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Abstract

When we hear a story that describes motion, do we naturally imagine the motion described? To what extent do the mental images generated through language share processing resources with perception? In our studies, people read a story describing upward or downward motion and were later asked to interpret an unrelated ambiguous figure. The figure could have been seen as a bird flying upward or downward, and the participants were simply asked to "draw a worm in the bird's beak". People's interpretations of the ambiguous figure revealed a congruity effect when the stories depicted visual motion of a real world object. Those who had read a story describing upward motion were more likely to interpret the ambiguous image as a bird flying up than those who read a story describing downward motion. However, there was no effect when the stories depicted metaphorical motion. These findings suggest that more concrete linguistic descriptions of motion do generate representations or mental states that interact with perception. Further these studies provide hints about the level at which representations generated by normal language processing interact with perceptual processing.

Keywords: Embodiment; Simulation; Imagery; Language; Perception; Motion

Introduction

Humans are able to quickly and easily translate between visual and verbal representations. We can verbally describe visual scenes, and we can construct mental or physical images from linguistic descriptions. In this paper we are interested in the extent to which the representations derived in the course of normal language comprehension interact with perceptual processes.

Previous research has demonstrated remarkable overlap between the representations and processes that underlie mental imagery and those used in the service of perception itself. For example, imagining motion or inferring motion implied in frozen motion photographs activates the same motion sensitive regions of the brain (e.g., the visual area MT) as actually perceiving motion (Goebel et al., 1998; Kourtzi & Kanwisher, 2000). Further, imagining motion is sufficient to produce a motion after-effect or waterfall illusion (Winawer, Witthoft, Huk, & Boroditsky, 2005). The motion after-effect (MAE) is the result of adaptation in motion-sensitive direction-selective neurons in the brain. Viewing motion upward, for example, serves to adapt upward-selective neurons in MT, temporarily depressing their firing rate. Following adaptation to upward motion, a stationary stimulus will appear to drift downward (in the direction opposite of adaptation). This same phenomenon has been observed when subjects simply imagine motion in one direction and are then tested on a real motion stimulus (Winawer et al., 2005). Viewing still images that imply motion (e.g., photos of sprinters in mid leap) also produces such adaptation (Winawer, Huk, & Boroditsky, in press). These results demonstrate that imagining motion activates (and adapts) the very same direction-selective neurons as are involved in normal motion perception.

In this paper we ask whether the representations derived in the course of normal language processing also interact with perceptual processing. When people hear a story that describes motion, do they naturally form the same kinds of representations as when asked to vividly imagine motion or when simply inferring motion from a frozen-motion photograph? In our study, people read a story that described motion either upward or downward and then were asked to interpret an unrelated ambiguous image. The figure (shown in Figure 1) could be seen as a bird flying upward or downward (the participants were simply asked to "draw a worm in the bird's beak"). Would reading a story describing motion upward, for example, bias the way people interpreted an unrelated ambiguous figure? And if so, which way would the influence go?

Some researchers have suggested that language processing involves simulating the visual scenes being described (Barsalou, 1999; Bergen, Lindsay, Matlock, & Narayanan, 2007; Gallese & Lakoff, 2005; Glenberg & Kaschak, 2002; Matlock, Ramscar, & Boroditsky, 2005; Richardson, Spivey, Barsalou, & McRae, 2003; Zwaan, Madden, Yaxley, & Aveyard, 2004). The simulations on this proposal re-enact the same neural patterns of firing that would occur if the visual scene being described were actually being perceived. On a very radical version of this proposal, hearing a story about downward motion would activate the same neurons in visual cortex as are involved in seeing downward motion. In this case, downward-selective neurons in the motion-sensitive area MT, for example, would be activated when reading about a mudslide or a waterfall. On less radical versions of this proposal, processing language might only partially re-enact perceptual representations, or re-enact them at a higher more abstract level of processing not necessarily involving low-level visual processing areas. An alternative view is that representations created in the process of normal language comprehension do not necessarily share processing with or interact with perceptual states (Anderson, 1978; Fodor & Pylyshyn, 1988).

If mental images generated during normal language comprehension share very low-level properties with perception, then processing language about motion might induce low-level visual phenomena such as visual motion adaptation or the motion after-effect. If this is the case, participants who read a story about downward motion may become more likely to see the ambiguous image as moving in the direction opposite of adaptation. Another possibility is that mental images generated through language interact with perceptual processing, but at a higher more abstract level. If this is the case we may expect motion language to bias people's performance in perceptual tasks, but not necessarily through low-level mechanisms like motion adaptation. The third possibility is of course that processing motion language does not generate mental images or at least not the sort that interact with or influence perceptual processes. The experiments presented in this paper were designed to explore these three possibilities.

Previous Evidence:

Previous research has suggested that people spontaneously and non-consciously create mental images in everyday interactions, and that these images share some of the same properties as when people are explicitly asked to imagine (Barsalou, 1999; Bergen et al., 2007; Gallese & Lakoff, 2005; Glenberg & Kaschak, 2002; Matlock et al., 2005; Richardson et al., 2003; Zwaan et al, 2004). Language is one domain in which mental imagery seems particularly useful. People often talk about objects and events that are not in the immediate environment, so having a mechanism that enables perceptual simulation in the absence of any sensory stimulus might help to increase the salience of sparsely represented features or provide additional cues to memory.

One line of evidence suggesting that people perceptually simulate linguistic input comes from people's spontaneous eye movements during both language processing and imagery. When imagining scenes or listening to stories describing visual scenes, people spontaneously move their eyes in ways that would be consistent with visually exploring that kind of scene (Spivey & Geng, 2001; Spivey, Tyler, Richardson, & Young, 2000). For example, when hearing stories about canyons or skyscrapers people make vertical eye-movements even in the absence of any visual stimulus (Spivey & Geng, 2001). The same consistent patterns of visual exploration have been found when people are processing fictive motion language (e.g., the fence runs through the field) where there is no literal motion (Richardson & Matlock, 2007). Processing spatial meaning, whether concrete or abstract, appears to recruit low-level mechanisms of perceptual exploration.

Language comprehension has not only been shown to elicit what appears to be active perception in the absence of any perceptual stimulus, but it has also been shown to affect processing of perceptual stimuli that bear some resemblance (either in gross structure or specific content) to the described scene (e.g., Bergen et al., 2007; Richardson et al., 2003; Meteyard, Bahrami, and Vigliocco, 2007; Zwaan et al., 2004).

Listening to sentences appears to bring perceptual mechanisms online to the extent that they can affect concurrent perceptual processing. Does in-the-moment perceptual imagery triggered during language comprehension have lasting perceptual consequences? Might these consequences, for example, affect perception in subsequent tasks and on unrelated visual stimuli? And if so, in what direction? Previous work makes two opposite predictions.

One documented phenomenon regarding visual motion is direction-specific priming (Pantle, Gallogly, & Piehler, 2000). Viewing apparent motion in one direction biases participants to perceive a subsequent, ambiguously moving stimulus as moving in that same direction. Moreover, Bernstein and Cooper (1997) demonstrated that ambiguous images that appear to move in a particular direction are more likely to be disambiguated in a way that makes them face the direction of motion. These results predict that an ambiguous perceptual stimulus presented just after reading a description of motion in a single direction might appear to move and/or face that same direction.

Research on the motion after-effect on the other hand might make the opposite prediction. Adapting to visual motion in one direction causes an after-effect, such that a stationary stimulus viewed following adaptation is seen as moving in the opposite direction of the adapting motion. Adapting to motion upward for example, will make a subsequent stationary stimulus appear to drift downward. This kind of motion adaptation has been found not only for real and apparent motion, but also for implied and imagined motion (Winawer et al., in press; Winawer et al., 2005). If imagined motion can produce a motion after-effect, then it is possible that increasingly abstract forms of processing also have this capability. If processing linguistic descriptions of motion in a particular direction creates the kind of mental images that produce a motion after-effect, then perhaps reading about motion upward would cause people to see the ambiguous figure as moving downward.

Experiment 1 is designed to examine whether perceptual phenomena, such as priming or adaptation, that result from watching prolonged motion in a single direction also emerge while understanding stories depicting literal motion. Participants are first given a story to read, followed by a perceptual task to perform. The story is written from the perspective of the participant, and in it the participant watches an elevator move either upward or downward. The subsequent perceptual task requires participants to visually interpret an ambiguous, monochromatic image of a bird (Tinbergen, 1951). The figure can be seen as a goose flying in one direction or as a hawk flying in the opposite direction. The bird in our study is oriented vertically on the page so that one interpretation of the image yields an upward-facing bird, and the other interpretation of the image yields a downward facing bird. The story participants read prior to making the perceptual interpretation makes no mention of any type of bird, but it does describe either upward or downward motion. The question is whether reading a story describing directional motion will increase the likelihood of one perceptual interpretation versus another.

There are three ways in which reading a story about motion could affect which direction the ambiguous bird appears to face. One possibility is that language processing will have no effect on perception. We might expect such a null effect if language processing in this case does not successfully evoke imagery, or if imagery has no effect on orthogonal and/or non-concurrent spatial tasks. Another possibility is that processing a verbal description of motion will lead to a congruency effect in the perceptual task. That is, the direction in which the ambiguous image appears to face will match the direction of motion described in the story. Such a result might be obtained if higher-level perceptual representations created by the story exert top-down influence on the perceptual task (although there are possible low-level mechanisms, such as sustained sub-threshold activation of visual-motion areas from language comprehension during the perceptual task). The third possibility is that processing a verbal description of motion will lead to an incongruency effect in the perceptual task. That is, the direction in which the ambiguous image appears to face will mismatch the direction of motion in the story. Such a result might be obtained if participants adapt to the direction of motion depicted in the story, causing the bird image to appear to move in the opposite direction.

The study was designed to establish whether and how processing a verbal description of motion will affect the visual interpretation of an unrelated stimulus. The direction of the effect will help inform our understanding of which perceptual mechanisms, if any, might be recruited during language comprehension.

Experiment 1: Literal Motion

Method

Participants

Four hundred and sixty-five undergraduate students from Stanford University and University of California Merced participated in the study for course credit.

Materials

Participants completed the task on paper as part of a large questionnaire packet that contained many unrelated tasks. Subjects were instructed: 'Please read the following paragraph:' The paragraphs used are shown in Table 1.

Table 1: Stories read by participants in Experiment 1.

Upward Story You are standing on the 29th floor of an artsy 57-story building looking into a beautiful atrium. You notice a group of third-grade children beginning a treasure hunt on the first floor. They pile into the giant glass elevator across from you with the first clue in hand. You watch as they solve the first clue which sends them to the 9th floor for the next one. From there, they have to rush to the 20th floor. From the 20th floor, they follow the clue to the 29th floor. They solve the clue on the 29th floor and then have to hurry to the 38th floor. From the 38th floor, the clue sends them to the 49th floor. The final clue sends them from the 49th floor all the way to the 57th floor, where they excitedly collect their prize!
Downward Story You are standing on the 29th floor of an artsy 57-story building looking into a beautiful atrium. You notice a group of third-grade children beginning a treasure hunt on the first floor. They pile into the giant glass elevator across from you with the first clue in hand. You watch as they solve the first clue which sends them to the 49th floor for the next one. From there, they have to rush to the 38th floor. From the 38th floor, they follow the clue to the 29th floor. They solve the clue on the 29th floor and then have to hurry to the 20th floor. From the 20th floor, the clue sends them to the 9th floor. The final clue sends them from the 9th floor all the way to the first floor, where they excitedly collect their prize!

One story described upward motion while the other story described downward motion. Each subject read only one story. Both stories were written in the second person (i.e. from the perspective of the observer). In both stories, the participant was anchored at the middle floor of a tall building where he or she watched an elevator move. In the first story, the elevator started at the bottom of the building and moved all the way to the top, passing the participant along the way. In the second story, the elevator started at the top of the building and moved all the way to the bottom, passing the participant along the way. In both stories, the elevator's trajectory was depicted via changing floor numbers only. As a result, neither directional prepositions nor directional verbs were necessary to establish upward or downward motion. Rather, the directionality of the story emerged at the sentence level.

Both stories were followed by the same comprehension question: 'Do the children collect any prizes before the final floor? YES NO'. This question was included to test for basic story comprehension to make sure participants read the story. Participants who incorrectly circled 'no' were excluded from subsequent analyses.

On a separate page, participants saw an ambiguous figure, centered on the page. The image could either be interpreted as a hawk facing one direction or a goose facing the opposite direction. The figure was positioned vertically on the page such that one could interpret it as a bird flying either upward or downward. Whether the goose or the hawk pointed upward was counterbalanced across participants and across story types.

Figure 1: Ambiguous goose/hawk images.

Below the image of the bird were the instructions: 'Please draw a worm in the bird's beak.' This was done to avoid explicitly asking subjects about their interpretation of the ambiguous figure and to not draw attention to the ambiguity. Participants who drew the worm at the top of the image were coded as having made an 'upward' interpretation of the image, and participants who drew the worm at the bottom of the image were coded as having made a 'downward' interpretation of the image.

Results

87 participants either omitted or incorrectly answered the comprehension question and were excluded from all analyses. Of those remaining, 22 participants noticed that the bird image had two possible interpretations (i.e. drew worms in both beaks) and were also excluded.

Overall, participants were equally likely to interpret the image as a goose or a hawk. Slightly more participants (52%) made the goose interpretation than the hawk interpretation (48%), but this difference was not reliable, $\chi^2(1, N = 356) = .55$, $p > .45$. This manipulation check confirms that the goose/hawk image is truly ambiguous.

There was an overall bias for participants to see a downward facing bird (57%) rather than an upward facing bird (43%), $\chi^2(1, N = 356) = 7.60$, $p < .01$.

Importantly, participants' interpretation of the ambiguous bird image was influenced by the direction of the story they had just read. Participants were significantly more likely to see a bird facing in the same direction as the motion in the story (57%) than the opposite direction (43%), $\chi^2(1, N = 356) = 7.02$, $p < .01$

Discussion

Participants in this study read stories describing upward or downward literal motion prior to disambiguating an image of a bird that could be perceived as upward facing or downward facing. The goal of the study was to see whether there would be any transfer from spatial language to spatial perception, and, if so, in which way. One possibility was that language might have a priming effect on perception. That is, reading a story describing downward motion might bias participants to see a downward facing bird. Another possibility discussed was that language might have an adaptation effect on perception. That is, reading a story describing downward motion might adapt participants to downward motion, hence biasing them to see an upward facing bird. The results show a congruity effect and support the "perceptual priming" prediction. Participants were reliably more likely to perceive a bird to be facing the same direction as the story they had just read.

One possible explanation for the bias in people's perceptual interpretation is that rising and falling numbers in the stories are themselves capable of generating abstract notions of "UP" or "DOWN". Thus the priming effect found in Experiment 1 might result without any description of concrete motion in the stories. To better understand the contributions of motion language and number, Experiment 2 tests increasingly abstract descriptions of motion while keeping constant the rising and falling numbers in the stories. Is number alone capable of interacting with perception, or is some degree of linguistic motion required?

The extent to which linguistic descriptions need be concrete in order to bias perception is another question left unaddressed by Experiment 1. Participants brought with them considerable visual experience with the movement of the objects depicted by the stories. Perhaps our ability to generate simulations of the type that prime perception is limited to domains that we have direct sensory experience with. Or perhaps even abstract domains evoke such simulations. The linguistic descriptions in Experiment 2 describe the upward or downward movement of stock prices – a domain which people have no visual experience with. Hence, Experiment 2 is suited to test both whether linguistic motion is sufficient and whether *literal* linguistic motion is necessary for forming mental states that prime perception.

Experiment 2: Metaphorical Motion

In experiment 2, participants first read a story that described either upward or downward metaphorical motion. The stories included the same rising and falling numbers as used in the elevator stories in Table 1, but, instead of describing physical motion, the numbers described the moving price of a stock (either increasing from 1 to 57, or decreasing from 57 to 1). After reading the story, participants were asked to interpret the ambiguous goose/hawk image.

Method

Participants

Three hundred and forty-eight undergraduate students from Foothill College (Los Altos Hills, CA) and University of California Merced participated in the study for course credit.

Materials

The procedure for Experiment 2 was identical to that in Experiment 1. The two experiments differed in the stories people read prior to interpreting the ambiguous figure. While participants in the first experiment read about a rising or falling elevator, participants in the second experiment read about rising or falling stock prices. The paragraphs used are shown in Table 2.

Table 2: Stories read by participants in Experiment 2.

Upward Story
It is your company's first day on the stock market and you are watching carefully to see what happens with the price. The stock opens at 1 dollar a share. Before you know it, the price goes to 9 dollars. From there the price goes to 20 dollars. From 20 dollars, the stock rushes to 29 dollars. From 29 dollars, the stock goes to 38 dollars. From 38 dollars, the price rushes to 49 dollars. Finally, the price goes all the way to 57 dollars.

Downward Story
It is your company's first day on the stock market and you are watching carefully to see what happens with the price. The stock opens at 57 dollars a share. Before you know it, the price goes to 49 dollars. From there the price goes to 38 dollars. From 38 dollars, the stock rushes to 29 dollars. From 29 dollars, the stock goes to 20 dollars. From 20 dollars, the price rushes to 9 dollars. Finally, the price goes all the way to 1 dollar.

Both stories in Table 2 were followed by the same comprehension question: 'In the story you just read, was it your company's first day on the market? YES NO'.

214 participants were tested on Version 1 of the metaphorical stories (as seen in Table 2). These stories contained no directional verbs and were designed to closely mirror the literal stories from Experiment 1. 78 participants were tested on a slightly different version (Version 2) of the metaphorical stories in which the stock prices 'plummeted' or 'skyrocketed'. These stories were designed with additional cues to the depicted motion trajectory, with the direction of motion encoded both at the verb and sentence levels. 54 participants were tested on a third version of the metaphorical stories adapted from Version 2. These stories depicted rising or falling championship ratings, in which low ratings were positive and high ratings were negative. Ratings in Version 3 'plummeted' from 49 to 57, whereas stock prices in Version 2 'skyrocketed' from 49 to 57. These stories were designed to de-correlate the spatial information provided by the verbs and numbers in version 2.

Results

37 participants in Experiment 2 either omitted or incorrectly answered the comprehension question and were excluded from all analyses. 29 participants noticed that the bird image had two possible interpretations (i.e. drew worms in both beaks) and were also excluded.

The pattern of results did not significantly differ across the three versions of Experiment 2, $\chi^2(1, N = 282) = .260$, $p > .80$, so the data from all metaphorical stories were combined for subsequent analyses.

Participants were equally likely to interpret the bird image as a goose or a hawk. Slightly more participants (53%) made the goose interpretation than the hawk interpretation (47%), but this difference was not reliable, $\chi^2(1, N = 282) = 1.15$, $p > .25$, again confirming the ambiguity of the image.

There was an overall bias for participants to see a downward facing bird (60%) rather than an upward facing bird (40%), $\chi^2(1, N = 282) = 10.30$, $p < .01$.

Importantly, participants' interpretation of the ambiguous goose/hawk image was not influenced by the direction of the metaphorical story they had just read. Participants were slightly less likely to see a bird facing in the same direction as the motion in the story (48%) than the opposite direction (52%), but this difference was not reliable, $\chi^2(1, N = 282) = 7.02$, $p > .45$. The pattern of results found in Experiment 2 differs reliably from the pattern found in Experiment 1, $\chi^2(1, N = 638) = 5.29$, $p < .05$.

Discussion

Participants in Experiment 2 read stories describing upward or downward metaphorical motion prior to disambiguating an image of a bird that could be perceived as upward facing or downward facing. One goal of the study was to see whether there would be any transfer from metaphorical spatial language to spatial perception, suggesting that linguistic descriptions need not refer to physical motion in order to interact with perception. The results show no bias in participants' interpretation of the ambiguous stimulus as a function of reading about metaphorical motion in a particular direction. This finding is consistent with previous reports of concrete linguistic information priming perception, while abstract linguistic information does not (Bergen et al., 2007; Boroditsky, 2000). Furthermore, these results suggest that increasing and decreasing numbers alone are not sufficient to produce the perceptual bias reported in Experiment 1.

General Discussion

Together, Experiments 1 and 2 suggest that reading stories describing literal visual motion (but not metaphorical motion) generates representations that prime perception in a subsequent, unrelated task. Understanding the exact mechanisms through which this priming takes place is the subject of future work. One possibility is that reading a story that describes upward motion simply activates an abstract notion of "UP" which can then bias many aspects of unrelated visual and other behavior. However, the abstract notion of "UP" generated by the metaphorical stories in Experiment 2 was insufficient in biasing perception. Another possibility is that reading about upward motion creates more perceptual representations, and the patterns of activation create a bias in future perceptual processing.

The apparent recruitment of lower-level perceptual processes in Experiment 1 but not Experiment 2 suggests that the mechanisms that govern the comprehension of literal versus metaphorical linguistic motion might differ in some respect. An alternative possibility is that the same mechanisms are recruited for simulating both literal and metaphorical motion, but the simulations themselves have different timecourses. Richardson and Matlock (2007) demonstrated that figurative language takes longer to process than literal language. This finding suggests that the length of the delay between reading the story and the perceptual test might differ for the literal and metaphorical stories in the present study. Probing at just the right time might be critical for obtaining an effect. Probing too early might interrupt an ongoing simulation, and probing too late might risk excessive decay of the prime. Furthermore, the point in the language-processing stream at which the perceptual probe is administered might matter for whether perceptual adaptation or perceptual priming is found. In the present studies, this delay was not only unsupervised, but it was also modulated by the time participants spent answering the comprehension question. Ongoing studies explore whether varying this delay might yield a response profile different from that observed in the present studies.

Conclusions

Reading descriptions of literal motion, but not metaphorical motion, affected the way people perceived an unrelated visual image presented immediately after processing the motion language. Specifically, participants showed a consistent bias to interpret an ambiguous visual image as facing in the same direction as the motion described in an unrelated story. This congruity effect suggests that there is overlap between the representations and processes involved in understanding language and in interpreting visual images. The direction of the effect and its interaction with the concreteness of the language helps us rule out some candidate mechanisms. It appears that people do generate mental images of a sort in the course of normal language processing, and the outcomes of language processing can interact with perception. Future research will help us understand more about the nature of these representations and how they interact.

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