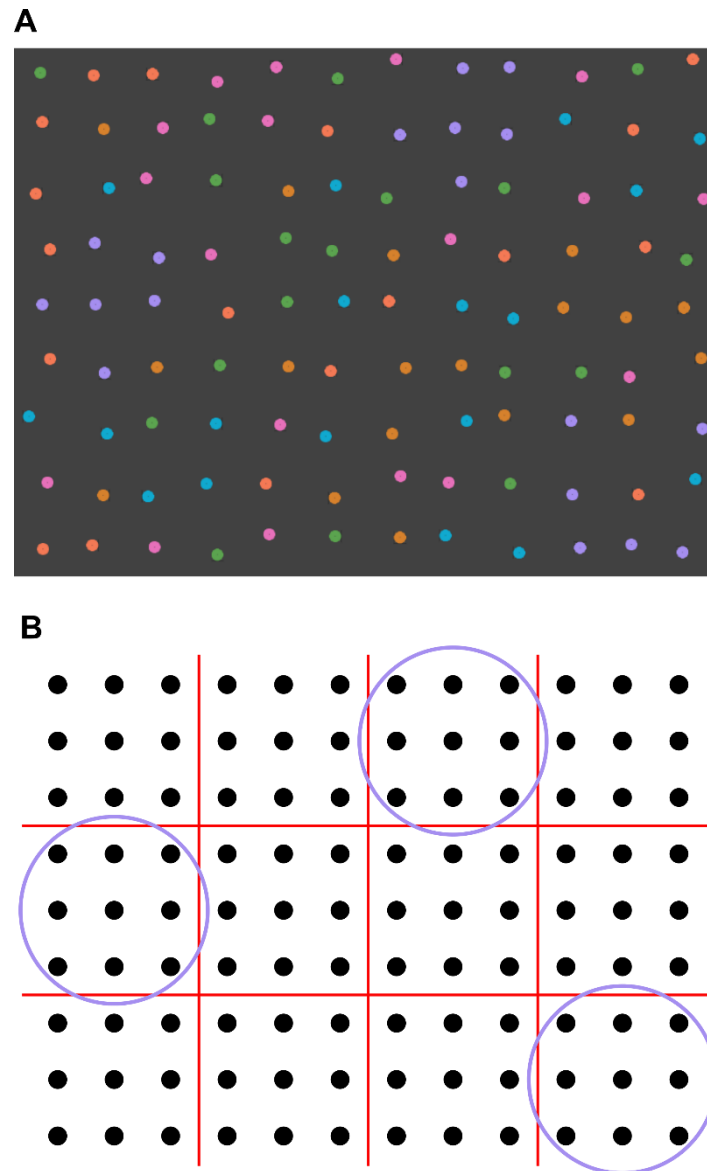
## 234 **2.2. Materials**

235 Stimuli were presented on a BenQ XL24211Z monitor (BenQ, Taipei, Taiwan) with a refresh rate of 144  
236 Hz and a resolution of  $1920 \times 1080$  pixels. The experiment took place in a dimly lit and soundproof  
237 room. The head of the participants was kept stable with a chin and forehead rest positioned 57 cm  
238 away from the monitor. Eye movements from the dominant eye were recorded using an EyeLink 1000  
239 Plus (SR Research, Ontario, Canada) sampled at 2000 Hz and with an average spatial accuracy of  $0.15^\circ$ .  
240 The online saccade detection corresponded to an above-threshold velocity of  $30^\circ/s$  and acceleration  
241 of  $8000^\circ/s^2$ .

242

243 Each trial involved 108 coloured disks from six colour categories (18 stimuli per category) equalised in  
244 size ( $0.5^\circ$  diameter) and luminance ( $20 \text{ cd/m}^2$ ). Three of these categories (54 stimuli) were targets, and  
245 the other three (54 stimuli) were distractors. The colours were selected based on the six categories  
246 found for isoluminant colours in Witzel & Gegenfurtner (2013) and refer to the basic colour terms  
247 “pink”, “orange”, “yellow”, “green”, “blue” and “purple”. The stimuli were presented on a dark grey  
248 background with a luminance of  $7 \text{ cd/m}^2$ . As shown in the trial snapshot in Figure 1A, stimuli were  
249 distributed across a non-visible grid composed of twelve columns and nine rows and occupying  $28^\circ \times$   
250  $20^\circ$  of the visual field. The columns/rows of the grid were separated by an empty space of about  $2^\circ$ .  
251 However, the position of the stimuli within the grid was slightly jittered ( $\pm 0.5^\circ$ ) to create a less uniform  
252 appearance, modifying the size of the initial  $2^\circ$  gap between stimuli.

253



254

255 *Figure 1. Example of a trial. A. Example of a trial from the patched-organization condition, with purple high-*  
 256 *value targets, orange and green low-value targets, and pink, blue and yellow distractors. B. Illustration of the*  
 257 *grid used to assign targets to locations in the grid. The black points represent the target locations in the grid*  
 258 *before the spatial jitter was applied, and the red lines show how the grid could be divided into 12 areas of 9*  
 259 *targets in the patched-organization condition. The purple circles indicate the areas selected for the patches of*  
 260 *purple high-value targets for this particular trial.*

261

### 262 2.3. Procedure

263 In four blocks of 20 trials each, participants had to select multiple instances of three target types (e.g.,  
 264 purple, orange and green) and ignore multiple instances of three distractor types (e.g., pink, yellow  
 265 and blue). Target types were associated with a certain amount of points, and the trial ended once the

266 participant had selected enough targets to reach a pre-specified number of points. The four blocks  
267 differed in the point value associated with the three target types (value block or no-value block) and  
268 by the effector used to select the targets (computer mouse or eye gaze). In the value blocks,  
269 participants had to earn 176 points to terminate the trials. Selecting targets from one of the target  
270 types (e.g., purple, the “high-value targets”) made participants earn 6 points and selecting targets from  
271 the two other target types (e.g., orange and green, the “low-value targets”) made them earn 2.5 points.  
272 The number of points for each target was chosen so that participants needed to select at least one  
273 item from each target type to complete the trials: if participants selected all 18 high-value targets, they  
274 would need to select at least 28 low-value targets to terminate the trials (which corresponds, e.g., to  
275 the 18 instances of one of the low-value categories, and half of the targets from the second low-value  
276 category). Participants were however not forced to select all the high-value targets, and they could  
277 select high- and low-value targets in any order, so that all combinations leading to 176 points would  
278 terminate the trials. Participants were told that they did not need to count the points because trials  
279 would automatically end once they had earned enough points. In the no-value blocks, all target types  
280 were associated with 1 point, and participants had to earn 54 points to terminate the trials. In other  
281 words, participants’ task was to select all targets from all the three target categories. Participants had  
282 to complete each block type two times, one per effector type. During mouse foraging, participants  
283 were asked to select the targets by clicking on them with the left button of a computer mouse, while  
284 during gaze foraging they had to do so by fixating the targets with their eyes. Moreover, to manipulate  
285 target proximity, the spatial organization of the targets was manipulated within each block. Each block  
286 contained 10 trials where targets and distractors were randomly assigned to one of the 108 locations  
287 (“random organization”), intermixed with 10 trials where targets from one of the categories (which  
288 corresponded to the high-value targets in the value blocks) were distributed into three “patches”. The  
289 idea here was to contrast target value and target proximity, since on “patched” trials prioritization of  
290 target value (i.e., selecting all the high-value targets first) would force observers to travel through the  
291 distant patches, while passing over quite a few of the low-value targets on the way. During the value

292 blocks, the target category presented in patches was always the high-value category (e.g., purple).  
293 During the no-value blocks, the target category presented in patches was held constant for a given  
294 individual (e.g., blue). For the sake of clarity, in what follows and in the results section, we will refer to  
295 “high-value targets” for all targets presented in patches, irrespective of whether they were in the value  
296 block (in which they were indeed associated with high value) or in the no-value block (where they were  
297 not associated with a particular value). On trials organized with patches of high-value targets, the  
298 display was divided into twelve areas of nine targets (as illustrated in Figure 1B). The 18 high-value  
299 targets were randomly distributed in three of these areas, with two constraints: (1) there had to be at  
300 least two areas separating each patch of high-value targets, and (2) there had to be at least one high-  
301 value target within each patch (i.e., it was not possible for the 18 high-value targets to be equally  
302 distributed in two of the three patches with the third one being composed of distractors and low-value  
303 targets). Once the high-value target locations were assigned, all other targets were randomly assigned  
304 to the 90 remaining locations in the grid. For example, Figure 1A shows a trial in the patched-  
305 organization condition, and Figure 1B shows three areas selected for the purple high-value targets of  
306 Figure 1A (for a given trial). On trials with random spatial organization, all stimuli were randomly  
307 assigned to the 108 possible locations. In all conditions, the overall spatial layout and location of  
308 targets and distractors was generated independently on each trial.

309

310 Each block began with a nine-point calibration. The position of the dominant eye was checked before  
311 each trial, and if it was further than  $0.75^\circ$  away (left, right, up or down) from the centre of the screen,  
312 the trial was cancelled and repeated later in the block, and a new calibration began before the next  
313 trial started. Moreover, each block was preceded by 2 training trials to familiarize the participant with  
314 the tasks. During the training, the trials were always from the random spatial organization condition.  
315 In all blocks, participants were instructed to finish the trials as fast as possible, without selecting any  
316 distractor. When a target was selected, it disappeared, while distractor selection led to an error-  
317 message screen. As in previous research involving similar paradigms (e.g., Á. Kristjánsson et al., 2014;

318 Tagu & Kristjánsson, 2020; Thornton et al., 2019), we clearly explained to the participants before the  
319 experiment started that if they selected a distractor, the error message would be displayed and the  
320 entire foraging array with the 108 stimuli would be presented again later in the block. When a trial was  
321 successfully completed, a feedback screen appeared indicating the number of remaining trials in the  
322 block and the trial response time. Participants had to successfully complete 20 trials to terminate the  
323 blocks. The stimuli were surrounded by a  $1.5^\circ \times 1.5^\circ$  rectangular interest area, and the stimulus  
324 selection was triggered when a mouse click (mouse foraging) or an eye fixation (gaze foraging) was  
325 detected in that area. The distance between items on screen and the strength of the spatial jitter  
326 applied to stimulus locations were chosen so that the interest areas never overlapped. During gaze  
327 foraging, target selection was triggered when an eye fixation longer than 150 ms was detected in the  
328 interest area, and distractor selection was triggered when an eye fixation longer than 350 ms was  
329 detected in the interest area. To make the gaze foraging task comparable to the mouse foraging task,  
330 it was important to provide observers with the possibility to both “miss” the targets they had not yet  
331 identified and briefly fixate some of the distractors before quickly shifting their gaze somewhere else  
332 once they had identified them as distractors (as they would do in a non-gaze-contingent task). The  
333 fixation times were chosen based on pre-tests run on two well-trained participants, where 150 ms  
334 turned out to be the optimal timing to prevent false detections of target selections during visual  
335 exploration without affecting fixation durations, and 350 ms the optimal timing to prevent omissions  
336 of distractor selections while enabling quick identification of the stimuli as distractors and continued  
337 exploration of the scene (see Tagu & Kristjánsson, 2020, for similar manipulations).

338

339 The order of the tasks was counterbalanced so that half of the participants started with the no-value  
340 blocks and the other half with the value blocks. Moreover, half of them performed mouse foraging  
341 before gaze foraging while the other half did the reverse. The target identities were counterbalanced  
342 as well so that for half of the participants the targets were purple, orange and green among pink,  
343 yellow and blue distractors, while for the other participants the target and distractor identities were

344 reversed. The identity of the high-value category was also counterbalanced, so that each colour was  
345 associated with the high-value targets for 1/6 of the observers. To prevent any influence of the  
346 associations between target types and values from the value blocks to the no-value blocks, target and  
347 distractor identities were reversed for a given observer between the value- and no-value blocks but  
348 were held constant between the mouse and gaze foraging tasks.

349

#### 350 **2.4. Data analysis**

351 In line with previous studies (e.g., Á. Kristjánsson et al., 2014; T. Kristjánsson et al., 2020; Tagu &  
352 Kristjánsson, 2020), we assessed *foraging strategy* by measuring the number of “runs” on a given trial.  
353 A “run” refers to the sequential selection of targets of the same category. In our experiment, the  
354 number of runs could vary from 3 (one run per target category, such as when a participant never  
355 switches between target categories) to 54 (one run per target, such as when a participant always  
356 switches between target categories). Note that 54 could only be reached in the no-value blocks, as  
357 participants did not select all the targets in the value blocks. Hence, because of the differing number  
358 of target selections the number of runs may mechanically be higher in the no-value block than in the  
359 value block. To take this potential bias into account, we instead analysed the “proportional number of  
360 runs”, that corresponds to the number of runs divided by the actual number of target selections on  
361 the trial. Furthermore, *foraging dynamics* were assessed by measuring inter-target times (the time in  
362 milliseconds that elapses between two successive target selections) and inter-target distances  
363 (distance in degrees of visual angle between two successive target selections). Note that the first and  
364 last target selections on a trial were removed from these analyses as they are known to show different  
365 dynamics than other selections (Á. Kristjánsson et al., 2019). To examine oculomotor dynamics during  
366 foraging, after having measured the total number of fixations on each trial, we filtered the eye  
367 movement data and only included fixations that were associated with target selection (i.e., eye  
368 fixations occurring just before the mouse click during mouse foraging or the ones triggering target  
369 selection during gaze foraging) and their subsequent saccades to the analysis (for similar analyses, see

370 Tagu & Kristjánsson, 2020). We then examined the average fixation duration and saccade amplitude  
371 for these “critical” eye movement data associated with target selection and search for the next target.  
372 In this article, we only present analyses run on these critical eye movement data, but all data from  
373 critical and non-critical eye movements are available on the Open Science Framework (OSF) page  
374 associated with this article at <https://doi.org/10.31234/osf.io/48pzy>.

375  
376 All the dependent variables were analysed using repeated-measure analyses of variance (ANOVA).  
377 Within-subject factors included block type (no-value block, value block), effector (mouse, gaze) and  
378 spatial organization (random, patches). Moreover, we assessed the evidence in favour of the  
379 alternative hypothesis  $H_1$  versus the null hypothesis  $H_0$  using Bayes Factor analyses<sup>2</sup> ( $BF_{10} > 1$  is  
380 considered evidence in favour of  $H_1$ , whereas  $BF_{10} < 1$  is considered evidence in favour of  $H_0$ ) with the  
381 BayesFactor R package version 0.9.12–4.2 (Morey and Rouder 2018). The Bayes Factor analysis was  
382 performed using the default Jeffreys-Zellner-Siow priors (Rouder et al., 2012).

383

### 384 **3. Results**

#### 385 **3.1. Foraging strategy: internal biases towards value, proximity and priming**

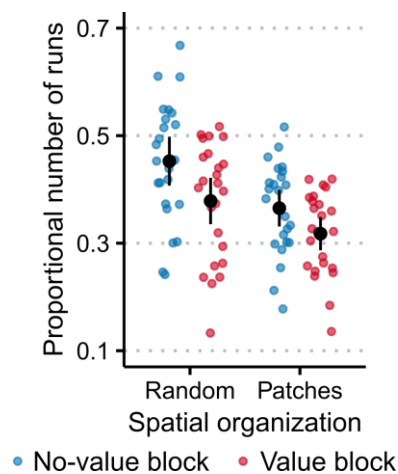
386 The first aim of this study was to confirm the existence of internal biases towards value, proximity and  
387 priming that would predict search strategy during visual foraging. Our main indicator of search strategy  
388 is the proportional number of runs, that can distinguish between conditions where individuals are  
389 biased towards priming (small number of runs) and conditions where individuals are biased towards  
390 proximity (high number of runs). As expected, manipulating target value strongly affected run patterns,

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<sup>2</sup> Bayes Factors comprised between 1 and 3 yield anecdotal evidence for  $H_1$ , values between 3 and 10 yield moderate evidence for  $H_1$ , values between 10 and 30 bring strong evidence for  $H_1$ , values between 30 and 100 yield very strong evidence for  $H_1$ , and values above 100 yield extreme evidence for  $H_1$ . In the same manner, Bayes Factors comprised between 0.33 and 1 yield anecdotal evidence for  $H_0$ , values between 0.1 and 0.33 yield moderate evidence for  $H_0$ , values between 0.033 and 0.1 yield strong evidence for  $H_0$ , values between 0.01 and 0.033 yield very strong evidence for  $H_0$ , and values below 0.01 yield extreme evidence for  $H_0$  (criteria proposed by Jeffreys, 1961, and modified by Lee and Wagenmakers, 2014)



391 the value block being associated with fewer (proportional) runs ( $M = .35$ ,  $SD = .09$ ) than the no-value  
 392 block ( $M = .41$ ,  $SD = .10$ ;  $F[1,23] = 13.8$ ,  $p < .001$ ,  $\eta_p^2 = .37$ ,  $BF_{10} > 100$ ; see Figure 2). In other words, the  
 393 run patterns suggest that individuals are biased towards proximity in the no-value block, while they  
 394 are more biased towards priming in the value block. Importantly, run patterns also varied with spatial  
 395 organization ( $F[1,23] = 188.7$ ,  $p < .001$ ,  $\eta_p^2 = .89$ ,  $BF_{10} > 100$ ), the proportional number of runs being  
 396 higher on trials with random spatial organization ( $M = .42$ ,  $SD = .10$ ) compared with trials organized  
 397 with patches of targets ( $M = .34$ ,  $SD = .08$ ). This suggests that the inclusion of patches of targets gives  
 398 more weight to priming (as opposed to proximity) in the selection balance than when spatial  
 399 organization is random. Although the interaction between spatial organization and block type is  
 400 significant in the ANOVA ( $F[1,23] = 4.5$ ,  $p < .05$ ,  $\eta_p^2 = .16$ ,  $BF_{10} = 0.46$ ), the observed data in Figure 2  
 401 suggests a rather weak interaction, and the Bayes Factor is in favour of the null hypothesis. Overall,  
 402 this suggests that spatial organization and block type independently affect the selection balance.



403

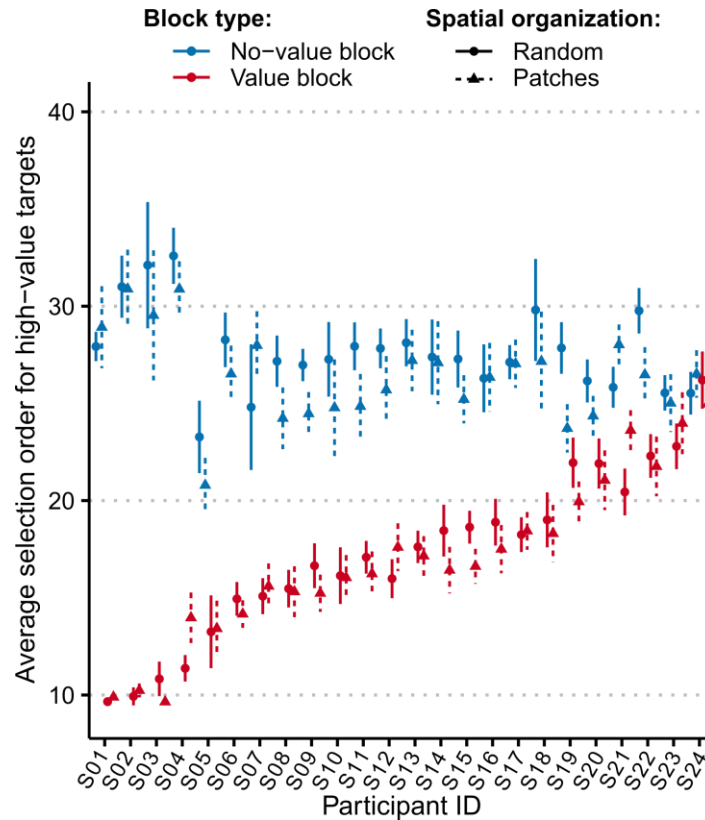
404 **Figure 2.** Interaction between the effects of block type and spatial organization on the proportional number  
 405 of runs. Blue dots represent individual data points from the no-value block and red dots represent individual  
 406 data points from the value block. Black dots and error bars represent the mean with 95% confidence intervals.

407

408 Until now, we have reported results on proportional number of runs, that give a good contrast  
 409 between prioritization of proximity (associated with many switches between target categories) and  
 410 prioritization of priming (associated with few switches between target categories). However, these  
 411 analyses do not provide a clear picture of how target value affects this competition between primed

412 targets and proximal targets. Indeed, by definition, prioritization of value would mechanically involve  
413 prioritization of primed targets, as all high-value targets are from the same category. A more direct  
414 way to address whether target value affects foraging strategy consists in analysing the order in which  
415 high-value targets and low-value targets were selected. To this aim, we computed the “selection  
416 order”, which ranges from 1 (first target being selected) to the total number of target selections on  
417 the trial (i.e., in no-value blocks, selection order always ranged from 1 to 54). Note that if an observer  
418 selects all the 18 high-value targets before the 36 low value targets on a given trial, the average  
419 selection order for the high-value targets of that trial would be  $\frac{\sum_{n=1}^{18} n}{18} = 9.5$ . Similarly, selecting the  
420 high-value targets at random times during the trial would lead to an average selection order of  $\frac{\sum_{n=1}^{54} n}{54} =$   
421 27.5. Remember that in the no-value blocks, “high-value targets” refer to the target category  
422 presented in patches in the non-random spatial organization condition, but these targets are not  
423 actually associated with a particular value. In Figure 3, we present the individual data on average  
424 selection order for high-value targets across trials. A quick look at the figure clearly shows that  
425 participants selected high-value targets earlier in the trial than low-value targets in the value block but  
426 did not do so in the no-value block. Interestingly, we also see considerable individual differences: while  
427 participants S01 to S03 clearly prioritized the high-value targets in the value block, participants S19 to  
428 S24 showed average selection orders over 20, suggesting weak prioritization of high-value targets, and  
429 the other observers covered the range between these two extremes. Figure 3 also shows that in the  
430 no-value block, almost all participants selected high-value targets at random times during the trial,  
431 with average selection orders close to 27.5. Moreover, in this analysis the prioritization of target  
432 proximity can also be assessed by comparing selection order of high-value targets during trials with  
433 random spatial organization and trials organized with patches of targets. Individual data from the no-  
434 value block show prioritization of proximity, with the target category presented in patches selected  
435 earlier during trials with a spatial organization in patches (blue triangles with dashed-line error bars in  
436 Figure 3) compared with trials with random spatial organization (blue disks with whole-line error bars

437 in Figure 3). Note that this was not the case during the value blocks, where high-value targets were  
 438 prioritized both when presented in patches and when randomly scattered among less valuable targets.  
 439



440

441 **Figure 3.** Individual data on selection order for high-value targets as a function of block type and spatial  
 442 organization. Disks with whole-line error bars represent data from trials with random spatial organization,  
 443 and triangles with dashed-line error bars represent data from trials organized with patches of targets. Blue  
 444 lines represent data from the no-value block and red lines data from the value block. Participant IDs were  
 445 ordered during the analysis, according to the average selection order. Error bars represent within-individual  
 446 standard errors of the mean.

447

448 The ANOVA on selection order for high-value targets confirmed that selection order was significantly  
 449 higher in the no-value block ( $M = 27.0$ ,  $SD = 2.1$ ) than in the value block ( $M = 17.1$ ,  $SD = 4.2$ ;  $F[1,23] =$   
 450  $81.7$ ,  $p < .001$ ,  $\eta_p^2 = .78$ ,  $BF_{10} > 100$ ). Furthermore, the analysis confirmed that spatial organization had  
 451 only a small influence – if any – on selection order for high-value targets ( $F[1,23] = 7.7$ ,  $p < .01$ ,  $\eta_p^2 =$   
 452  $.25$ ,  $BF_{10} = 0.21$ ), with a Bayes Factor in favour of the null hypothesis. Similarly, the interaction between  
 453 spatial organization and block type ( $F[1,23] = 7.5$ ,  $p < .012$ ,  $\eta_p^2 = .25$ ,  $BF_{10} = 0.34$ ) suggests that the

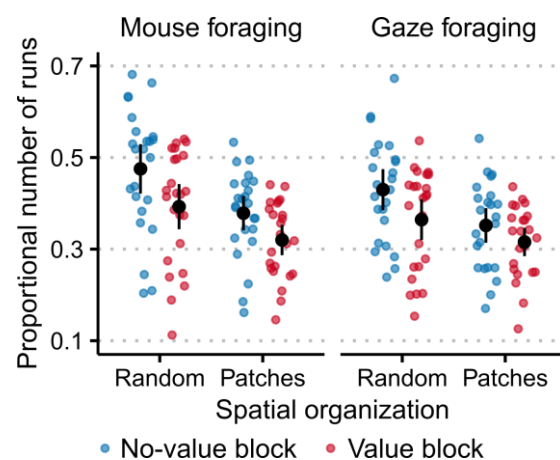
454 potential effect of spatial organization on selection order for high-value targets is only found in the no-  
 455 value block (organization in patches:  $M = 26.4$ ,  $SD = 2.3$ ; random organization:  $M = 27.7$ ,  $SD = 2.2$ ;  $p <$   
 456  $.002$  for Tukey HSD post-hoc test), not in the value block (organization in patches:  $M = 17.0$ ,  $SD = 4.2$ ;  
 457 random organization:  $M = 17.2$ ,  $SD = 4.3$ ;  $p = .89$  for Tukey HSD post-hoc test). Again, note however  
 458 that the effect of spatial organization should be interpreted with caution, since even in the no-value  
 459 block the effect is relatively weak and the Bayes factor is in favour of the null hypothesis. Overall, the  
 460 results in Figure 3 suggest that foraging behaviour in the value block is driven by target value, while it  
 461 is driven by target proximity in the no-value block. However, the analysis highlights strong individual  
 462 differences in the influence of target value on selection order, which could be linked to different levels  
 463 of individual internal biases towards value, proximity and priming.

464

### 465 3.2. The role of overt and covert orienting in target selection during visual foraging

466 The second aim of this study was to test the potential role of eye movements in target selection during  
 467 visual foraging. Hence, this section is dedicated to comparing the mouse foraging task – in which  
 468 observers were free to overtly orient to the next target during target selection – and the gaze foraging  
 469 task – in which observers had to select targets by fixing their gaze on the current target and therefore  
 470 needed to use covert orienting for identifying the next target during target selection.

471



472

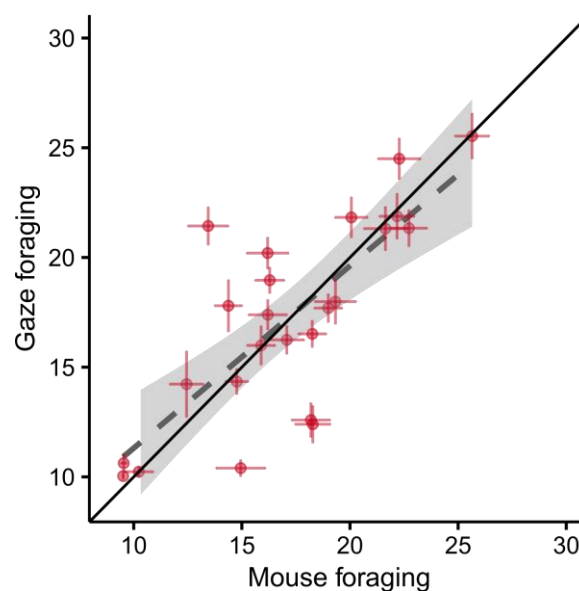
473 **Figure 4.** Interaction between effector type, block type and spatial organization on the proportional number  
 474 of runs. Blue dots represent individual data points from the no-value block and red dots represent individual

475 data points from the value block. The left panel represents data from the mouse foraging task, and the right  
 476 panel represents data from the gaze foraging task. Black dots and error bars represent the mean with 95%  
 477 confidence intervals.

478

479 Interestingly, our main indicator of foraging strategy – the proportional number of runs – does not  
 480 seem to vary much between mouse ( $M = .39, SD = .09$ ) and gaze ( $M = .37, SD = .09$ ) foraging ( $F[1,23] =$   
 481  $4.1, p > .05, \eta_p^2 = .15, BF_{10} = 1.45$ ), with only anecdotal evidence in favour of  $H_1$ . Moreover, as Figure 4  
 482 shows, the ANOVA and Bayes Factor analyses suggest that the effector type used for target selection  
 483 did not significantly modulate the effects of block type ( $F[1,23] = 1.4, p = .26, \eta_p^2 = .06, BF_{10} = .27$ ) nor  
 484 of spatial organization ( $F[1,23] = 5.8, p < .03, \eta_p^2 = .20, BF_{10} = .34$ ) on the proportional number of runs  
 485 (note that the 3-way interaction is also non-significant:  $F < 1, BF_{10} = .26$ ). Overall, this analysis and  
 486 Figure 4 importantly reveal that proportional run numbers do not vary between mouse- and gaze  
 487 foraging, suggesting that blocking eye movements during target selection does not affect foraging  
 488 strategy.

489



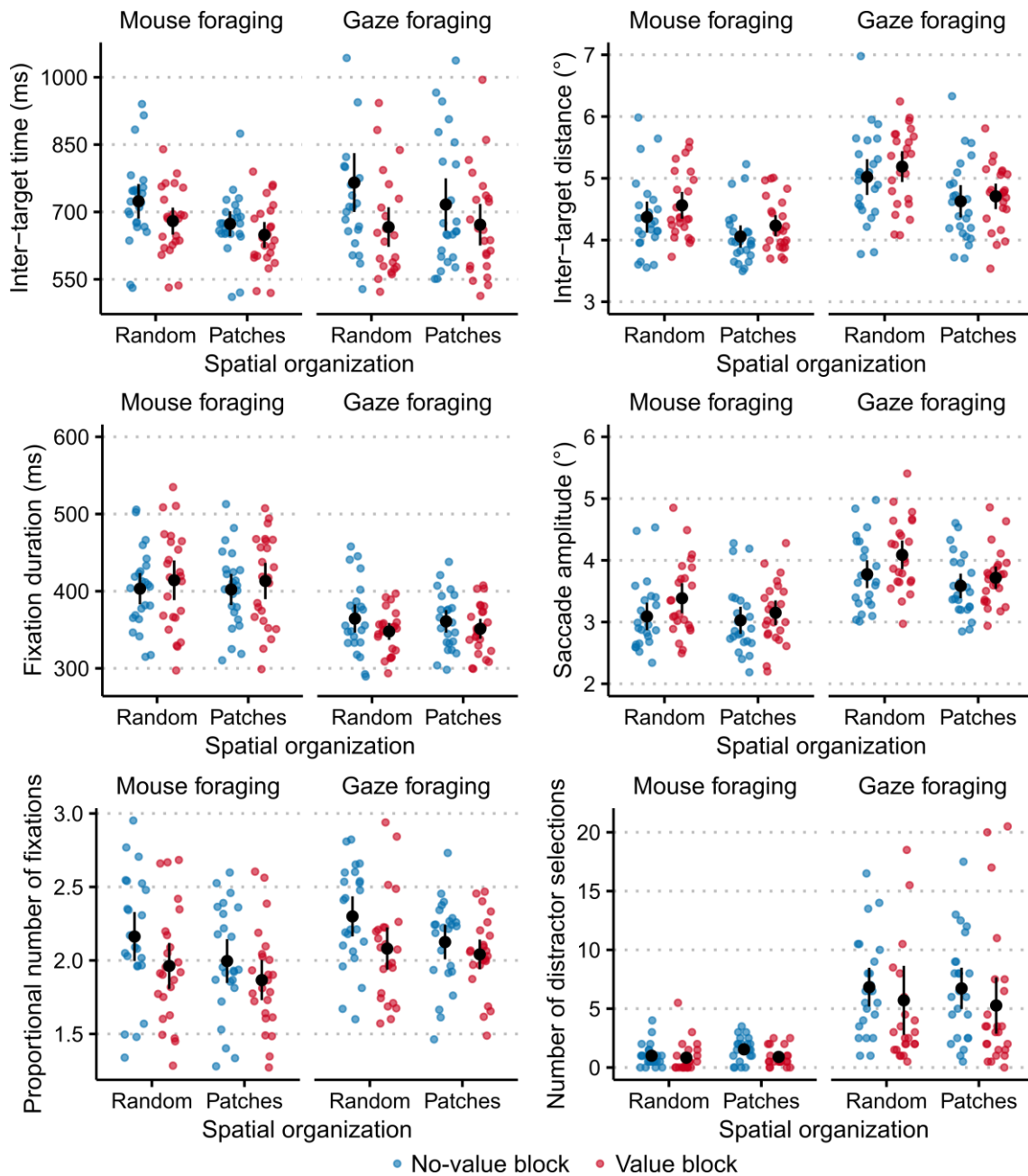
490

491 **Figure 5.** Correlation between selection order for high-value targets during mouse foraging (abscissa) and  
 492 selection order for high-value targets during gaze foraging (ordinate). Red dots represent individual data  
 493 points from the value block and error bars represent within-individual standard errors of the mean. The grey  
 494 dashed line shows the best linear fit with 95% confidence intervals, and the black plain line depicts what  
 495 would be absolute equality between mouse and gaze foraging.

496

497 Figure 5 shows little differences between mouse and gaze foraging in selection order for high-value  
498 targets, as shown by the linear relationship between the selection order for high-value targets during  
499 mouse foraging and the selection order for high-value targets during gaze foraging ( $r = .77, p < .001,$   
500  $95\%CI = [.53, .90]$ ). In other words, the individual differences observed in the value block in Figure 3  
501 are similar for mouse and gaze foraging, suggesting that individuals do not change their foraging  
502 strategy with effector type. Again, this shows that preventing observers from overtly orienting to the  
503 next target during target selection does not change their foraging strategy.

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**Figure 6.** Results on inter-target times, inter-target distances, fixation durations, saccade amplitudes, proportional number of fixations and number of distractor selections, that overall show a cost associated with gaze foraging. Blue dots represent individual data points from the no-value block and red dots represent individual data points from the value block. In each plot, left panels represent data from the mouse foraging task, and right panels represent data from the gaze foraging task. Black dots and error bars represent the mean with 95% confidence intervals.

It is important to note, however (as shown in Figure 6) that gaze foraging is also associated with more variable inter-target times ( $F[1,23] = 34.7, p < .001, \eta_p^2 = .60, BF_{10} > 100$ ) and higher inter-target distances ( $F[1,23] = 44.1, p < .001, \eta_p^2 = .66, BF_{10} > 100$ ) than mouse foraging, suggesting that keeping

516 the same foraging strategy with both effector types comes at a cost. Similarly, oculomotor dynamics  
517 revealed that gaze foraging was associated with more numerous eye fixations<sup>3</sup> ( $F[1,23] = 7.0, p < .02,$   
518  $\eta_p^2 = .23, BF_{10} > 100$ ) longer fixation duration ( $F[1,23] = 34.7, p < .001, \eta_p^2 = .60, BF_{10} > 100$ ) and lower  
519 saccade amplitude ( $F[1,23] = 49.3, p < .001, \eta_p^2 = .68, BF_{10} > 100$ ) than mouse foraging (see Figure 6).  
520 In the general discussion we suggest that these data indicate that gaze foraging is harder than mouse  
521 foraging (see also Tagu & Kristjánsson, 2020, for similar discussion), and that although blocking overt  
522 orienting during target selection does not modulate foraging strategies, this comes at a cost. A final  
523 piece of evidence for the higher cost associated with gaze than mouse foraging is the higher number  
524 of distractor selections made by observers during gaze ( $M = 6.1, SD = 4.4$ ) than mouse foraging ( $M =$   
525  $1.1, SD = 0.7; F[1,23] = 35.6, p < .001, \eta_p^2 = .61, BF_{10} > 100$ ; see Figure 6).

526

#### 527 **4. Discussion**

528 Target selection during visual foraging is accomplished with two successive processes: first the  
529 identification of a set of candidate targets for the next selection, and second the selection of the best  
530 option among these candidates. Past research has mainly focused on the second step and has been  
531 aimed at identifying the factors influencing the identity of the target being selected, which notably  
532 include internal biases towards target value, proximity and priming (see e.g., Wolfe et al., 2018).  
533 However, little attention has been paid to the first step of the target selection process, namely the  
534 factors influencing the identification of a set of candidates. Here, our aims were (1) to confirm that  
535 individual differences found on run patterns during visual foraging could be explained by internal  
536 biases towards target value, proximity and priming, using a single feature-foraging task, and (2) to  
537 examine the respective contributions of overt and covert orienting to the first step of target selection,  
538 the identification of a set of candidates for the next selection.

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<sup>3</sup> Note that, as for the number of runs, analyses were actually run on the “proportional” number of eye fixations, that corresponds to the number of fixations divided by the number of target selections in the trial.



539

**540 4.1. Balancing value, proximity and priming**

541 Critically, our results show that both target value and proximity strongly shape foraging behaviour, as  
542 shown by the main effects of the target value and spatial organization manipulations on almost all  
543 dependent variables. Moreover, the results found on selection order suggest some hierarchization  
544 between value and proximity: when all items have the same value, participants mainly prioritize  
545 proximal targets over primed targets, but when targets have differing values, participants tend to  
546 prioritize more valuable targets. This result is consistent with previous research showing strong  
547 prioritization of high-value targets, even when they are rare (e.g., Wolfe et al., 2018). One could  
548 however argue that the effect of block type in our study could be driven more by the difference in task  
549 instructions between the blocks (earn a prespecified number of points in the value block or select all  
550 the targets on screen in the no-value block) than by the difference in target value manipulations. The  
551 results of Á. Kristjánsson et al. (2020) however suggest that this is not very likely since they found no  
552 difference in foraging strategy between an exhaustive foraging task and a non-exhaustive foraging  
553 task. Moreover, Wolfe et al. (2019) found slightly different foraging strategies in the two tasks showing  
554 that observers asked to select all available targets tend to prioritize primed targets (i.e., they foraged  
555 in few long runs) compared with observers who could move to a new display before having selected  
556 all available targets (who foraged in many runs of short length). So, although we acknowledge that  
557 these differences in task instructions may have slightly affected the results, we argue that the  
558 instruction we gave in the no-value block (select all available targets to terminate the trial) was more  
559 likely to trigger run behaviour similar to what we observed in the value block (i.e., few long runs).  
560 Observing an effect of block type on run behaviour in these conditions therefore highlights how large  
561 and robust the influence of target value on foraging strategy is.

562

563 Interestingly, using single-target visual search, Nowakowska et al. (2021) recently investigated whether  
564 individual differences in visual search performance could be explained by differences in motivation. In  
565 one of their experiments, the manipulation of motivation was achieved with reward manipulations.  
566 Participants had to complete two blocks of trials, and after having completed the first block,  
567 participants from the reward group were told that they would receive more money if they improved  
568 their performance in the second block compared to the first block, while participants from the flat-  
569 payment group were only asked to be as fast and as accurate as possible. The results however revealed  
570 that although both groups improved their performance from the first to the second block, this  
571 improvement was not larger for the reward group than for the flat-payment group. The authors  
572 therefore conclude that practice, rather than motivation and reward, makes participants more  
573 efficient searchers. This absence of a reward effect may appear contradictory with the strong effect of  
574 block type in the present study. However, before comparing the two experiments, it is important to  
575 delineate the methodological differences that may explain the different results. Firstly, while  
576 Nowakowska et al. (2021) manipulated explicit reward (the actual money earned by the participants  
577 after having completed the experiment), we here manipulated target value: in the value block, some  
578 targets were worth more points than others, but participants did not earn any more money in the  
579 value block compared with the no-value block. Actually, in the current study participants were equally  
580 motivated in both blocks of trials. Note however that the absence of reward does not necessarily  
581 means less motivation. On the contrary, here, after each trial, participants saw a feedback screen  
582 showing the trial response time and were therefore strongly motivated to “beat their score” on the  
583 subsequent trials (a bit like in a video game). Secondly, while the reward manipulation in Nowakowska  
584 et al. (2021) involves a between-subject design, the target value manipulation we used involves a  
585 within-subject design. This is important and may partly explain the differences between the two  
586 studies. Thirdly, and maybe most importantly, in Nowakowska et al. (2021) observers had to find a  
587 single target per trial, while the current study involves many target selections per trial. Recent studies  
588 have shown that the results from single-target visual search do not necessarily apply to visual foraging

589 tasks, and vice versa (see e.g., T. Kristjánsson et al., 2020; Ólafsdóttir et al., 2020). To our knowledge,  
590 reward manipulations and differences in motivation have actually never been tested in visual foraging  
591 tasks, and future studies are needed to test whether the results from Nowakowska et al. (2021) could  
592 apply to foraging behaviours. Similarly, the potential generalizability of the foraging effects described  
593 here to single-target visual search should be addressed in future studies.

594

595 A last line of thought that we would like to highlight regarding the interactions between value,  
596 proximity and priming comes from previous research on single-target search suggesting that priming  
597 of features boosts both the speed of the search, as evidenced by lower reaction times with repeated  
598 features (Goolsby & Suzuki, 2001; Maljkovic & Nakayama, 1994; Treisman, 1992), and perceptual  
599 sensitivity, as evidenced by higher accuracy, or  $d'$ , with repeated features (Ásgeirsson et al., 2015;  
600 Geyer et al., 2010; Sigurdardóttir et al., 2008). This research therefore reveals that single-target search  
601 is more efficient when based on priming of previous features than when based on spatial location (for  
602 recent reviews, see Á. Kristjánsson & Ásgeirsson, 2019; Wolfe & Horowitz, 2017). As discussed in the  
603 introduction, foraging studies have however revealed that the prioritization of priming over spatial  
604 location – or proximity – depends on other factors, such as task difficulty (Á. Kristjánsson et al., 2014),  
605 and that during easy feature-based foraging, favouring proximity can be equally efficient, or even more  
606 efficient, than favouring priming. Here, we show that target value is also an important factor to  
607 consider, and that value tilts the selection balance towards priming, even during an easy feature-based  
608 foraging task. Hence, our results (notably on inter-target times) replicate the increase in search speed  
609 with priming, previously found in single-target visual search, using multitarget foraging. Future studies  
610 may reveal whether value and priming also boost perceptual sensitivity during visual foraging, for  
611 example by using a paradigm allowing assessment of perceptual performance. One possibility could  
612 be for example the addition of an adjustment task where observers judge the exact colours of the  
613 target they just selected on a colour wheel. If priming boosts perceptual sensitivity during foraging,

614 performance on the adjustment task should be better when the adjustment is made within a run than  
615 when it is made just after a switch.

616

#### 617 **4.2. Individual differences and internal biases**

618 As discussed in the introduction, individual differences are often observed in visual foraging tasks  
619 (Clarke et al., 2020; Jóhannesson et al., 2017; Á. Kristjánsson et al., 2014; Tagu & Kristjánsson, 2020;  
620 Wolfe et al., 2018). Individuals show, by default, internal biases towards value, proximity and priming  
621 (Wolfe et al., 2018). There is however evidence that these internal biases can be weighted by factors  
622 such as task difficulty (e.g., Á. Kristjánsson et al., 2014), time constraints (e.g., Thornton et al., 2020)  
623 or selection modality (e.g., Thornton et al., 2019). Importantly, the current results (1) confirm the  
624 existence of different internal biases towards value, proximity and priming, as observed in Figure 3,  
625 and (2) show that these internal biases can be weighted by the target value manipulation, but that the  
626 effector manipulation does not affect foraging strategy much. Consistent with Clarke et al. (2020), this  
627 suggests that these by-default internal biases – or individual differences – are stable over repetitions  
628 of the same task (i.e., repetition of a given block type with both effectors), but that an observer's  
629 foraging behaviour in one task (e.g., no-value block) is not predictive of their behaviour in another task  
630 (e.g., value block). Again, we do, however, see some sort of hierarchization between these internal  
631 biases. Although the magnitude of the effect of block type on selection order differs between  
632 individuals, our results clearly show that when targets are associated with differing value, all observers  
633 tilt their selection balance towards value (rather than proximity). Moreover, the effect of target  
634 proximity, found on selection order in the no-value block, disappears in the value block, as if target  
635 value had “won” the competition. These results therefore reinforce the assumption that whatever the  
636 strength of the observer's default internal biases, target value seems to weigh higher in the selection  
637 balance than proximity and priming (see also Wolfe et al., 2018; Wolfe & Horowitz, 2017). Importantly,  
638 now that the current study has cast light on how internal biases towards value, proximity and priming  
639 could affect target selection and lead to individual differences in foraging behaviour, future studies

640 from visual and computer science could use these data to build new computational models of foraging  
641 behaviour for precisely predicting the foraging behaviour of individuals according to the task  
642 characteristics. Such future studies could make an important contribution to the young field of human  
643 visual foraging.

644

### 645 **4.3. Overt and covert orienting**

646 Another crucial result is that our effector type manipulation did not have much influence on run  
647 patterns and selection order, suggesting that observers kept foraging using the same strategy during  
648 mouse and gaze foraging. With this manipulation, our aim was to investigate the role of eye  
649 movements in the first step of the target selection process, namely the identification of a set of  
650 candidates for the next selection. During mouse foraging, observers were free to overtly orient within  
651 the display, whereas this behaviour was restricted during gaze foraging where observers were more  
652 likely to use covert orienting to avoid involuntary distractor selections. The results however indicate  
653 that favouring overt or covert orienting for the identification of a set of candidates does not have much  
654 influence on the selection of one of these candidates. On the contrary, the results suggest that  
655 observers modified their foraging and oculomotor dynamics (e.g., reaction times, fixation durations)  
656 in order to continue foraging with the same strategy with both effectors. Namely, gaze foraging was  
657 associated with a higher number of fixations, larger saccade amplitude and shorter fixation durations  
658 than mouse foraging. These results are consistent with visual exploration in a focal mode during mouse  
659 foraging and an ambient mode during gaze foraging (Goldberg & Kotval, 1999; Krejtz et al., 2016; Over  
660 et al., 2007; Unema et al., 2005; Velichkovsky et al., 2002). This is surprising as previous research (Tagu  
661 & Kristjánsson, 2020) did not reveal any differences in oculomotor dynamics between mouse and gaze  
662 foraging. Note however that the study of Tagu & Kristjánsson (2020) involved a comparison between  
663 feature-based and conjunction-based foraging, and that the effects linked to this factor were so strong  
664 that they might have masked the potential effects of other manipulations. Here, by using feature-

665 based foraging only, our paradigm may have been far more sensitive to the effector-type manipulation,  
666 revealing differences in oculomotor dynamics between mouse and gaze foraging.

667

668 Tagu & Kristjánsson (2020) showed that easy feature-based foraging was associated with the focal  
669 mode (long fixation durations and small saccade amplitudes), and difficult conjunction-based foraging  
670 was associated with the ambient mode (short fixations and large amplitudes) of visual exploration.  
671 Hence, the association of gaze foraging with the ambient mode found here may suggest that gaze  
672 foraging was a more difficult task than mouse foraging. Consistent with this assumption, the results of  
673 Tagu & Kristjánsson (2020) revealed that participants made more distractor selections and were more  
674 likely to select items in runs (i.e., to prioritize priming over proximity) during gaze-conjunction foraging  
675 than during mouse-conjunction foraging. During both mouse and gaze foraging, participants were  
676 more likely to prioritize priming over proximity during conjunction-based foraging, compared with  
677 feature-based foraging. Here, in an easier feature-based foraging paradigm, participants were overall  
678 more likely to prioritize proximity over priming (especially in the no-value block), as shown by the very  
679 high number of runs. However, it seems that continuing to prioritize proximity over priming during  
680 more difficult gaze foraging came at a cost, as shown notably by the higher number of distractor  
681 selections, the higher number of fixations, and exploration in an ambient mode (which by definition  
682 would not favour a strategy consisting of locating the nearest target, see Tagu & Kristjánsson, 2020).  
683 All in all, the current results and past evidence therefore suggest that the most efficient and least costly  
684 strategy during gaze foraging would be to forage in long runs of selecting items from the same category  
685 and to prioritize priming over proximity (see also Thornton et al., 2019).

686

687 Importantly, our results suggest that eye movements are not required for completing the first step of  
688 the target selection process, namely the identification of a set of candidates for the next selection. In  
689 other words, being able to overtly orient (mouse foraging) or not (gaze foraging) during target selection  
690 does not seem to modulate behaviour at the second step, the selection of the best candidate target.

691 It is however important to note that in our tasks, there is no guarantee that observers used overt  
692 orienting during mouse foraging. Even if the paradigm allowed them to overtly orient, they could, of  
693 course, covertly attend to peripheral targets to identify a set of candidates for the next selection.  
694 Consistent with this assumption, our results revealed that observers made fewer fixations and  
695 saccades during mouse than during gaze foraging. Moreover, the fact that being able to overtly orient  
696 or not does not change foraging strategy suggests that covert attention is involved at the first step of  
697 the target selection process, both during mouse and gaze foraging. Although the effector manipulation  
698 did not influence foraging strategy, it is worth noting that it did affect oculomotor dynamics. Moreover,  
699 gaze foraging, where it is more difficult to use overt orienting, comes at a cost, with higher inter-target  
700 times and distances and more distractor selections. Hence, our results suggest that overt orienting is  
701 not involved in the identification of candidates for the next selection, but that it *is* involved in the  
702 selection of the best option among these candidates. Future research may examine more specifically  
703 the potential roles of overt and covert orienting in the target selection process, focusing in particular  
704 on the importance of covert attention for target selection. Preview methods (Castelhano & Henderson,  
705 2007), which consist in flashing the search display for a fraction of seconds only, may for example be  
706 another interesting tool to consider for inducing covert orienting during visual foraging.

707

708 In addition to the potential involvement of overt and covert orienting, another fundamental difference  
709 between mouse and gaze foraging is that during mouse foraging, observers can anticipate the next  
710 selection with eye movements. While selecting the current target, observers may already have  
711 identified a set of candidates for future selections, for example with covert orienting, and may have  
712 already initiated the planning of an overt movement towards the target they want to select next  
713 (Kosovicheva et al., 2020; Thornton & Horowitz, 2004). In four experiments, Kosovicheva et al. (2020)  
714 indeed recently demonstrated that during visual foraging the selection of the next target can be  
715 planned ahead, in parallel with the current selection. But if such anticipation is possible during mouse  
716 foraging, the gaze foraging paradigm prevented observers from anticipating the next selection with

717 their eyes. In the current study, the distance between eye position and current target position at the  
718 time of target selection is on average  $2.07^\circ$  ( $SD = 0.71^\circ$ ) during mouse foraging, while it is only  $0.73^\circ$   
719 ( $SD = 0.11^\circ$ ) during gaze foraging. In other words, participants' eyes may already be "on their way"  
720 towards the next target during mouse foraging, while this was not the case during gaze foraging.  
721 Hence, although the effector-type manipulation revealed that the identification of candidates for the  
722 next selection can be performed through covert orienting, it also confirms that the selection of the  
723 next target can be planned in advance, in parallel with the current selection. All in all, our results  
724 therefore suggest that overt orienting is not needed for identification of a set of candidate targets for  
725 the next selection, but that it may be necessary for efficient selection of the best option among these  
726 candidates. This last assumption would moreover explain why the effector-type manipulation modified  
727 foraging and oculomotor dynamics without influencing foraging strategy. This assumption however  
728 needs to be addressed in future foraging studies specifically designed to test the involvement of overt  
729 and covert orienting at the different stages of the target selection process.

730

#### 731 **4.4. Summary and conclusions**

732 For the first time, we have assessed how target value, proximity and priming affect foraging strategy,  
733 foraging dynamics and oculomotor dynamics in a multi-target visual search task. Moreover, by  
734 contrasting mouse and gaze foraging, we have investigated how differently favouring overt and covert  
735 orienting could affect foraging behaviour. Our results critically reveal some hierarchization between  
736 the three forces that tilt the selection balance as the presence of targets with differing values overrides  
737 any potential influence of target proximity on foraging behaviour. Moreover, we have shown that  
738 target value modifies all aspects of foraging behaviour by influencing foraging strategy, foraging  
739 dynamics and oculomotor dynamics. Finally, by contrasting mouse and gaze foraging we have shown  
740 that overt orienting is not necessary for identifying candidates for the next selection, but that it may  
741 be involved in the selection of the best option among these candidates.

742



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745

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747

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751

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755

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