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Eye movements during speech planning: Talking about present and remembered objects

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Earlier work has shown that speakers naming several objects usually look at each of them before naming them (e.g., Meyer, Sleiderink, & Levelt, 1998). In the present study, participants saw pictures and described them in utterances such as “The chair next to the cross is brown”, where the colour of the first object was mentioned after another object had been mentioned. In Experiment 1, we examined whether the speakers would look at the first object (the chair) only once, before naming the object, or twice (before naming the object and before naming its colour). In Experiment 2, we examined whether speakers about to name the colour of the object would look at the object region again when the colour or the entire object had been removed while they were looking elsewhere. We found that speakers usually looked at the target object again before naming its colour, even when the colour was not displayed any more. Speakers were much less likely to fixate upon the target region when the object had been removed from view. We propose that the object contours may serve as a memory cue supporting the retrieval of the associated colour information. The results show that a speaker’s eye movements in a picture description task, far from being random, depend on the available visual information and the content and structure of the planned utterance.

In many everyday actions, we use visual information to guide our movements. For instance, we *can* chop onions in the dark, but most of us probably prefer to see the onions, the knife, and our fingers. Since objects can be seen most clearly when fixated, we normally fixate upon the objects relevant to the task at hand. Laboratory studies have confirmed that people carrying out simple actions, such as making a cup of tea or preparing a sandwich, usually look at the objects involved, just before reaching for them, and that during these actions they rarely

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look at other things (e.g., Hayhoe, 2000; Johansson, Westling, Bästöm, & Flanagan, 2001; Land, Mennie, & Rusted, 1999). Ballard, Hayhoe, and Pelz (1995; see also Hayhoe, Bensinger, & Ballard, 1998) traced participants' eye movements while they were copying patterns of coloured blocks. They found that the participants' actions and eye movements were closely time locked; i.e., the participants typically acquired visual information just before they needed it rather than acquiring it ahead of time and storing it in working memory. Similarly, research directed at spoken language processing showed that listeners carrying out instructions, such as "Put the candle into the box", looked at the target objects before reaching for them and that their gaze patterns reflected upon the ease of discriminating between the target and the other objects included in the display (e.g., Allopenna, Magnuson, & Tanenhaus, 1998; Spivey, Tanenhaus, Eberhard, & Sedivy, 2002; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995).

Given these findings, it is not surprising that people also tend to look at the objects they talk about. When speakers name two or more objects, they usually fixate upon each of them just before mentioning them (e.g., Griffin, 2001; van der Meulen, 2001; see Griffin & Bock, 2000, for a description of the more complex viewing patterns arising when speakers describe pictures of events). Unsurprisingly, the time speakers spend looking at the objects (the viewing time¹) depends on the time required for recognizing them (Meyer et al., 1998). In addition, the viewing times for objects about to be named depend on a number of variables known to affect the retrieval of their names: Name agreement (Griffin, 2001), name frequency (Griffin, 2001; Meyer et al., 1998), and the length of the nouns or phrases referring to the objects (Meyer, Roelofs, & Levelt, 2003; for a review see Levelt & Meyer, 2000).

Though people often look at the objects involved in their actions, they do not *always* do so. We can carry out many well-learned actions without visual guidance. For instance, we can reach for an object (e.g., a cup) without averting our gaze from a more interesting site (e.g., a newspaper). Similarly, van der Meulen, Meyer, and Levelt (2001) observed that speakers sometimes name objects without fixating upon them first. They asked Dutch speakers to name pairs of objects shown next to each other. The experiment consisted of pairs of trials featuring the same left object. In one test block, the speakers were asked to name all objects in noun phrases. They produced sentence pairs such as "The angel is next to the bed. The angel is next to the ball". In another test block, they were asked to use a pronoun to refer to the repeated object. They produced utterances such as "The angel is next to the bed. *It* is next to the ball". On the first trial of a

¹ We use the term viewing time to refer to the time interval between the onset of the first and the offset of the last fixation in a set of successive fixations on a target region. Thus the viewing for a region includes the durations of any intra-region saccades.

pair, the speakers almost always (on 99% of the trials) looked at the left object before naming it. However, when they named the same object again on the next trial, the inspection rate was lower and depended on the type of expression: When the speakers used noun phrases, they fixated upon the left object on 91% of the trials; when they used the pronoun, they inspected the object on only 71% of the trials. On most of the remaining trials the speakers' eyes moved from the fixation point at the bottom of the screen directly to the right object.

In this experiment, the pronoun was always "hij", corresponding to "it" in English. The noun phrase and pronoun conditions differed in the set sizes for the referring expression (one pronoun versus 24 different noun phrases). To control for possible set size effects, van der Meulen et al. (2001) carried out a similar experiment in German, where the form of the personal pronoun ("er", "sie", or "es") depends on the grammatical gender of the referent noun. As in the Dutch experiment, the pictures were arranged in pairs of trials sharing the left object. In each block of the experiment, only three different left objects were used, whose names differed in grammatical gender. On each trial the speakers either selected one of three noun phrases or one of three pronouns. Van der Meulen et al. obtained essentially the same pattern of results as in the Dutch experiment, except that the inspection rates for the targets were generally lower. On the first trial of a pair the inspection rate for the left object was 82%. On the second trial it dropped to 67% in the noun phrase condition and to 51% in the pronoun condition.

Why would speakers choose to name objects without fixating upon them first? In accounting for their results, van der Meulen et al. (2001) focused on the similarity of the multiple-object naming task to a reading task. Proficient readers do not fixate upon all words of a text, but sometimes skip words, especially those that are short and/or highly predictable from the text context (e.g., O'Regan, 1979; Rayner, 1998). In loose analogy to the E-Z Reader model developed by Reichle, Pollatsek, Fisher, and Rayner (1998; see Kennedy, 2000, for a comparison of models of gaze control in reading), van der Meulen et al. proposed that speakers naming several objects initially planned an eye movement to each object they named. However, they speculated that a planned eye movement may be cancelled if the object's name or another appropriate referring expression became available early enough, i.e., before the eye movement had reached a late planning phase during which it could not be cancelled any more. Therefore, any variable that substantially reduces the time required to retrieve an appropriate referring expression for an object should increase the object's likelihood of being named without prior fixation. If, as in the German experiment described above, only three different objects can appear in a particular position, extrafoveal information may suffice to discriminate between them, and due to repetition priming their names may be very fast to retrieve. This would explain why the eye movement from the fixation point to the left object was sometimes cancelled even on the first trial of a pair. On the second

trial, name retrieval was further facilitated by the availability of a memory representation of the object or its name generated during the preceding trial, which may have led to the further decrease in the fixation rates for the object. Since speakers were more likely to fixate upon the object again when they used a noun phrase, i.e., the same phonological form as on the first trial, than when they used a pronoun, this memory representation probably was not the phonological or phonetic form of the utterance, but a more abstract conceptual or semantic-syntactic representation.

It is important to keep in mind that van der Meulen et al. (2001) did not show that the speakers indeed sometimes planned and then cancelled eye movements to the target objects. It is also possible that on trials where no fixation on the target object was observed, no eye movement towards it was planned in the first place. In any event, the data demonstrate that speakers do not always fixate upon the objects they are about to name and they suggest that the likelihood of objects being named without prior fixation is related to the ease of object identification (which was different in the small response sets of the German experiment and the larger response sets of the Dutch experiment) and to the ease of retrieving the corresponding expressions (which was different for nouns and pronouns).

In the present study we continued to investigate the speakers' gaze patterns during the description of sets of objects. As in the experiments by van der Meulen et al. (2001), we asked speakers to refer twice to the same target object. However, they now first named the target object ("the chair..."), then referred to another object to its right ("... which is next to the cross...") and then named the colour of the target ("... is brown"). We expected that the speakers would almost always look at the target object before producing its name ("the chair"). The main question was whether they would regularly look at it again before producing the colour adjective appearing at the end of the sentence. We compared the speakers' gaze patterns to those occurring when the same pictures were described in utterances with different structures: In simple noun phrases, in which the colour was not named ("The chair is next to the cross"), in adjective-noun phrases ("The brown chair is next to the cross"), and in relative clauses ("The chair, which is brown, is next to the cross"). In these utterances all information referring to the left object is expressed before anything is said about the right object. Therefore, one would strongly expect the speakers to look first at the left and then at the right object. Returns from the right object to the target object should be rare. By contrast, in the adjective-final condition, information about the object category and the colour is displayed in the same location, but category and colour are not mentioned in adjacent utterance fragments. If the speakers' gaze pattern is exclusively governed by the spatial arrangement of information in the display, it should be the same in all four conditions. In contrast, if the gaze pattern is affected by the order in which information is expressed linguistically, a different gaze pattern—more frequent returns from

the right to the target object—should be found in the adjective-final condition than in remaining conditions.

The adjective-final condition of the present experiments bears some resemblance to the second-mention trials of the experiments by van der Meulen et al. (2001). In both cases, speakers referred twice to the same object. However, in the experiments by van der Meulen et al., speakers referred to the object category on both occasions (either in a noun or a pronoun). When they mentioned the target for the second time, they could therefore rely on representations of the object category or the name that they had generated before. This was not true in the present experiments: In order to name the object category (“the chair”), the colour of the object did not have to be determined. If speakers plan utterances strictly incrementally, i.e., at any time only create the representations required for the upcoming utterance fragment, they should not generate a representation of the colour adjective during the first inspection of the target object. Therefore they should either have to look at the target object again when it is time to plan the colour adjective or rely on extrafoveal information. On the hand, one might argue that the colour will, of course, be seen during the first inspection of the object. This may lead to automatic activation of the colour concept and possibly the colour name (see Damian & Bowers, 2003; Morsella & Miozzo, 2002). A working memory representation of the colour or its name may remain available for some time, allowing participants to produce the colour adjective without looking at the target again.

There were a number of reasons why we were interested in the speakers’ gaze patterns during the production of different types of phrases. First, the experimental results should contribute to a theory of eye movement control during picture description, similar to the theories proposed for reading. Such a theory should predict whether, when, and for how long speakers look at the objects they talk about. So far, much less is known about the eye movements of viewers inspecting and describing pictures than about eye movements during reading (see, for instance, recent reviews by Liversedge & Findlay, 2000, and Rayner, 1998; see also Rayner, Liversedge, White, & Vergilino-Perez, 2003). The gaze pattern of viewers inspecting and describing pictures are undoubtedly more variable and more difficult to predict than those of readers, but the evidence from the studies mentioned above demonstrates that they are not random. The use of simple pictures and simple descriptions may be a good way of starting to explore how visual and linguistic variables jointly determine a person’s eye gaze.

Second, the results should contribute to our understanding of when speakers rely on visual information and when they use memory representations of objects or expressions referring to them instead. In order to produce coherent discourse, speakers must have a record of what they have referred to in previous utterances. So far, surprisingly little is known about the properties of these representations and the ways speakers use them. By determining when speakers look back at an

object referred to before and when they do not do so but, presumably, rely on a stored representation of the object, we hope to gain new insights into the properties of these representations.

Once a more refined picture of eye gaze during picture naming has been gained, we can compare the coordination between eye gaze and speech to eye guidance in other types of behaviour. As noted above, it appears that in many every day actions (e.g., reaching for objects) eye gaze and action are closely linked. This may also be true for the coordination between eye gaze and speech. Alternatively, the coupling could be less tight for a number of reasons, for instance, because speakers generate and maintain quite durable verbal representations while they speak, or because the act of verbally referring to an object does not directly alter the physical environment and therefore keeping track of the positions of objects may be less important.

Finally, we pursue a methodological goal. It has been shown that the time speakers spend looking at an object is related to the time required to fully plan the utterance about it (e.g., Meyer et al., 2003). We can therefore use the viewing times for objects as indicators of speech planning time. Similarly, if we can identify which variables determine whether a speaker will look at an object before naming it, we can use the likelihood of object fixations to study these variables. In order to use eye monitoring fruitfully in speech production research, we must determine exactly how speech planning processes and eye gaze are linked.

EXPERIMENT 1

Method

Participants. The experiment was carried out with eight students of the University of Birmingham, whose native language was English. They had normal or corrected to normal vision and either received course credit or were paid for their participation.

Materials. On each trial, the participants saw two coloured objects underneath each other on the left side of the screen and two black line drawings of geometrical figures (a cross, star, square, or circle) on the right side (see Figure 1 for an example). They described each display in a pair of parallel sentences, such as “the chair is next to the cross and the snail is next to the star” or “the chair, which is next to the cross, is brown and the snail, which is next to the star, is blue”. Before each test block, the participants were told which utterance format to use. The target object was always the top left object (the chair in the example). Earlier experiments had shown that speakers producing single sentences such as “the chair is next to the cross” fixated upon the objects in the order of mention, but almost always looked at the first object again towards the end of the utterance, probably in preparation for the next trial (e.g.,

Figure 1. One of the displays used in Experiments 1 and 2.

Meyer et al., 1998). The expected high base rate of late returns of gaze to the left object would make it difficult to evaluate how likely speakers producing utterances such as “the chair next to the cross is brown” would be to look at the left object again in order to obtain colour-relevant information. Therefore we presented a second object pair at the bottom of the screen. We knew from an earlier experiment (van der Meulen, 2001) that speakers naming four objects in the order top left, top right, bottom left, bottom right usually inspect all four objects in the order of mention before looking at the top left object again. In the present study, we determined how often speakers would deviate from this default pattern and would look at the top left object again after having fixated on the top right object, but before turning to the bottom object.

To generate the pictures, we selected four geometrical figures and 56 line drawings of simple objects from a picture gallery provided by the Max Planck Institute for Psycholinguistics (Nijmegen, The Netherlands). The 56 line drawings formed 4 practice and 24 experimental pairs. One member of each pair appeared in the middle of the top-left quadrant of the screen, and the other member appeared underneath in the bottom-left quadrant of the screen. The two objects appearing together belonged to different semantic categories. Their names were phonologically unrelated but had the same number of syllables (see Appendix for a listing of the object names).

The objects appeared in one of four colours (red, green, blue, or brown). In all displays, the top and bottom object shown together differed in colour. Each colour was used in two practice items. Across the 24 experimental items, each colour combination was used twice. The two geometrical figures appearing together in a display were also different. Each geometrical figure appeared in two practice items and each combination of figures appeared in two experimental items. The drawings of the objects fitted into a rectangular frame of 5 cm by 5 cm, corresponding to visual angles of 4.7° horizontally and vertically when viewed from the participant’s position, approximately 60 cm away from the

screen. The geometrical figures fitted into frames of 1.5 cm by 1.5 cm. The horizontal midpoint to midpoint distance between the object on the left and the figure on the right was 15 cm (14.1°). The screen background was light grey.

Design. The experiment consisted of four test blocks, in each of which each practice item and experimental item was shown once. The participants used the same sentence frame to describe all pictures within a block, but different frames in different blocks. The four frame types were: (1) noun phrases, such as “the chair is next to the cross and the snail is next to the star”, (2) adjective-noun phrases such as “the brown chair is next to the cross and the red snail is next to the star”, (3) relative clauses, such as “The chair which is brown is next to the cross and the snail which is red is next to the star”, and (4) adjective-final clauses, such as “the chair which is next to the cross is brown and the snail which is next to the star is red”. The sentence frames defined the experimental conditions. The order of the conditions was counterbalanced across speakers. The items within blocks were presented in a different random order to each participant.

Apparatus. The experiment was controlled by the experimental software package NESU provided by the Max Planck Institute for Psycholinguistics, Nijmegen. The pictures were presented on a Samtron 95 Plus 19-inch screen. Speech was recorded using a Sony ECM-MS907 microphone and a Sony TCD-D8 DAT recorder. Eye movements were monitored using an SMI EyeLink Hispeed 2D eye tracking system. The spatial resolution of the eyetracker is about 0.1°. Throughout the experiment, the x- and y-coordinates of the participant's point of gaze of the right eye was estimated every 4 ms. The positions and durations of fixations were computed online using software provided by SMI.

Procedure. Participants were tested individually. At the beginning of the experiment, they received a booklet showing the drawings used in the experiment and were asked to name them aloud. They were corrected when their responses were different from the expected names. They were then told that they would see pictures showing two coloured objects and two geometrical figures each, which they should describe using the sentence format specified by the experimenter prior to each experimental block.

Then the headband of the eye tracking system was placed on the participant's head and the system was calibrated. The practice trials and experimental trials of the first block followed. At the beginning of each trial a fixation point was shown in the centre of the top-left quadrant. After 800 ms it was replaced by a practice picture or an experimental picture. In the noun phrase and adjective-noun conditions each picture was shown for 10 s. In the remaining two conditions, in which longer utterances were required, each picture was shown

for 12 s. The intertrial interval was 500 ms. There were short pauses between blocks, during which the experimenter explained how the items of the next block should be described and the eye tracker was calibrated again.

Results and discussion

We excluded from the analyses trials on which participants named any of the objects incorrectly or repaired their utterances (63 trials, corresponding to 8.2% of the total of 768 trials). Analyses of variance showed that these trials were distributed evenly across the experimental conditions. We also excluded 12 trials on which the equipment had not functioned correctly.

We determined in which order the speakers looked at the objects and geometrical figures. A fixation was classified as being on an object or a figure if its spatial coordinates lay within the corresponding quadrant of the screen. Successive fixations on the same quadrant were combined to gazes to that quadrant. On all trials, the speakers looked at each quadrant at least once. We expected that the speakers would almost always first look at the top-left object, which was to be referred to first. This was true for 690 out of 693 valid trials. Furthermore, we expected that the speakers would then look at the geometrical figure in the top-right quadrant of the screen, which was to be named second. This expectation was borne out for 659 trials. Finally, we expected that in the noun phrase, adjective-noun phrase, and relative clause conditions, speakers would then turn to the bottom-left object. As Figure 2a shows, this expectation was also confirmed: On 472 out of 498 trials, speakers looked at the bottom left object after having looked at the top-right one, and on all but one trial, they then looked at the bottom-right object. Thus, on 89.54% of the valid trials in these three conditions (471 out of 526 valid trials), the participants looked at the four objects in the order of mention. This gaze pattern will be called the “simple path” hereafter.

In the adjective-final condition, speakers also usually looked first at the top-left and then at the top-right object. However, then they normally did *not* look at the bottom left object, as the participants in the other conditions had done, but instead, on 146 out of 161 trials (90.68%), looked at the top-left object again (see Figure 2b). On 136 of these trials they then turned to the bottom-left object. On the remaining 10 trials they looked at the top-right object next. Thus, in the adjective-final condition, the most common gaze pattern (called “path with regression” hereafter), found on 136 out of 167 valid trials (81.43%), was top left, top right, top left, bottom left. This pattern was found on only 4 of 526 trials in the remaining three conditions. The dominant pattern in those conditions, the simple path, was observed on only 7 of the 167 trials (4.19%) of the adjective-final condition.

In the statistical analyses, we examined how likely the speakers were in each condition to adopt the simple path and the path with regression given that they

Number of valid trials: 526.

Number of valid trials: 167.

Figure 2. Scan paths in (a) the noun, adjective-noun, and relative clause conditions, and (b) the adjective-final condition of Experiment 1.

had fixated upon the top-left and the top-right object first (see Table 1). Analyses of variance comparing the noun, adjective-noun, and relative clause conditions yielded no significant effects indicating that the path with regression was equally unlikely to be followed and that the simple path was equally likely to be followed in these three conditions. Next we compared the mean likelihood of observing the simple path and the path with regression across these three conditions to the corresponding rates in the adjective-final condition. Regressions were significantly more likely in the adjective-final condition than in the remaining conditions, $t1(7) = 15.40$, $p < .01$ (subject analysis), $t2(23) = 29.19$, $p < .01$ (item analysis), and the simple path was significantly less likely to be observed in the adjective-final condition than in the other conditions, $t1(7) = 21.28$, $t2(23) = 50.88$, both $p < .01$.

TABLE 1
Results of Experiment 1. Frequencies of occurrence of the simple path, of the path with regression, and of all paths starting with the sequence "top-left, top-right region" (total)

<i>Utterance format</i>	<i>Simple path</i>	<i>Path with regression</i>	<i>Total</i>
Noun phrases	165	1	173
Adjective-noun phrases	154	0	161
Relative clauses	151	3	164
Adjective-final sentences	7	136	161

Thus, the gaze pattern in the adjective-final condition was markedly different from the pattern observed in the remaining three conditions. When the speakers did not name the colour of the top-left object or named it immediately before or after producing the object name, they looked at the top-left and top-right object in the order of mention and then looked at the bottom objects. By contrast, when they named the colour of the left object after naming the right object, they usually looked at the left object again before looking at the bottom objects. Since the same pictures were shown in all conditions, these results show that the speakers' gaze patterns were not exclusively governed by the properties of the pictures but depended also on what they said about them.

In the experiments carried out by van der Meulen et al. (2001), speakers sometimes named objects they had seen before without fixating upon them. As explained above, we assume that in such cases the name of the object or the corresponding pronoun could be rapidly generated building upon a working memory representation of the object or its name. In the adjective-final condition of the present experiment speakers occasionally adopted the simple path (on 7 out of 167 trials), but usually (on 136 trials) their eyes returned to the top-left object before they named its colour. This suggests that if the speakers created any representation of the colour or colour name during the first inspection of the target object at all, this representation was usually not strong or persistent enough to induce colour naming without prior refixation of the target object.

EXPERIMENT 2

We proposed above that the speakers in the adjective-final condition of Experiment 1 looked at the top-left object again after having looked at the top-right object because they still had to plan the colour adjective. If this is correct, the regressions to the top-left object should occur before rather than after the onset of the adjective. One of the goals of Experiment 2 was to verify that this was indeed the case. To this end, we replicated the adjective-final condition of Experiment 1, but we now recorded and digitized the participants' speech,

determined when each content word began, and aligned the eye movements with the speech output.

The main goal of the experiment was to assess why the speakers usually looked at the target object again before naming its colour. One possibility is that they quite deliberately directed their eyes to the target in order to gain information about its colour or to check colour information retained in working memory. On this account one would not expect speakers to look at the target object again if they knew that the colour information would be removed after their first inspection of the target. To test this prediction, we compared two conditions: The constant colour condition was identical to the adjective-final condition of Experiment 1. In the disappearing colour condition, the display was initially the same as in the constant colour condition. However, shortly after the speaker's eyes had landed on the right object, the left object lost its colour, i.e., the original coloured drawing of the left object was replaced by a black line drawing of the same object. These conditions were tested between participants, and the participants knew that the colour of the target would remain visible or that it would be removed while they were inspecting the right object. If speakers regressed to the left object in order to obtain or verify colour information, regressions should be quite unlikely in the disappearing colour condition.

Alternatively, speakers might look at the target object again even when they know that the colour will not be shown any more. This hypothesis gains some plausibility from informal observations that speakers often look at the objects they are talking about even when they discuss properties that are not visible (as might, for instance, be the case for a chef discussing and looking in despair at a bland soup). Griffin (in press) recently reported that speakers asked to "lie about" a picture by mislabelling the objects (e.g., calling a cat a dog) still looked at each object before referring to it. In addition, a number of studies have shown that in a variety of cognitive tasks people tend to look at locations where relevant information was displayed earlier on. For instance, readers answering questions about short sentences they have just read often carry out large regressive eye movements to the relevant text fragments. Importantly, such regressive eye movements to the target regions can frequently be observed even when the text is removed as soon as the question appears (Kennedy, Brooks, Flynn, & Prophet, 2003). Brandt and Stark (1997) compared the scan paths of viewers inspecting complex scenes to the scan paths arising when they imagined the same scenes and found these scan paths to be quite similar (see also Laeng & Teodorescu, 2002). More closely related to the present experiments are memory experiments by Richardson and Spivey (2000) and Spivey and Geng (2001). In the trials of the latter study, participants first inspected four shapes appearing in different colours and tilted slightly to the left or right and then looked at a central fixation point. Then the display was erased for 1 s and subsequently reappeared with one object missing. The participants were then asked to specify the colour or tilt of the missing object. On most of the trials, the participants' eyes

remained on the central fixation point during this phase, but on 24% of the trials they fixated upon the region where the target had been shown before. Each of the other three regions was only fixated upon on 7% of the trials. As Spivey and Geng point out, it is not entirely clear why the participants looked at the target location again as there was no evidence that this facilitated the retrieval of the colour or tilt information. Richardson and Spivey (p. 252) proposed that the query about an object leads to the activation of information associated with the object, including a specification of the location where it was last seen. This in turn may trigger an eye movement to that location even when the object is not displayed there any more. Presumably, such eye movements occur because very often objects retain their positions and therefore an eye movement to the position where a target object was last seen does yield useful information.

Spivey and Geng (2001) removed the entire target object from view, whereas in the disappearing colour condition of our Experiment 2 only the colour of the object was removed. To allow us to compare our results more directly to those obtained by Spivey and Geng, we included a third condition, the disappearing object condition, in which we removed the entire left object while the speakers were looking at the right object. This also permitted us to assess whether speakers would be more likely to look at the contours of the target object than at the empty target region. The object contours should be more closely associated with the colour than the location where the object had been shown and might therefore constitute a more powerful memory cue for the retrieval of the colour (e.g., Ceraso, Kourtzi, & Ray, 1998; Francis & Irwin, 1998; Wilton, 1989, 1992). Thus, if the participants' eye movements are determined by the usefulness of the sites for the task at hand, they might look more frequently at the object contours than at the empty quadrant.

The disappearing colour condition and the disappearing object condition differed not only in the presence or absence of the target object, but also in whether there was any object in the top-left region. Perhaps speakers are unlikely to revisit this region in the disappearing object condition because an empty space is not a good target for an eye movement (e.g., Krieger, Rentschler, Hauske, Schill, & Zietsche, 2000; Mackworth & Morandi, 1967). To examine this possibility, we included a fourth condition, the hidden object condition, in which the target was replaced by a constant, irrelevant object (a wall) while the speaker was looking at the right object.

In sum, all participants of Experiment 2 produced adjective-final utterances such as "the chair which is next to the cross is brown". We tested four groups of participants who experienced different types of display changes: There was no change (constant colour group), the colour of the left object was removed (disappearing colour group), the entire left object was removed (disappearing object group), or the left object was replaced by a neutral object (hidden object group).

Method

Participants. The experiment was carried out with 48 participants. They were undergraduate students of the University of Birmingham and native speakers of English. They were paid for participating in the experiment or received course credits.

Materials and design. We used the same 4 practice and 24 experimental items as in Experiment 1. In addition, we created black line drawings of the target objects. These replaced the coloured target objects in the disappearing colour condition. In the hidden target condition a black line drawing of a wall replaced the top-left object while the participant was inspecting the top-right object. The four experimental conditions were varied between participants, with 12 speakers being tested under each condition. Each experimental session consisted of two test blocks. In each block, all items were presented once. The items were presented in different random orders in each block and to each participant.

Procedure. The participants were instructed in the same way as the participants of the adjective-final condition of Experiment 1. In addition, the speakers tested in the disappearing colour, disappearing object, and hidden object conditions were told that the colour of the top-left object or the entire object would disappear, or that the top-left object would be hidden behind another object soon after trial onset.

As in Experiment 1, each trial began with the presentation of a fixation point in the centre of the top-left quadrant. After 800 ms it was replaced by a practice or experimental display. In the constant colour condition, the experimental display remained in view for 8050 ms. In all other conditions, a display change was initiated 100 ms after the onset of the first fixation on the top right object. On average this occurred 1188 ms after trial onset. The changed display remained in view until the end of the trial, i.e., until 8050 ms after the onset of the original display. The inter-trial interval was 500 ms.

Results and discussion

The data from 253 trials (10.98% of all trials) were excluded from further analyses because of naming errors, speech disfluencies, or repairs. These trials were distributed evenly across the four conditions, with the percentages of excluded trials ranging between 10.24% and 12.63%. In addition, the data from 29 trials were excluded because the participants did not inspect each of the four regions of the display at least once or because of technical errors (four trials). We were particularly interested in errors involving the first colour adjective. There were only thirteen such errors (four cases where incorrect colour adjectives were used and nine hesitations). All of these errors occurred in the

hidden or disappearing object condition. This suggests that naming the colour of the object was slightly more difficult in these conditions than in the others, but even in these more difficult conditions, accuracy was still above 98%.

As for Experiment 1, we first examined in which order the participants inspected the four objects (see Figure 3). On 2006 out of 2022 trials (99.21% of the trials) they first fixated upon the top-left object. Next, they usually (on 1965 out of 2022 trials, or 97.18% of the trials) looked at the top-right object. On 41 trials speakers looked first at the top-left object, then at the bottom-left object, then at the top-left object again, and then at the top-right object. For unknown reasons, such “detours” to the bottom-left object occurred more frequently (27 times) in the disappearing colour condition than in any of the other conditions (with maximally 6 such cases each). From the top-right object, the speakers’ gaze often turned to the bottom-left object and from there to the bottom-right object. This simple path, in which each of the four objects was inspected once, in the order in which their names were mentioned, was observed on 490 trials (24.23% of 2022 trials). Far more often, on 1235 out of 2022 trials (61.08%), the speakers’ gaze turned from the top-right object to the top-left object and only then turned to the bottom-left object. Thus, as expected, the dominant gaze pattern in this experiment was the same as in the adjective-final condition of Experiment 1. On most trials, the participants looked at the top-left object at trial onset and again after inspection of the top-right object.

Table 2 shows the frequencies of the simple path and the path with regression in each condition. Speakers rarely adopted the simple path in the constant colour and in the disappearing colour conditions, but did so very frequently in the disappearing and hidden objects conditions. Conversely, the path with regression was frequently observed in the constant and disappearing colour conditions but less frequently in the disappearing and hidden object conditions.

Number of valid trials: 2022.

Figure 3. Scan paths in Experiment 2.

TABLE 2
Results of Experiment 2. Frequencies of occurrence of the simple path, of the path with regression, and of all paths starting with the sequence "top-left, top-right region" (total)

<i>Condition</i>	<i>Simple path</i>	<i>Path with regression</i>	<i>Total</i>
Constant colour	25	398	496
Disappearing colour	60	327	471
Disappearing object	206	261	506
Hidden object	199	249	492

In the statistical analyses, we compared how likely each of the two paths was to be observed given that speakers had inspected first the top-left and then the top-right object. The four experimental conditions differed significantly in the likelihood of regressions, $F(3, 44) = 3.35$, $p < .05$; $F(3, 69) = 58.82$, $p < .01$. Dunnett t -tests (one-tailed, $p < .05$, by participants and items) showed that regressions were significantly less likely in the disappearing and hidden object conditions than in the constant colour baseline condition. The difference between the baseline condition and the disappearing colour condition failed to reach significance. The results obtained for the likelihood of observing the simple path were similar. There was a main effect of condition, $F(3, 44) = 6.12$, $p < .01$; $F(3, 69) = 133.31$, $p < .01$. Again, Dunnett t -tests ($p < .05$) showed that the constant colour baseline condition differed significantly from the disappearing and hidden object conditions, but not from the disappearing colour condition. Thus, the speakers' gaze was as likely to return to the top-left quadrant of the display when the colour of the target object had been removed as when the colour was still present. Regressions were less likely when the target object had been removed or hidden.

We recorded the participants' speech and measured the onset time of each content word in the first clause. This allowed us to assess the temporal coordination between the speakers' eye gaze and speech. Due to equipment faults the speech data from nine participants from different groups were lost. The following analyses are based on the responses of the remaining 39 participants. 14.53% of their data were lost due to naming errors, repairs, and stuttering. In addition, 2.63% of the data were discarded because the onset of one of the content words could not be determined accurately enough. This left the data from 1600 trials for analysis. In these utterances, the first noun (the name of the top-left object) began, on average 939 ms after picture onset, the second noun (the name of the top-right object) began 2112 ms, and the colour adjective 2769 ms after picture onset. Analyses of variance showed that none of these word onset times was systematically affected by the experimental conditions.

On all valid trials, the participants looked at the top-left object at least once before naming it. On 1546 (out of 1600 trials, 96.63%), there was only one gaze to the top-left object (i.e., one set of successive fixations) before the onset of its name. The gaze remained on the object from picture onset for 984 ms, i.e., until slightly after the noun onset. The mean viewing time for the left object (measured as the time interval between the onset of the first and the end of the last fixation) was independent of the experimental condition. On most of the remaining trials the participants looked at the left object, then briefly at the right object and then returned to the left object before initiating its name.

On 1595 out of 1600 trials, the speakers looked at the top-right object at least once before naming it. On 1467 trials (91.69%) there was only one gaze to that object before the onset of its name, starting on average 997 ms before and ending 29 ms after noun onset. Analyses of variance showed that viewing time for the right object was not systematically affected by the experimental condition. Thus, there is no evidence that the display changes triggered any early returns to the left quadrant of the screen. Overall the results obtained for the first two objects confirm earlier findings that speakers naming several objects usually look at each of them, just once, for about 1 s before naming them (Griffin, 2001; van der Meulen, 2001).

The central issue to be examined was how likely the participants in each experimental condition would be to look at the top-left object just before naming its colour. As noted, the speakers always looked at the top-left object before producing its name. On 1164 trials (72.75% of 1600 trials) they looked at the object again *after* the onset of the noun, but *before* the onset of the colour adjective. These gazes to the top-left object were likely to be related to the planning of the adjective. On 1085 trials, there was only one such gaze to the top left object, starting 651 ms before and ending 151 ms after adjective onset.

The leftmost column of Table 3 shows how likely speakers were to produce the colour adjective *without* looking at the top-left region again. These percentages correspond closely to the percentages of trials on which the simple path was observed in the same sample (Table 4). This is important because it validates the path-based analyses described above for the larger sample of participants of Experiment 2 and for those of Experiment 1. The second column of Table 3 shows how likely speakers were to produce the colour adjective after having looked at the top-left region again. One would expect these percentages to correspond to those obtained for the path with regression (second column of Table 4), but they are all substantially higher. This is because our definition of the path with regression was very restrictive: We only counted trials on which the participants inspected the top-left, top-right, top-left, and bottom-left quadrant once each in this order. We did not include trials on which participants looked more than once at the top-right object before returning to the top-left object, trials on which there were more than two gazes to the top-left quadrant, or trials on which participants did not turn directly to the bottom-left object after

TABLE 3

Results for 39 participants of Experiment 2. Percentages of trials on which the colour was named without vs. after a return of gaze to the top-left object, viewing times (VT; mean and standard error, *SE*, by participants) for the top-left quadrant associated with colour naming, and number of participants per condition (*n*)

Condition	No return	Return of gaze	VT (ms)		<i>n</i>
			Mean	<i>SE</i>	
Constant colour	6.57	93.43	619	26	11
Disappearing colour	16.20	83.80	531	45	9
Disappearing object	51.27	48.73	319	40	9
Hidden object	38.79	61.21	451	55	10

their second gaze to the top-left quadrant. Nevertheless, the overall pattern of results was the same for the path-based analysis and for the analysis taking the timing of the participants' eye movements relative to their speech into account: The participants were far less likely to look at the top-left region again when the object had disappeared or had been hidden from view than when it was still visible. Whether or not the colour of the object was still available did not greatly affect the gaze pattern.

The statistical analysis of the participants' likelihood of naming the colour of the top-left object without fixating upon it again supports this conclusion. The difference between the four conditions was highly significant, $F(3, 35) = 6.64$, $p < .01$; $F(3, 39) = 111.56$, $p < .01$. Dunnett *t*-test ($p < .01$) showed that the constant colour control condition differed significantly from the disappearing and hidden object condition, but not from the disappearing colour condition.

We also examined for how long the top-left region was inspected when it was refixated at all before adjective onset. The average viewing time, shown in the third column of Table 3, was longest in the constant colour condition and shortest in the disappearing object condition. The main effect of condition was significant, $F(3, 35) = 9.02$; $F(3, 69) = 60.89$, both $p < .01$. Dunnett *t*-tests

TABLE 4

Results for 39 participants of Experiment 2. Frequencies and percentages of trials on which the simple path and the path with regression were observed and total number of analysed trials (starting with the sequence "top-left, top-right region")

Condition	Simple path	Path with regression	Total
Constant colour	25 (5.51%)	364 (80.17%)	454
Disappearing colour	55 (15.58%)	224 (63.46%)	353
Disappearing object	189 (50.67%)	165 (44.24%)	373
Hidden object	156 (39.6%)	226 (54.99%)	411

yielded the same pattern of results as we had found for the regression rates: The constant colour condition differed significantly from the disappearing and hidden object conditions ($p < .05$), but not from the disappearing colour condition. Thus, the participants looked for longer at the top-left quadrant when the object was still present than when it was not visible any more.

GENERAL DISCUSSION

In Experiment 1, we studied the gaze patterns of speakers naming objects in short sentences (“the chair is next to the cross”) or mentioning the colour of the first object (the target) as well. The speakers named the colour before the object category (“the brown chair is next to the cross”), immediately afterwards in a relative clause (“the chair which is brown...”), or after having mentioned a second object first (“the chair which is next to the cross is brown”). In all conditions except the last-mentioned one (the adjective-final condition), the participants looked at the two objects in the order of mention and rarely looked at the left object again before looking at the second set of objects shown in the bottom half of the display. In the adjective-final condition the speakers usually looked at the left object again after having inspected the right object and before looking at the bottom objects, most likely because they still had to name the colour of that object. This experiment established that the speakers’ gaze pattern was not exclusively determined by the visual display but depended on the structure of the planned utterances as well, and that regressive eye movements from the right to the left object occurred almost exclusively when the colour of the left object was named after the right object had been referred to.

The constant colour condition of Experiment 2 was identical to the adjective-final condition of Experiment 1. We found again that the speakers were highly likely to look at the top-left object again after having looked at the top-right object and before looking at the bottom objects. The analysis of the temporal coordination of the speakers’ eye gaze and speech showed that they looked at the left object again *before*, rather than after, the onset of the adjective. This supports the view that the regressions to the target were related to the requirement to name its colour. In sum, the speakers looked at each of the objects they referred to in the order of mention. When they named a new property (the colour) of an object they had named before, their eyes usually returned to that object.

These observations are in line with the findings of other studies reviewed in the introduction demonstrating tight links between eye movements and actions (e.g., Hayhoe, 2000). People tend to look at the objects involved in their actions. Such behaviour is, of course, entirely reasonable as many activities can be carried out most efficiently under visual guidance and objects are best seen when fixated upon. Moreover, eye gaze and action tend to be closely linked in time: People generally direct their gaze to the objects they interact with just before information about them becomes relevant for the ongoing action (e.g., Johansson et al., 2001). In the present study we found that eye gaze and speech were tightly

coordinated as well. Colour information was present at trial onset and should not be difficult to perceive and remember for a short period of time (of less than 1 s). Nevertheless, as long as the display did not change, the participants usually looked at the target object again before naming its colour.

In Experiment 2, we explored whether the participants would look at the top-left quadrant of the screen when they were about to produce the colour adjective even when, by that time, the colour of the target object or the entire object had been removed from view. In the disappearing and hidden object conditions the participants looked less frequently at the top-left object than in the constant colour condition, but they still did so on about 50% of the trials. These results are similar to those found in a study of reading by Kennedy et al. (2003) mentioned above. In this study readers answered questions about short sentences they had just read with the sentences either still being present or removed at question onset. Kennedy et al. found that in both conditions readers often fixated upon the target fragment again, but the likelihood of regressive eye movements to the target fragment was higher in the text-present than in the text-absent condition.

In a memory experiment we mentioned above, Spivey and Geng (2001) found that participants often refixated the region where a target was displayed before, but they did not obtain any evidence that eye movements to empty locations facilitated the retrieval of information about the targets shown there earlier. Spivey and Geng proposed that the eye movements might have been due to a general tendency of the cognitive system to rely on external rather than memory information wherever possible. When information about an object is required, an eye movement to the appropriate location is likely to be launched, even on those relatively rare occasions when the object is not visible in that location any more. Spivey and Geng's proposal may be a valid account of the behaviour of the participants in the disappearing and hidden object conditions of the present experiment as well. However, the proposal does not offer an account for the higher regression rates found in the disappearing colour condition. Here speakers were almost as likely as in the constant colour condition to fixate upon the target object again and the regression rate was more than twice as high as in the hidden object condition, where the target object was replaced by an irrelevant object, $t(1) = 1.91$, $df = 35$, $p < .05$, one-tailed; $t(2) = 7.89$, $df = 69$, $p < .01$. This is an interesting finding because the directly relevant information, the colour of the object, was absent here as well, just as in the hidden object condition. As we proposed above, it is possible that the target contours constituted a better cue for the retrieval of the colour than the former location of the target object. Thus, the likelihood of regressions to a particular site may depend on the usefulness of the information to be found there.

How can the usefulness of the information to be found in a particular region affect the likelihood of the speakers' eye movements to this location? One possibility is that the speakers in different experimental groups already prepared in different ways for colour naming during their first inspection of the targets. In earlier work (van der Meulen et al., 2000) we proposed that speakers usually plan and carry out an eye movement to each object they refer to, but that such

eye movements may be cancelled if the referring expression is very rapidly available. We can account for differences in the regression rates between the experimental conditions of the current experiment by assuming that in anticipation of different kinds of display changes the speakers generated representations during the first inspection of the targets that were more or less likely to cause the cancellation of the regressive eye movement. When the speakers knew that the colour information would be available later, there was no need to attend to the colour at all. Though the colour may be automatically registered, no attempt needed to be made to submit it to working memory for later retrieval. In all other conditions, colour information had to be processed more thoroughly. The anticipation of a retrieval cue (the contours of the object) may affect the initial encoding of the colour. For instance, the speakers may always generate a conceptual representation of the colour, but in the disappearing and hidden object condition they may be more likely than in the disappearing colour condition to initiate the retrieval of colour name. In short, the differences in the rates of regressive eye movement may be related to differing degrees of preparation for the colour name at trial onset.

A finding that is compatible with this proposal is that the mean viewing times for the target regions during the second inspection (related to adjective naming) differed significantly across the four conditions. The mean viewing time was much shorter in the disappearing object condition and the hidden object condition than in the disappearing colour condition and the constant colour condition (see Table 3). Other experiments (e.g., Griffin, 2001; Meyer et al., 1998) have shown that the viewing time for an object that is to be named depends on the time required to formulate an utterance about it. Thus, the observed ranking of the viewing times in the present experiment would imply, somewhat counterintuitively perhaps, that the retrieval of the colour adjective was slowest in the constant colour condition and fastest in the disappearing object condition. This result can, however, easily be accounted for on the assumption that speakers in the constant colour condition rarely prepared the colour name beforehand, whereas the participants in the hidden and disappearing object condition often did.²

² One might expect parallel results for the time required for producing the adjectives. As noted we found no difference between the conditions in the adjective onset latencies. In evaluating this result, it should be kept in mind that the participants generated connected speech and that the timing of the adjective onset depended largely on the time required for the production of the preceding words. Thus, differences in the speed of retrieving the adjective probably were difficult to detect. Similarly, one might expect differences in the preparation for the later retrieval of the colour name to lead to differences in speech onset latencies or in the first inspection viewing times for the targets. However, the latencies and the viewing times for the first inspection of the targets were long and quite variable, probably because the utterance fragment related to the first object ('The chair which is next to...') was long. Thus, a short time period required to retrieve the lexical representation of the colour name may not be detectable. In addition, this process may occur in parallel with other processes, e.g., the articulatory preparation of the phrase.

Alternatively, the usefulness of the retrieval cue could affect later processes. Speakers might process the targets in much the same way during the first inspection, but the anticipation of the type of information available in the top-left quadrant of the screen would be one of the variables affecting the likelihood of regressive eye movements being initiated to this location. To account for the differences in the second-pass viewing times described above, a different principle would have to be invoked, for instance that uninformative sites are left faster than informative ones. Further experiments are necessary to discriminate between these hypotheses. A more general issue to be considered in future research is whether speakers naming objects without looking at them cancel planned eye movements or whether eye movements to such objects are never planned in the first place.

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APPENDIX

Names of objects (top left–bottom left) used on experimental trials

Spade-kite, broom–zip, snail–comb, axe–crane, drill–owl, purse–sink, swan–lamp, sock–tent, leaf–straw, ghost–slide, pipe–drum, pen–belt, giraffe–racquet, squirrel–jester, canoe–windmill, camel–whistle, cigar–bucket, anchor–cocktail, mushroom–kettle, candle–ladder, hammer–present, rocket–toilet, button–guitar, mirror–tunnel