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Perception of Auditory Motion Affects Language Processing

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Abstract

Previous reports have demonstrated that the comprehension of sentences describing motion in a particular direction (towards, away, up, or down) is affected by concurrently viewing a stimulus that depicts motion in the same or opposite direction. We report three experiments that extend our understanding of the relationship between perception and language processing in two ways. First, whereas most previous studies of the relationship between perception and language processing have focused on visual perception, our data show that sentence processing can be affected by the concurrent processing of auditory stimuli. Second, it is shown that the relationship between the processing of auditory stimuli and the processing of sentences depends on whether the sentences are presented in the auditory or visual modality.

Perception of Auditory Motion Affects Language Processing

A number of recent studies have shown that sensorimotor information is routinely activated during language comprehension. Evidence for the role of sensorimotor information in language processing has come from both behavioral (Kaschak, Madden, Therriault, Yaxley, Aveyard, Blanchard, & Zwaan, 2005; Glenberg & Kaschak, 2002; Richardson, Spivey, Barsalou, & McRae, 2003; Zwaan, Madden, Yaxley, & Aveyard, 2004) and neuroimaging studies (e.g., Pulvermuller, 1999; Kan, Barsalou, Solomon, Minor, & Thompson-Schill, 2003). These findings have been taken as support for the claim that language is understood through sensorimotor simulations of the actions and events being described (Kaschak & Glenberg, 2000; Zwaan, 2004).

Kaschak et al. (2005) explored the relationship between visual perception and language comprehension. Participants listened to and made judgments on sentences that described motion in one of four directions: towards the observer, away from the observer, upward and downward. While listening to the sentences, participants viewed black-and-white stimuli depicting motion in the same four directions. Participants were faster to respond to sentences when the direction of motion in the sentence mismatched the direction of motion in the stimulus (e.g., responding to a sentence about an *away* action while viewing the *towards* stimulus). Kaschak et al. (2005) described these results in terms of a competition for processing resources in the visual system. When viewing a *towards* stimulus, the neurons tuned to fire to "towards" motion are engaged. This makes it relatively difficult to simulate the action of a sentence that describes motion towards the participant, because the resources needed to do so are engaged by the perceptual stimulus. On the other hand, it is comparatively easy to simulate a sentence about *away* motion when viewing a *towards* stimulus because the stimulus and simulation do not compete for the same resources.

The specificity of the interaction between the perception of motion and the comprehension of sentences about motion provides a strong demonstration that the mechanisms responsible for processing visual stimuli are also engaged during language comprehension. The experiments reported below were designed to advance our understanding of this phenomenon in two ways. First, nearly all studies of the interaction between perceptual stimuli and sentence processing have involved visual stimuli (e.g., Chambers, Tanenhaus & Magnuson, 2004; Kaschak et al., 2005; Zwaan et al., 2004; Zwaan, Stanfield, & Yaxley, 2002; Stanfield & Zwaan, 2001). Our experiments ask if these effects can be extended to stimuli presented in the auditory modality. If so, this would provide some of the first evidence that the simulations that arise during language comprehension incorporate information from modalities other than vision.

The second way in which we hope to advance our understanding of the relationship between perceptual and linguistic processing is by examining whether the pattern of data observed in Kaschak et al. (2005) is affected by the modality in which both the percept and linguistic input are presented. This question is inspired by explorations of cross-modal perception (Rees, Frith, & Lavie, 2001; Tellinghuisen & Novak, 2003; see Lavie, 2005, for a review). Several recent studies have converged on the conclusion that attentional capacity is limited within a specific perceptual modality, but not across modalities. If one is asked to perform a primary visual task (such as a visual search), the effect of any visual distractors on primary task performance will depend on the demands of the primary task. If this task is easy (i.e., low attentional demands), the visual distractors will disrupt task performance; if it is difficult, the visual distractors will not be processed (due to a lack of attentional capacity) and therefore will not affect task performance. When the distractors are presented in a different modality than the primary task (e.g., visual primary task with auditory distractors), the distractors will disrupt primary task performance regardless of the processing demands of the task. Evidence for these conclusions has been garnered in both behavioral (e.g., Tellinghuisen & Nowak, 2003) and neuroimaging (e.g., Rees, Frith, & Lavie, 1997) paradigms.

If we presume that language processing is as demanding as the "hard" tasks used in perceptual experiments (e.g., a visual search task or a syllable counting task; e.g., Tellinghuisen & Nowak, 2003; Rees et al., 2001), then the relationship between the perceptual stimulus and a concurrently presented sentence should differ depending on whether the stimulus and sentence are presented in the same modality or not. In the context of Kaschak et al.'s (2005) paradigm, the following predictions emerge. If the linguistic input and the percept are presented in different modalities, comprehension will be easier when the direction of motion depicted in the stimulus mismatches the direction of motion described by the sentence than when the perceived and described motion direction match. Because the sentence and stimulus are presented in different modalities, both can be processed at the same time, and conflict should emerge when the percept and sentence require the use of the same processing mechanisms. This prediction was supported by Kaschak et al.'s (2005) experiments, where a mismatch advantage was observed with auditorily presented sentences and a visual percept. In contrast, when the stimulus and sentence are presented in the same modality, comprehension should be easiest when the direction of motion depicted in the stimulus matches the direction of motion described in the sentence. The attention-demanding nature of sentence processing should temporarily obviate the processing of the perceptual stimulus (per Lavie, 2005). Thus, participants will not process the percept concurrently with the sentence. In a functional sense, it will be as if they serially process a stimulus depicting motion in one direction, and then process a sentence about motion in the same direction. This functionally "sequential" processing should result in a match advantage because the directional information active in the perceptual system (e.g., the active *towards* neurons) should facilitate the development of a simulation about motion in the same direction.

Experiment 1

Our first experiment is designed to replicate Kaschak et al.'s (2005) results with an auditory percept. Because Kaschak et al. (2005) presented the percept and language in different modalities, participants in this experiment were presented with sentences through the visual modality using a rapid serial visual presentation (RSVP) paradigm. We used the RSVP paradigm because it forced participants to process the sentences under time pressure, as was the case for the participants in our earlier study who listened to sentences. Participants read sentences presented word-by-word and made sensibility judgments. The sentences were similar to those used by Kaschak et al. (2005), except that they highlighted auditory aspects of the described situations (see Appendix A for examples). While reading and making sensibility judgments, participants listened to auditory stimuli conveying motion towards, away, upwards, and downwards relative to the listener. The auditory stimuli were bands of white noise manipulated to create the impression of motion. According to the predictions outlined above, responses should be faster when the direction of motion described in the sentence mismatches the direction of motion conveyed by the stimulus (e.g., reading a *towards* sentence while listening to an *away* stimulus) than when the two match.

Method

Participants. Thirty-eight introductory psychology students from Florida State University participated in exchange for course credit. Two of these participants were excluded from the data analysis because their accuracy on the sensibility judgment task was below 75%.

Materials. We constructed 32 critical sentences for this experiment. There were 8 sentences describing motion in each of 4 directions (towards, away, up, and down). These sentences made explicit reference to an auditory dimension of the situation being described (see Appendix A). We constructed 48 filler sentences similar in nature to the critical sentences, but without describing motion. Eight of the fillers were constructed to be sensible, and the remaining 40 were non-sensical.

To ensure that participants would interpret the critical sentences as depicting motion in the direction that we had intended, we performed a norming study. The critical sentences were presented (in random order) to 15 introductory psychology students. These participants were asked to judge whether the motion depicted in each sentence was moving towards them, away from them, upwards, or downwards. The participants agreed with our intuitions about the direction of motion in each sentence 85% of the time. This value is slightly lower than expected because a small number of items (6) produced relatively low levels of agreement (participants agreed with our intuitions < 65% of the time).

The auditory motion stimuli were broad-spectrum bands of sound ("white noise") similar in nature to those used in Neelon and Jenison's (2004) study of auditory motion aftereffects. For each direction of motion, a 30-second stimulus was created. This stimulus consisted of 7 unique 4-second passes of noise that covered a range of motion in a particular direction. For example, the "down" stimulus consisted of a series of 4-second passes of noise that gave the perception of motion from 30 degrees above midline to 30 degrees below midline. Thus, participants heard repeated passes of motion during the experiment, rather than a single pass of motion in each direction. The "up" and "down" stimuli were generated to move between 30 degrees above and 30 degrees below midline. The "towards" and "away" stimuli were generated by changing the amplitude of the sound by 20 dB (+ 20 dB for the "towards" stimulus, and – 20 dB for the "away" stimulus) within each 4-second pass[1].

Given the aims of these experiments, it was important to ensure that our auditory stimuli were perceived as moving in the intended direction. The "up" and "down" stimuli were used in Neelon and Jenison's (2004) study of auditory motion aftereffects, and produced reliable effects in the intended direction. However, the "towards" and "away" stimuli had not been used in previous research. We polled a small group of research assistants (who were naïve to the purposes of these studies), and they were 100% accurate in judging the direction of motion conveyed by the stimulus.

Procedure. Sentences were presented word-by-word in an RSVP paradigm at a rate of 225 ms per word. Participants were instructed to read the sentences, and judge if they were sensible or not by pressing Y or N labeled keys on the keyboard. Participants were also told that they would be wearing headphones that played white noise during the study, and that the purpose of the noise was to limit the amount of distraction they would experience from noise outside the testing room. The sentences and stimuli were presented such that each sentence was read while participants listened to either a matching stimulus (a *towards* sentence and a *towards* stimulus) or a mismatching stimulus (a *towards* sentence and an *away* stimulus). Participants listened to 8 presentations of each auditory percept, each lasting around 30 seconds. During each presentation, participants read and responded to 10 sentences (2 match, 2 mismatch, and 6 filler items). Four counterbalanced lists ensured that sentences were presented equally often with a matching and mismatching stimulus.

Design and Analysis. The dependent measure was the time required for participants to make a sensibility judgment for each sentence. The time started at the offset of the last word of the sentence. We conducted separate analyses with participants and items as a random factor. Analyses conducted across participants are denoted *F1*, and analyses conducted across items are denoted *F2*. The following procedures were used to screen for outliers. First, all response times less than 100 msec and greater than 2000 msec were eliminated. Then, for each participant (or item) in each cell of the design (Match vs. Mismatch) we eliminated RTs more than 2 SDs from the cell mean. T The outlier screening led to the exclusion of 16% of the response times. The data from three items were eliminated from the analysis because they contained typographical errors that rendered them nonsensical. The remaining data were analyzed using a 2 (Match vs. Mismatch) x 4 (Counterbalance list) ANOVA. In the analysis by participants, Counterbalance list was a between-participants factor. All factors were within items. Throughout the paper, Counterbalance list and Direction of motion (towards, away, up, or down) will be included as factors in the statistical analyses if they account for a significant portion of the variance in response times (see Pollatsek and Well, 1995). Because they are of little theoretical interest, effects involving these factors are not reported below.

Results and Discussion

The results are presented in Table 1. The data show that participants were faster to respond in the Mismatch condition than in the Match condition [$F1(1, 32)= 5.00$, $p < .05$; $F2(1, 28)= 2.99$, $p < .10$]. The presence of a mismatch advantage demonstrates that Kaschak et al.'s (2005) results were not particular to the relationship between visual stimuli and language comprehension. They extend to at least one other perceptual modality, audition. In addition, this result provides support for the prediction that a mismatch advantage should occur when sentences and percepts are presented in different modalities.

Experiment 2

Experiment 1 showed that participants were faster to respond to sentences when the direction of motion depicted in the sentence mismatched the direction of motion depicted by the auditory stimulus they were processing at the same time. The putative explanation for this finding is that conflict arises when the auditory perception system is required to process two stimuli involving motion in the same direction (i.e., the sound of the motion described in the sentence, and the sound of the auditory motion stimulus). Although a processing conflict arises in the Match conditions when the sentence and percept are presented in different modalities (Experiment 1, and Kaschak et al.'s, 2005, experiments), we hypothesized that a different pattern would emerge when the sentence and percept were presented in the same modality. This hypothesis was based on recent studies of cross-modal perception, where it has been shown that when a primary experimental task is attentionally demanding, secondary stimuli presented in the same modality are filtered out of the processing stream (Lavie, 2005). If this is the case, we expected that presenting sentences auditorily would temporarily block the processing of the auditory percept. In a functional sense, it would be as if the auditory percept and sentence are presented sequentially. We expect that when the external percept and sentence are both presented auditorally, the processing conflict seen in the Match condition in Experiment 1 should be removed. Instead, the direction of motion in the auditory percept will prime the processing of a sentence about motion in the same direction, leading to faster responses in the Match condition.

Method

Participants. Forty introductory psychology students from Florida State University participated in exchange for course credit.

Materials. The materials were identical to those used in Experiment 1. An adult male speaker recorded the sentences for the auditory sentence presentation.

Procedure. The procedure was identical to that used in Experiment 1, except that sentences were presented auditorily. Sentences and auditory percepts were presented binaurally over headphones. The volume of the sentences was adjusted such that they were clearly audible above the auditory motion percepts.

Design and Analysis. The design was the same as that of Experiment 1. Unlike in the previous experiment, participants could make responses before the end of the sentence. Data were normalized such that a response time of 0 ms would occur exactly at the end of the sentence, whereas negative response times represented responses made before the end of the sentence and positive response times represented responses made after the end of the sentence. To remove outliers, we first omitted any response times shorter than –100 msec and longer than 2000 msec. Then, we removed responses more than 2 SD's from each participant's (or item's) mean in each condition. The outlier screening led to the exclusion of 1% of the response times. The analysis by participants was conducted as a single factor ANOVA (Match vs. Mismatch). The analysis by items was conducted with Counterbalance list and Direction of motion included as factors.

Results and Discussion

The results are presented in Table 1. Responses were faster when the direction of motion in the sentence matched the direction of motion in the stimulus [$F(1, 39)= 4.24$, $p < .05$; $F2(1, 24)= 4.71$, $p < .05$]. This is consistent with our prediction that presenting the sentence and percept in the same modality should remove the competition for resources responsible for the mismatch advantage in Experiment 1 (and in Kaschak et al. 2005), and produce a priming effect when the percept and events described in the language depict motion in the same direction.

Experiment 3

Experiment 1 showed that a mismatch advantage arises when one responds to visually presented sentences describing events with a particular direction of motion while listening to stimuli also depicting motion in a particular direction. Experiment 2 demonstrates that this effect is reversed when the language and percept are presented in the same modality. Although this pattern of results is consistent with reports from tasks involving cross-modal perception (e.g., Tellinghuisen & Nowack, 2003; Lavie, 2005), it remains possible that differences between visual RSVP and auditory sentence presentations led participants to behave in different ways regarding the relationship between the sentence and percept. To help rule out this concern, Experiment 3 was designed to demonstrate the match and mismatch advantages from Experiments 1 and 2 in the same experiment.

Method

Participants. The participants were 105 introductory psychology students from Florida State University. They received course credit in exchange for their participation. Twenty-three participants were excluded from the data analysis due to their performance on the sensibility judgment task. We excluded participants from Experiments 1 and 2 if their performance on the sensibility judgment task was worse than 75% correct (no participants were excluded from Experiment 2 on this basis). In the present experiment, we noted that many participants met the 75% correct criterion overall, but showed performance that was inconsistent across conditions (i.e., their accuracy in one condition was much worse than in the other conditions). Thus, we included only those participants who had an overall accuracy of 75% on the judgment task, and maintained a 75% accuracy rate across all 4 critical conditions in the design (the four conditions created by crossing sentence modality with match vs. mismatch).

Materials. The materials from Experiments 1 and 2 were used in this experiment.

Procedure. The procedure was the same as that used for Experiments 1 and 2, with the following changes. Half of the participants made sensibility judgments on visually presented sentences in the first half of the experiment, and made judgments on auditorily presented sentences in the second half of the experiment. The other half of the participants performed the tasks in the opposite order. To maintain a sufficiently large number of observations per cell of the experiment, the direction of motion of the sentence, the direction of motion of the stimulus, and the modality of sentence presentation were not fully crossed for each participant. Participants responded to sentences with two directions of motion (e.g., *towards* and *away*) in one modality, and responded to the other two directions in the opposite presentation modality. The auditory stimuli were presented so that they either matched or mismatched the direction of motion described in the sentence. Sixteen counterbalanced lists were constructed so that: 1) half of the participants received visually presented sentences first and half received auditorily presented sentences first, 2) sentences appeared equally often in the first and second half of the experiment, and 3) sentences appeared equally often in each presentation modality with matching and mismatching auditory stimuli.

Design and Analysis. Response times for the visually and auditorily presented sentences were collected as in Experiments 1 and 2, with the primary difference between the two modes of presentation being that participants could respond before the end of the auditorily presented sentences, but not before the end of the visually presented sentences. To screen for outliers, we first omitted response times longer than 5000 msec and shorter than –200 msec (auditory sentences) or 0 msec (visual sentences). Then, we omitted any response times more than 2 SD's from the mean in each cell of the design (auditory match, auditory mismatch, visual match, visual mismatch). The outlier screening led to the exclusion of 15% of the response times. The three items omitted from Experiment 1 were omitted from these analyses because they contained errors that made them nonsensical. The remaining RTs were analyzed with a 2 (Modality: Visual vs. Auditory sentences) x 2 (Match: Match vs. Mismatch) ANOVA. All factors were within participants and items.

Results and Discussion

The results are presented in Table 1. As in Experiments 1 and 2, participants showed a match advantage when the sentences were presented auditorily and a mismatch advantage when the sentences were presented visually. This was manifested in a significant interaction of Modality and Match [$F1(1, 81)= 4.04$, $p < .05$;$F2(1, 28)=4.50$, $p < .05$]. Individually, the match effect for auditorily presented sentences was significant [$F1(1, 81)= 5.89$, $p < .05$;$F2(1, 28)=3.74$, $p = .06$], but the mismatch effect for visually presented sentences was not [$F1$ and $F2 < 1$]. The main effects of Modality and Match were not significant [Modality: $F1 < 1$; $F2(1, 28)= 3.84$, $p > .05$; Match: $F1(1, 81)= 2.29$, $p > .05$; $F2 < 1$].

General Discussion

The mismatch advantage observed in Experiment 1 presumably reflects a competition for resources in the auditory processing system. Perception of the auditory stimulus engages particular aspects of this system (e.g., those that respond to *towards* motion), making them less available for the construction of a simulation of a sentence describing auditory motion in the same direction. Our putative explanation for the match advantage observed in Experiment 2 is that it is the result of the limited attentional or processing capacity within one perceptual modality (Lavie, 2005). The demands of listening to sentences for the purpose of making sensibility judgments may have been high enough that participants were temporarily unable to process the ongoing auditory stimuli. On this view, the fact that the sentence and stimulus were not processed simultaneously means that there was no competition for resources. Instead, there was a priming effect that arose when participants processed a stimulus depicting motion in one direction immediately before processing a sentence that described motion in the same direction.

A critical factor in determining how a given perceptual stimulus will affect the comprehension of language (or vice versa) appears to be the temporal overlap between the processing of percept and the language. Several previous studies have shown a match effect between sentence processing and (visual) perceptual processing (e.g., Zwaan et al. 2002; Zwaan et al. 2004; Stanfield & Zwaan, 2001). In all of these cases, the sentence and relevant visual percept were presented sequentially. If our account of the match effect observed in Experiment 2 is correct, it would add further weight to this claim. When the sentence and percept are not processed concurrently (in this case, because of attentional demands rather than because of the design of the experiment), a match effect occurs. This result provides a complement to the results of Zwaan et al. (2004), who observed facilitation for perceptual judgments following the comprehension of sentences describing motion in the same direction as that implied by the subsequent visual stimuli. Here, we observed facilitation of comprehension of motion sentences when these sentences were preceded by a perceptual stimulus conveying motion in the same direction. Apparently facilitation occurs from comprehension to perception and vice versa. On the other hand, when the percept and linguistic input are processed at the same time (as in Kaschak et al. 2005, and Experiments 1 and 3 here), a mismatch advantage arises due to a competition for processing resources.

The specificity of the interaction between language comprehension and perception observed here suggests both that there is a fairly high degree of specificity in the simulations constructed during sentence comprehension and that the processing mechanisms involved in the perception of motion are actively engaged during the comprehension of sentences about motion. At the same time, there are many aspects of the perception-language interplay that still need to be addressed. For example, one can ask if the relationship between perception and language comprehension changes when the content of the perceptual stimulus (auditory or visual) matches the content of the sentence. In all of our experiments, the percepts involved were unrelated to the content of the sentences (e.g., the sound of white noise approaching you does not resemble the sound of a horse galloping in your direction). The observed pattern of results might change if the content of the stimulus matched the content of the sentence more closely (e.g., hearing the sound of a horse approaching you while reading a sentence about the same action). We are currently exploring this question.

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Notes

[1] Samples of the motion stimuli can be heard at:

http://www.psy.fsu.edu/~kaschaklab/downloads.htm

Author's Note

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Appendix A: Critical Sentences for Experiments 1-3

Towards

The commuter had just arrived on the platform when the subway roared into the station.
The crew of the aircraft carrier watched as the fighter jet seared in from the horizon
The policeman was at the crash site when the siren approached from the distance.
The sound of chains dragging on the sidewalk loomed as the gang approached for the fight.
The surfer heard the next wave crashing toward him.
The unhorsed knight looked up in awe as his opponent came charging towards him on his black stallion.
Waving frantically, the lost hiker heard the chopper head toward him.
When they turned the knob, the workers heard the oil rush towards them in the pipeline

Away

John heard the siren fade into the distance as the ambulance drove away to the hospital.
The baggage handler gazed in awe as the propeller plane sped away down the runway.
The beach comber heard the seagulls around him fly off into the distance.
The children looked on as the noisy barrel clanged away down the hill.
The dog barked loudly as it ran off across the prairie.
The muffler of Luke's car scraped the pavement as he drove down the road.
The speeding car was playing loud music as it rushed away and down the avenue
The victims screamed as the rising water swept them away down the river.

Up

He heard the elevator approach from the floor below.
The fireworks made a piercing noise as they shot into the sky.
The flare loudly whistled as it shot up into the sky.
The jet pack roared into the sky.
The ranger listened while a snowmobile worked its way up the mountain
The rollercoaster clanked up the tracks to the top of the hill.
With a deafening sound, the rocker blasted off.
With nails scratching the bark, the cat raced up the tree.

Down

Screaming in panic, the woman jumped from the burning building.
The bucket clanged against the bricks as it fell into the well.
The foreman heard the weight of the piledriver fall onto the pillar.

The hawk screeched as it descended upon its prey.
The helicopter descended onto the roof with a great deal of noise.
The sentry heard the enemy riders thunder down the hill.
The snow crunched as the skier sped down the mountain.
The trapped miners listened as the drill descended towards them.

Table 1: Mean Response Times (in msec) and Proportion of Correct Responses for Experiments 1 – 3 (Standard Error of the Mean in Parentheses)

Response Times

	Visual Sentence		Auditory Sentence	
	Match	Mismatch	Match	Mismatch
Experiment 1	620(43)	575(43)	---	---
Experiment 2	---	---	515(37)	560(41)
Experiment 3	732(40)	711(35)	681(53)	761(59)

Accuracy

	Visual Sentence		Auditory Sentence	
	Match	Mismatch	Match	Mismatch
Experiment 1	.83(.02)	.85(.02)	---	---
Experiment 2	---	---	.91(.01)	.94(.01)
Experiment 3	.87(.01)	.86(.01)	.86(.02)	.86(.02)