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ABSTRACT

In complex stimuli, there are many different possible ways to refer to a specified target. Previous studies have shown that when people are faced with such a task, the content of their referring expression reflects visual properties such as size, salience and clutter. Here, we extend these findings and present evidence that (i) the influence of visual perception on sentence construction goes beyond content selection and in part determines the order in which different objects are mentioned and (ii) order of mention influences comprehension. Study 1 (a corpus study of reference productions) shows that when a speaker uses a relational description to mention a salient object, that object is treated as being in the common ground and is more likely to be mentioned first. Study 2 (a visual search study) asks participants to listen to referring expressions and find the specified target; in keeping with the above result, we find that search for easy-to-find targets is faster when the target is mentioned first, while search for harder-to-find targets is facilitated by mentioning the target later, after a landmark in a relational description. Our findings show that seemingly low-level and disparate mental "modules" like perception and sentence planning interact at a high level and in task-dependent ways.

Keywords: Referring expressions; visual search; visual salience;

1 INTRODUCTION

When referring to an entity (the *target*) in a visual scene, speakers often describe it relative to some nearby *landmark*: "the woman next to the stairs". Previous research demonstrates that speakers choose these landmarks with reference to the visual properties of the scene, and in particular that they prefer those that are larger and easier to see (Kelleher et al., 2005; Duckham et al., 2010; Clarke et al., 2013). Much less is known about how these perceptual effects extend to the information-structural ordering of elements in a description. Although alternative orders are available ("next to the stairs is a woman"), most existing models of reference do not address the production format question: how speakers choose to package the

26 content of a referring expression when it includes both a target and one or more disambiguating landmarks.
27 In this work, we demonstrate via a corpus study of reference productions that visual perception influences
28 the order chosen: larger and more visually salient landmarks are more likely to precede the target. The
29 results from a subsequent comprehension study using a visual search task show that this pattern of ordering
30 also helps the listener to find the target faster. The production and comprehension results indicate that
31 dialogue participants' perceptions of the scene have far-reaching effects on both referring expression
32 generation (REG) and understanding. Visual perception is not confined to providing inputs to a content
33 selection mechanism, as in many popular models, but also contributes toward high-level decisions about
34 the expression's structure.

35   Theories which acknowledge a role for perception in ordering the description do so in two ways. In
36 least-effort theories, speakers compose references using cognitively inexpensive heuristics (Beun and
37 Cremers, 1998). In particular, speakers order large objects first because they see them earliest. Such an
38 approach is in line with egocentric models of production in which speakers use what they are familiar with
39 to estimate what objects may be visible and shared (Horton and Keysar, 1996). Neo-Gricean theories, on
40 the other hand, treat ordering preferences as an example of *audience design*, in which speakers construct
41 referring expressions which will help their listeners find the target quickly and easily. Thus, one critical
42 prediction of the neo-Gricean approach is that such speaker behavior is actually helpful for listeners.

43   Our visual search study shows that this is in fact the case: listeners find the target object faster when
44 a highly salient landmark is referred to earlier rather than later, and when a difficult-to-see landmark is
45 referred to later rather than earlier. Thus, neo-Gricean theories remain a viable explanation for the ordering
46 preference. In particular, the pattern fits neatly into more general theories of *information structure* which
47 state that given (familiar) information typically precedes new information in the sentence (Prince, 1981;
48 Ward and Birner, 2001). Although many researchers have stated that perceptually salient entities can
49 be treated as familiar by discourse participants (Ariel, 1988; Roberts, 2003), few have given a detailed
50 account of the kinds of perceptual factors which contribute. Cognitive semantics defines partitions in
51 cognitive semantics between figure and ground (Talmy, 1978): Figures are elements that are smaller or less
52 immediately perceivable (visual salience) and of greater concern or relevance (task salience), while Ground
53 is likely to be larger, more immediately perceivable, and more familiar. Although the work on figure and
54 ground indicates how elements in complex descriptions relate, it does not specify which orderings are
55 preferred in production or comprehension. Here we show, in line with prior work on information structure
56 and the on distinction between figure and ground, that computational models of visual salience correctly
57 predict which objects speakers are likely to place earlier in their descriptions. Furthermore, listeners are
58 found to be sensitive to order of mention, showing facilitation when a target that is easy to find is mentioned
59 first and also when a hard-to-find target is preceded by a mention of a more salient easy-to-find landmark.

60   Earlier studies evaluating automatically generated referring expressions have shown that the most human-
61 like ones are not always the most helpful for listeners (Belz and Gatt, 2008), suggesting that at least
62 some tendencies in human REG do not involve clear estimates of listener needs. Our results imply that
63 information structural patterns are not among them, and on the contrary may even be the product of
64 deliberate optimization. Moreover, although systems for automatic REG have given little attention to
65 ordering in the past, our results suggest that the use of perceptual data may lead to both more human-like
66 references and better performance.

2 MOTIVATION

Humans are highly proficient at referring expression generation (REG), and human-like performance is often taken as a goal for automatic REG systems (Viethen and Dale, 2006). But more human-like referring expressions are not necessarily more helpful ones. Large individual differences are often found in RE production, and it is reasonable to expect that some speakers will be better at giving good instructions than others. Belz and Gatt (2008) compare task-based evaluations (search time and accuracy) to intrinsic ones (string similarity to human models) on computationally generated referring expressions from the ASGRE challenge (Belz and Gatt, 2007) and find no correlation between the two. While this experiment involved simple domains (furniture and people, identified by discrete-valued attributes), it stands as a warning that not all human behavior in REG should be interpreted as facilitating visual search. Thus, the question of ordering preferences for relative descriptions is really two questions: how speakers actually behave, and how they should normatively behave to facilitate visual search for listeners.

REG models which use relative descriptions are often separated into those focused on *identifying* a target object among distractors and those *locating* it in space (Barclay, 2010). We view both of these as strategies for accomplishing the higher-level goal of placing an unknown but visible entity into *common ground* (Clark and Wilkes-Gibbs, 1986), the set of entities which each participant knows is familiar to the other. However, the properties of the domain and task constraints may affect which of these strategies is most appropriate, and therefore what sort of behavior experimenters observe.

In relatively small domains where targets are easy to spot, the primary focus is on identification. When human speakers generate relative descriptions for easy-to-see targets, they mention the landmark after the target, as in the GRE3D7 corpus Viethen and Dale (2011), which was specifically set up to elicit relative descriptions using small 3-dimensional images of geometric objects. Models of REG in these kinds of domains (surveyed in Krahmer and van Deemter (2012)) do not emphasize ordering strategies or the need to make syntactic decisions during the planning phase.

Models for visually complex domains such as direction-giving (Barclay, 2010; Gkatzia et al., 2015) must both disambiguate and locate the target. Even when the target is unambiguous, it may still be necessary to use disambiguating descriptions for landmarks (Barclay, 2010). Studies in this kind of domain have followed Talmy (1983) in finding that large, relatively stationary "background" objects make good landmarks for locating an entity rather than simply disambiguating it. For the most part, however, these studies have also focused on what is said (the choice of landmarks and prepositions) rather than the order of mention and the syntactic strategies used to achieve it.

This study extends an earlier one, Elsner et al. (2014), which does look for ordering preferences in human-authored relative descriptions. That study found that larger objects were more likely to be ordered earlier in the description. However, there was no effect on order of mention from a low-level visual salience model, raising potential doubts about whether ordering preferences are truly driven by visual salience. The lack of effect for salience could potentially be due to poor performane of the computational visual salience models: many different salience models have been developed over the last 15 years and there is no agreed on standard, or even a strict defintion of what is meant by low-level salience! Furthermore, our stimuli consisted of cluttered cartoon images which may be problomatic for models trained on photographs of natural scenes. In this study, we re-analyze the same data with a more sophisticated salience model and obtain an improved fit to the data, suggesting that the hypothesised effect of low-level salience is real. Duan et al. (2013), studying the same corpus, find visual effects on determiner selection, and similarly conclude

that perception has an impact on late stages of the generation pipeline. These studies focus on generation, leaving open the question of whether the effects they observed were useful to listeners or not.

The question of which speaker behaviors help listeners is tightly connected to the question of whether speakers actively reason about their audience to *try* to help them, a process called *audience design*. Experimental evidence for audience design is widespread. Speakers overspecify descriptions more when they believe the task is important (for example, instructing a surgeon on which tool to use) (Arts et al., 2011). They can keep track of which objects they've discussed with a particular listener (Horton and Gerrig, 2002). And they are more likely to tell listeners about an atypical element of an illustrated action ("stabbed with an icepick" vs "a knife") when they know listeners can't see the illustration (Lockridge and Brennan, 2002). Audience design is widely accepted as a theoretical assumption underlying neo-Gricean models of reference (Frank and Goodman, 2012; Vogel et al., 2013) and experiments with language games (Degen and Franke, 2012; Rohde et al., 2012). But despite speakers' capabilities for design, not all speaker behavior is audience-driven. Speakers also try to minimize their own effort by mentioning objects and attributes in the order they see them (Pechmann, 1989), avoiding cognitively expensive scanning of irrelevant parts of the scene (Beun and Cremers, 1998), and using their own private knowledge as a proxy for common ground (Horton and Keysar, 1996). Strategies like these make the speaker's task easier, but these savings potentially come at the listener's expense.

Both models offer potential explanations for order-of-mention effects. Pechmann (1989) describes speakers' use of non-canonical adjective orders ("red big") for visual scenes and argues that such orderings result from an incremental sentence planning strategy (speakers initially perceive the target object's color and only later establish its size relative to other objects in the scene).

Accounts of ordering preferences in non-visual settings usually attribute them to audience design in the form of information-structural principles. Prince (1981) distinguishes between entities which are new to the discourse and those which have previously been mentioned. The first element in an English sentence is generally reserved for old information (already in common ground), while new information is placed at the end (Ward and Birner, 2001, *inter alia*). A variety of non-canonical syntactic constructions, such as *there*-insertion, are analyzed as strategies for enforcing these structural principles. In particular, Maienborn (2001) states that sentence-initial locatives can be *frame-setting* modifiers, which are a type of sentence topic explaining in what context the remaining information is to be interpreted. Information-structural ordering principles can be said to be driven by audience design, since understanding what information is in common ground requires reasoning about the listener. In particular, objects which are clearly perceptually accessible to the listener are treated as familiar (Roberts, 2003).

Thus, the ordering preferences examined here could arise from either mechanism. In an effort-minimization model, speakers talk earlier about large objects because they notice them first. In an audience-design model, speakers talk earlier about large objects because they believe their listeners will notice them first. Thus, either model predicts that **more visually salient objects are placed early in the sentence**. Our first contribution is to verify that this prediction is in fact true.

The two models differ in their predictions about listener behavior. If the ordering effect is due to effort minimization, it may or may not be helpful for listeners. If it is due to audience design, then (assuming speakers who try to be helpful actually are so), it should facilitate listeners' visual search for the target. Thus, **if this ordering principle does not facilitate visual search, it cannot be an audience design effect**. Our second contribution is to show that it does in fact facilitate visual search.

3   CORPUS STUDY

150 In this section, we test whether speakers prefer to place visually salient landmarks earlier in their referring
151 expressions. The study expands upon Elsner et al. (2014), which used the same corpus of referring
152 expressions, by adding better models of low-level visual salience in order to demonstrate that the effect is
153 actually salience-driven, and includes an additional feature that encodes whether the landmark is spatially
154 located to the left or right of the target in the scene. The procedures for using mixed-effects linear models
155 have also been altered slightly in line with recommendations by Barr et al. (2013).

156   A relative description of an object has two elements: the *anchor* (the object to be located) and the
157 *landmark* (mentioned only as an aid). Typically the anchor is the *target* of the expression overall, but some
158 REs nest relative descriptions— "the woman next to the man next to the building"— in which case "man"
159 is the landmark relative to "woman" but the anchor relative to "building".
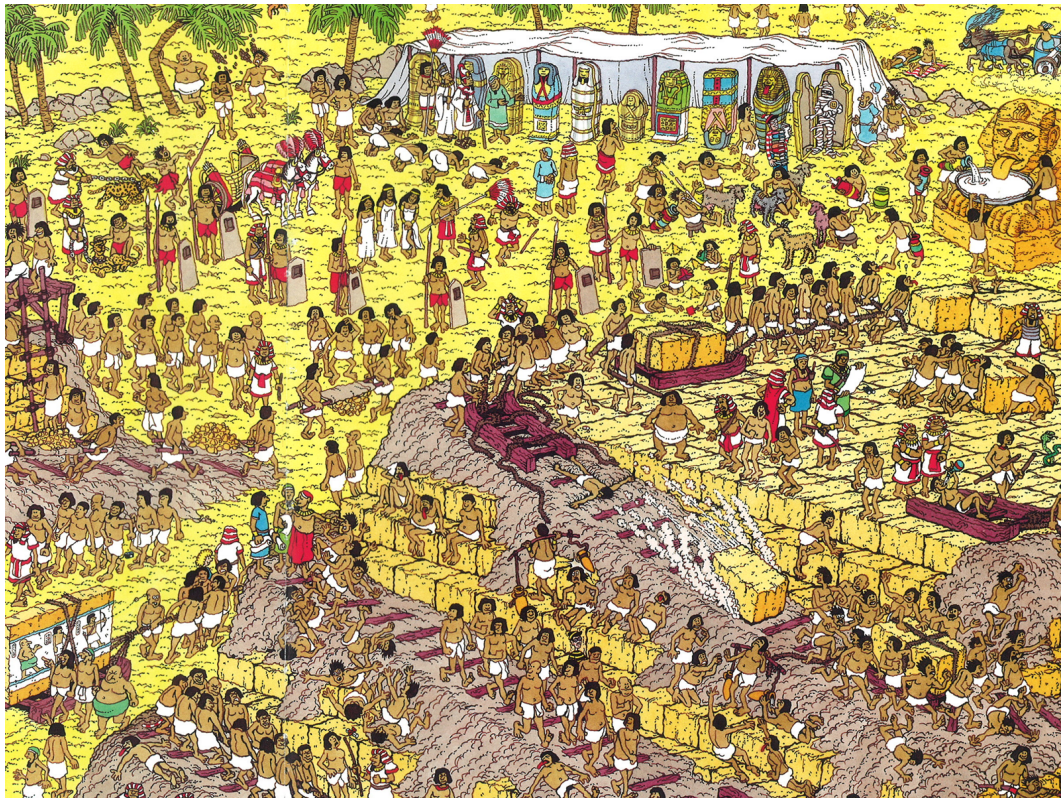

Figure 1. Example stimulus used in the production and comprehension studies. In production, participants had to identify a designated target. In comprehension, the four referring expressions for this trial were (i) "at the upper right, the sphinx" [landmark only]; (ii) "at the upper right, the man holding the red vase with a stripe" [target only]; (iii) "at the upper right, the man holding the red vase with a stripe to the left of the sphinx" [landmark follows target]; (iv) "at the upper right, to the left of the sphinx, the man holding the red vase with a stripe on it" [landmark precedes target].

160   In a complex image like the scenes in Where's Wally (see Figure 1), there are many ways to describe
161 a particular entity. We distinguish four strategies for ordering the landmark relative to the anchor, which
162 we illustrate with examples from our corpus (all referring to targets in Figure 1), with text describing the
163 landmark in *italics* and text describing the anchor (in these cases also the target) in **bold**:

164 • PRECEDE: Directly in front of *the crypt that is green* there is **a man with no shirt and a white wrap**
165   **on**.

166 • PRECEDE-ESTABLISH: Find *the sphinx (half man half lion)*. To the left of *it* is **a guy holding a red**
167   **vase with a stripe on it**.

168 • INTERLEAVED: Near the bottom right, **a man walking** beside *the rock* **with his right foot forward**.

169 • FOLLOW: **The man in a white loincloth** at the upper left of the picture **standing** next to *a bald man*.

170 These ordering strategies[1] are distinguished based on the surface order of first mentions in the text. In
171 the PRECEDE strategy, the first mention of the landmark occurs before any mention of the anchor. In the
172 PRECEDE-ESTABLISH strategy, the landmark is first mentioned in its own clause, without a relation to the
173 anchor (typically using "there is", "look" or "find"), and related to the anchor later. In the INTERLEAVED
174 strategy, the anchor is described first, then the landmark, and then the anchor again. In the FOLLOW strategy,
175 the anchor is mentioned first, then the landmark.

3.1 Dataset and annotation

177 We analyze a collection of referring expressions for target people in images taken from the Where's Wally
178 childrens picture books (Handford, 1987, 1988, 1993). The dataset[2] was originally collected by Clarke
179 et al. (2013) in a study showing the effects of perceptual features (clutter and salience) on the selection of
180 landmarks in REs. Mechanical Turk was used to collect the data using a task in which participants were
181 asked to produce descriptions for targets over 11 images. In each image, 16 cartoon people were designated
182 as targets and each participant saw each scene only once, with one of the targets designated with a colored
183 box, as shown in Figure 1. The participant was instructed to type a description of the person in the box so
184 that another person viewing the same scene (but without the box) would be able to find them.

185 The text of the instructions is shown in Figure 2. It asks participants to both identify and locate the target
186 object (and as such is conceptually similar to the "please, pick up the X" frame used in (Viethen and Dale,
187 2011)).

> You will see a series of pictures (30 in total). In each picture, there will be one person who is marked with a superimposed circle. Your task is to write a description of that person, such that someone else reading your description and seeing the same picture without the superimposed circle would be able to identify which person you intended.
> - Your description should make it possible to identify the intended person quickly and easily.
> - Give as much or as little detail as you think will help.
> - Treat each picture as a separate item.

Figure 2. Instructions for the picture description task in (Clarke et al., 2013).

188 Participants were trained on what makes a good referring expression in this domain by carrying out two
189 visual searches based on different descriptions. The dataset contains 1672 descriptions, contributed by 152
190 different participants.

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[1] There are also 6 examples of ESTABLISH constructions without the PRECEDE order, which we discard from further analysis.

[2] Released as the Wally Referring Expressions Corpus (WREC): http://datashare.is.ed.ac.uk/handle/10283/337.

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191   The REs are annotated for visual and linguistic content. The annotation scheme indicates which substrings
192 of the RE describe the target object, another mentioned object or an image region such as "the left of the
193 picture". References to parts or attributes of objects are not treated as separate objects; "a man holding a
194 red vase" in Figure 1 is a single object. The mentioned objects are linked to bounding boxes (or for very
195 large objects, bounding polygons) in the image. For each mention of a non-target object, the annotation
196 indicates whether it is part of a relational description of a specific anchor, and if so which; if it is not, it
197 receives an ESTABLISH tag. These annotations are used to determine the ordering strategies used in this
198 study. In some cases, the linkage between objects is implicit:

199   • *. . . a group of 11 slaves is following* a slavemaster from left to right across the image. Choose **the third**
200   **slave in line (the second bald slave)** [=of the 11 slaves]

201   In the RE above, the "group of 11 slaves" is introduced with an ESTABLISH construction, since in that
202 clause, the group is not used as a landmark to locate another object. The group is later used as a landmark
203 (implicitly, via the expression "third slave"). Since the first mention of the group precedes the anchor "third
204 slave", this is marked PRECEDE, and therefore falls into the PRECEDE-ESTABLISH pattern.

205 **3.2   Distribution of ordering strategies**

206   Our analysis covers each pair of anchor and landmark mentioned in the corpus (often more than one
207 per description). In all, there are 3290 such pairs in the dataset. As shown in the first row of Table 1, the
208 PRECEDE strategies, in aggregate, slightly outnumber the FOLLOW strategy; this is due to the overwhelming
209 preference for image regions ("the left") to precede their anchors. The INTERLEAVED ordering is less
210 common, but still quite well-represented.

211   To verify that this distribution does not simply reflect different participants' differing interpretations of
212 the task description (so that some participants focused only on *identifying* targets while others focused
213 only on *locating* them), we analyze the distribution of strategies within subject. We examine the strategies
214 chosen for all pairs consisting of a target and non-image-region landmark. All but 3 of 152 participants
215 use more than one strategy, and the median number of strategies used is 3 (of the 4 total). This shows
216 that subjects selected strategies in a scene- and target-dependent way, and thus variation does not reflect
217 differences across participants in their interpretation of the task.

218   We conduct four one-vs-all regression analyses to analyze which factors predict the choice of each order.
219 The factors selected for analysis include measurements of visual salience (the **area** of the anchor and
220 landmark bounding boxes, their **distance to screen center (centr.)** (calculated to the centre of the object's
221 bounding box), and a **low-level salience score indicating pixel dissimilarity from the background**.
222 These properties are known to make objects more visually salient and easier to find (Wolfe, 2012), and to
223 increase their chances of being chosen as landmarks (Golland et al., 2010; Kelleher et al., 2005; Clarke
224 et al., 2013). We also include visual factors for the **distance** between the two objects, and for the **signed**
225 **left-right distance** (in case the string ordering is affected by which object appears further left in the image).
226 We also include the **number of dependents** (landmarks mentioned relative to the object in the description)
227 as a linguistic factor. Large numbers of dependents tend to lead to a "heavier" phrase which is more
228 likely to need its own clause, or to shift to the end of a sentence (White and Rajkumar, 2012). Finally, we
229 include some task-based factors: whether the anchor is the overall **target** of the expression and whether the
230 landmark is an object or an **image region**.

231   The low-level salience score used in this study is a computational measurement of how visually distinctive
232 the object is, based on a comparison of its visual features with the rest of the image. The score used here

differs from the Torralba et al. (2006) score used in Elsner et al. (2014), which was not found to be a significant predictor of ordering strategy. In this study, we compute an improved score by reanalyzing the Wally images with five low-level salience models, creating five salience maps for each image. The salience models used were: Achanta (Achanta et al., 2009), AIM (Bruce and Tsotsos, 2007), AWS (Garcia-Diaz et al., 2012), CovSal (Erdem and Erdem, 2013), RCS (Vikram et al., 2012) and SIG (Hou et al., 2012). Images were preprocessed by downsampling by a factor of four. For each salience map, we compute the mean salience within every labeled bounding box in the image. Since the output of the salience models is highly correlated, we then perform PCA (Principal Components Analysis) on the scaled matrix of salience measurements and take the first principal component of the transformed data as a cross-model consensus salience score.

We transform area to square root area and log-transform distance (between objects) and centrality (distance from object to centre of image) values. Centrality values are negated, so that higher numbers indicate more central objects. We then scale all continuous factors to zero mean and unit variance and deviation-code binary factors as -.5, .5. We fit a binomial generalized linear model of the data, using uncorrelated random slopes and intercepts for speaker and item (Barr et al., 2013) using LME4 Bates et al. (2011).[3] No interaction terms were included. Models for PRECEDE and FOLLOW converged using the default optimization settings. Models for PRECEDE-EST and INTER failed to converge with these settings. For these analyses, image regions were discarded from the dataset (since regions essentially always PRECEDE and never use these strategies); the coefficient for this effect is indicated as $-\infty$. Then the effects with the smallest coefficients were removed until convergence; these coefficients are shown as X. Significance of factor main effects was tested using ANOVA to compare a model including all factors and a model leaving out the factor of interest.[4]

Table 1. One-versus-all regression effects predicting order of anchor and landmark in relative descriptions

	PRECEDE	PRECEDE-EST	INTER	FOLLOW
% (n) instances	28% (918)	15% (493)	24% (797)	33% (1081)
intercept	2.64	-3.38	-2.44	-5.26
anch area	-0.42**	-0.21	-0.22**	0.40**
anch centr	0.16*	X	X	-0.13
anch deps	-0.19	-0.77**	0.26**	0.11
anch=targ	0.16	-0.32	0.84**	-0.80**
anch sal	-0.09	0.00	0.00	0.05
distance	0.02	X	X	0.03
sign. lr. dist.	-0.01	X	X	0.01
lmk=reg	15.68**	$-\infty$	$-\infty$	-16.42**
lmk area	3.97**	-0.67	1.53**	-4.48**
lmk centr	-1.12**	-1.03	-0.03	1.37**
lmk deps	0.07	1.31**	-0.57**	-0.75**
lmk sal	0.22**	0.13	-0.07	-0.17*

Results of the regression analysis appear in Table 1. The largest effects are those relating to image regions, which overwhelmingly occur in the PRECEDE order (15.68 PRECEDE versus -16.42 FOLLOW). Area of the landmark also has a substantial effect; larger objects tend to PRECEDE (3.97) and INTERLEAVE (1.53)

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[3] In LME4, the model is specified as $follow \sim area + (0 + area|speaker) + (0 + area|image) + \ldots + (1|speaker) + (1|image)$.

[4] P-values are presented without the Bonferroni correction for multiple comparisons. A set of 52 comparisons at the .05 level includes about 3 type II errors on average.

258 while smaller ones FOLLOW (-4.48). Objects with many dependents ("heavy" phrases) occur more often in
259 PRECEDE-ESTABLISH constructions (1.31) and less often in INTERLEAVE and FOLLOW (-.057, -.075).

260 Smaller, but still significant, effects include anchor area; larger anchors are less likely to be PRECEDED
261 by landmarks (-0.42) and more likely to be FOLLOWED (0.40). The target is more likely to INTERLEAVE
262 around a landmark (.84). Finally, the low-level salience score has slight effects for landmarks, but not for
263 anchors: more visually distinctive landmarks are more likely to PRECEDE their anchors (0.22) and less
264 likely to FOLLOW them.

265 No significant effect is found for either distance measurement.

3.3 Analysis

267 The strong effects of anchor and landmark area support the hypothesis that more visually salient objects
268 are considered part of common ground and that speakers place them earlier in their descriptions. The
269 effects of the low-level salience score, though weak, point in the same direction. The effects of centrality
270 are counterintuitive (more central landmarks are less likely to PRECEDE). This pattern is difficult to explain,
271 since increasing centrality normally makes objects more salient (Judd et al., 2012). We speculate that the
272 effect might be due to the frequent use of region descriptors like "at the top right" to restrict attention to
273 off-centered areas of the image.

274 While the low-level salience score has a significant effect, its contributions are minor. This may indicate
275 that area, rather than overall visual salience, is indeed the major contributing factor for ordering. But this
276 explanation fits poorly with both visual and linguistic theories, since it posits a special-case visual process
277 and an exception to our usual understanding of how objects enter common ground. A better explanation
278 is probably that computational salience modeling simply does not capture all the complex factors which
279 make up visual distinctiveness in a domain like Where's Wally. Clarke and Keller (2014) show that many
280 popular low-level salience models fail to account for viewer perceptions even in simple contrived stimuli.
281 Thus, the composite score used in this analysis is likely capturing only some of the visual distinctiveness of
282 objects in the scene.

283 The primary motivation for the PRECEDE-ESTABLISH construction appears to be linguistic; it occurs
284 when the landmark itself has many dependent sub-landmarks and thus requires its own clause. It is less
285 likely to be chosen if the anchor is large and easily spotted on its own (in which case the preferred order
286 is FOLLOW). But it is also not as often selected for large landmarks (which don't require dependent
287 sub-landmarks or their own clause). These findings are in accord with Ward and Birner (1995), who state
288 that objects introduced by existential "there is" should be new to the discourse. The ESTABLISH strategy is
289 a way of putting these important but hard-to-see landmarks on the left of the clause without marking them
290 as common-ground information.

4 PERCEPTION STUDY

291 If speakers prefer to use the PRECEDE order for easier to find (larger and more salient) landmarks versus
292 the FOLLOW order for harder to find (smaller and less salient) ones, do these tendencies help listeners
293 to find the target objects quickly? We conduct a visual search experiment using the Wally images and
294 controlled linguistic stimuli to evaluate this hypothesis. Since area, centrality and low-level distinctiveness
295 models gave equivocal results as proxies for visual salience in the previous section, in this experiment,
296 we measure visual salience more directly. We use target-only and landmark-only visual search tasks as

297 indicators of how easy each object is to see on its own, and analyze the relative descriptions in the context
298 of these scores for their components.

4.1 Stimuli

300 Stimuli consist of a Where's Wally image paired with a referring expression. There are four conditions,
301 illustrated with examples referring to Figure 1. We selected a single target and landmark in each image, so
302 that the objects and attribute-based descriptions used in the TARGET and LANDMARK stimuli for a given
303 scene also feature in the LANDMARK PRECEDES and LANDMARK FOLLOWS stimuli:

304 • TARGET: At the upper right, **the man holding the red vase with a stripe**.

305 • LANDMARK: At the upper right, *the sphinx*.

306 • LANDMARK PRECEDES: At the upper right, to the left of *the sphinx*, **the man holding the red vase
307 with a stripe on it**.

308 • LANDMARK FOLLOWS: At the upper right, **the man holding the red vase with a stripe** to the left of
309 *the sphinx*.

310 The targets and landmarks are chosen to represent a range of relative size and perceived visual salience
311 values, and to be approximately balanced across regions of the screen. In each case, the target person is one
312 of the people used as targets in Clarke et al. (2013); when possible, the landmark is also one mentioned
313 by speakers in the corpus, although in a few cases this was not possible since speakers did not mention
314 a landmark of the desired size. Descriptions of targets and landmarks contained enough attributes to
315 make them unambiguous in isolation (so that a relative description was an overspecification, not the only
316 disambiguating detail).

317 All stimuli were read by a British English speaker. Recordings in the *landmark* condition are the fastest
318 (mean length 2.6 seconds) followed by the *target* condition (3.0 sec). The relative description cases are
319 longer and therefore slower; when the landmark precedes, the mean length is 4.4 seconds while when it
320 follows, the mean length is 4.2.

4.2 Experimental procedures

322 The experiment was conducted in the Eye Movements and Attention laboratory at the University of
323 Aberdeen. Experimental scripts were created and run using MatLab and run on a PowerMac. Stimuli
324 were presented on a 61cm Sony Trimaster EL computer screen, 1080 x 1920 computer screen. Participant
325 responses were recorded using an Apple keyboard and mouse. An EyeLink 1000 was used to conduct
326 eye-tracking, although eye-movements are not analysed here. The protocol for each of the experiments was
327 reviewed and approved by the Psychology Ethics Committee at the University of Aberdeen.

328 Thirty-two participants (median age 23, range = 19 - 42 years old, 21 females) took part in the study.
329 Participants were recruited from the population of students and other members of the academic community
330 at the University of Aberdeen. All participants had normal or corrected-to-normal vision and were native
331 English speakers. The experiment was conducted with the full understanding and signed consent of each
332 participant. Participants were remunerated £5-10 for their time, depending on the number of experiments
333 they had taken part in.

334 Immediately following image onset, an audio recording of the search instruction was played to participants
335 over headphones, giving them the necessary information required to find the target. Participants pressed the
336 space bar on the keyboard when they had found the specified target. They were then required to use the

337 mouse to click on the target. This was done so that we had a record of search accuracy and participants
338 were not able to just press space without finding the target. Reaction time was recorded as the time from
339 image onset to when the space bar had been pressed. There was no requirment for the participant to listen
340 to the whole referring expression.

341 ## 4.3 Outliers

342 The complete dataset consists of 896 trials (32×28). We filter the reaction time data from the perception
343 study by discarding instances where the listener failed to find the target, or incorrectly signalled success
344 before actually finding it. A single participant was discarded for excessively long reaction times. All trials
345 for which the reaction time recorded was less than .5 sec or greater than 10 sec were discarded, as were
346 trials for which the time between the keypress signalling successful detection and the click to indicate the
347 found item was greater than 5 sec. These filters exclude 186 trials after which 669 remain. A software error
348 prevented measurement of the click location for 56 trials, so we have accuracy information for only 613 of
349 these.

350 ## 4.4 Results

351 Overall, participants reacted faster to the non-relative expressions (median 3.9 seconds for targets and
352 3.7 for landmarks) than the relative ones (4.6 seconds for target-first REs and 4.9 for landmark-first REs).
353 These times are approximately a second longer than the stimuli, and indicate that our visual search task
354 was reasonably easy, especially given the cluttered nature of the scenes. In particular, the short search
355 times for target-only expressions demonstrate that the relative descriptions were truly overspecified, since
356 participants could find the targets without them. As usual in complex visual search tasks, standard deviations
357 are substantial (between 1.0 and 1.3 for all cases).

358 Our analysis focuses on comparisons between the two orders for relative REs (PRECEDE and FOLLOW).
359 We hypothesize that, when the target is easier to find than the landmark, search is facilitated by landmark
360 FOLLOWING the target, while when the landmark is easier, search is facilitated by the landmark PRECEDING.
361 We separate the stimuli into three categories, "target-easier", "target-harder" and "both-similar", based on
362 the empirical reaction times for the target-only and landmark-only cases. For each image, we compute:

$$Z(median(rt_{targ-only}) - median(rt_{lmark-only})) \qquad (1)$$

363 This is a Z-transformed score of how much easier it is for participants to find the target than the landmark.
364 We select the bottom third (9 instances) as "target-easier", the middle third (9 instances) as "both-similar",
365 and the upper third (10 instances) as "target-harder".

366 Figure 3 shows a plot of reaction time as a function of referring expression order within each group.
367 Median RTs are lower for the landmark FOLLOW order in the "both-similar" and "target-easier" groups and
368 higher in the "target-harder" group. The overall median RT for the relative referring expressions is 4.7 sec.
369 In the "target-easier" group, the median for FOLLOW expressions is 4.3 while for PRECEDE expressions
370 it is 4.9. For the "target-harder" group, the median for FOLLOW expressions is 5.3 while for PRECEDE
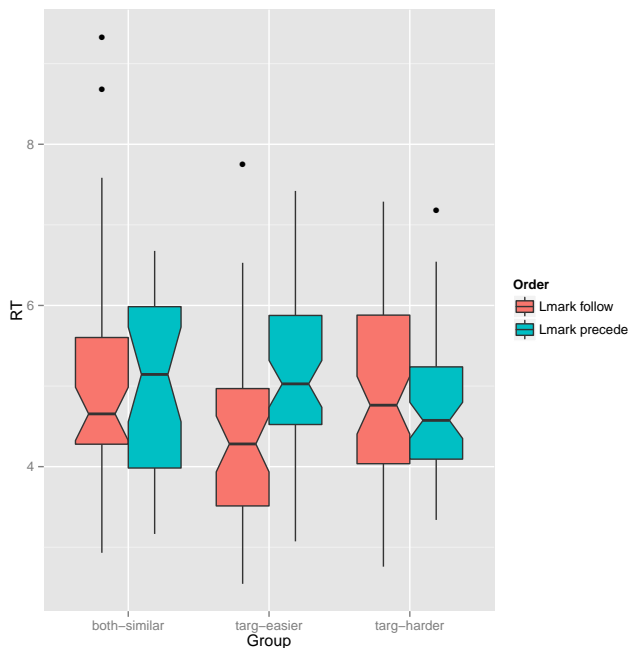371 expressions it is 4.7.

Figure 3. Notched boxplot of reaction time as a function of referring expression order (red: target first, blue: landmark first) grouped by which object is easier to find. Notches represent 95% confidence interval of the median (computed with GGPlot default settings).

372   We perform the Mann-Whitney test for differing medians on each group. For the "both-similar" group,
373 the test fails to find significance ($p > .05$); for the "target-easier" group, $p < .01$ and for the "target-harder"
374 group, $p < .05$.[5]

375   In addition to this analysis based on grouping the items, it is also possible to look at the median
376 $(target - lmark)$ (Eq. 1) as a continuous predictor. In Figure 4, we plot it against the analogous quantity
377 for the two relative referring expressions, median $(follow - precede)$. Points on the left represent instances
378 where the target is found faster than the landmark in isolation. Points at the bottom represent instances for
379 which the FOLLOW order leads to a faster search. Thus, our hypothesis would predict a positive correlation.
380 The estimated Pearson linear correlation is .52, (95% confidence interval .17 to .75).

381   Participants are relatively accurate (of 613 cases with accuracy information, 487 found the correct item
382 with an error less than 150 pixels on either axis). We checked for an accuracy effect by group similar to the
383 effect on reaction times, but there is none. Unsurprisingly, the majority of identification errors for relative
384 descriptions (62 of 77) occur in the "target-harder" group, indicating that when the target takes longer to
385 find, it is also more likely to be misidentified. But these are distributed evenly across the two RE orders.[6]

4.5   Discussion

387   Under both analyses of the visual search study, the results are as predicted by our hypothesis: search
388 is facilitated by mentioning the easier-to-find object first. The difference in medians suggests an average
389 effect of about .6 sec in either direction. Since the reaction time is measured from the start of the utterance,
390 the results imply that giving the target description later in the trial can sometimes be beneficial, even though
391 listeners in this condition must wait longer before they can possibly react.

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[5]   The null hypothesis for the "target-harder" medians cannot be rejected at a Bonferroni-corrected level of $.05/3 = .016$.

[6]   We also ran the analyses above excluding trials on which a misidentification occurred; results are qualitatively similar, except that the test of whether median RTs differ in the "target-harder" group cannot be rejected.
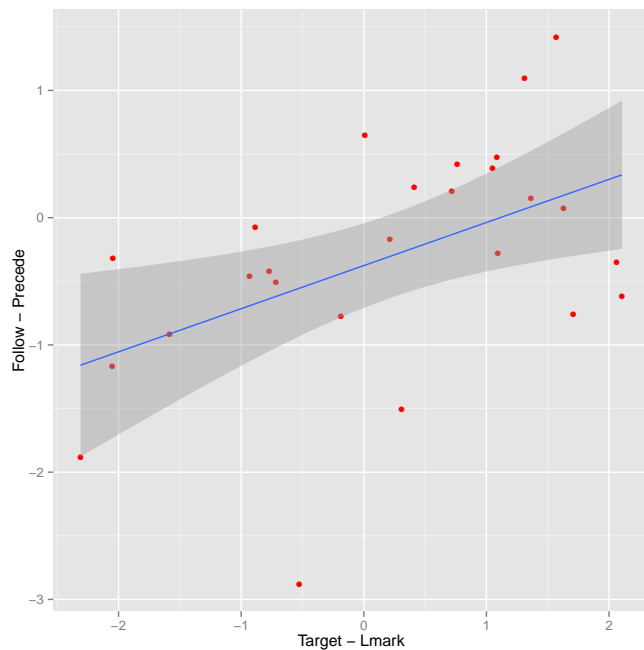

Figure 4. Plot of median (target-first - landmark-first) reaction time as a function of median (target - landmark) reaction time. Each point represents a stimulus; fitted regression line uses linear model.

Several caveats apply. First, although we find the expected facilitation effect when comparing among differently ordered relative descriptions, overall, participants reacted faster to the *non*-relative (target-only) expression. Even for the "targ-harder" group, mentioning the target alone yields a median search time of 4.2 seconds, while a relative description with the landmark first yields a median of 4.7.

If target-only descriptions actually lead to faster search than relative ones, why use a relative description at all? Clarke et al. (2013) show that relative descriptions are extremely common in human REs for these scenes, an effect also shown in a variety of previous work (Viethen and Dale, 2008). Overspecification is often intended to ensure the listener that they have actually found the right object (Koolen et al., 2011; Arts et al., 2011). If the listener believes confirmatory information is coming, they may wait to be sure they find the right object. (Listeners are no more accurate in these conditions, however.)

Secondly, the analysis does not correct for possible per-participant or per-item effects. This is partly due to the small amount of data, and partly to the use of median statistics to group the items as easier or harder. Since no participant heard more than one condition for a given stimulus, the easier/harder grouping reflects data from different participants than the reaction times plotted for relative descriptions within that group, complicating any analysis of individual differences.

5 CONCLUSION

Our analysis finds evidence for both of our hypotheses: speakers treat visually salient landmarks as being in common ground, preferring to place them early in their descriptions, and this ordering principle aids listeners in finding the target of a relative description quickly. These findings remain consistent with an audience-design model of perceptual effects in REG. In other words, speakers keep mental track of which objects in the scene are easier or harder to perceive. They use this information to preferentially select easier-to-see objects as landmarks, and they treat easier- and harder-to-see landmarks differently when

planning the syntax of their descriptions. Both of these tendencies stem from the desire to make sure their listeners can efficiently find the object they are trying to point out.

While the results are consistent with such a model, we should emphasize that they do not rule out a least-effort model in which speakers talk more about things they themselves see earlier. To eliminate this possibility, we could give the speaker and listener different views of the scene (for instance, by occluding part of the scene for the listener (Brown-Schmidt et al., 2008)). Alternately, we could look more closely at the time course of REG, using eye-tracking to determine when speakers discover the objects they mention and how much planning time intervenes.

Our findings definitely indicate that the choice of ordering strategy must be sensitive to visual features and cannot simply be left to an off-the-shelf micro-planning and realization component. This differentiates it from purely surface phenomena like dependency length minimization and heavy NP shift, which can be implemented at a late stage of the pipeline White and Rajkumar (2012). Choosing the correct strategy has a modest, but significant impact on listener performance. We find differences of about .6 seconds for referring expressions of about 4.7 seconds in length; in other words, the median subject's search will be about 10% easier if the correct ordering is used. Since we also found that relative descriptions lead to slower searches in general, this result should be considered with some caution. The stimuli used in this study were deliberately overspecified so that subjects could find the appropriate object using the non-relative description alone. Real relative descriptions are not always overspecified, but might be necessary to disambiguate the target; in these cases, they will presumably not cause a slowdown. The direction and magnitude of the slowdown effect might also vary depending on the complexity and visual clutter of the scene. Nonetheless, we believe that new REG systems should use perceptual information to properly order the relative descriptions they generate.

Our findings show that seemingly low-level and disparate mental "modules" like perception and sentence planning interact at a high level and in task-dependent ways. But we have yet to determine what sort of mental representations these systems use to communicate, or what underlies the considerable variation we find among both speakers and listeners. Our datasets are too small to tell us whether this variation reflects different populations, each using different strategies, or whether there is comparable variation within a single individual. Nor can it tell us whether larger-scale cognitive differences (for example, in attention, memory or executive function) could account for these differences.

5.1 Data Sharing

The referring expressions used in the corpus study are publically available as the WREC (Wally Referring Expression Corpus): `http://datashare.is.ed.ac.uk/handle/10283/337`. See Clarke et al. (2013). The recorded stimuli used in the comprehension experiment are provided as supplements to this paper.

DISCLOSURE/CONFLICT-OF-INTEREST STATEMENT

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

AUTHOR CONTRIBUTIONS

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