Searching near and far: the attentional template incorporates viewing distance

Surya Gayet[1,2,C], Elisa Battistoni[3], Sushrut Thorat[2,4], & Marius V. Peelen[2]

[1] Helmholtz Institute, Experimental Psychology, Utrecht University, Utrecht, The Netherlands

[2] Donders Institute for Brain, Cognition and Behaviour, Radboud University, Nijmegen, The Netherlands

[3] Center for Mind/Brain Sciences, University of Trento, Rovereto, Italy

[4] Institute of Cognitive Science, Osnabrück University, Osnabrück, Germany.

[C] Corresponding author, contact via s.gayet@uu.nl

Abstract

According to theories of visual search, observers generate a visual representation of the search target (the 'attentional template') that guides spatial attention towards target-like visual input. In real-world vision, however, objects produce vastly different visual input depending on their location: your car produces a retinal image that is ten times smaller when it's parked fifty compared to five meters away. Across four experiments, we investigated whether the attentional template incorporates viewing distance when observers search for familiar object categories. On each trial, participants were pre-cued to search for a car or person in the near or far plane of an outdoor scene. In 'search trials', the scene reappeared and participants had to indicate whether the search target was present or absent. In intermixed 'catch-trials', two silhouettes were briefly presented on either side of fixation (matching the shape and/or predicted size of the search target), one of which was followed by a probe-stimulus. We found that participants were more accurate at reporting the location (Exp. 1&2) and orientation (Exp. 3) of probe-stimuli when they were presented at the location of size-matching silhouettes. Thus, attentional templates incorporate the predicted size of an object based on the current viewing distance. This was only the case, however, when silhouettes also matched the shape of the search target (Exp 2). We conclude that attentional templates for finding objects in scenes are shaped by a combination of category-specific attributes (shape) and context-dependent expectations about the likely appearance (size) of these objects at the current viewing location.

29

Significance statement

When searching for an object in our surroundings, traditional theories of visual search posit that we generate a mental picture of the object we are looking for (the "attentional template"). Depending on *where* we look (e.g., further away), however, an object will produce a vastly different (i.e., smaller) image on the retina. Here we show that observers flexibly adjust their attentional template, based on their current search location, effectively accounting for viewing distance by searching for a smaller version of the object when searching further away. These findings reconcile traditional theories of visual search with the challenges imposed by naturalistic vision.

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Materials and resources

All materials (stimuli, experiment scripts, raw data, data processing scripts, complete output of statistical analyses) are publicly accessible via the following online repository: https://osf.io/84tbv/.

42

Introduction

Every moment in time our retinae collect unfathomable amounts of information from the world around us. Because the vast majority of this visual input is irrelevant to our current behavioral goals, our visual system is equipped with means to favor behaviorally relevant visual input over irrelevant visual input. One such means lies at the heart of most leading theories of visual search: these theories posit that observers generate a visual representation of the object they are looking for (a so-called attentional template), thus optimally preparing the visual processing stream to favor visual input that resembles the template (such as the target object), at the expense of visual input that does not (Duncan, & Humphreys, 1989; Wolfe, 1994; Desimone, & Duncan, 1995; Kastner, & Ungerleider, 2001; Wolfe, & Horowitz, 2004; Eimer, 2014; for reviews, see Battistoni, et al., 2017; Beck, & Kastner, 2009). Evidence for template-based visual search mostly comes from lab-based studies using impoverished visual displays, which stand in stark contrast with the complexity of naturalistic visual environments.

55 Therefore, it remains a matter of debate to what extent well-established mechanisms of visual search

56 generalize to real-world vision (Wolfe & Horowitz, 2004; Wolfe, et al., 2011; Peelen, & Kastner, 2014;

57 Wolfe, 2021).

58 Human observers are particularly proficient in detecting objects in naturalistic scenes (Potter,

59 1975; Thorpe, et al., 1996; Li, et al., 2002; Peelen, et al., 2009; Wolfe, et al., 2011), despite their

60 inherent complexity and clutter, as compared to the typical impoverished displays that are used in

61 most studies investigating visual search. This proficiency suggests that mechanisms of visual search

62 are particularly well-adapted to complex naturalistic vision (Peelen, & Kastner, 2014). Natural scenes

63 provide a rich source of information that observers can capitalize on during search, by constraining

64 the likely locations and identity of objects in the scene (i.e., contextual guidance; Torralba et al., 2006;

65 Neider, & Zelinsky, 2006; Droll & Eckstein, 2008; Malcolm, & Henderson, 2010; Spotorno, et al., 2014;

66 Boettcher et al., 2018; for a review, see Castelhano, & Krzyś, 2020). Naturalistic environments,

67 however, pose a fundamental challenge to the core principle of template-based visual search: the

68 image that any given target object will produce on the retinae is unknown in advance, because it varies

69 with the (unknown) location of the target object. Its color or brightness depends on the illumination

70 (e.g., in the sun, in the shade or under artificial lighting), its shape depends on the viewpoint (e.g.,

71 viewed from the side, from above, or at an angle), and –most dramatically– its size can vary by orders

72 of magnitudes depending on the distance between the target object and the observer. Consequently,

73 it remains unknown to the observer what template needs to be generated to effectively search for a

74 given target object, which calls into question the usefulness of template-based visual search during

75 real-world vision.

76 In this study we test one key mechanism that could solve this problem, focusing on the

77 predictable relationship between viewing distance and retinal object size. We test the hypothesis that

78 human observers account for viewing distance when searching for a given object. This would entail

79 that observers effectively search for a smaller projection of the object when searching far away

80   (generating a smaller attentional template), and for a larger projection of the object when searching

81   nearby (generating a larger attentional template). In favor of this hypothesis, it has been shown that

82   attentional templates can be flexibly adjusted to match the current task demands during naturalistic

83   search (Yu et al., 2023). For instance, observers can adjust the tuning (or: precision) of the attentional

84   template, to account for the uncertainty of target object appearance (Lleras et al., 2022; Witkowski,

85   & Geng, 2022; Hout, & Goldinger, 2015; Bravo, & Farid, 2012), or adjust the feature content of the

86   attentional template to optimally distinguish the target object from anticipated distractor objects

87   (Howard, et al., 2011; Boettcher et al., 2020; Lerebourg et al., 2023). Moreover, priming the upcoming

88   target object with word-cues or semantically congruent scenes benefits subsequent search (Stein, &

89   Peelen, 2017; Robbins, & Hout, 2020; Malcolm & Henderson, 2009), suggesting that observers adjust

90   their attentional template to account for the provided context. Most specifically, we recently showed

91   that when participants prepare to search for a target object nearby (compared to far away), patterns

92   of neural activity emerge in visual cortex that are similar to activity patterns evoked by viewing large

93   (compared to small) images of this target object (Gayet, & Peelen, 2022). This shows that the human

94   visual system anticipates the size of an object depending on the viewing distance. But does this visual-

95   like activity evoked during search preparation benefit search behavior in any way? In other words: do

96   human observers generate distance-dependent (i.e., size-specific) attentional templates to aid visual

97   search? One finding supporting this possibility is that observers sometimes fail to identify an object

98   that is disproportionally large compared to its background (Eckstein, et al., 2017). Going against our

99   hypothesis, however, are results from studies showing that attentional templates can be invariant to

100   such visual attributes as orientation (Reeder, & Peelen, 2013) and size (Bravo, & Farid, 2009). This

101   invariance may particularly apply to highly familiar real-world object categories (cars, people), for

102   which detection is highly efficient (e.g., Li, et al., 2002; Thorpe, et al., 1996; see also Stein, & Peelen,

103   2017). According to this view, an object-specific attentional template (e.g., of a car) would benefit

104   search irrespective of its orientation or size. Here, we ask whether the attentional template

105   incorporates (retinal object) size during naturalistic visual search, when size can be directly inferred

106   from the scene context (i.e., viewing distance).

107   To answer this question, we conducted a series of behavioral lab-based experiments, in which

108   participants were searching for one of two possible object categories (a person or a car), at different

109   viewing distances within outdoor scene photographs. The viewing distance informed participants of

110   the (retinal image) size of the target object, allowing them to incorporate size information in their

111   preparatory attentional template. To test whether the attentional template indeed contained size

112   information we used a dual-task design. In "*search trials*" participants searched for a pre-cued object

113   category (a car or person) and reported which of two briefly presented scenes contained the target

114   object. Critically, the size of the target object was –in principle– predictable, based on the layout of

115   the search scene (Experiment 1) or on a cue instructing where to search (in depth; Experiments 2-3).

116   The goal of these trials was to motivate participants to instill a preparatory attentional template that

117   could potentially incorporate size information. In intermixed "*catch trials*", we used a dot-probe task

118   that allows for probing attentional biases (MacLeod, et al., 1986), and has been used to reveal the

119   contents of the attentional template (Reeder, & Peelen, 2013; Reeder, et al., 2015; Gayet, & Peelen,

120   2019). In this task, the search cue is unexpectedly followed by two task-irrelevant silhouettes (on both

121   sides of fixation), of a car or person of differing sizes. Participants are tasked with responding to a

122   simple target stimulus presented to the left or right of fixation, immediately after the presentation of

123   the silhouettes. The idea is that, if one silhouette matches the attentional template to a better extent

124   than the other silhouette (e.g., a car versus a person silhouette), attention will be directed to the

125   location of the matching silhouette, thus improving target reports at that location. In the current

126   study, this approach allowed us to measure a specific aspect of the search template that is key to

127   naturalistic visual search (whether it incorporates the size of the target object, as predicted from

128   viewing distance), while preserving the experimental control of reductionist experiments.

129   To preface the results, we demonstrate that attentional templates are retinal size-specific

130   (Experiments 1-3). These size-specific attentional templates, however, only favor size-consistent visual

131   objects that resembles the search target; they do not favor all objects of the predicted size

132   (Experiments 1-2). The data further show that observers could infer the predicted retinal size of the

133   search target from the viewing distance in the scene, following a location cue, even when the viewing

134   distance changed trial-by-trial (Experiments 2-3). This showcases the ability of observers to flexibly

135   change the size of their attentional template when searching at different locations of a visual scene.

136   Importantly, visual discrimination performance (on an orthogonal task) was better at the location of

137   size-consistent compared to size-inconsistent silhouettes (Experiment 3), which implies that size-

138   consistent objects attracted spatial attention. Together, these findings show that observers infer the

139   predicted retinal size of a search target from the viewing distance in a scene to favor target-like visual

140   input during naturalistic visual search.

Experiment 1

Methods

Transparency and openness

The current study adheres to all Transparency and Openness Promotion (TOP) guidelines regarding research transparency; in the OSF project dedicated to this study (https://osf.io/84tbv/) we provide (1) the experiment scripts and stimuli that were used for data collection, (2) the raw data, (3) the data pre-processing and analysis scripts, and (4) the complete output of all statistical analyses. The experiments in this study were not pre-registered. Nonetheless, we believe that the risk of false positive inflation caused by the degrees of freedom in data analysis choices is minimized by (1) applying minimal data exclusion, by (2) presenting three internal (conceptual) replications of the main finding, by (3) using the exact same analysis pipeline in all studies, and by (4) showing consistent statistical outcomes across different types of statistical tests. The years of data collection were 2017 (Experiment 1), 2019 (Experiment 2), and 2021 (Experiment 3).

Participants

Thirty healthy students from the University of Trento participated in Experiment 1, which comprised two experimental sessions conducted on different days. All participants (25 women; mean age 23.3 years, SD = 3.8) had normal or corrected-to-normal vision and provided written informed consent to take part in the study. Most participants received monetary compensation (€8,-/session), but three participants took part for course credits. The experiment was approved by the Ethics Committee of the University of Trento. The sample size for Experiment 1 was based on resource availability; formal power analyses were conducted for all subsequent experiments (see Methods section of Experiment 2).

Setup

Stimuli were presented on a 19" Philips 109P monitor with a screen resolution of 1024 x 768 pixels and a refresh rate of 100Hz. Stimulus presentation and response registration were done with MatLab
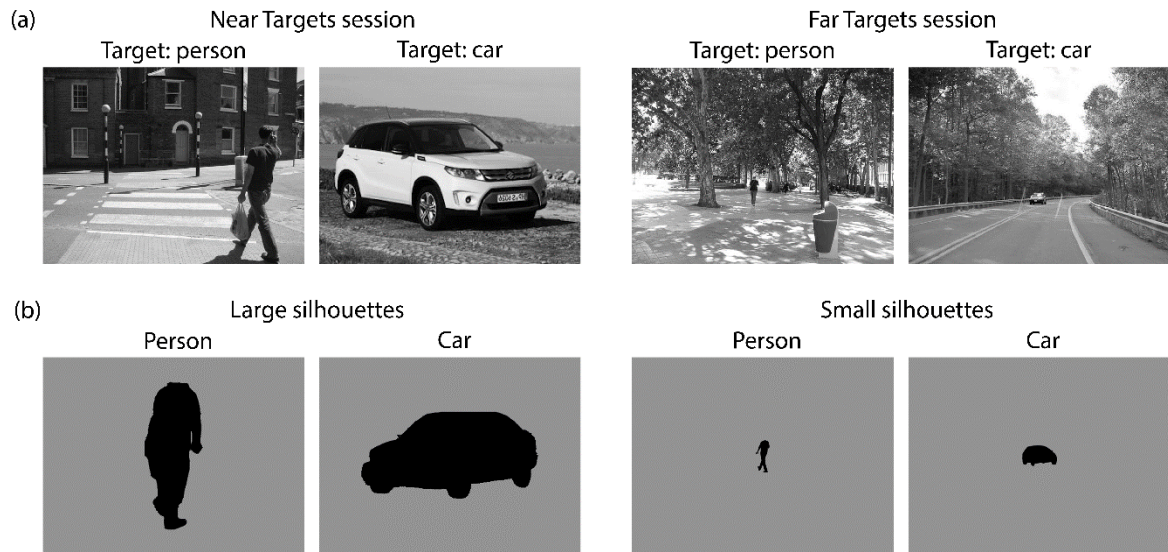
168   8.0 using Psychtoolbox-3 (Brainard, 1997; Pelli, 1997). All stimuli were presented on a uniform gray

169   background, with a black plus-sign ("+") at the center serving as a fixation point. Viewing distance was

170   fixed at 55cm from the monitor using a chin-rest.

171

Natural scene stimuli (search trials)

173   A total of 378 outdoor scene photographs were found via Google Image search or retrieved from

174   previous studies. Of those, 162 had target objects (i.e., people or cars) in the foreground (near

175   location), which were thus relatively large: 54 scenes with cars, 54 scenes with people, and 54 scenes

176   with cars and people. Another 162 scenes had target objects in the background (far location), which

177   were thus relatively small: again, this comprised 54 scenes with cars, 54 scenes with people, and 54

178   scenes with cars and people. The remaining 54 scenes contained no target objects. In order to increase

179   the number of scene stimuli, each of these 378 scenes was horizontally mirrored, amounting to a total

180   of 756 unique scene stimuli. The 324 scenes with near/large target objects were used in one

181   experimental session (the Near Target session), the 324 scenes with far/small target objects were used

182   in another experimental session (the Far Target session), and the remaining 108 scenes without target

183   objects were used in both sessions (see Figure 1a).

184   All scenes were converted to greyscale and rescaled to 427 (horizontal) by 320 (vertical) pixels,

185   subtending 15.8 by 11.7 degrees of visual angle. The average height of the target objects was 52 pixels

186   for "far" persons, 240 pixels for "near" persons, 56 pixels for "far" cars, and 287 pixels for "near" cars.

187   Of note, the largest "far" object of the stimulus set was smaller than the smallest "near" object, thus

188   ensuring the validity of the session-specific manipulation of expected object size.

189

Figure 1. Example of stimuli used in the different experimental conditions of Experiment 1. (a) Scene stimuli used in the search task. During the Near Targets session, target objects (person or car) were located in the foreground, and their retinal image size was therefore relatively large. During the Far Targets session, target objects were located in the foreground, thus producing a relatively small retinal image. (b) Silhouette stimuli used in the catch trials. The sizes of the silhouettes were matched to the sizes of the target objects presented within the search trial scenes.

190

191

Silhouette stimuli (catch trials)

The stimuli used in the catch trials were black silhouettes of cars and people, presented on the uniform gray background. A total of 576 silhouettes were selected from stimuli used in previous experiments, or created based off images of cars and people found via Google Image search, using GIMP (https://www.gimp.org). This resulted in 144 unique silhouette stimuli in each size (large, small) and category (person, car) condition (see Figure 1b). These silhouettes were scaled to match the sizes of the target objects presented within the natural scenes that are used in the search task.

199

Experimental procedure

The experiment consisted of two sessions of 45 minutes each; a "Near Targets" session in which all target objects in the scenes were relatively nearby (and thus subtended a large retinal image), and a "Far Targets" session in which all target objects in the scenes were relatively far away (and thus subtended a small retinal image). Each participant completed both sessions on separate days, and the

205 second session was completed within a week of the first session. The order of sessions ("Near Targets"

206 first or "Far Target" first) was counterbalanced across participants. Each session comprised nine blocks

207 of 64 trials each, of which 48 search trials (75%) and 16 catch trials. The silhouettes were large in half

208 of the catch trials, and small in the other half. Therefore, each block comprised catch trials with two

209 size-consistent silhouettes (i.e., large silhouette in "Near Targets" session, small silhouette in "Far

210 Targets" session) and trials with two size-inconsistent silhouettes (i.e., large silhouette in "Far Targets"

211 session, small silhouette in "Near Targets" session). The order of trials within a block was pseudo-

212 randomized, so that search trials, catch trials with large silhouettes, and catch trials with small

213 silhouettes were intermixed. The only restriction was that the first three trials of each block were

214 always search trials, to ensure that participants were engaged in the (size-specific) search task before

215 the first catch trial appeared. At the start of each session participants performed one practice block

216 to familiarize with the task.

217

218 *Search trials*
219 The order of events in search trials is depicted in the top row of Figure 2. Each search trial started with

220 a central fixation cross (500 ms), followed by the letter "C" or "P" (500 ms), which instructed

221 participants to search for a car or person in the upcoming scene images (for Italian speaking

222 participants, this was replaced with a "M" or "P", for "macchina" and "persona" respectively).

223   After another fixation cross (1000 ms), during which observers could prepare for the search

224 task, two scenes were simultaneously presented for 67ms on either side of fixation, in one of four

225 possible combinations: (1) car in the left scene, person in the right scene; (2) person in the left scene,

226 car in the right scene; (3) both person and car in the left scene, no target objects in the right scene;

227 and (4) no target objects in the left scene, both person and car in the right scene. These combinations

228 ensured that viewing one object (e.g., a car) in a scene was not predictive of the location of the other

229 object, hence inciting participants to search for the cued object (rather than inferring its location from

230 the location of the other object).

231   The scenes were followed by a blank screen of variable duration (range [10ms, 300ms]), and

232   two backward masks that covered the same presentation area as the scenes (350ms). The duration

233   between scene offset and mask onset was titrated using an adaptive staircase procedure, aiming at a

234   search task performance of 75% correct in both ("Near Targets" and "Far Targets") experimental

235   sessions. This was done by reducing the duration of the blank screen by 20ms when accuracy (from

236   the 6th trial onwards) rose above 75% and by increasing its duration by 20ms when accuracy dipped

237   below 75% correct.

238   The masks were followed by a fixation cross (1660ms), during which observers reported which

239   target scene (left or right of fixation) contained the target object, using the "z" and "n" arrow keys (for

240   left or right scene, respectively). Finally, a feedback screen (500ms) indicated whether they were

241   correct ("+1") or incorrect ("+0").

242   To test whether the staircase procedure was successful in equating search task difficulty

243   between the Near Targets session and Far Target session, we conducted a 2x2 repeated-measures

244   ANOVA with the factors Object (person versus car) and Distance (near versus far), on both accuracy

245   and response times. A main effect of Distance on accuracy showed that participants were more

246   accurate in localizing target objects in the Near Targets session (M = 87.9%, SD = 4.2) than the Far

247   Target session (M = 74.5%, SD = 6.5), $F(1,29)$ = 179.12, p < .001, η^2 = .729. Similarly, a main effect of

248   Distance on reaction times showed that participants were faster in localizing target objects in the Near

249   Targets session (M = 549ms, SD = 93) than the Far Target session (M = 609ms, SD = 100), $F(1,29)$ =

250   11.18, p = .002, η^2 = .257. These results show that larger objects remained easier to find that smaller

251   objects, despite the thresholding procedure that was aimed at equating performance between

252   Distance conditions. This probably reflects that localization of relatively large objects was too easy

253   with a presentation time of 67ms, even at the shortest scene-mask interval of 10ms (which motivated

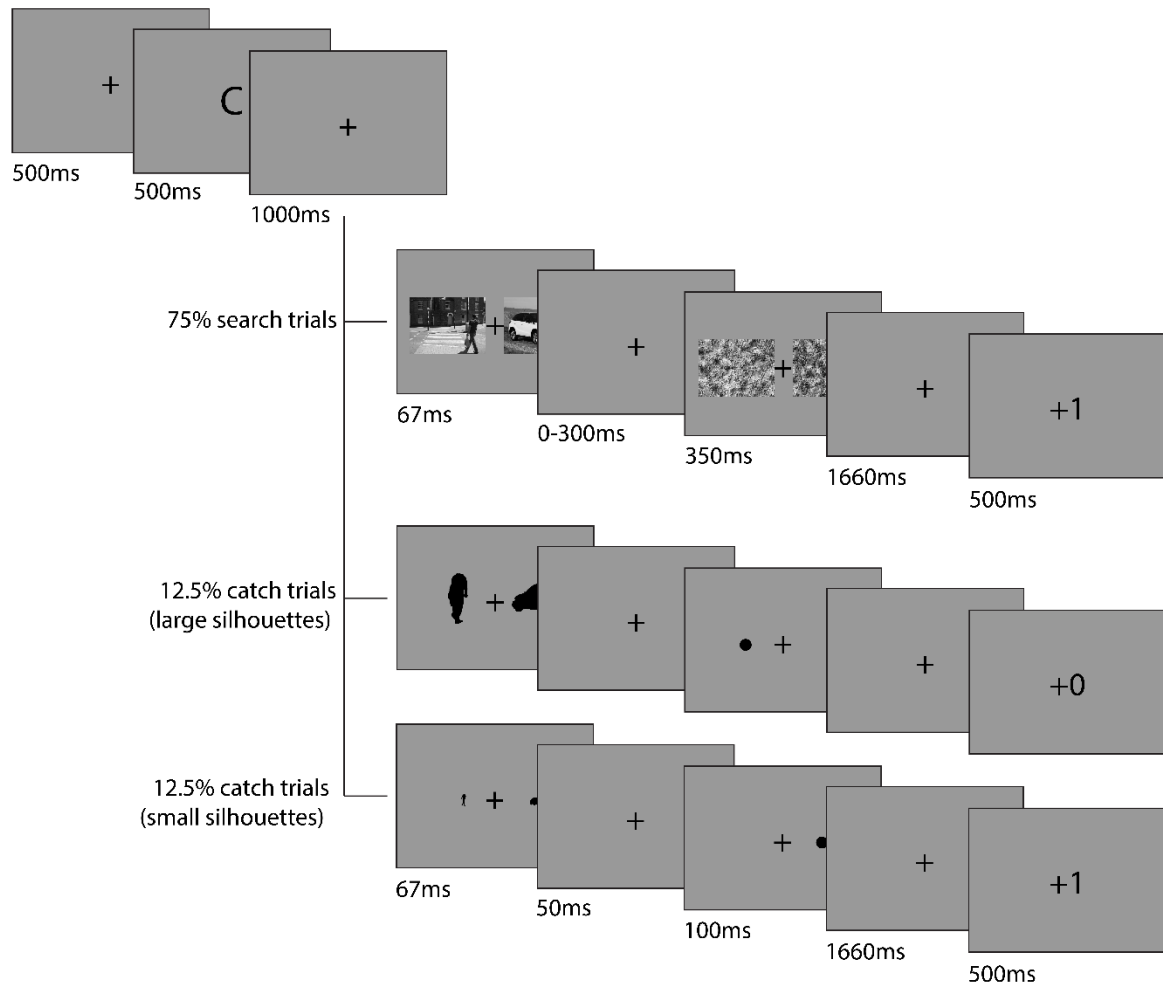254   us to use a different staircase procedure in Experiments 2 and 3).

255

256 *Catch trials*

257 The order of events in catch trials (dot-probe task) is depicted in the second and third row of Figure 2.

258 The start of a catch trial was indistinguishable to that of a search trial, thus inciting participants to

259 generate an attentional template in anticipation of the search task. That is, the trial started with a

260 fixation cross (500ms), a letter cue (500ms), and another fixation point (1000ms). Then, instead of two

261 scenes, two silhouettes were presented on either side of fixation (for 67ms). The two silhouettes were

262 either both small or both large (i.e., they were both either consistent or inconsistent with the size of

263 search targets in the current session), and one silhouette was always of a car and the other of a person

264 (i.e., one silhouette matched and the other silhouette mismatched the category of the search target).

265 After the silhouettes, a fixation point was briefly presented (50ms), and a small circular target

266 dot appeared on one side of fixation (100ms); at the location of the silhouette that matched the

267 category of the search target (*valid* trials) or at the location of the mismatching silhouette (*invalid*

268 trials).

269 After the offset of the target dot, the fixation cross remained on screen for 1660ms, during

270 which participants could report the location of the target dot (left or right of fixation), using the "z"

271 and "n" arrow keys (for left or right scene, respectively). Participants were instructed to ignore the

272 task-irrelevant silhouettes. Finally, a feedback screen (500ms) indicated whether they were correct

273 ("+1") or incorrect ("+0").

274

Figure 2. Schematic depiction of the experimental procedure of Experiment 1. Each block was made up of 64 trials presented in random order, comprising 48 search trials (75%) and 16 intermixed catch trials, half of which with small silhouettes and half of which with large silhouettes. In all trials a letter cue instructed participants to search for a car or person. In search trials, participants reported which of two scenes (left or right of fixation) contained the cued target object. In catch trials, two task-irrelevant silhouettes appeared followed by a small target dot. Participants reported where (left of right of fixation) the target dot appeared.

275

276   *Data analysis*

277   We focus our analyses of catch trials on accuracy because pilot experiments revealed that our effects

278   of interest were better captured by accuracy differences than reaction times differences between

279   conditions. For transparency, and to verify that our reported effects are not the result of changes in

280   speed-accuracy trade-offs, we report all reaction time analyses in Supplemental Materials S1. Before

281   performing the analyses, we collapsed the catch-trial data across all conditions of non-interest (e.g.,

282   the specific category of the silhouette); additional analyses in Supplemental Materials S2 show that

283   none of the outcomes reported in the main manuscript depend on these conditions of-non interest.

284   All tests reported in the Results section and Supplemental Materials are two-tailed within-

285   subject tests with a significance threshold of 0.05. To compare between pairs of conditions, we use

286   paired-samples t-tests when normality assumptions are met (according to a Shapiro-Wilk test, with a

287   significance threshold of 0.05), and we use Wilcoxon signed-rank tests when they are violated. In case

288   multiple factors are included in the analysis (e.g., Experiment 1), we always use Repeated-Measures

289   ANOVAs, which are robust to violations of normality (Blanca, Arnau, García-Castro, & Bono, 2023) and

290   offer more flexibility than the non-parametric alternatives. Whenever parametric tests are used, we

291   report parametric measures of central tendency (mean), effect sizes (d_z, or η^2), and spread (standard

292   deviation). Conversely, whenever non-parametric tests are used, we report non-parametric measures

293   of central tendency (median), effect sizes (rank-biserial correlation), and spread (inter-quartile range).

294   Finally, for all critical tests, we also conducted two-sided one-sample bootstrap tests ($1*10^6$

295   permutations) comparing the difference between conditions-of-interest to zero.

296   To address the main question of whether observers incorporate the predicted retinal size of

297   a target object in the attentional template, we analyzed participants' average accuracy on catch trials.

298   Catch trial data were analyzed as a function of two experimental factors: category-validity (of the

299   target dot location relative to the silhouettes), and size-consistency (of the silhouettes with the search

300   task session). In valid trials the target dot appeared at the location of a silhouette that matched the

301   search cue (i.e., a car silhouette when participants were cued to search for a car, or a person silhouette

302   when participants were cued to search for a person). In invalid trials the target dot appeared at the

303   opposite location, where the silhouette mismatched the search cue (i.e., a car silhouette when

304   participants were cued to search for a person, or a person silhouette when participants were cued to

305   search for a car). In half of the trials, the silhouettes were size-consistent, which entails that the size

306   of the silhouettes was consistent with the size of the search targets (i.e., large silhouettes in the "Near

307   Targets" session, and small silhouettes in the "Far Targets" session). In the other half of the trials, the

308   silhouettes were size-inconsistent, which entails that the size of the silhouettes was inconsistent with

309   the size of the search targets (i.e., large silhouettes in the "Far Targets" session, and small silhouettes

310 in the "Near Targets" session). Figure 3a illustrates the four conditions of the 2x2 factorial design.

311 Mean accuracy scores were computed for each participant and for each of the four conditions of

312 interest, only excluding trials in which no response was provided within the 1660ms time window.
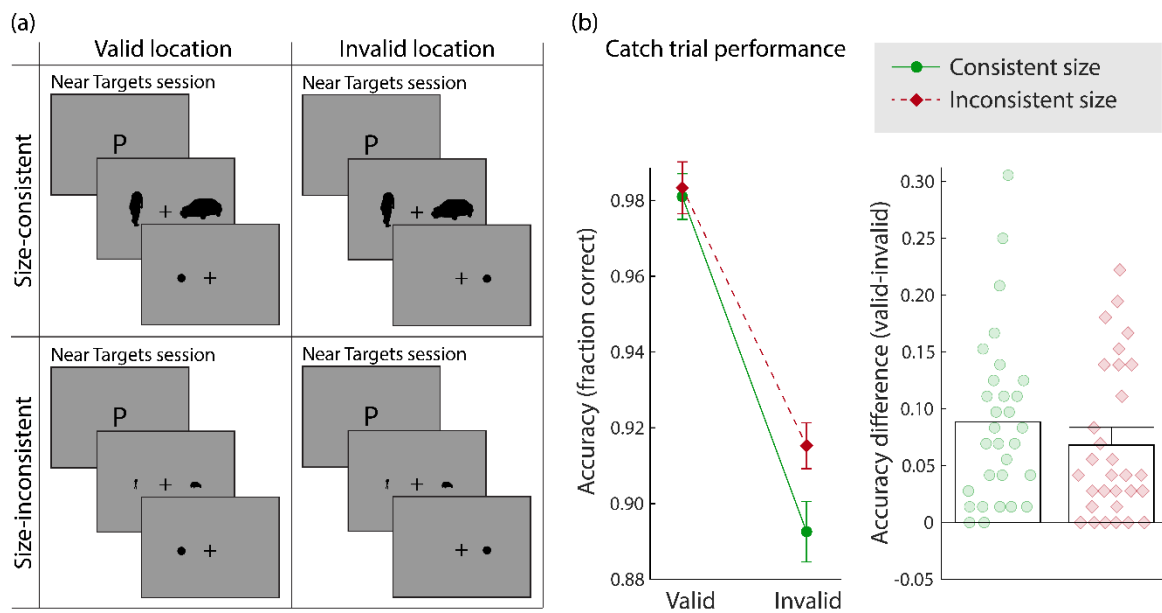
313

Results

Catch trial analysis

316 If participants generate an attentional template that incorporates the predicted retinal size of a target

317 object, the category-validity effect (higher accuracy for reporting target dots appearing at the

318 category-valid location than the category-invalid location) should be more pronounced on trials with

319 size-consistent silhouettes than with size-inconsistent silhouettes. This would imply that size-

320 consistent silhouettes more closely resemble the attentional template than size-inconsistent

321 silhouettes and, thus, that size information is incorporated in the attentional template.

322 Following size-consistent silhouettes, participants were more accurate on category-valid trials

323 (M = 98.6%, IQR = 2.8) than on category-invalid trials (M = 89.6%, IQR = 10.8), W = 406, p < .001, *rank-*

324 *biserial correlation* = 1.00 ($p_{bootstrap}$ < .001, *95% CI* [6.3%, 11.6%]). Following size-inconsistent

325 silhouettes as well, participants were more accurate on category-valid trials (M = 99.3%, IQR = 1.4)

326 than on category-invalid trials (M = 93.8%, IQR = 12.2), W = 300, p < .001, *rank-biserial correlation* =

327 1.00 ($p_{bootstrap}$ < .001, *95% CI* [4.5%, 9.3%]). The occurrence of this validity effect shows that the

328 attentional template contained category-selective information (i.e., distinguishing between car and

329 person targets). Most importantly –and confirming our main hypothesis– this category-validity effect

330 was larger for size-consistent silhouettes (M = 7.6%, IQR = 9.0) than for size-inconsistent silhouettes

331 (M = 4.2%, IQR = 11.5), as showcased by a significant interaction effect between category-validity and

332 size-consistency on response accuracy, $F(1,29)$ = 9.88, p = .004, η^2 = .009 ($p_{bootstrap}$ = .002, *95% CI* [0.7%,

333 3.2%]). This pattern of results (visualized in Figure 3b) supports the hypothesis that participants

334 incorporated the expected size of target objects in their attentional template.

335   Note that the main effect of size-consistency was also significant, $F(1,29) = 9.50$, $p = .004$, $\eta^2 =$

336   .009 ($p_{bootstrap} = .001$, *95% CI* [0.5%, 2.1%]), which shows that –irrespective of the location of the target

337   dot– presenting two size-consistent silhouettes interfered more with catch-trial localization

338   performance than presenting two size-inconsistent silhouettes (i.e., the vertical offset between lines

339   in Figure 3B).

Figure 3. Experimental design and results for the dot-probe task (catch trials) of Experiment 1. (a) Visualization of the two-by-two factorial design (for simplicity, all four cells depict "Person" search, in a "Near Targets" session). The dot target appeared either at a valid location (i.e., at the location of a person silhouette following the "P" search cue, or at the location of a car silhouette following the "C" search cue) or an invalid location (vice versa). The size of the silhouettes was either consistent with the size of the search targets (i.e., large silhouettes in a "Near Targets" session, or small silhouettes in a "Far Targets" session) or inconsistent (vice versa). (b) Left: mean proportion correct in each of the 2x2 conditions depicted in panel a. Right: validity effect (performance on valid minus invalid trials) for the size-consistent and size inconsistent conditions. Transparent dots are individual participant means; error bars in the interaction plot represent the within-subject standard error of the mean (Cousineau, 2005); The whisker on the right-most bar of the difference plot shows the 95% confidence interval of the paired difference between size-consistency conditions.

340

341   *Interim discussion*

342   The goal of Experiment 1 was to test whether observers incorporate the expected size of a target

343   object in their attentional template. This hypothesis was confirmed. Category-specific silhouette

344   stimuli influenced localization reports of the target dot *more* when they matched the expected size of

345   the cued target object (e.g., small silhouettes in a "Far Target session") than when they mismatched

346   the expected size (e.g., small silhouettes in a "Near Target session"). This implies that the expected

347   size of the cued target object was used during search preparation, otherwise the dot-probe

348   performance for size-consistent and size-inconsistent silhouette conditions would not differ.

349   In this experiment, however, observers might not have predicted the size of the target object

350   based on the viewing distance, but could have based their expectations of object size on the

351   prevalence of (larger or small) target objects within an experimental session. As such, it remains

352   unclear whether observers could also incorporate object size in their attentional template during real-

353   world search, where size needs to be inferred from the viewing distance in the scene, on a moment-

354   to-moment basis.

355   The goal of Experiment 2A was to test whether observers also incorporate object size in their

356   attentional template when they need to infer the size of the target object from the current search

357   location in a scene, as would be done during real-world visual search. To this end, participants now

358   previewed the search scene that contained a location cue, informing participants about the viewing

359   distance to the object (and thus its retinal size). This approach also allows to test whether observers

360   can incorporate a new predicted object size in their attentional template in a trial-by-trial manner,

361   which would indicate that observers can flexibly alter their attentional template as a function of search

362   location (e.g., from saccade to saccade during real-world visual search). Because event-based designs

363   (such as Experiment 2) are typically less powerful than block-based design (such as Experiment 1), we

364   decided to directly pit the two conditions-of-interest against each other within each trial, by

365   contrasting a size-consistent silhouette with a size-inconsistent silhouette (both of the target object

366   category).

367

Experiment 2

Methods

Participants

Fifty four healthy students from Radboud University participated in Experiment 2. Two participants were excluded for failing to perform above chance level in the target probe localization task, according to a one-sided binomial test against 0.5. This resulted in a final sample of 26 participants in Experiment 2A (18 females, mean age of 22.35 years, *SD* = 2.67) and another 26 participants in Experiment 2B (22 female, mean age of 22.58 years, *SD* = 3.19).

The sample size of 26 was determined on the basis of a power analysis for a paired-samples t-test, conducted in G*Power. We aimed at 80% power for detecting an effect at least as large as that observed in our recent study (Experiment 1 of Gayet, & Peelen, 2019; d_z = 0.637). In this study we also compared performance on a dot-probe task between targets appearing at the location of size-consistent versus size-inconsistent visual objects. Due to an error in our power analysis, we eventually had 88% power for detecting said effect, as the required sample size for 80% power was actually 22.

All participants had normal or corrected-to-normal vision and provided written informed consent to take part in the study. Participants either received monetary compensation (€10,-/session) or course credits (1 participant). The experiment was approved by the Ethics Committee of the Social Sciences Faculty of Radboud University Nijmegen, The Netherlands (ECSW2017-2306-517).

Setup

Participants were tested in a dark room where a chinrest kept their viewing distance fixed at 57 cm of a 24" BenQ monitor with a screen resolution of 1920 x 1080 pixels and a refresh rate of 120Hz. Stimulus presentation and response registration were done with MatLab 2015b using Psychtoolbox-3 (Brainard, 1997; Pelli, 1997). All stimuli were presented on a uniform gray background (30 Cd/m^2), with a white outer circle (83.60 Cd/m^2; 0.30 degrees of visual angle; dva) and a black inner circle (0.19 Cd/m^2; 0.10 dva), serving as a central fixation dot.
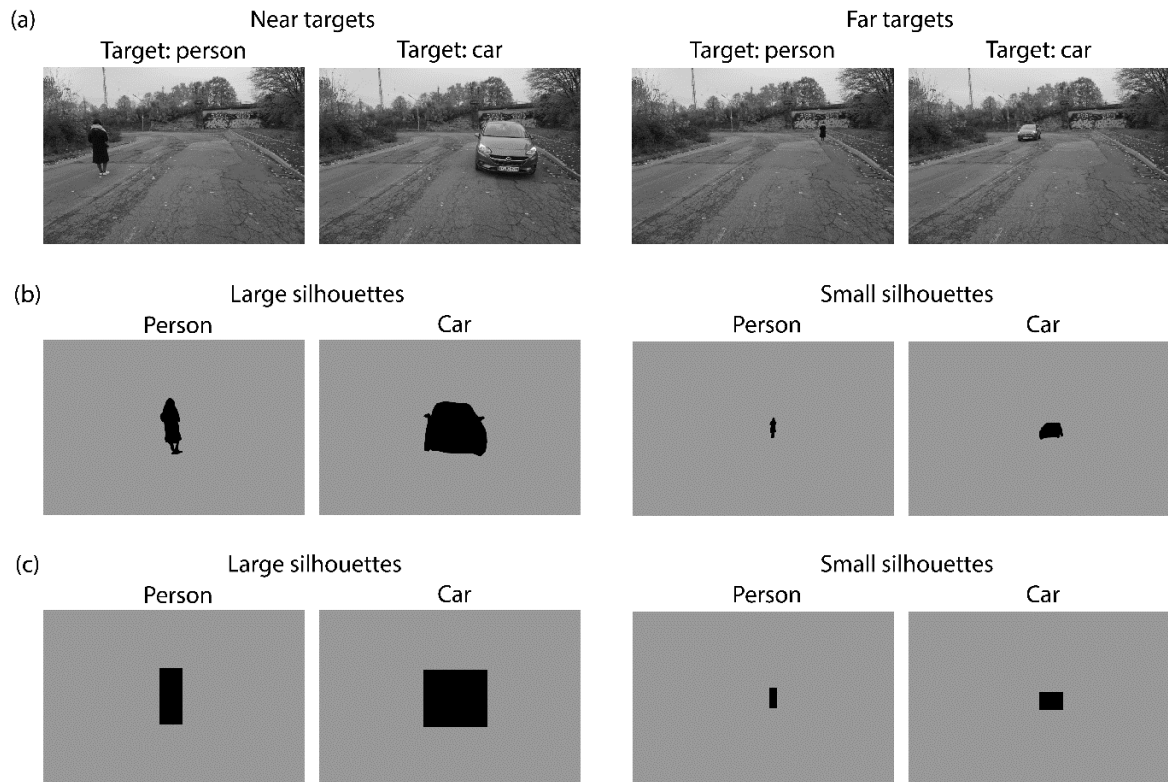
394

396 A total of 126 outdoor scenes were created for the purpose of this experiment, using a HD digital

397 photo camera. Photographs were taken at 14 different locations, and 9 different stimuli were created

398 at each of these locations from the exact same viewpoint (using a tripod): scenes comprised either a

399 car or a person, positioned either nearby or far away, and positioned either on the left or right half of

400 the scene (to induce spatial uncertainty). Also, one 'empty 'scene was created, in which no target

401 object was present.

402   All scenes were converted to greyscale (see Figure 4a), and were scaled to subtend 13.3 by

403 9.0 dva. Finally, based on each of the 14 empty scenes, four additional stimuli were created by

404 superimposing a red or blue horizontal line indicating where the near or far objects touched the

405 ground in that specific scene (i.e., the wheels of the car, or the feet of the person). These lines would

406 serve as distance cues. Note that, in contrast to Experiment 1, distance (and therefore object size) was

407 manipulated within-scene, and therefore distant objects were inherently smaller than nearby objects.

408 As such, there was no need to compare the mean retinal object-sizes between near and far conditions.

409

Figure 4. Example of stimuli used in the different experimental conditions of Experiments 2 and 3. (a) Scene stimuli used in the search task. Target objects (person or car) in each of 14 scene families could be either located in the foreground or background (large or small target image). (b) Silhouette stimuli used in the catch trials of Experiment 2A, which were cropped out of the corresponding (near and far, car and person) search scenes. (c) Corresponding silhouette stimuli used in the catch trials of Experiment 2B, which were rectangles with the same height and width as the original silhouettes.

410

411

Silhouette stimuli (catch trials)

The stimuli used in the catch trials of Experiment 2A were black silhouettes of cars and people, cropped out of the scene stimuli described above, and presented on the uniform gray background (Figure 4b). This resulted in 112 silhouettes; 28 exemplars in each car or person, and near or and far condition (i.e., 2 exemplars in each condition, for each specific scene). Importantly, because the silhouettes were cropped out of the scenes and because the distance cues were based on the positions of the objects in the scenes, the size of each silhouettes corresponds exactly to the size of the target objects (that participants could expect) in the scenes.

The stimuli used in the catch trials of Experiment 2B were black rectangles, with the exact same (maximum) height and width as the silhouettes used in Experiment 2A. Thus, the sizes and

height-to-width ratios of these pseudo-silhouettes matched the sizes and height-to-width ratios of the target objects in each scene.

Experimental procedure

The experiment consisted of a single session of approximately 60 minutes, starting with verbal and visual instructions, a practice block with search trials only (24 trials), a practice block with catch trials only (24 trials), and a practice block with both trial types intermixed (24 trials total, of which 6 catch trials). Then, participants completed 16 experimental blocks of 32 trials each, of which 24 search trials (75%) and 8 catch trials that were randomly intermixed.
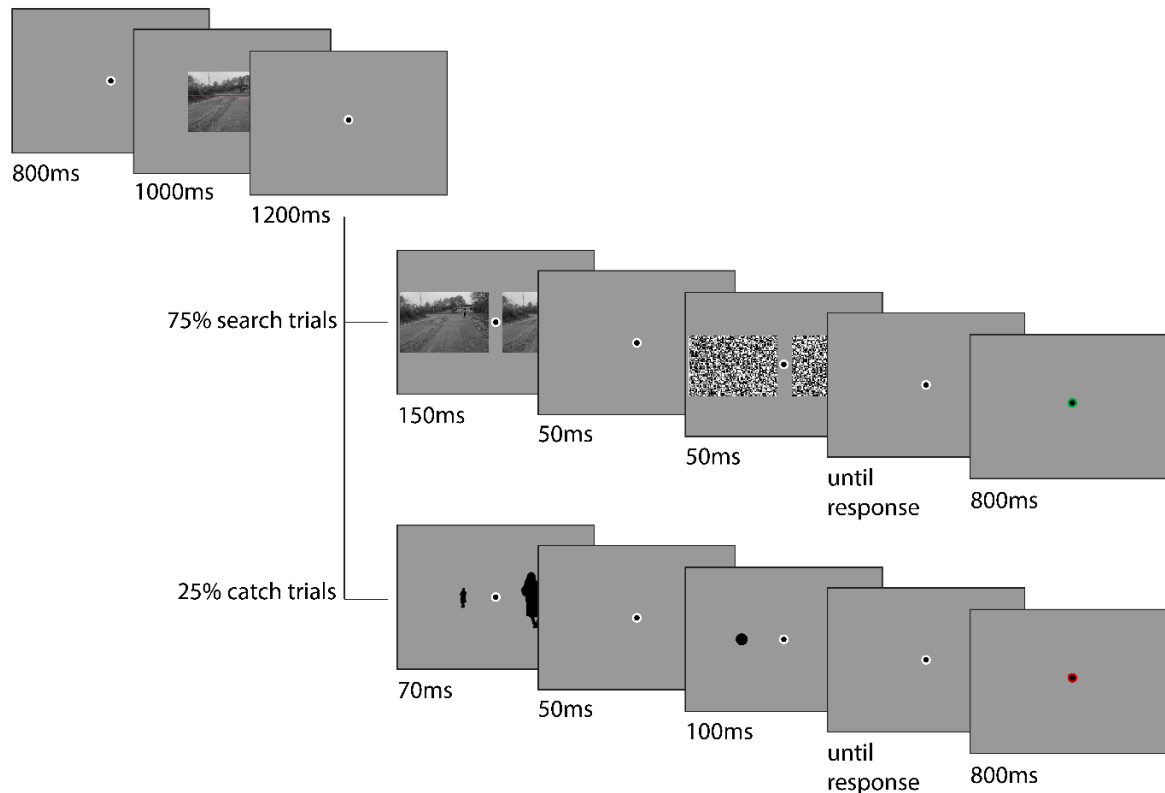
Search trials

The order of events in search trials is depicted in Figure 5 (top row). Each search trial started with a central fixation dot (800ms), followed by an empty scene (i.e., devoid of target objects) overlayed with a colored bar (1000ms). The color of the bar (blue or red) indicates the category of the target object (blue for car and red for person for even participant numbers, and the opposite for odd participant numbers). The vertical position of the bar indicates the location of the target object in depth, thus allowing to predict the size of the target object.

After another fixation cross (1200ms), the same outdoor scene that was previewed before was simultaneously presented for 150ms on both sides of fixation, one of which comprised the target object while the other one contained no object at all. Scene offset was followed by a fixation screen (50ms), a white-noise mask (50ms), and another fixation screen that lasted until participants provided a response. Participants indicated by means of a key press which image (left or right of fixation) contained the target object. The white part of the fixation dot turned green or red to indicate whether the response was correct or not.

In order to equate task difficulty between the different search target conditions (near and far, car and person), we superimposed pink (i.e., 1/f) noise onto the scene stimuli, and adaptively adjusted

448   the percentage of noise using Accelerated Stochastic Approximation (ASA; Kesten, 1958), separately

449   for each search target condition. Unlike traditional up-down staircase procedures, ASA adjusts the

450   step sizes by taking into account the stability of the estimated threshold. In doing so, we expected to

451   stabilize performance levels at 75% correct in all search conditions (Faes, 2007). In contrast to

452   Experiment 1, the onset asynchrony between the scene stimuli (mixed with pink noise) and the mask

453   stimuli (white noise) remained fixed at 50ms.

454   To test whether this staircase procedure was successful in equating difficulty between search

455   target conditions, we conducted a repeated-measures ANOVA with the factors Object (person versus

456   car) and Distance (near versus far), on both accuracy and response times. In Experiment 2A, far target

457   search and near target search differed neither in terms of accuracy, $F(1,25) = 0.024$, $p = .879$, $\eta^2 < .001$,

458   nor in terms of reaction times, $F(1,25) = 0.041$, $p = .841$, $\eta^2 < .001$. Similarly, in Experiment 2B, far

459   target search and near target search differed neither in terms of accuracy, $F(1,25) = 1.425$, $p = .244$,

460     $\eta^2 = .032$, nor in terms of reaction times, $F(1,25) = 0.197$, $p = .661$, $\eta^2 = .003$. Accuracies in all search

461   task conditions ranged between 77.2% and 79.5% correct, and reaction times ranged between 590 ms

462   and 631 ms. Taken together, the staircase procedure of Experiment 2 was successful in equating task

463   difficulty across near and far search conditions, in terms of both accuracy and reaction times.

464

Figure 5. Schematic depiction of the experimental procedure of Experiment 2A. Each block was made up of 32 trials presented in random order, comprising 24 search trials (75%) and 8 intermixed catch trials, each containing a large and a small silhouette (both of the cued object category). In all trials, the vertical position of a colored bar instructed participants where (in depth) the target object would appear. The color of the bar (red or blue) indicated which target object to search for (car or person). Participants reported which of two versions of the same scene (left or right of fixation) contained the cued target object. In catch trials, two task-irrelevant silhouettes appeared, followed by a small target dot. Participants reported where (left of right of fixation) the target dot appeared. The procedure of Experiment 2B was identical to that of Experiment 2A, but the silhouettes were replaced by rectangles (see Fig. 4c).

465

466 *Catch trials*

467 Figure 5 (bottom row) illustrates the order of events in catch trials (dot-probe task) of Experiment 2A.

468 The start of a catch trial was indistinguishable to that of a search trial, thus inciting participants to

469 generate an attentional template in anticipation of the search task. Instead of the two search scenes,

470 however, two silhouettes were presented for 70ms, on either side of fixation: a large and a small

471 silhouette of the cued target object, that was cropped out of the corresponding search scene. These

472 silhouettes were vertically centered on the fixation dot, and presented on the left and right side of

473 fixation at equal eccentricity (the eccentricity was varied on a trial by trial basis, to match the

474 horizontal position of the objects in the scenes). After a fixation screen (50ms), a black target dot

475 would appear (19 Cd/m^2; 0.3 dva in diameter) at the center of one of the two previously presented

476 silhouettes. On half of the trials, the target dot appeared at the location of the large silhouette, on the

477 other half of the trials the target dot appeared at the location of the small silhouette (see Figure 6b).

478 Participants reported the location of the target dot (left or right of fixation) by keypress, after which

479 the white part of the fixation dot turned green or red to indicate whether they reported the location

480 of the target dot correctly or not.

481 Experiment 2B was identical to Experiment 2A, except that the silhouettes in the catch trials

482 were replaced by rectangles encompassing the maximum height and width of each silhouette. As such,

483 the silhouette were still size-valid or size-invalid with regards to the current search task (and even

484 comprised height-to-width ratios that could distinguish between car and person silhouettes), but

485 lacked the target object-specific shape contours (see Figure 6b).

486

487 *Data analysis*

488 The analysis approach is identical to that of Experiment 1, unless otherwise specified. To address the

489 main question of whether the predicted retinal size of target objects is incorporated in the attentional

490 template, we analyzed how accurately participants reported the location of the target dot. Data was

491 analyzed as a function of one experimental factor, size-validity: On half of the trials the target dot

492 appeared at the location of a size-consistent silhouette (i.e., the large silhouette during near search,

493 or the small silhouette during far search). In the other half of the trials the target dot appeared at the

494 location of the size-inconsistent silhouette (i.e., the large silhouette during far search, or the small

495 silhouette during near search). Mean accuracy scores were computed for each participant and for

496 both conditions of interest. No trials were excluded from analysis.

497 If participants generate an attentional template that incorporates the predicted retinal size of

498 a target object, we expect to observe a size-validity effect in Experiment 2A. More accurate responses

499 to targets appearing at the location of a size-consistent silhouette than a size-inconsistent silhouette

500 implies that size information was extracted from the viewing distance in the scene and incorporated
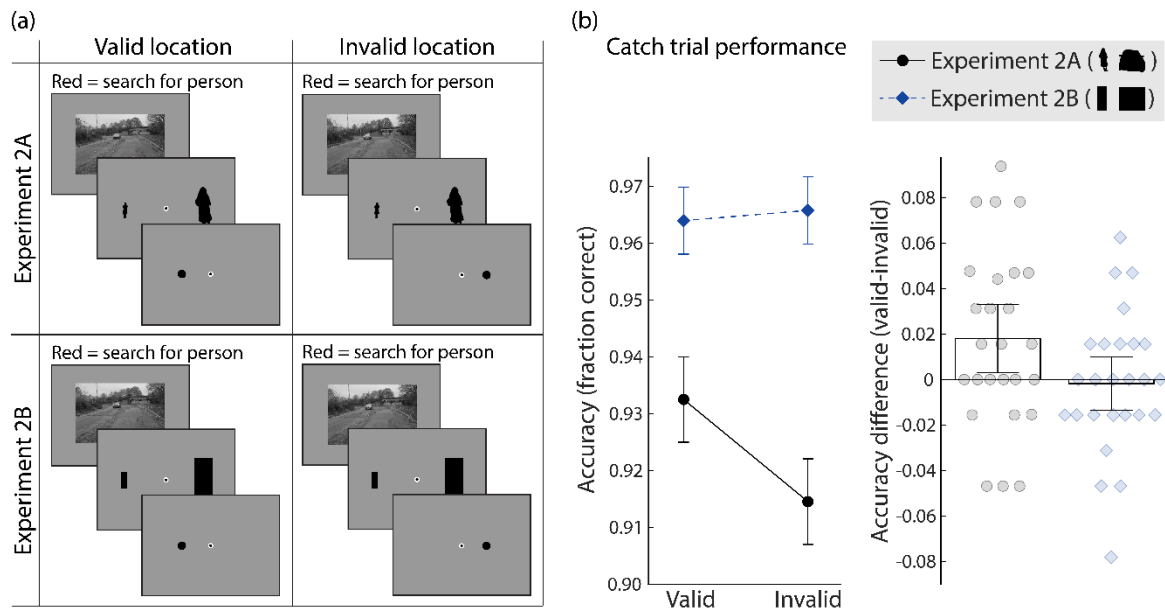
501   in the attentional template. If a size-validity effect is found in Experiment 2A but not in Experiment

502   2B, this would show that the size information in the attentional template only applies to visual input

503   that matches the category-specific shape of the target object (i.e., of a car or person). If, instead, a

504   size-validity effect is observed in both Experiment 2A and 2B, this would show that attentional

505   templates favor category-matching and size-matching visual input independent of one another (i.e.,

506   as if there were multiple attentional templates biasing search in parallel).

507

508   ## Results

509   *Catch trial analysis*

510   To test the main hypothesis that attentional templates change as a function of viewing distance, we

511   performed a paired-samples t-test on catch trial accuracy, contrasting accuracy for target dots

512   appearing at the location of size-consistent silhouettes with target dots appearing at the location of

513   size-inconsistent silhouettes (see Figure 6c). In Experiment 2A, participants were more accurate in

514   locating the dots appearing at the position of a size-consistent silhouette (M = 93.1%, SD = 7.6)

515   compared to a size-inconsistent silhouette (M = 91.2%, SD = 7.8), $t(25)$ = 2.54, p = .018, d_z = 0.498

516   ($p_{bootstrap}$ = 0.010, *95% CI* [0.5%, 3.4%]). This was not the case in Experiment 2B, where the silhouettes

517   were replaced by rectangles, p > 0.7, d_z = -0.059 ($p_{bootstrap}$ = .796, *95% CI* [-1.3%, 1.0%]). Following the

518   general approach of equivalence testing (Lakens, et al., 2018), we established that the effect in

519   Experiment 2B was significantly smaller than half the effect size observed in Experiment 2A, p = .035,

520   which we deemed to be negligible. An independent-samples t-test contrasting the validity effect of

521   both experiments confirmed that the validity effect was larger in Experiment 2A (M = 1.9%, SD = 3.9)

522   than Experiment 2B (M = -0.2%, SD = 3.1), $t(50)$ = 2.17, p = .034, d_z = 0.603 ($p_{bootstrap}$ = .014, *95% CI*

523   [0.4%, 3.9%]). Together, these data show that observers incorporate the expected size of a target

524   object (as inferred from the viewing distance in the scene) in their attentional template. This

525   attentional template, however, does not prioritize any visual input of the expected object size, but

526   only visual input of the expected object size that also matches the visual characteristics of the object

527   category.

528   We also noted that performance was generally lower in Experiment 2A (M = 92.2%, SD = 8.7)

529   than Experiment 2B (*M* = 96.5%, *SD* = 8.7), *W* = 217, *p* = .027, *Hodges-Lehmann Estimate* = .023 (Mann-

530   Whitney test used due to the violation of assumption of equal variances). This might reflect that –

531   overall– presenting visual stimuli that are more relevant to the participant (i.e., silhouettes compared

532   to rectangles) interferes more with localization of the dot target.

Figure 6. Experimental design and results for the dot-probe task (catch trials) of Experiment 2. (a) Visualization of the within-subject designs of Experiment 2A and 2B. For illustrative purpose we here only depict trials in which participants were cued to search for a distant (i.e., relatively small image of a) person. There were two validity conditions: the target dot either appeared at the location of the size-consistent (here: large) or the size-inconsistent silhouette (here: small). (b) in Experiment 2B the silhouettes were replaced by filled rectangles, encompassing the (maximum) height and width of each silhouette. (c) Mean proportion correct for the size-consistent versus size-inconsistent locations in Experiment 2A (silhouettes) and 2B (rectangles). Error bars represent the *95% CI* of the paired difference between conditions.

533

534

535   *Interim discussion*

536   The goal of this experiment was to test whether observers flexibly incorporate the expected size of a

537   target object in their attentional template. The observation that target dots were more accurately

538   reported at the location of a size-consistent silhouette compared to a size inconsistent silhouette of

539   the target object demonstrates that size information was incorporated in the attentional template.

540   Moreover, the present results extend the results of Experiment 1, by showing that participants

541   predicted the retinal size of the cued search target, based explicitly on the viewing location in the

542   scene. This demonstrates how observers could incorporate size information for efficient template-

543   based search under naturalistic conditions, by updating the expected object size during search (e.g.,

544   across eye-movements).

545   The present results do not show, however, whether these size-specific attentional templates

546   influence visual search by shifting spatial attention toward the location of size-matching visual input.

547   There are two distinct accounts that could explain the accuracy difference in localizing target dots that

548   appear at the location of size-consistent versus size-inconsistent silhouettes. One possibility is that

549   participants mistook the size-consistent silhouette (more often than the size-inconsistent silhouette)

550   for the search target; if participants report the location of the size-consistent silhouette, this gives a

551   correct target localization response in size-consistent (i.e., valid) trials and an incorrect target

552   localization response in size-inconsistent (i.e., invalid) trials. The other possibility is that the size-

553   consistent silhouette attracted spatial attention due to its match with the attentional template,

554   causing improved visual discrimination performance at the attended location and, consequently,

555   better target localization performance.

556   Experiment 3 was designed to directly test this second possibility. Here, the target dot is

557   replaced with a triangle pointing upward or downward (see Figure 7a), and participants are instructed

558   to report the orientation of the arrow target (up versus down). In this case, mistakenly responding to

559   the size-consistent silhouette (left versus right localization) would not influence discrimination

560   performance on the arrow target (up versus down discrimination). As such, better discrimination

561   performance of the arrow target at the location of the size-consistent compared to the size-

562   inconsistent silhouette, would unequivocally demonstrate that spatial attention was drawn toward

563   the size-consistent silhouette, thereby enhancing target discrimination performance.

564

Experiment 3

Methods

Differences with Experiment 2

All methods were identical to that of Experiment 2A, except for (1) the use of upward and downward

pointing target triangles instead of a target dot in the catch trials, (2) the ensuing use of an up-down

response instead of left-right response in catch trials, and (3) the set-up on which the experiment was

conducted.

Search trials

In Experiment 3, far target search and near target search differed neither in terms of accuracy, $F(1,25)$

= 1.159, p = .292, η^2 = .015, nor in terms of reaction times, $F(1,25)$ = 2.943, p = .099, η^2 = .028.

Accuracies in all search task conditions ranged between 78.4% and 82.9% correct, and reaction times

ranged between 653 ms and 676 ms. As such, the staircase procedure of Experiment 3 was also

successful in equating task difficulty across near and far search conditions, in terms of both accuracy
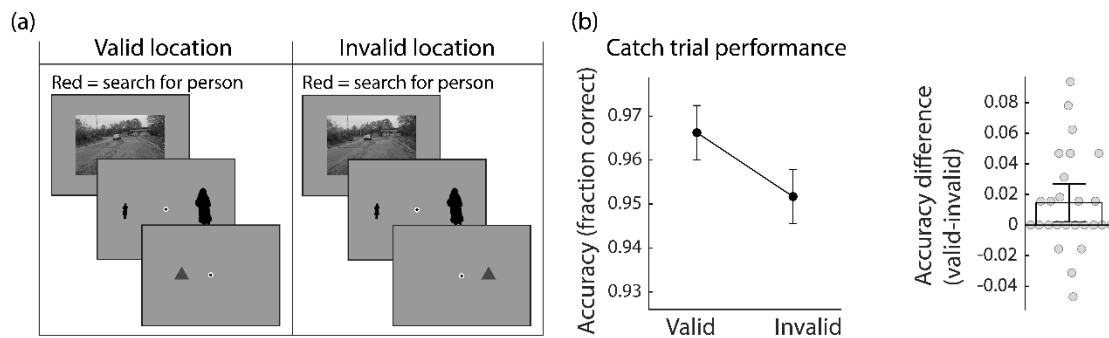
and reaction times.

Participants

Another twenty-six healthy students from Radboud University participated in Experiment 3 (20

females, mean age of 20.51 years, *SD* = 2.82). The sample size was based on the same power analysis

as Experiments 2A and 2B. Participants received monetary compensation (€10,-/session). The

experiment was approved by the Ethics Committee of the Social Sciences Faculty of Radboud

University.

Results

Catch trial analysis

To test the main hypothesis that size-specific attentional templates guide spatial attention, we

performed a Wilcoxon signed-rank t-test on catch trial accuracy, contrasting up-down discrimination

performance for target triangles appearing at the location of size-consistent silhouettes with that of

593   size-inconsistent silhouettes (Figure 7b). Participants were more accurate in reporting the orientation

594   of the triangles when they appeared at the location of a size-consistent silhouette (M = 98.4%, IQR =

595   3.0) compared to a size-inconsistent silhouette (M = 96.1%, IQR = 4.7), W = 108.5, p = .038, *rank-*

596   *biserial correlation* = .596 ($p_{bootstrap}$ = .014, *95% CI* [0.3%, 2.7%]). This shows that size-specific

597   attentional templates cause spatial attention to shift toward template-matching visual input.

598

Figure 7. Experimental design and results for the dot-probe task (catch trials) of Experiment 3. (a) The procedure and experimental design of Experiment 3 are identical to that of Experiment 2A, but now the target was a triangle, and participants reported whether it was pointing upward or downward. Note that the intermixed search task trials still required left/right responses. (b) Mean proportion correct for the size-consistent (valid) versus size-inconsistent (invalid) locations. Error bars represent the *95% CI* of the paired difference between conditions.

599

600

General Discussion

602   According to the idea of template-based search, observers generate a visual representation of the

603   target object prior to search onset, which favors target-like visual input at the expense of non-target

604   visual input. Here, we investigated whether human observers adjust the size of the attentional

605   template to account for viewing distance during search, capitalizing on the predictable relationship

606   between retinal object size and viewing distance. This would entail that observers effectively search

607   for a smaller "image" of an object when searching further away, and for a larger "image" of that same

608   object when searching closer by. We used a dot-probe task (MacLeod, et al., 1986) to probe the

609   content of the search template (Reeder, & Peelen, 2013), intermixed with a search task that incited

610   participants to search for a given object (person or car), at a specific viewing distance in a scene

photograph. To summarize our findings: (1) in Experiment 1 we confirm earlier results that observers incorporate category-specific shape information in the attentional template, allowing the visual input to favor car-like visual input over person-like visual input and vice versa, depending on the search target; (2) most importantly, in Experiments 1, 2A, and 3, we demonstrate that observers incorporate the expected retinal size of the target object in the attentional template, favoring visual input of the expected retinal size over differently sized visual input; (3) the results of Experiment 3 show that the template causes a shift of spatial attention toward size-matching objects; (4) in Experiments 2A and 3, we demonstrate that observers flexibly predict the retinal size of a target object from the real-world viewing distance in a scene; and finally, (5) Experiments 1 and 2 show that distance-dependent size information and category-specific shape information are entangled, yielding a single attentional template that is both shape and size specific.

Confirming earlier work (Reeder, & Peelen, 2013; Reeder, et al., 2015), the results show that participants incorporate the category of the target object (i.e., person or car) in their attentional template. This conclusion stems from the finding that participants in Experiment 1 were more accurate in reporting the location of a target dot at the location of a category-valid (e.g., person silhouette following a "person" search cue) than a category-invalid silhouette (e.g., person silhouette following a "car" search cue). This effect was observed in virtually all participants, and was between two and four times larger than the size-based validity effect observed in Experiment 2A. Since the dot-probe task used uniform black silhouettes, category-specific attentional templates (at least partly) rely on differences in shape attributes. Earlier work showed that category-specific attentional templates (for cars and persons) consist of category-diagnostic object parts (e.g., the wheel of a car, or an arm of a person), and that these are rotationally invariant (Reeder, & Peelen, 2013). Similarly, here the difference in behavioral responses to targets following category-valid versus category-invalid silhouettes implies that category-specific information was maintained during search preparation. Accordingly, we conclude that observers incorporate target object-specific attributes in the attentional template, thus favoring target-like visual input during naturalistic visual search.

637   The key finding of the present study is that participants incorporate the expected size of a

638   target object in their attentional template. Our conclusion stems from the observation that the

639   category-specific effect on target-dot report (discussed above) increased when silhouettes were of

640   the expected size (within the current experimental session) compared to the unexpected size. This is

641   consistent with the idea that the attentional template is a visual representation of the object category

642   that is scaled to the expected size of the target object (Gayet, & Peelen, 2022). Can this finding explain

643   how observers search for objects at different distances within a three-dimensional real-world

644   environment? During real-world search, the expected size of a target object does not vary on a day-

645   by-day basis, however, but rather depends on (1) the viewing distance that observers extract from the

646   search scene, which (2) varies on a moment-to-moment basis. The data of Experiments 2A and 3 show

647   that, indeed, when participants are cued (on a trial-by-trial basis) to search at a particular location in

648   a natural scene photograph, an attentional template is generated with a size that corresponds to the

649   viewing distance at the current search location. Specifically, when cued to search for a relatively

650   distant target object, observers are better at reporting the target-dot following a small silhouette of

651   the target object, but when cued to search for a relatively nearby target objects, observers are better

652   at reporting the target-dot following a large silhouette of the target object. The present study provides

653   the first behavioral evidence that human observers take into account the predicted size of search

654   targets (as inferred from the viewing distance) when generating attentional templates to search for

655   objects in a naturalistic scene. This finding could explain why observers sometimes fail to recognize

656   objects that are inappropriately sized given the surrounding scene context (Eckstein, et al., 2017).

657   Based on the present study alone, it remains unknown whether the size of the attentional template is

658   adjusted continuously, to match the specific viewing distance at the current search location, or

659   whether it is adjusted categorically, favoring *relatively* larger objects over smaller objects during near

660   search (e.g., Bravo, & Farid, 2009; Becker et al., 2010; 2013). Nonetheless, the findings that attentional

661   templates incorporate viewing distance contributes to the literature on mechanisms of attentional

662   selection in naturalistic visual search (Eimer, 2014; Peelen, & Kastner, 2014).

663   Embedding the present findings in the broader literature on attentional selection in visual

664   search, we can ask how observers go about finding their keys on a cluttered desk, or searching for

665   their friend at a crowded festival. The answers to this question distinguish between two types of

666   search strategies: environmental cues that guide attention, and feature-based guidance (Wolfe, &

667   Horowitz, 2017). A large body of work has shown how – during naturalistic search – participants

668   quickly direct their gaze toward locations that are likely to contain the target object, such as shoes on

669   the floor, a phone on the desk, or a toothbrush near the bathroom sink (e.g., Neider, & Zelinsky, 2006;

670   Droll & Eckstein, 2008; Boettcher et al., 2018), even when set sizes are very large (Wolfe, et al., 2011).

671   In parallel, other studies have shown that feature-based attention benefits naturalistic visual search

672   (Bahle, et al., 2018; Bahle, & Hollingworth, 2019; Hollingworth, & Bahle, 2020), by drawing attention

673   to target-specific features such as color or shape across the visual field (Maunsell, & Treue, 2006;

674   Nuthmann, & Malcolm, 2016; Peelen, & Thorat, 2022). Such spatially-global effects of attention have

675   also been observed for category-level (car, person) search in natural scenes (Peelen, et al., 2009). The

676   present study shows one way in which these two mechanisms (i.e., scene guidance and feature-based

677   guidance) interact: when observers are searching for their phone, they use a template comprising

678   phone-specific visual features (small, black, rectangular), some of which are adjusted according to

679   environmental cues (in this case, the size is adjusted based on the viewing distance extracted from

680   the scene).

681   We considered two ways in which size information in the attentional template could have

682   affected behavior in the dot-probe task. Either participants mistakenly responded to the silhouettes

683   instead of responding to the target-dot (erroneously recognizing size-valid silhouettes as target

684   objects, more often than size-invalid silhouettes). Alternatively, size-valid silhouettes attracted

685   attention, thereby enhancing visual detection of the target-dot at the attended location. Experiment

686   3 was designed to discriminate between these possibilities, by replacing the target-dot detection task

687   with a target-triangle (up-down) discrimination task. Here, we capitalized on the fact that

688   performance on a variety of visual tasks should be better at the attended location compared to the

689   unattended location (Carrasco, et al., 2000). The data showed that participants were more accurate

690   in reporting the orientation of the target-triangle when it followed a size-valid silhouette (e.g., small

691   silhouette of the target object during distant search) compared to when it followed a size-invalid

692   silhouette (e.g., small silhouette of the target object during nearby search). Under these

693   circumstances, mistakenly responding to the silhouette (as if it was the search target) would not affect

694   the accuracy for reporting the orientation of the triangle. Instead, if size-valid silhouettes attracted

695   spatial attention (due to their match with the attentional template), participants should be better at

696   discriminating the orientation of the briefly presented triangle-target. Considering that the magnitude

697   of the size-validity effect was virtually identical between Experiment 2A (target-dot) and Experiment

698   3 (target-triangle), it can be argued that size information (extracted from viewing distance) mainly

699   impacts visual search performance by attracting attention toward target objects of the predicted

700   retinal image size.

701   The present results show how the attentional template can incorporate multiple aspects of

702   the search target; in this case, its category-specific shape and its context-dependent size. Importantly,

703   these two aspects of the attentional template are codependent: object-selectivity is more pronounced

704   for objects of the expected target size (Experiment 1) and size-selectivity is more pronounced for

705   objects of the expected target shape (Experiment 2). This argues against the existence of two

706   independent attentional templates (a size-specific template and a shape-specific template), and

707   demonstrates that a single attentional template incorporates both category-specific shape

708   information and context-dependent size information (see also Gayet, & Peelen, 2022). The

709   contributions of these two aspects to visual search performance seem asymmetrical, however. The

710   findings of Experiment 1 show that category-selectivity is observed not only for size-consistent

711   silhouettes, but also for size-inconsistent silhouettes. Thus, when searching for a car at a particular

712   distance, car-like visual input is favored over non-car-like visual input, even when it does not match

713   the predicted object size. The findings of Experiment 2, on the other hand, show that size-selectivity

714   is observed only for target object silhouettes, and not for rectangular silhouettes that only preserved

the height and width of the target objects. Can we then conclude that, when searching for a car, visual input of the predicted object size is only favored over differently sized visual input when it contains car-like visual shape properties? This might be too simplistic. Here, the (rectangle) silhouettes were very crisp, and clearly lacked the shape attributes of a car. During real-world vision, the exact shape (or color, etc.) of a visual object might be more uncertain, for instance because it is out of focus, occluded, or viewed peripherally. When the shape (or other property) of an object is uncertain, this can be accounted for by widening the tuning of their attentional templates accordingly (Lleras et al., 2022; Witkowski, & Geng, 2022; Hout, & Goldinger, 2015; Bravo, & Farid, 2012). From this perspective, we might expect that visual input of the predicted object size is favored as long as its shape (or some other property) does not provide sufficient evidence *against* it being the search target.

Nonetheless, within our experimental paradigm, shape information guided attention irrespective of whether the silhouette size was consistent with the search distance, whereas size information only guided attention when the shape of the silhouettes was consistent with the search target. We consider four possible (non-exclusive) explanations for this asymmetry. First, it could be that shape information generally dominates size information in visual search, akin to how color information tends to dominate over other stimulus attributes (e.g., Williams, 1966; Wolfe & Horowitz, 2004). Arguably, visual shape properties are more diagnostic of a target object, and less variable over time, compared to size information. Second, the dominance of one attribute over another could depend on the specific task; here, participants were instructed to report the location of a person or car (as defined by its visual shape properties), they were not instructed to search for an object of a particular size. Reversing the instructions might reverse the relative dominance of the two features in driving visual search. Third, the relative dominance of shape over size (and orientation; Reeder, & Peelen, 2013) might be specific to highly familiar object categories, for which detection is particularly efficient (Li, et al., 2002; Thorpe, 1996; Stein, & Peelen, 2017; Treisman, 2006). When searching for less familiar objects, observers might rely more heavily on context-dependent attributes (such as inferred retinal size), because they fail to extract the most distinctive category-specific visual features.

741　Fourth, the relative dominance of the shape and size properties might depend on the diagnosticity of

742　shape-information and size-information for distinguishing between the two types of target objects

743　(cars and persons), and between the target objects and their surroundings (size might be more

744　relevant when distractor objects have similar shapes as the target; e.g., searching for a soccer ball

745　among basket balls and tennis balls). The idea that the contents of the template are context-

746　dependent is very common in the literature about attentional templates (Navalpakkam, & Itti 2007;

747　Geng, & Witkowski, 2019). It is known that templates are influenced by prior knowledge about, for

748　example, the scene lay-out (Li, et al., 2018), distractor identity (Howard, et al., 2011; Lerebourg et al.,

749　2023), and object co-occurrence (Mack, & Eckstein, 2011): different tasks and set-ups result in

750　different templates. Taken together, it is likely that the exact way in which different (object-specific

751　or context-dependent) features are combined in the attentional template depends on both task and

752　stimulus context (for a recent discussion, see Yu, et al., 2023).

753　　　　The current results imply that attentional templates incorporate the expected retinal (or:

754　proximal) size of target objects, not their perceived (or: distal) size. This provides support to behavioral

755　studies showing that, in naturalistic visual search, an object's predicted proximal size (Sherman, et al.,

756　2011; Eckstein, et al., 2017) or proximal shape (Morales, et al., 2020; Aldegheri, Gayet, & Peelen, 2023)

757　contributes to attentional guidance and object recognition. Using proximal rather than distal features

758　of target objects to guide visual search makes sense, when considering feed-forward accounts of visual

759　perception; from a feed-forward perspective, retinal size is extracted faster than perceived (or

760　veridical) size. Thus, biasing visual input based on proximal features would allow for earlier selection

761　of target-like visual input than selection based on distal features. On the other hand, scene context

762　modulates representations of object size even in primary visual cortex (Murray, et al., 2006; Fang, et

763　al., 2008; Sperandio, et al., 2012; Sperandio, & Chouinard, 2015), although this may reflect delayed

764　feedback processes (Schmidt, & Haberkamp, 2016; Zeng, et al., 2020). Moreover, the visual system as

765　a whole seems to preferentially represent the perceived size of objects rather than their retinal size

766　(Murray, et al., 2006; Sterzer, & Rees, 2006; Fang, et al., 2008; Liu, et al., 2009; Cate, et al., 2011;

767 Konkle, & Oliva, 2011; 2012; Schwarzkopf, et al., 2011; Amit, et al., 2012; Sperandio, et al., 2012;

768 Pooresmaeili, et al., 2013; Chouinard, & Ivanowich, 2014; Gabay, et al., 2016). As such, using distal

769 stimulus features to guide visual search would also allow for relatively early and effective visual

770 selection. In line with this, we previously showed that memory templates favor perceptually size-

771 matching objects over perceptually size-mismatching objects, even when both objects have the exact

772 same retinal size (Gayet, & Peelen, 2019). Considering human observers' proficiency in naturalistic

773 visual search, it is very well possible that search preparation simultaneously capitalizes on proximal

774 (retinal image-based) as well as distal (perceived) features, thus favoring target-like visual input over

775 irrelevant visual input at multiple steps of the visual processing hierarchy.

776

777 Conclusion

778 During real-world visual search, any given object that we are searching for can produce a wide variety

779 of visual input, depending on where it is located in the world. The eventual appearance of the object

780 therefore remains unknown during search, complicating template-based visual search. Conversely,

781 however, the specific location in the scene at which we currently search for an object strongly

782 constrains the appearance of the object. Notably, when the real-world size of the object is known, the

783 viewing distance directly informs the participant of the retinal image size that the object produces.

784 Here, we show that observers predict the appearance of the target object from the current search

785 location in the scene. Specifically, participants formed predictions about the retinal size of the object,

786 given the (cued) viewing distance. This size information is then incorporated in the attentional

787 template, so that target-like visual input is favored – in particular – when its retinal size is consistent

788 with the viewing distance. Put simply: we provide direct behavioral evidence that the attentional

789 template is scaled to account for viewing distance (in line with recent neuroimaging evidence, Gayet,

790 & Peelen, 2022). Finally, we show that visual input that matches this category-selective and size-

791 specific attentional template attracts attention. Together, these findings demonstrate how

792 preparatory attentional templates operate during naturalistic visual search.

793

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802

Author contributions

Surya Gayet: Conceptualization, Methodology, Software, Formal Analysis, Investigation, Resources, Data Curation, Writing – Original Draft, Visualization, Supervision, Project Administration, Funding Acquisition. **Sushrut Thorat:** Conceptualization, Methodology, Resources, Writing – Review & Editing. **Elisa Battistoni:** Conceptualization, Methodology, Software, Investigation, Resources, Writing – Review & Editing. **Marius V. Peelen:** Conceptualization, Methodology, Writing – Review & Editing, Supervision, Funding Acquisition.

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Declaration of interests

The authors declare no competing interests.

813

Inclusion and diversity statement

We worked to ensure gender balance in the recruitment of human subjects. We worked to ensure that the study questionnaires were prepared in an inclusive way. While citing references scientifically relevant for this work, we also actively worked to promote gender balance in our reference list.

Constraints on Generality (COG) statements

Our participant sample was recruited among the student population of the University of Trento (Italy), and Radboud University (The Netherlands), and therefore consists of highly educated, predominantly Caucasian, subjects with a predominantly Western background. Also females are overrepresented in the sample. Based on this, we advocate caution in generalizing our findings to other populations. At the same time, the present study investigates fundamental properties of visual search that are commonly studied across species, including human primates, non-human primates, and even non-primate mammals. Therefore, we do not expect the general principles studied here to vastly differ between primate species, let alone between human gender, ethnic, or cultural groups.

References

Aldegheri, G., Gayet, S., & Peelen, M. V. (2023). Scene context automatically drives predictions of object transformations. *Cognition*, *238*, 105521.

Amit, E., Mehoudar, E., Trope, Y., & Yovel, G. (2012). Do object-category selective regions in the ventral visual stream represent perceived distance information?. *Brain and Cognition*, *80*(2), 201-213.

Bahle, B., & Hollingworth, A. (2019). Contrasting episodic and template-based guidance during search through natural scenes. *Journal of Experimental Psychology: Human Perception and Performance*, *45*(4), 523.

837   Bahle, B., Matsukura, M., & Hollingworth, A. (2018). Contrasting gist-based and template-based guidance during real-world visual search. *Journal of Experimental Psychology: Human Perception and Performance*, *44*(3), 367.

840   Battistoni, E., Stein, T., & Peelen, M. V. (2017). Preparatory attention in visual cortex. *Annals of the New York Academy of Sciences*, *1396*(1), 92-107.

842   Beck, D. M., & Kastner, S. (2009). Top-down and bottom-up mechanisms in biasing competition in the human brain. *Vision Research*, *49*(10), 1154-1165.

844   Becker, S. I., Folk, C. L., & Remington, R. W. (2010). The role of relational information in contingent capture. *Journal of Experimental Psychology: Human Perception and Performance, 36*(6), 1460–1476.

847   Becker, S. I., Folk, C. L., & Remington, R. W. (2013). Attentional capture does not depend on feature similarity, but on target-nontarget relations. Psychological Science, 24(5), 634–647.

849   Blanca, M. J., Arnau, J., García-Castro, F. J., Alarcón, R., & Bono, R. (2023). Non-normal data in repeated measures ANOVA: impact on Type I error and power. *Psicothema*, *35*(1), 21-29.

851   Boettcher, S. E., Draschkow, D., Dienhart, E., & Võ, M. L. H. (2018). Anchoring visual search in scenes: Assessing the role of anchor objects on eye movements during visual search. *Journal of Vision*, *18*(13):11.

854   Boettcher, S. E., van Ede, F., & Nobre, A. C. (2020). Functional biases in attentional templates from associative memory. *Journal of Vision*, *20*(13):7.

856   Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision*, *10*(4), 433-436.

857   Bravo, M. J., & Farid, H. (2009). The specificity of the attentional template. *Journal of Vision*, *9*(1), 34.

858   Bravo, M. J., & Farid, H. (2012). Task demands determine the specificity of the search template. *Attention, Perception, & Psychophysics*, *74*, 124-131.

860 Carrasco, M., Penpeci-Talgar, C., & Eckstein, M. (2000). Spatial covert attention increases contrast

861   sensitivity across the CSF: support for signal enhancement. *Vision Research*, *40*(10-12), 1203-

862   1215.

863 Castelhano, M. S., & Krzyś, K. (2020). Rethinking space: A review of perception, attention, and memory

864   in scene processing. *Annual Review of Vision Science*, *6*, 563-586.

865 Cate, A. D., Goodale, M. A., & Köhler, S. (2011). The role of apparent size in building-and object-specific

866   regions of ventral visual cortex. *Brain Research*, *1388*, 109-122.

867 Chouinard, P. A., & Ivanowich, M. (2014). Is the primary visual cortex a center stage for the visual

868   phenomenology of object size?. *Journal of Neuroscience*, *34*(6), 2013-2014.

869 Cousineau, D. (2005). Confidence intervals in within-subject designs: a simpler solution to Loftus and

870   Masson's method. *Tutorials in Quantitative Methods for Psychology*, *1*(1), 42-45.

871 Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of

872   Neuroscience, 18*(1), 193-222.

873 Droll, J., & Eckstein, M. (2008). Expected object position of two hundred fifty observers predicts first

874   fixations of seventy seven separate observers during search. *Journal of Vision*, *8*(6), 320.

875 Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological

876   Review*, *96*(3), 433-458.

877 Eckstein, M. P., Koehler, K., Welbourne, L. E., & Akbas, E. (2017). Humans, but not deep neural

878   networks, often miss giant targets in scenes. *Current Biology*, *27*(18), 2827-2832.

879 Eimer, M. (2014). The neural basis of attentional control in visual search. *Trends in Cognitive

880   Sciences*, *18*(10), 526-535.

881 Faes, L., Nollo, G., Ravelli, F., Ricci, L., Vescovi, M., Turatto, M., ... & Antolini, R. (2007). Small-sample

882 characterization of stochastic approximation staircases in forced-choice adaptive threshold

883 estimation. *Perception & Psychophysics*, *69*, 254-262.

884 Li, F. F., VanRullen, R., Koch, C., & Perona, P. (2002). Rapid natural scene categorization in the near

885 absence of attention. *Proceedings of the National Academy of Sciences*, *99*(14), 9596-9601.

886 Fang, F., Boyaci, H., Kersten, D., & Murray, S. O. (2008). Attention-dependent representation of a size

887 illusion in human V1. *Current Biology*, *18*(21), 1707-1712.

888 Gabay, S., Kalanthroff, E., Henik, A., & Gronau, N. (2016). Conceptual size representation in ventral

889 visual cortex. *Neuropsychologia*, *81*, 198-206.

890 Gayet, S., & Peelen, M. V. (2019). Scenes modulate object processing before interacting with memory

891 templates. *Psychological Science*, *30*(10), 1497-1509.

892 Gayet, S., & Peelen, M. V. (2022). Preparatory attention incorporates contextual expectations. *Current*

893 *Biology*, *32*(3), 687-692.

894 Geng, J. J., & Witkowski, P. (2019). Template-to-distractor distinctiveness regulates visual search

895 efficiency. *Current Opinion in Psychology*, *29*, 119-125.

896 Hollingworth, A., & Bahle, B. (2020). Feature-based guidance of attention by visual working memory

897 is applied independently of remembered object location. *Attention, Perception, &*

898 *Psychophysics*, *82*, 98-108.

899 Hout, M. C., & Goldinger, S. D. (2015). Target templates: The precision of mental representations

900 affects attentional guidance and decision-making in visual search. *Attention, Perception, &*

901 *Psychophysics*, *77*, 128-149.

902 Howard, C. J., Pharaon, R. G., Körner, C., Smith, A. D., & Gilchrist, I. D. (2011). Visual search in the real
903 world: Evidence for the formation of distractor representations. *Perception*, *40*(10), 1143-
904 1153.

905 Kastner, S., & Ungerleider, L. G. (2001). The neural basis of biased competition in human visual
906 cortex. *Neuropsychologia*, *39*(12), 1263-1276.

907 Kesten, H. (1958). Accelerated stochastic approximation. *The Annals of Mathematical Statistics*, 41-
908 59.

909 Konkle, T., & Oliva, A. (2011). Canonical visual size for real-world objects. *Journal of Experimental*
910 *Psychology: Human Perception and Performance*, *37*(1), 23.

911 Konkle, T., & Oliva, A. (2012). A real-world size organization of object responses in occipitotemporal
912 cortex. *Neuron*, *74*(6), 1114-1124.

913 Lakens, D., Scheel, A. M., & Isager, P. M. (2018). Equivalence testing for psychological research: A
914 tutorial. *Advances in Methods and Practices in Psychological Science*, *1*(2), 259-269.

915 Lerebourg, M., de Lange, F. P., & Peelen, M. V. (in press). Expected distractor context biases the
916 attentional template for target shapes. *Journal of Experimental Psychology: Human*
917 *Perception and Performance*.

918 Li, C. L., Aivar, M. P., Tong, M. H., & Hayhoe, M. M. (2018). Memory shapes visual search strategies in
919 large-scale environments. *Scientific Reports*, *8*(1), 4324.

920 Li, F. F., VanRullen, R., Koch, C., & Perona, P. (2002). Rapid natural scene categorization in the near
921 absence of attention. *Proceedings of the National Academy of Sciences*, *99*(14), 9596-9601.

922 Liu, Q., Wu, Y., Yang, Q., Campos, J. L., Zhang, Q., & Sun, H. J. (2009). Neural correlates of size illusions:
923 an event-related potential study. *NeuroReport*, *20*(8), 809-814.

924   Lleras, A., Buetti, S., & Xu, Z. J. (2022). Incorporating the properties of peripheral vision into theories

925   of visual search. *Nature Reviews Psychology*, *1*(10), 590-604.

926   Mack, S. C., & Eckstein, M. P. (2011). Object co-occurrence serves as a contextual cue to guide and

927   facilitate visual search in a natural viewing environment. *Journal of Vision*, *11*(9), 9-9.

928   MacLeod, C., Mathews, A., & Tata, P. (1986). Attentional bias in emotional disorders. *Journal of*

929   *Abnormal Psychology*, *95*(1), 15-20.

930   Malcolm, G. L., & Henderson, J. M. (2009). The effects of target template specificity on visual search

931   in real-world scenes: Evidence from eye movements. Journal of Vision, 9(11):8.

932   Malcolm, G. L., & Henderson, J. M. (2010). Combining top-down processes to guide eye movements

933   during real-world scene search. *Journal of Vision, 10*(2):4

934   Maunsell, J. H., & Treue, S. (2006). Feature-based attention in visual cortex. *Trends in*

935   *Neurosciences*, *29*(6), 317-322.

936   Morales, J., Bax, A., & Firestone, C. (2020). Sustained representation of perspectival

937   shape. *Proceedings of the National Academy of Sciences*, *117*(26), 14873-14882.

938   Murray, S. O., Boyaci, H., & Kersten, D. (2006). The representation of perceived angular size in human

939   primary visual cortex. *Nature Neuroscience*, *9*(3), 429-434.

940   Navalpakkam, V., & Itti, L. (2007). Search goal tunes visual features optimally. *Neuron*, *53*(4), 605-617.

941   Neider, M. B., & Zelinsky, G. J. (2006). Scene context guides eye movements during visual

942   search. *Vision Research*, *46*(5), 614-621.

943   Nuthmann, A., & Malcolm, G. L. (2016). Eye guidance during real-world scene search: The role color

944   plays in central and peripheral vision. Journal of Vision, 16(2):3.

945   Peelen, M. V., Fei-Fei, L., & Kastner, S. (2009). Neural mechanisms of rapid natural scene categorization

946   in human visual cortex. *Nature*, *460*(7251), 94-97.

947   Peelen, M. V., & Kastner, S. (2014). Attention in the real world: toward understanding its neural

948   basis. *Trends in Cognitive Sciences*, *18*(5), 242-250.

949   Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into

950   movies. *Spatial Vision*, *10*(4), 437-442.

951   Pooresmaeili, A., Arrighi, R., Biagi, L., & Morrone, M. C. (2013). Blood oxygen level-dependent

952   activation of the primary visual cortex predicts size adaptation illusion. *Journal of*

953   *Neuroscience*, *33*(40), 15999-16008.

954   Potter, M. C. (1975). Meaning in visual search. *Science*, *187*(4180), 965-966.

955   Reeder, R. R., & Peelen, M. V. (2013). The contents of the attentional template for category-level

956   search in natural scenes. *Journal of Vision*, *13*(3), 13.

957   Reeder, R. R., van Zoest, W., & Peelen, M. V. (2015). Involuntary attentional capture by task-irrelevant

958   objects that match the attentional template for category detection in natural

959   scenes. *Attention, Perception, & Psychophysics*, *77*, 1070-1080.

960   Robbins, A., & Hout, M. C. (2020). Scene priming provides clues about target appearance that improve

961   attentional guidance during categorical search. *Journal of Experimental Psychology: Human*

962   *Perception and Performance*, *46*(2), 220.

963   Schmidt, F., & Haberkamp, A. (2016). Temporal processing characteristics of the Ponzo

964   illusion. *Psychological Research*, *80*, 273-285.

965   Schwarzkopf, D. S., Song, C., & Rees, G. (2011). The surface area of human V1 predicts the subjective

966   experience of object size. *Nature Neuroscience*, *14*(1), 28-30.

967   Sherman, A. M., Greene, M. R., & Wolfe, J. M. (2011). Depth and size information reduce effective set

968   size for visual search in real-world scenes. *Journal of Vision*, *11*(11), 1334-1334.

969   Sperandio, I., & Chouinard, P. A. (2015). The mechanisms of size constancy. *Multisensory*
970   *Research*, *28*(3-4), 253-283.

971   Sperandio, I., Chouinard, P. A., & Goodale, M. A. (2012). Retinotopic activity in V1 reflects the
972   perceived and not the retinal size of an afterimage. *Nature Neuroscience*, *15*(4), 540-542.

973   Spotorno, S., Malcolm, G. L., & Tatler, B. W. (2014). How context information and target information
974   guide the eyes from the first epoch of search in real-world scenes. *Journal of Vision, 14*(2):7.

975   Stein, T., & Peelen, M. V. (2017). Object detection in natural scenes: Independent effects of spatial
976   and category-based attention. *Attention, Perception, & Psychophysics*, *79*, 738-752.

977   Sterzer, P., & Rees, G. (2006). Perceived size matters. *Nature Neuroscience*, *9*(3), 302-302.

978   Thorat, S., & Peelen, M. V. (2022). Body shape as a visual feature: evidence from spatially-global
979   attentional modulation in human visual cortex. *NeuroImage*, *255*, 119207.

980   Thorpe, S., Fize, D., & Marlot, C. (1996). Speed of processing in the human visual
981   system. *Nature*, *381*(6582), 520-522.

982   Torralba, A., Oliva, A., Castelhano, M. S., & Henderson, J. M. (2006). Contextual guidance of eye
983   movements and attention in real-world scenes: the role of global features in object
984   search. *Psychological Review*, *113*(4), 766.

985   Treisman, A. (2006). How the deployment of attention determines what we see. *Visual*
986   *Cognition*, *14*(4-8), 411-443.

987   Williams, L. G. (1966). The effect of target specification on objects fixated during visual search.
988   *Perception & Psychophysics, 1*(5), 315–318.

989   Witkowski, P. P., & Geng, J. J. (2022). Attentional priority is determined by predicted feature
990   distributions. *Journal of Experimental Psychology: Human Perception and Performance,*
991   *48*(11), 1201-1212.

992 Wolfe, J. M. (1994). Guided search 2.0 a revised model of visual search. *Psychonomic Bulletin &*
993   *Review*, *1*, 202-238.

994 Wolfe, J. M. (2021). Guided Search 6.0: An updated model of visual search. *Psychonomic Bulletin &*
995   *Review*, *28*(4), 1060-1092.

996 Wolfe, J. M., Alvarez, G. A., Rosenholtz, R., Kuzmova, Y. I., & Sherman, A. M. (2011). Visual search for
997   arbitrary objects in real scenes. *Attention, Perception, & Psychophysics*, *73*, 1650-1671.

998 Wolfe, J. M., & Horowitz, T. S. (2004). What attributes guide the deployment of visual attention and
999   how do they do it? *Nature Reviews Neuroscience*, *5*(6), 495-501.

1000 Wolfe, J. M., & Horowitz, T. S. (2017). Five factors that guide attention in visual search. *Nature Human*
1001   *Behaviour*, *1*(3), 0058.

1002 Wolfe, J. M., Võ, M. L. H., Evans, K. K., & Greene, M. R. (2011). Visual search in scenes involves selective
1003   and nonselective pathways. *Trends in Cognitive Sciences*, *15*(2), 77-84.

1004 Yu, X., Zhou, Z., Becker, S. I., Boettcher, S. E., & Geng, J. J. (2023). Good-enough attentional
1005   guidance. *Trends in Cognitive Sciences, 27*(4), 391-403.

1006 Zeng, H., Fink, G. R., & Weidner, R. (2020). Visual size processing in early visual cortex follows lateral
1007   occipital cortex involvement. *Journal of Neuroscience*, *40*(22), 4410-4417.

Supplementary Materials

This is the supplement to the study entitled "*Searching near and far: the attentional template incorporate viewing distance*", by Surya Gayet, Sushrut Thorat, Elisa Battistoni, and Marius Peelen.

S.1 Analyses of reaction time data

This supplement comprises the analyses of reaction times for the critical catch trial data (dot-probe task). In the main manuscript, we chose to only report the analyses of accuracy data, because pilot studies revealed that performance differences between our conditions-of-interest expressed themselves through accuracy differences rather than reaction time differences. In this supplement, we provide the complete set of analyses that were applied to the accuracy data in the main manuscript, to the reaction time data. To summarize the results of the analyses reported below: (1) in none of the reported experiments was the pattern of reaction time data opposite to the pattern of accuracy data. This shows that the results obtained for the accuracy data were not the consequence of speed-accuracy trade-offs. At the same time, (2) none of the key findings of the accuracy analyses replicated in the reaction time data. This shows that – at least under the current circumstances – our experimental manipulations consistently influenced response accuracy alone, leaving response speed unaffected.

S1.1 Experiment 1

Akin to the analysis reported in the main manuscript, we tested whether the category-validity effect (faster responses to target dots appearing at the category-valid location than the category-invalid location) would differ between catch trials with size-consistent and size-inconsistent silhouettes.

Following size-consistent silhouettes, participants were faster on category-valid trials (M = 378ms, IQR = 61) than on category-invalid trials (M = 408ms, 58), W = 464, $p < .001$, *rank-biserial correlation* = 1.00 ($p_{bootstrap} < .001$, *95% CI* [25ms, 45ms]). Following size-inconsistent silhouettes as

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1033 well, participants were faster on category-valid trials (M = 386ms, IQR = 68) than on category-invalid

1034 trials (M = 403ms, 49), W = 458, p < .001, *rank-biserial correlation* = .97 ($p_{bootstrap}$ < .001, *95% CI* [23ms,

1035 38ms]). The occurrence of this validity effect shows that the attentional template contained category-

1036 selective information (i.e., distinguishing between car and person targets). Contrary to the effects

1037 observed with accuracy, however, the category-validity effect on reaction times did not differ

1038 between size-consistent and size-inconsistent silhouettes. That is, the interaction effect between

1039 category-validity and size-consistency on response times was not significant, $F(1,29)$ = 1.02, p = .320,

1040 η^2 = .003 ($p_{bootstrap}$ = .303, *95% CI* [-13ms, 4ms]). In sum, the reaction time analysis do not –by

1041 themselves– provide evidence for size-specific attentional templates, but do argue against speed-

1042 accuracy trade-offs as an account of the accuracy-based results described in the main manuscript.

1043

1044 *S1.2 Experiment 2*
1045 To test whether silhouette size influenced response speed, we contrasted response times to target

1046 dots appearing at the location of size-consistent silhouettes with target dots appearing at the location

1047 of size-inconsistent silhouettes. Contrary to the effects observed with accuracy, in Experiment 2A the

1048 size-consistency of the silhouettes did not influence reaction times, p > .7, d_z = 0.068 ($p_{bootstrap}$ = .704,

1049 *95% CI* [-7ms, 5ms]). In Experiment 2B, where the silhouettes were replaced by rectangles, the size-

1050 consistency of the silhouettes did not influence reaction times either, p > .9, d_z = 0.016 ($p_{bootstrap}$ = .949,

1051 *95% CI* [-6ms, 5ms]). An independent-samples t-test contrasting the validity effect of Experiment 2A

1052 (silhouettes) with that of Experiment 2B (rectangles) confirmed that the validity effect did not depend

1053 on silhouette type, p > .8, d_z = 0.059 ($p_{bootstrap}$ = .792, *95% CI* [-7ms, 8ms]). Akin to Experiment 1, the

1054 reaction time analysis do not –by themselves– provide evidence for size-specific attentional

1055 templates, but also argue against the existence of a speed-accuracy trade-off.

1056

S1.3 Experiment 3

1058 Following the approach of Experiment 2, a Wilcoxon signed-rank tests was conducted on catch trial

1059 response times, contrasting (up-down) discrimination speed for target triangles appearing at the

1060 location of size-consistent silhouettes to those appearing at the location of size-inconsistent

1061 silhouettes. The results revealed that size-validity of the silhouettes did not affect reaction times, *p* =

1062 .199, *rank-biserial correlation* = .293 ($p_{bootstrap}$ = .429, *95% CI* [-4ms, 8ms]). Again, the reaction time

1063 analysis do not –by themselves– provide evidence for size-specific attentional templates, but also

1064 argue against the existence of a speed-accuracy trade-off.

1065

S.2 The influence of search distance and target object

1066

1067 In the main manuscript we show that participants have better catch-trial performance when the target

1068 appears at the location of a silhouette that is size-consistent with the search distance (compared to a

1069 size-inconsistent silhouette). In doing so, we only report the overall effect of size-consistency,

1070 collapsed across Search Distance and Target Object conditions. The reason for this is that, within

1071 individual conditions (e.g., near search only), template-matching silhouettes and template-

1072 mismatching silhouettes differ in visual characteristics (e.g., they are small or large), which could affect

1073 catch-trial performance in a stimulus-driven manner. As such, when separating the data into Search

1074 Distance and Target Object conditions, influences of template-based attentional selection (which we

1075 are interested in) cannot be distinguished from stimulus-driven effects. Nonetheless, reporting the

1076 size-consistency effect as a function of search distance and target object can be useful for revealing

1077 such underlying stimulus-driven effects. Therefore, we report in the current supplement to what

1078 extent our key finding depends on the search distance or target object (and thus on the specific

1079 silhouette type; large or small, and car or person). To summarize our findings: the size-consistency

1080 effect did not reliably depend on either search distance or target object, whenever silhouettes

1081 attracted attention in a template-specific manner (Experiments 1, 2A, and 3), but performance was

1082   better at the location of small 'silhouettes' than large 'silhouettes' whenever we did not find template-

1083   specific effects (Experiment 2B).

1084

1085   *S2.1 Experiment 1*

1086   We set out to investigate whether the observed effect of size-consistency on dot-target localization

1087   in Experiment 1 depends on search distance (or silhouette size) or target object (or silhouette shape).

1088   To this end, we conducted a 2x2 Repeated Measures ANOVA on the critical interaction effect (the

1089   difference in the category-validity effect between trials with size-consistent versus size-inconsistent

1090   silhouettes), with the factors Search Distance (near versus far) and Target Object (person versus car).

1091   We found that our key metric of size-consistency did not differ between near search (*M* = 1.4%, *SD* =

1092   5.1) and far search (*M* = 2.7%, *SD* = 6.1), since the main effect of Search Distance was not significant,

1093 $F(1,29) = 0.67$, $p = .420$, $\eta^2 = .006$ ($p_{bootstrap} = .417$, *95% CI* [-1.8, 4.4]). Similarly, size-consistency did not

1094   differ between person search (*M* = 1.1%, *SD* = 6.4) and car search (*M* = 3.0%, *SD* = 6.6), since the main

1095   effect of Target Object was not significant either, $F(1,29) = 0.86$, $p = .361$, $\eta^2 = .012$ ($p_{bootstrap} = .355$,

1096   *95% CI* [-2.0, 5.7]). In sum, we found no evidence that the specific search task (near versus far, or car

1097   versus object) or the specific silhouette type (large versus small, or car versus silhouette) affected the

1098   observed effect of size-consistency on dot-target localization accuracy.

1099

1100   *S2.2 Experiment 2*

1101   Next, we tested whether the observed effect of size-consistency on dot-target localization in

1102   Experiment 2A depended on search distance (or silhouette size) or target object (or silhouette shape).

1103   To this end, we conducted a 2x2 Repeated Measures ANOVA on the size-validity effect (the difference

1104   in performance between target-dots appearing at the location of the size-consistent versus the size-

1105   inconsistent silhouette), with the factors Search Distance (near versus far) and Target Object (person

1106   versus car). Akin to Experiment 1, we found that the size-validity effect did not differ between near

1107   search (*M* = -0.8%, *SD* = 12.9) and far search (*M* = 4.7%, *SD* = 13.3), since the main effect of Search

1108   Distance was not significant, $F(1,25) = 1.28$, $p = .269$, $\eta^2 = .023$ ($p_{\text{bootstrap}} = .249$, *95% CI* [-3.7, 15.1]).

1109   Similarly, the size-validity effect did not differ systematically between person search ($M = 1.6\%$, $SD =$

1110   6.3) and car search ($M = 2.3\%$, $SD = 6.4$), since the main effect of Target Object was not significant

1111   either, $F(1,25) = 0.13$, $p = .718$, $\eta^2 < .001$ ($p_{\text{bootstrap}} = .712$, *95% CI* [-3.2, 4.3]). Similar to Experiment 1,

1112   we found no evidence that the specific search task (near versus far, or car versus object) or the specific

1113   silhouette type (large versus small, or car versus silhouette) affected the observed effect of size-

1114   consistency on dot-target localization accuracy.

1115   In Experiment 2B, we used rectangles instead of car and shape silhouettes, and did not

1116   observe a size-validity effect. In this case, the size-validity effect was negative during near search (M

1117 $= -5.8\%$, $SD = 6.8$) and positive during far search ($M = 5.4\%$, $SD = 7.3$), which reflects that performance

1118   was higher when the target-dot appeared at the location of the small rather than large rectangles.

1119   This was supported by a main effect of Search Distance, $F(1,25) = 20.17$, $p < .001$, $\eta^2 = .278$ ($p_{\text{bootstrap}} <$

1120   .001, *95% CI* [6.7 16.2]). The size-validity effect did not differ systematically between person search

1121   ($M = 0.1\%$, $SD = 5.0$) and car search ($M = 0.5\%$, $SD = 4.6$), since the main effect of Target Object was

1122   not significant, $F(1,25) = 0.17$, $p = .682$, $\eta^2 < .001$ ($p_{\text{bootstrap}} = .966$, *95% CI* [-1.7, 2.0]). Thus, in this

1123   experiment where no overall size-validity effect was observed (template-matching silhouettes did not

1124   attract attention), we found that search distance strongly modulated the size-validity effect, reflecting

1125   that attention was attracted toward small rather than large rectangles.

1126   Together these analyses of Search Distance in Experiments 2A and 2B may suggest that

1127   attentional templates can override bottom-up stimulus salience in guiding attention toward target-

1128   like visual input. This interpretation should be made with caution, however, because a mixed ANOVA

1129   comparing the effect of search distance between the two experiments showed that the effect of

1130   Search Distance on the size-validity effect did not depend significantly on the silhouette type (Exp 2A

1131   vs 2B), $p > .2$.

1132   The observation that Search Distance (or more precisely: rectangle size) substantially affects

1133   catch-trial performance in Experiment 2B (but not in 2A), also argues against the existence of a ceiling

1134   effect in Experiment 2B. Thus the absence of a size-consistency effect between silhouettes and search

1135   distance in Experiment 2B (which is found in Experiment 2A) is unlikely to be caused by the overall

1136   higher accuracies in 2B.

1137

1138   *S2.3 Experiment 3*

1139   Finally, we tested whether the effect of size-consistency on orientation discrimination of the triangle

1140   target, observed in Experiment 3, depended on search distance (or silhouette size) or target object (or

1141   silhouette shape). To this end, we conducted a 2x2 Repeated Measures ANOVA on the size-validity

1142   effect (the difference in orientation discrimination performance between triangles appearing on the

1143   location of the size-consistent versus the size-inconsistent silhouette), with the factors Search

1144   Distance (near versus far) and Target Object (person versus car). Akin to Experiment 1 and 2, we found

1145   that the validity effect did not differ between near search (*M* = 0.3%, *SD* = 6.0) and far search (*M* =

1146   2.6%, *SD* = 5.8), since the main effect of Search Distance was not significant, $F(1,25) = 1.36$, $p = .255$,

1147 $\eta^2 = .028$ ($p_{bootstrap} = .240$, *95% CI* [-1.4, 6.1]). Similarly, size-consistency did not differ systematically

1148   between person (*M* = 1.5%, *SD* = 4.9) and car search (*M* = 1.5%, *SD* = 4.4), since the main effect of

1149   Target Object was not significant either, $F(1,25) < 0.01$, $p = .977$, $\eta^2 < .001$ ($p_{bootstrap} > .999$, *95% CI* [-

1150   2.0, 2.5]). Similar to Experiments 1 and 2A, we found no evidence that the specific search task (near

1151   versus far, or car versus object) or the specific silhouette type (large versus small, or car versus

1152   silhouette) affected the observed effect of size-consistency on catch-trial performance.