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A Motion Aftereffect from Literal and Metaphorical Motion Language: Individual Differences

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Abstract

Do people spontaneously form visual mental images when understanding language, and if so how truly visual are these representations? We test whether processing linguistic descriptions of motion produces sufficiently vivid mental images to cause direction-selective motion adaptation in the visual system (i.e., cause a motion aftereffect illusion). We tested for motion aftereffects (MAEs) following explicit motion imagery, and after processing literal or metaphorical motion language. Intentionally imagining motion produces an aftereffect in the overall sample with some participants showing a greater aftereffect than others. We then find that participants who show the strongest imagined motion aftereffects also show aftereffects in the natural course of processing motion language (without instructions to imagine). Individuals who do not show strong motion aftereffects as a result of imagining motion also do not show them from processing motion language. However, the aftereffect from language gained strength as people were exposed to more and more of a motion story. For the last two story installments (out of 4), understanding motion language produced reliable MAEs across the entire sample. The results demonstrate that processing language can spontaneously create sufficiently vivid mental images to produce direction-selective adaptation in the visual system. The timecourse of adaptation suggests that individuals may differ in how efficiently they recruit visual mechanisms in the service of language understanding. Further, the results reveal an intriguing link between the vividness of mental imagery and the nature of the processes and representations involved in language understanding.

Keywords: embodiment, language comprehension, perception, motion aftereffect, individual differences

Introduction

A good story can draw you in, conjure up a rich visual world, give you goose-bumps, or even make you feel like you were really there. To what extent is hearing a story about something similar to really witnessing it? What is the nature of the representations that arise in the course of normal language processing? Do people spontaneously form visual mental images when understanding language, and if so how truly visual are these representations? In this paper we make use of the motion aftereffect illusion to test whether processing linguistic descriptions of motion produces sufficiently vivid mental images to cause direction-selective adaptation in the visual system (i.e., cause a motion aftereffect).

A number of findings suggest that people do spontaneously engage in imagery during language comprehension and that processing language affects performance in subsequent perceptual tasks (e.g., Bergen, Lindsay, Matlock, & Narayanan, 2007; Meteyard, Bahrami, & Vigliocco, 2007; Richardson, Spivey, Barsalou, & McRae, 2003; Rinck & Bower, 2000; Rinck, Hähnel, Bower, & Glowalla, 1997; Spivey & Geng, 2001; Stanfield & Zwaan, 2001; Zwaan, Madden, Yaxley, & Aveyard, 2004; Zwaan, Stanfield, & Yaxley, 2002;).

What mechanism might underlie these interactions between linguistic processing and perception? The explanation frequently offered is that the representations generated during the course of language comprehension share processing resources with perception, recruiting some of the very same brain regions (Barsalou, 1999). As evidence for this possibility fMRI measures have revealed that classically 'perceptual' brain areas are recruited in service of language comprehension (e.g., Saygin, McCullough, Alac, & Emmorey, 2010). While these findings are consistent with the hypothesis, questions remain. The spatial resolution of current fMRI technology is coarse. A typical voxel (the smallest unit of measurement) may include 100,000 neurons. It is possible then that what appear in fMRI to be the same regions activated in linguistic and visual tasks are in fact neighboring (or closely interleaved) but distinct neural populations, potentially with quite different computational properties.

One powerful paradigm for determining whether neural populations involved in particular tasks indeed overlap is that of adaptation. In this paper, we make use of one such adaptation measure, the motion aftereffect (MAE). The MAE arises when direction-selective neurons in the human MT+ complex lower their firing rate as a function of adapting to motion in their preferred direction. The net difference in the firing rate of neurons selective for the direction of the adapting stimulus relative to those selective for the opposite direction of motion produces a motion illusion. For example, after adapting to upward motion, people are more likely to see a stationary stimulus or a field of randomly moving dots as moving downward, and vice versa (e.g., Blake & Hiris, 1993). To quantify the size of the aftereffect, one can parametrically vary the degree of motion coherence in the test display of moving dots (as in Blake & Hiris, 1993). The amount of coherence necessary to null the MAE (i.e. to make people equally likely to report the motion as upward or downward) provides a nice measure of the size of the aftereffect produced by the adapting stimulus.

Winawer, Huk, and Boroditsky (2008, 2010) adapted this technique to test for MAEs after participants either viewed still images implying motion (e.g., a runner in mid-leap), or simply imagined motion without any visual stimulus. Both implied and purely imagined motion produced reliable MAEs. These studies support fMRI findings suggesting the hMT+ complex is recruited in the service of mental imagery (Goebel, Khorram-Sefat, Muckli, Hacker, & Singer, 1998; Grossman & Blake, 2001), and further suggest that this activation is driven by direction-selective neurons.

Here we explore whether natural language comprehension can likewise produce MAEs. To the extent that people spontaneously engage in imagery in service of language comprehension, understanding motion language should yield MAEs (albeit likely weaker than those produced during explicit, effortful imagery). The present study was designed to test this prediction. Participants listened to stories describing motion in a particular direction and then judged the direction of a moving field of dots. The direction in which motion language affects subsequent motion perception speaks to the mechanisms underlying language comprehension. One possibility is that motion language adapts the same direction-selective mechanisms that subserve motion perception; this would cause people to see a real visual stimulus (e.g., dynamic dots) as moving in a direction *opposite* to that described in the adapting language. Another possibility is that understanding motion language recruits higher-level convergence areas that process visual motion, resulting in a bias to see dot motion in the *same* direction. Such a congruence effect is reported by Sadaghiani et al (2009) who showed that hearing the words ‘right’ and ‘left’ biased participants to see an apparent motion stimulus as moving in the same direction. fMRI data revealed that this audiovisual interaction was driven more by activity in the anterior intraparietal sulcus (IPS) than hMT+. A third possibility is of course that motion language does not recruit visual motion processing resources of any kind, resulting in no bias in dot motion perception.

Further, the direction and extent of transfer from language to perception may depend on an individual’s visual motion imagery ability. People differ from one another in mental imagery ability, and these differences correlate with individual differences in spatial tasks and object perception (Kozhevnikov, Kosslyn, & Shephard, 2005). In Winawer et al (2010), most but not all participants showed MAEs as a function of imagining motion, and the degree of adaptation differed across people. We reasoned that people who show stronger adaptation as a result of imagining, should be more likely to show adaptation as a result of understanding motion language. It would be reasonable to expect that individuals who do not show an MAE as a result of explicitly imagining motion should also not show one as a result of processing motion language. To test for this possibility, we tested each participant both in an explicit visual imagery condition (as in Winawer et al (2010)), and in conditions where linguistic motion was used as an adapting stimulus. This allowed us to compare the effects of language for each participant with those of explicit imagery.

Finally, the present study is designed to test whether literal and metaphorical descriptions of motion recruit similar perceptual processes. To this end, we contrasted literal motion stories that described the motion of physical objects with metaphorical motion stories that used motion verbs to talk about changes in abstract entities (e.g. rising and falling stock prices).

Experiment

The experiment consisted of five parts: (1) a baseline task in which we measured participants’ motion direction sensitivity, (2) a familiarization task in which participants viewed the stimuli to be imagined later in the study (3) the main experimental task in which we tested for MAEs following imagining motion or listening to stories describing motion, (4) a memory task in which we measured participants’ recognition memory for the stories, and (5) an exit questionnaire in which we ascertained participants knowledge of the motion aftereffect and their explicit predictions about the direction of effects.

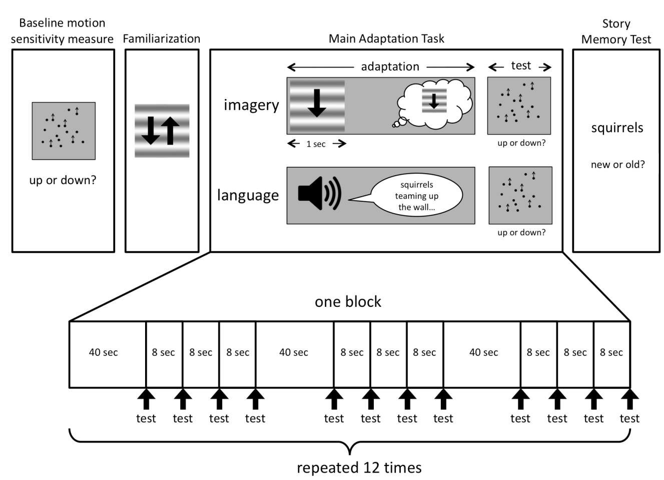

Figure 1: Schematic of experimental design highlighting the block and trial structure of the main adaptation task. In the imagery blocks, an upward or downward facing arrow superimposed on a static image of the grating indicated the direction in which to imagine the stripes moving. This cue faded slowly over the course of a second. Once the cue disappeared completely, a flickering fixation cross appeared at the center of the screen. Participants were instructed to fixate on the cross while imagining the stripes and to use the rate of the flicker to help them remember how fast the stripes should move. Participants were also instructed to use the fixation cross as a cue for when to start and stop imagining motion. In language blocks, participants listened to stories using headphones while fixating a dot centered on the monitor. Participants were told to listen carefully to the stories, as there would be a memory test. They were not instructed to imagine.

Methods

Participants Sixty Stanford students participated in exchange for payment.

Stimuli and Procedure

Main Experimental Task: The task design, procedure, and visual stimuli used were modeled on those used in Winawer et al (2010). On each trial participants judged the direction of dot motion after either listening to stories describing motion or engaging in explicit visual motion imagery. Trials were presented in 12 interleaved blocks. There were 6 block types, 3(motion type: imagined motion, literal motion, or metaphorical motion) by 2(motion direction: upward or downward).

Adaptation Stimuli: In the literal motion condition the stories used motion language to describe the movement of physical objects (e.g., squirrels, ping-pong balls). In the metaphorical motion condition, the stories used motion language to describe changes in abstract entities (e.g. stock prices, emotions). 12 literal and 12 metaphorical stories were used with an upward and a downward version for each, yielding a total of 48 stories. Individual participants heard 24 stories (either the upward or the downward version of each story, but not both). Example stories are in Table 1. In the imagery condition, participants were instructed to imagine upward and downward moving gratings (as in Winawer et al. (2010)). The trial structure for the language and imagery conditions is depicted in Figure 1.

Table 1: Sample stories heard by participants.

Literal Motion: Upward Story (Four installments)

1. You are running a psychology experiment in which you have trained hundreds of squirrels to race each other up a wall for a piece of food. Now you want to see what happens when they are all released at the foot of the wall at once. You watch through a small window in the next room as the cages are opened and the squirrels leap onto the wall in a frenzy. The little fur balls scurry up the wall in one relentless stream, despite obvious defeat in the race. Zip! The brown creatures surge up the wall with amazing agility. You see the same behavior in squirrel after squirrel – one swift jump onto the wall and an instantaneous burst upward. Zoom! The squirrels rush up the wall like a giant current. As if in a trance, the squirrels swiftly stream past your eyes in their race for the top of the wall.

2. Zoom! More and more squirrels jump onto the wall and scurry upwards. You watch them course up the wall in a blur.

3. The squirrels continue to sprint upwards in a flash. They spout onto the wall and surge directly toward the top.

4. Your eyes remain focused on the mob of squirrels teeming up the wall. You can no longer pick out individuals as they dash for the top.

Literal Motion: Downward Story (Four installments)

1. You are running a psychology experiment in which you have trained hundreds of squirrels to race each other down a wall for a piece of food. Now you want to see what happens when they are all released at the top of the wall at once. You watch through a small window in the next room as the cages are opened and the squirrels descend onto the wall in a frenzy. The little fur balls scurry down the wall in one relentless stream, despite obvious defeat in the race. Zip! The brown creatures surge down the wall with amazing agility. You see the same behavior in squirrel after squirrel – one swift drop onto the wall and an instantaneous burst downward. Zoom! The squirrels rush down the wall like a giant current. As if in a trance, the squirrels swiftly stream past your eyes in their race for the bottom of the wall.

2. Zoom! More and more squirrels drop onto the wall and scurry downwards. You watch them course down the wall in a blur.

3. The squirrels continue to sprint downwards in a flash. They pour onto the wall and surge directly toward the bottom.

4. Your eyes remain focused on the mob of squirrels teeming down the wall. You can no longer pick out individuals as they dash for the bottom.

Metaphorical Motion: Upward Story (Four installments)

1. You are standing in the middle of the trading floor at the New York stock exchange one busy morning. The room is buzzing with announcements of rising stock prices. First JP Morgan rockets dramatically. Accenture and Delaware blaze to new heights. Suddenly, Lincoln's stock surges, along with Time Warner. You hear animated reports of Toyota, Coca Cola, and The Gap going sky-high! You can hardly believe it, but Google's stock soars higher than ever. Walmart zips skyward, too. All morning, you marvel at the continually spiking stocks!

2. You hear that Ford and Exxon Mobile are really ramping up. Hewlett Packard is erupting too!

3. Next you hear that Nokia is boosting quickly. Likewise, Sprint, AT&T and Verizon are surging dramatically.

4. Stock prices heighten rapidly for Proctor and Gamble as well as Clorox. McDonalds' stock also jets to new heights!

Metaphorical Motion: Downward Story (Four installments)

1. You are standing in the middle of the trading floor at the New York stock exchange one busy morning. The room is buzzing with announcements of falling stock prices. First JP Morgan plummets dramatically. Accenture and Delaware tumble to new lows. Suddenly, Lincoln's stock plunges, along with Time Warner. You hear agitated reports of Toyota, Coca Cola, and The Gap hitting record lows! You can hardly believe it, but Google's stock sinks lower than ever. Walmart zips downward, too. All morning, you marvel at the continually diving stocks!

2. You hear that Ford and Exxon Mobil are really sinking down. Hewlett Packard is taking a nose-dive too!

3. Next you hear that Nokia is slumping quickly. Likewise, Sprint, AT&T and Verizon are tumbling dramatically.

4. Stock prices level rapidly for Proctor and Gamble as well as Clorox. McDonalds' stock also plunges to new lows!

Block structure: In the two language conditions, each block consisted of 3 stories with 4 installments each, for a total of 12 trials per block. Each story was broken up into one longer paragraph and three shorter 'top-up' installments so that multiple measurements could be collected for each story. The longer installments lasted on average 40.00 seconds, and the top-up installments 8.29 seconds. The imagery blocks mirrored this structure. Participants imagined motion for 40 seconds, and on the three subsequent 'top-up' trials, participants imagined motion for 8 seconds. This pattern was repeated 2 more times within the block to parallel the 3 stories used per block in the language conditions.

Adaptation Test: Following each story or imagery installment, participants judged the direction of motion coherence in a field of moving dots without feedback. The moving dot stimuli were presented as in Winawer et al. (2010). Each dot display had net motion coherence either up or down. For each subject, two coherence values were sampled: 12.5% and 25% of the coherence necessary for asymptotic performance (as assessed individually for participants in the baseline task). Coherence and direction of motion were fully crossed and balanced across trials and participants.

Exit questionnaire: At the end of the experiment we ascertained participants' familiarity with the motion aftereffect and also asked them to generate a prediction about which way they thought the effect would go. Participants were asked: *Have you ever heard of the Motion Aftereffect or Waterfall Illusion?* and *After viewing upward motion, which way would you expect a static image to appear to move?*

Results

The distance between the null points of the logistic fits for upward and downward motion (normalized coherence values at which participants are equally likely to report upward and downward motion) was computed for both the imagined and linguistic motion conditions for each participant. Positive values reflect adaptation. Six participants whose results exceeded three standard deviations from the mean for all participants were excluded from subsequent analyses. The literal and metaphorical linguistic motion conditions did not significantly differ from one another ($t(53) = 0.219$, $p > .5$), and so were combined for analysis. Results are plotted in Figures 2-4.

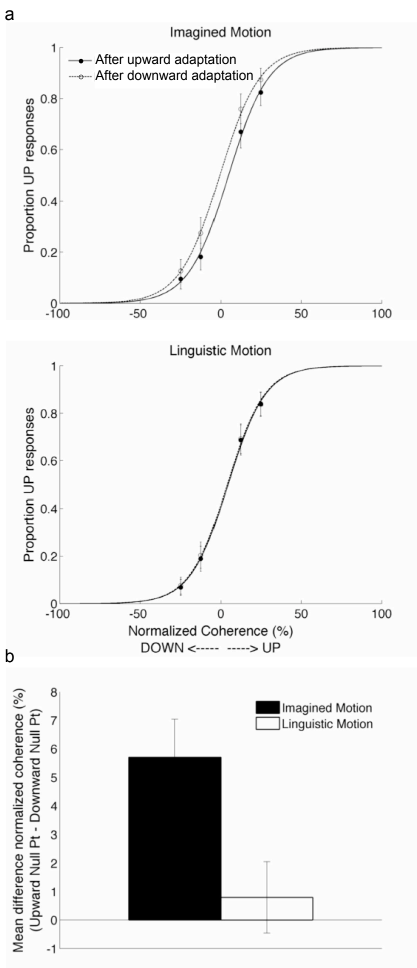

Figure 2: (a) Proportion of "UP" responses following imagined motion and linguistic motion across all participants. Error bars represent standard error. (b) Separation in motion response functions for imagined and linguistic motion across all participants. Positive values reflect adaptation. Error bars denote s.e.m.

In the overall sample, participants showed a reliable MAE after imagining motion (*M* = 5.7% normalized coherence, *SD* = 9.8%) ($F(1,53) = 18.26$, $p < .001$) (replicating Winawer et al, 2010), but not after listening to motion stories (*M* = 0.8% normalized coherence, *SD* = 9.2%) ($F(1,53) = 0.40$, $p > .5$). The two conditions differed reliably from one another ($F(1,53) = 10.81$, $p < .005$).

We reasoned that individuals who do not show MAEs as a result of explicitly imagining motion should also not show them as a result of processing motion language. However, participants who do show MAEs from motion imagery may show them from processing motion language as well. Indeed, there was a significant correlation between the effects of motion imagery and motion language ($r(52) = .34$, $p < .02$), such that stronger adaptation from imagining motion predicted stronger adaptation from understanding motion language (Figure 3).

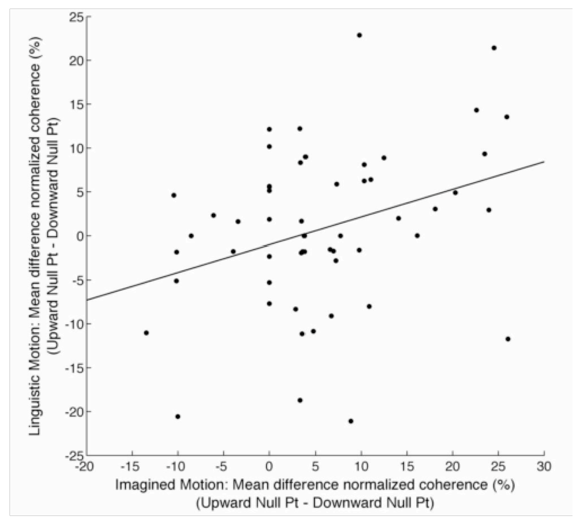

Figure 3: Correlation across all participants between the separation in motion response functions for imagined and linguistic motion, $r(52) = .34$, $p < .02$.

To confirm that participants who showed adaptation to imagined motion also showed it in response to linguistic motion, we sorted participants based on the magnitude and sign of the effect of explicit motion imagery and divided them into three groups of equal size (Imagery *Mdns* = 15.1%, 3.8%, -1.7%, and *SIQRs* = 6.6%, 1.6%, 5.0% normalized coherence) (Figure 4). We will refer to these as strong, weak, and no MAE groups respectively.

Indeed, the group that showed strong MAEs after explicitly imagining motion also showed reliable MAEs after listening to motion language (Language *Mdn* = 5.6%, *SIQR* = 4.7%) (n = 18, $p < .031$, sign-test, 2-tailed). There was no difference in the strength of this adaptation effect between the literal and metaphorical language conditions, n = 18, $p > .40$. The two groups that showed weak or no MAEs from imagery, did not show reliable MAEs from language: (*Mdn* = -1.7%, *SIQR* = 5.0%) (n = 18, $p > .05$), and (*Mdn* = 0.8%, *SIQR* = 5.1%) (n = 18, p > .5) for groups that showed weak or no MAEs respectively. The effects of language in the strongest MAE group differed reliably from the other two groups, $\chi^2(1, N=54)=7.27$, p<.01.

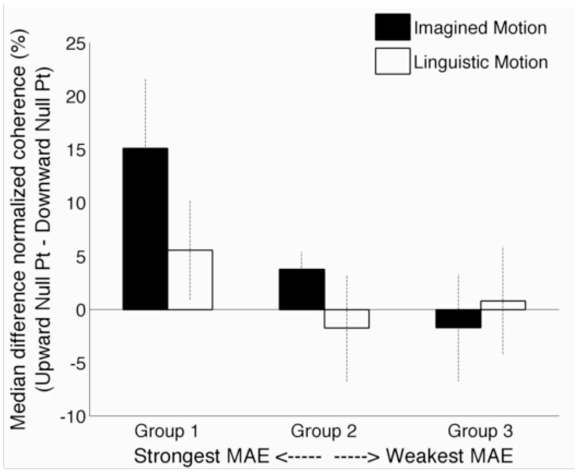

Figure 4: Participants were sorted based on the size of the aftereffect in the imagery condition and divided into three equal-sized groups. The plot shows the median separation between motion response functions for each group. Error bars denote SIQR.

To examine the timecourse of the MAE from imagined and linguistic motion, we subtracted the proportion of "up" responses following upward motion from those following downward motion across adaptation installments (e.g., the 4 installments of a story, or the analogous 4 imagery installments). The mean difference by installment across all participants is plotted in Figure 5. In the explicit imagery trials, the MAE appears after the initial 40-second installment of imagining (as would the MAE from real visual motion), and participants remain adapted for subsequent installments (there is no linear effect of installment, $F(1,53) = 0.076$, $p > .5$). In the two language conditions, however, the MAE does not emerge until later installments (there is a reliable linear effect of installment, $F(1,53) = 6.59$, $p < .05$). After the 3rd and 4th story installment, there is a reliable motion aftereffect including all participants, M=4.0%, SD = 12.7%; $F(1,53) = 5.42$, $p < .05$. Motion language appears to produce a reliable MAE across the entire sample only after sufficient exposure to each story.

These findings raise the possibility that individual differences in the MAE from linguistic motion reflect differences in how efficiently people recruit visual direction-selective mechanisms rather than qualitative differences in which mechanisms are recruited. Indeed, the linear effect of story installment does not differ among those who show strong, weak, and no MAEs from motion imagery ($F(2,51)=.144$, $p>.5$), with everyone showing the same trend toward more adaptation as they get further into the story.

Testing for effects of explicit bias: Of the 54 participants included in the analysis, 43 completed an exit questionnaire about their knowledge and predictions about the motion aftereffect (the remaining 11 omitted this portion of the study). Only three reported having heard of the motion aftereffect. Participants' expectations about the direction in which adapting to visual motion in one direction might affect subsequent visual processing did not reliably bias ($F(1,39) = 0.37$, $p>.50$) or interact with ($F(1,39) = 0.33$, $p>.50$) the effects of imagined and linguistic motion. This finding confirms that the results obtained in this study are not a product of participants' expectations or explicit biases regarding the direction of the effects.

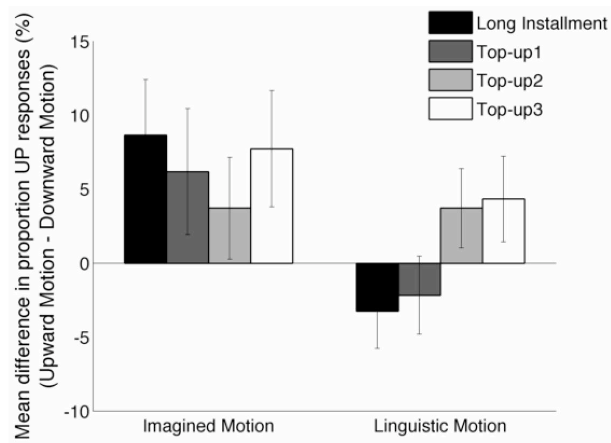

Figure 5: Mean difference in proportion upward responses following upward and downward motion across the four motion installments. The data are plotted for the overall sample. Positive values reflect adaptation, and error bars denote s.e.m.

Discussion

We tested whether processing linguistic descriptions of motion produces sufficiently vivid mental images to cause direction-selective motion adaptation in the visual system (i.e., cause a motion aftereffect illusion). We predicted that the perceptual consequences of processing language should depend on an individual's mental imagery ability. Imagery ability was operationalized as the extent to which explicit visual motion imagery produced an MAE in each participant. Put another way, imagery ability or vividness is the extent to which people recruit perceptual resources heavily enough to adapt them during explicit imagery.

We replicated previous work showing that intentionally imagining motion produces an aftereffect. We then found that participants who show the imagined motion aftereffect most strongly also show this aftereffect in the natural course of processing motion language (without instructions to imagine). The same effects held for both literal and metaphorical language. Individuals who did not show a motion aftereffect as a result of imagining motion also did not show an aftereffect from processing motion language overall. However, the aftereffect from language gained strength with the number of story installments. For the last two installments (out of 4), understanding motion language produced reliable MAEs across the entire sample. This finding suggests the possibility that individuals may differ in how efficiently they recruit visual mechanisms in service of language comprehension. Future work will examine the effects of systematically varying exposure to motion language and the degree of story immersion on the MAE. Participants' knowledge of the MAE and their explicit predictions about the direction that the MAE should go did not predict their pattern of results. This helps us ensure that the patterns observed were not simply due to participants' explicit biases or expectations.

A further question concerns the effects from metaphorical motion language. Some researchers have found that literal and metaphorical language produce similar transfer effects to perceptuo-motor tasks (e.g., Boulenger, Hauk, & Pulvermüller, 2009; Glenberg & Kaschak, 2002; Richardson et al., 2003), while others have found no evidence for transfer from metaphorical language (Bergen et al., 2007). In our study, literal and metaphorical motion language produced the same effects. Our stimuli and methods differ from previous studies in many ways. One potentially important difference is that our stimuli were connected narratives that built over time, whereas the studies just cited used isolated sentences. Our results suggest that for language processing to produce effects on low-level visual processing, a greater amount of exposure to or immersion in a connected narrative may be necessary.

The results of the present study demonstrate that at least for a subset of the population, processing language spontaneously creates sufficiently vivid mental images to produce direction-selective adaptation in the visual system. Future work will examine the source and possible cognitive consequences of the individual differences we observed. Why might some people be better able to recruit or effectively modulate the activity of sensory neurons through top-down processes? Further, are there resulting systematic differences in the content and nature of representations people form in the service of understanding language?

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References

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences, 22,* 577-660.

Bergen, B. K., Lindsay, S., Matlock, T., & Narayanan, S. (2007). Spatial and linguistic aspects of visual imagery in sentence comprehension. *Cognitive Science, 31,* 733-764.

Blake, R., & Hiris, E. (1993). Another means for measuring the motion aftereffect. *Vision Research, 33*, 1589-1592.

Boulenger, V., Hauk, O., & Pulvermüller, F. (2009). Grasping ideas with the motor system: semantic somatotopy in idiom comprehension. *Cerebral Cortex, 19,* 1905-1914.

Glenberg, A. M., & Kaschak, M.P. (2002). Grounding language in action. *Psychonomic Bulletin & Review, 9,* 558-565.

Goebel, R., Khorram-Sefat, D., Muckli, L., Hacker, H., & Singer, W. (1998). The constructive nature of vision: Direct evidence from functional magnetic resonance imaging studies of apparent motion and motion imagery. European Journal of Neuroscience, 10(5), 1563–1573.

Grossman, E. D., & Blake, R. (2001). Brain activity evoked by inverted and imagined biological motion. Vision Research, 41(10–11), 1475–1482.

Kozhevnikov, M., Kosslyn, S., & Shephard, J. (2005). Spatial versus object visualizers: A new characterization of visual cognitive style. *Memory and Cognition, 33*, 710-726.

Meteyard, L., Bahrami, B., & Vigliocco, G. (2007). Motion detection and motion verbs. *Psychological Science*, *18,* 1007-1013.

Richardson, D. C., Spivey, M. J., Barsalou, L. W., & McRae, K. (2003). Spatial representations activated during real-time comprehension of verbs. *Cognitive Science, 27,* 767–780.

Rinck, M., & Bower, G., H. (2000). Temporal and spatial distance in situation models. *Memory and Cogntion, 28,* 1310-1320.

Rinck, M., Hähnel, A., Bower, G., & Glowalla, U. (1997). *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*, 622-637.

Sadaghiani, S., Maier, J. X., & Noppeney, U. (2009). Natural, metaphoric, and linguistic auditory direction signals have distinct influences on visual motion processing. *Journal of Neuroscience, 29*, 6490 – 6499.

Saygin, A.P., McCullough, S., Alac, M., Emmorey, K. (2009). Modulation of BOLD response in motion sensitive lateral temporal cortex by real and fictive motion sentences. *Journal of Cognitive Neuroscience.* Early Access publication on Nov. 19, 2009, doi:10.1162/jocn.2009.21388.

Spivey, M., & Geng, J. (2001). Oculomotor mechanisms activated by imagery and memory: Eye movements to absent objects. *Psychological Research, 65,* 235-241.

Stanfield, R., & Zwaan, R. (2001). The effect of implied orientation derived from verbal context on picture recognition. *Psychological Science, 12,* 153-156.

Winawer J, Huk A, Boroditsky L. (2008) A motion aftereffect from viewing still photographs depicting motion. *Psychological Science, 19*, 276-283.

Winawer J, Huk A, Boroditsky L. (2010). A motion aftereffect from visual imagery of motion. *Cognition, 114*, 276-284.

Zwaan, R. A., Madden, C. J., Yaxley, R. H., & Aveyard, M. E. (2004). Moving words: dynamic representations in language comprehension. *Cognitive Science, 28,* 611-619.

Zwaan, R., Stanfield, R., & Yaxley, R. (2002). Language comprehenders mentally represent the shapes of objects. *Psychological Science, 13,* 168-171.