The Effect of Irrelevant Visual Input on Working Memory for Sign Language

Margaret Wilson
University of California, Santa Cruz

Karen Emmorey
The Salk Institute for Biological Studies

We report results showing that working memory for American Sign Language (ASL) is sensitive to irrelevant signed input (and other structured visual input) in a manner similar to the effects of irrelevant auditory input on working memory for speech. Deaf signers were disrupted on serial recall of lists of ASL signs when either pseudosigns or moving shapes were presented during a retention interval. Hearing subjects asked to recall lists of printed English words did not show disruption under the same interference conditions. The results favor models that hypothesize modality-specific representations of language within working memory, as opposed to amodal representations. The results further indicate that working memory for sign language involves visual or quasi-visual representations, suggesting parallels to visuospatial working memory.

We have previously argued that the structure of working memory for sign language is highly similar to working memory for spoken language (Wilson & Emmorey, 1997, 1998). Evidence for the architecture of speech-based working memory derives in part from the *phonological similarity effect,* the *articulatory suppression effect,* and the *word length effect*. Previous work has found parallel effects for sign language, suggesting that working memory has a similar architecture for the two language modalities.

Specifically, investigators (Bellugi, Klima, & Siple, 1975; Hanson, 1982; Wilson & Emmorey, 1997; Wilson, Emmorey, & Iverson, 2003) have found a phonological similarity effect for American Sign Language (ASL), wherein performance is hurt by interitem similarity of handshape or of location (two of the phonological parameters of ASL). In addition, Wilson and Emmorey (1997, 1998) found an effect of manual articulatory suppression, wherein performance suffers when the relevant articulators, the hands, are occupied with a meaningless gesture. Further, we found a sign length effect, wherein long signs (signs with path movement) were more difficult to remember than short signs (signs with no path movement). Finally, as in speech-based memory, the interactions among these effects depended on the manner of stimulus presentation. Based on these findings, we have claimed that the structure of working memory for language develops in response to language input regardless of the modality of that input, thus resulting in largely the same architecture across spoken and signed languages.

However, evidence also suggests certain key differences between working memory for signs and working memory for speech based on the differing information-processing capabilities of the visual and auditory modalities. Specifically, deaf signers appear to use spatial coding to represent the serial order of signs, in a manner that has no parallel in working memory for speech (Wilson, Bettger, Niculae, & Klima, 1997; Wilson et al., 2003).

This work was supported by NIH grant DC-00128–01 awarded to Margaret Wilson and NIH grant HD-13249 and NSF grant SBR-9809002 awarded to Karen Emmorey. We thank Brenda Falgier and Kevin Clark for help in developing stimuli and running subjects. We thank Dennis Galvan for his help in recruiting subjects. We are especially grateful to Gallaudet University, Washington, DC, California State University, Northridge, and the Deaf subjects who participated in these studies. Correspondence should be sent to Margaret Wilson, Department of Psychology, Social Sciences 2, University of California, Santa Cruz, CA 95064 (e-mail: mlwilson@cats.ucsc.edu).

These findings suggest that each form of language—spoken and signed—is tied to the sensory and motoric modalities in which the language is instantiated.

If this is true, then we ought to be able to find direct evidence of modality-specific coding for each form of language. Partial evidence already exists for spoken language. Working memory for spoken language is vulnerable to disruption from task-irrelevant auditory materials, and this holds true whether the to-be-remembered (TBR) materials are themselves spoken or merely printed. There is a large literature on this "irrelevant speech effect" or "irrelevant sound effect" (see Neath, 2000, for review). There is also a great deal of research on the suffix effect—reduced performance on list-final items when a spoken TBR list is followed by a single, irrelevant spoken word or syllable. In contrast, there is little or no literature on any "irrelevant visual stimulus effect" in working memory for spoken language.

This would seem to indicate modality specificity in working memory, in which speech and print materials are both retained in a speech-like code and can be disrupted by irrelevant material that shares the sensory modality of speech. However, these findings by themselves do not force a modality-specific explanation. Various authors have proposed that materials are held in working memory in an amodal phonological code, but that auditory input inherently has a peculiar ability—not shared by visual input—to disrupt working memory (see Wilson, 2001, for a review). For example, it has been suggested that visual stimuli result in representations in working memory that are less robust, less temporally distinctive, or contain less modality-specific information than auditory stimuli (e.g., Glenberg & Swanson, 1986; Jones, Beaman, & Macken, 1996; LeCompte, 1996; Marks & Crowder, 1997; Nairne, 1990; Neath, 2000). Irrelevant visual stimuli, on this type of account, are simply not capable of disrupting working memory in the same way that auditory stimuli can.

If these accounts are correct, we should not find disruption by visual input for any form of working memory, including working memory for sign language. However, if we do find that visual input can disrupt working memory, provided that the materials to be remembered are themselves visual, then we can conclude that effects of irrelevant input are modality specific and, by implication, that working memory itself is modality-specific.

Preliminary evidence along these lines comes from Siple and Brewer (1985), who examined the effect of a visual maze-tracking task and a motoric bow-tying task on working memory for signs. Both tasks disrupted working memory in deaf signers, with larger effects at longer delays and a larger effect for maze tracking than for bow tying. However, it is difficult to interpret these results, since both interference tasks likely involve multiple cognitive resources, including central executive monitoring.

In this study, deaf subjects are asked to passively view meaningless irrelevant material while holding a working memory load, to test for purely visual disruption. Two types of irrelevant visual material are tested. The first consists of pseudosigns, which are phonologically possible but nonoccurring ASL signs, analogous to English nonsense words like "garg" or "blick." The second type of irrelevant visual material is nonlinguistic, consisting of moving shapes. Like the pseudosign stimuli, these stimuli are dynamic, but the entirely nonlinguistic movement and shape information are quite unlike the sign stimuli and in particular are entirely non-linguistic.

First, though, we begin by testing a claim that is noncontroversial in the working memory literature, yet has rarely been explicitly demonstrated: visual stimuli do not disrupt working memory for spoken-language materials. To test this, hearing nonsigners are presented with words to remember, followed by the kind of visual interference already described.

We should note that the method of presenting interference material after the TBR material, rather than simultaneously (as can be done with printed words and auditory interference) resembles the method used to study the suffix effect rather than the irrelevant speech effect. However, the distinction between the suffix effect and the irrelevant speech effect is not critical for our purposes, because we are interested more broadly in the issue of modality specificity.

Finally, we should note that visual (print) presentation of TBR words is used rather than auditory (speech) presentation to maximize the possibility of interference from the irrelevant visual material. A modality-specific view of working memory should still predict no interference, since spoken language materials are converted to a phonological code in working memory, whether they are presented as speech or as print (see Wilson, 2001, for a review).

Experiment 1

Method

Participants

Twenty-six hearing participants were recruited from the University of California, San Diego, and from North Dakota State University. They ranged in age from 18 years to 36 years, with a mean age of 21. None had any deaf immediate family members, and none knew any form of sign language. (One additional participant was tested, but was excluded for not looking at the video screen during presentation of the irrelevant materials.)

Stimuli

Forty-two lists of eight words (14 lists for each of three conditions) were created from the following set, with each word used exactly once per list: broom, cigarette, degree, fence, key, line, salt, world. Concrete nouns were chosen to match the meanings of the ASL signs used in Experiment 2. In addition, six lists were created for practice. To create the stimulus sequences, each word was printed in lowercase 144-point Palatino font. One-second video clips of these printed words were concatenated with 500 ms ISIs, using Adobe Premiere digital editing software.

Each list was followed by task-irrelevant material of one of three types: baseline, shape, or pseudosign. For the baseline condition, the material consisted of eight 1-second presentations of a uniform light grey field, with 500 ms ISIs of a darker grey field. For the shape condition, eight jagged, meaningless shapes (Atteneave figures; Atteneave, 1957) were used as stimuli. Each shape was shown smoothly moving and rotating for 1 second, with acceleration and deceleration at the beginning and end of the movement. This acceleration pattern gave the displays a smooth, event-like quality. All eight shapes were shown on each trial, in random order, with 500 ms ISIs. For the pseudosign condition, eight sign-like hand movements were created recombining handshapes and movements of actual ASL signs. (Details of the structure of these pseudosigns are given in Experiment 2.) These pseudosigns were videotaped being produced by a deaf native signer. On each trial, all eight pseudosigns were shown in random order for 1 second each with 500 ms ISIs. In all three conditions, presentation of the interference material began 500 ms after termination of the last TBR stimulus.

Procedure

Trials from the three conditions—baseline, shape, and pseudosign—were mixed and presented repeatedly in a fixed order. Half the participants received trials in the order of baseline, shape, pseudosign, and half in the order of baseline, pseudosign, shape. Stimuli were presented on videotape using a Panasonic monitor/recorder AG-513. After presentation of each trial, the experimenter paused the videotape while the participant responded. Instructions requested participants to attend to the TBR items, to attempt to ignore the irrelevant material during the retention interval but to continue looking at the screen, and to report the TBR items in correct serial order when the experimenter paused the videotape. Participants spoke their responses aloud. The testing sessions were videotaped for later scoring of the responses. Responses were scored for the number of correct items reported in the correct serial position. Scores were then converted to percentages.

Results and Discussion

Mean performance for the baseline, shape, and pseudosign conditions respectively were 50.1% (*SE* = 3.7), 53.5% (*SE* = 3.1), and 49.9% (*SE* = 3.7). An analysis of variance (ANOVA) showed no effect of interference material, *F*(2, 50) = 2.44, *ns.*

To address the possibility that this null result could be the artifact of a floor effect (although true floor for this task is considerably lower), the data were reanalyzed using only data from the 18 highest-scoring participants, including no participant who scored below 40%. Mean performance for the baseline, shape, and pseudosign conditions, respectively, were 58.3% (*SE* = 3.9), 61.1% (*SE* = 2.9), and 58.4% (*SE* = 3.6). An ANOVA showed no effect of interference material, *F*(2, 34) = 1.00, *ns.* As will be seen in Experiment 2, it is possible to find a robust interference effect for this number of participants with performance at these levels.

As predicted, working memory for printed words was not disrupted by irrelevant visual material. This is in contrast to the disruptive effects of auditory material on speech-based TBR lists that have been abundantly documented in the literature. Thus, these results support the common assumption that the disruption does not extend to visual input.

As noted in our introduction, though, the contrasting results of visual and auditory input on spoken language materials do not by themselves force a modality-specific account of working memory. One could argue that no interference was found, not because spoken language materials are held in a quasi-auditory code and therefore no modality-specific interference was present, but because visual stimuli are simply incapable of creating such interference at all.

But if, instead, irrelevant materials disrupt when and only when they share modality with the representations held in working memory, then we should find that irrelevant visual stimuli do disrupt working memory for a visuospatial language. Experiment 2 tests working memory for signs in deaf signers of ASL, using the same three interference conditions used in Experiment 1.

Experiment 2

Method

Participants

Eighteen deaf signers of ASL were recruited from California State University Northridge, Gallaudet University in Washington, D.C., and the Salk Institute for Biological Studies in San Diego. They ranged in age from 17 years to 44 years, with a mean age of 22. All but one participant had hearing loss of 80 dB or greater. Nine subjects had deaf parents or an older deaf sibling and were exposed to signing from birth, three learned to sign by age 3, four learned to sign between the ages of 7 and 10, and two learned to sign in adolescence. (Two additional participants were excluded because they failed to look at the video screen during presentation of the irrelevant materials.)

Stimuli

Stimuli consisted of the ASL translations of the stimuli used in Experiment 1. These signs were concrete nouns chosen in pairs such that the phonological components of the two signs could be recombined to create meaningless pseudosigns. Forty-two lists of four signs were created from this set of items, with no item occurring more than once per list. (This list length was chosen to slightly exceed the average memory span for ASL [e.g., Bellugi et al., 1975; Hanson, 1982]. The disparity in memory span for hearing and deaf participants is likely due to differences between English and ASL articulation rate [Bellugi & Fischer, 1972; Marschark, 1996; cf. Ellis & Hennelley, 1980; Stigler, Lee, & Stevenson, 1986]). In addition, six lists were created for practice. ASL stimuli were produced by a native ASL signer and recorded on videotape. Stimulus sequences were then created in the same manner as in Experiment 1.

Interference material was the same as in Experiment 1. The eight pseudosigns were created by recombining elements of the eight stimulus signs. For example, the orientation and movement pattern of the sign BROOM were combined with the handshape of the sign CIGARETTE, creating a nonsense sign (see Figure 1). The signer who created the TBR stimuli also produced these pseudosigns. Pseudosigns were used to avoid any disruption based on semantic processing.

Procedure

Instructions were given in ASL by an experimenter who was a fluent signer, and participants' responses were also given in ASL. Participants were alerted that the pseudosigns would be meaningless. In all other respects, the procedure followed that of Experiment 1.

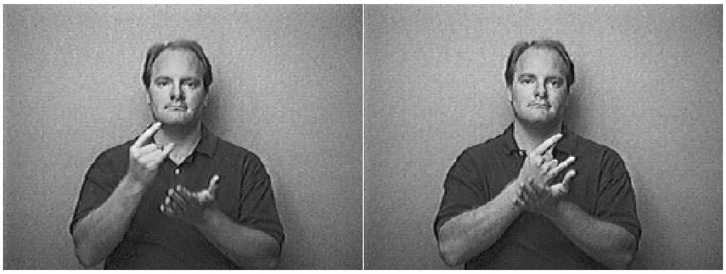
Results and Discussion

Mean performance for the baseline, shape, and pseudosign conditions, respectively, were 61.3% (SE = 5.0), 54.5% (SE = 6.1), and 49.3% (SE = 7.1). An ANOVA showed a significant effect of irrelevant material, $F(2, 34) = 9.42$, $p < .001$. Pairwise comparisons showed disruption relative to baseline for both the shape condition, $t(17) = 2.76$, $p < .05$, and the pseudosign condition, $t(17) = 3.55$, $p < .01$. Disruption was greater in the pseudosign condition than in the shape condition, $t(17) = 2.15$, $p < .05$.

To determine whether late language acquistion in some of the participants could be influencing the results, we separately analyzed early learners (exposed to

BROOM

CIGARETTE



PSEUDOSIGN

Figure 1 Illustration of two ASL signs from a TBR list and one of the pseudosigns presented during the retention interval. The initial and final pictures show the initial and final configurations of the signs/pseudosign. The movement between these two positions is repeated. The pictures are individual frames from the experimental videotape.

ASL by age 3, $n = 12$) and late learners (exposed to ASL at age 7 or later, $n = 6$). The same pattern of data was found for both groups. For the early learners, mean performance for the three conditions was 63.2% ($SE = 6.2$), 56.4% ($SE = 8.2$), and 49.8% ($SE = 9.4$), with a significant effect of condition, $F(2, 22) = 6.23, p = .007$. For the late learners, mean performance was 55.4% ($SE = 9.3$), 45.7% ($SE = 8.3$), and 43.5% ($SE = 10.5$), with a significant effect of condition, $F(2, 10) = 4.40, p = .043$. The same pattern also held when participants were divided into native signers ($n = 9$) and nonnative signers ($n = 9$), again with a significant effect of condition in both cases. Thus, while absolute level of performance appears to be higher in early learners than late learners, age of acquisition does not appear to be an important factor in the *pattern* of results of interest here.

Although Experiments 1 and 2 have certain methodological differences (format of the TBR materials, number of TBR items, and the fact that all TBR items were used in each trial for Experiment 1 but not Experiment 2), a statistical comparison between the two sets of results may nevertheless be considered informative. A 2 ×3 ANOVA showed no main effect of group, $F(1, 42) = 0.36$, *ns*), but a main effect of interference material, $F(2, 84) = 7.91, p < .01$, and an interaction, $F(2, 84) = 8.12, p < .01$. The interaction of group and interference material reflects the finding that deaf signers are affected by visual interference, but hearing nonsigners are not.

In contrast to Experiment 1, where irrelevant visual input created no disruption in working memory, these findings indicate that such disruption is possible, given appropriate TBR materials. Disruption of working memory for signs was produced by irrelevant sign-like material; in addition, the effect is not limited to irrelevant input that is language-like. Moving shapes, which were entirely nonlinguistic in their visual structure, produced significant disruption relative to baseline.

It appears that irrelevant pseudosigns are more disruptive than shapes. This finding parallels results suggesting that, for hearing subjects, irrelevant speech may be more disruptive than nonlinguistic materials such as music or tones (LeCompte, Neely, & Wilson, 1997; but see Jones & Macken, 1993). One possible interpretation is that materials that possess linguistic structure have a privileged status and are therefore maximally disruptive of working memory. However, pseudosigns may have created greater disruption simply because of their greater visual similarity to the TBR materials.

Discussion

The contrast to Experiment 1 allows us to eliminate several possible explanations for the disruption found in Experiment 2. First, the effect shown by the deaf participants cannot be attributed to disruption of attention or central executive functions. For example, the effect cannot be due to general processing demands created by the ecological importance of objects moving in the immediate environment. If such effects were responsible for the observed disruption, they should occur regardless of the language modality of the TBR materials.

Second, we can rule out an explanation in which visual input disrupts a visual imagery mnemonic for the semantic content of the TBR materials (e.g., creating a visual image of a key, a fence, etc.). We do know that when participants are instructed to use such a mnemonic, visual input can indeed disrupt performance (Quinn & McConnell, 1996). However, if this were responsible for our results, once again the disruption should occur regardless of the language of the TBR materials.

Finally, we can rule out a modality-specific interference account that appeals to the modality of the stimulus per se. Both groups received visual presentation of the TBR materials, followed by visual irrelevant input. Therefore, shared modality between the two sets of material is not sufficient to produce disruption. Instead, irrelevant material is disruptive when it shares modality with the representations being held in working memory—in the case of English words, a speech-based code, and in the case of ASL, a sign-based code.

Relevant to this issue of modality specificity is previous research on an "irrelevant picture effect" for nonlinguistic visual working memory. Although there has been difficulty in demonstrating a reliable effect of irrelevant visual input on visual memory or imagery (cf. Quinn & McConnell, 1996, p. 202), Quinn and McConnell have shown that dynamically changing visual white noise selectively disrupts an imagery mnemonic. Specifically, they found that while meaningful, nameable line drawings, presented simultaneously with spoken TBR materials, disrupted both rote rehearsal and an imagery mnemonic, nonmeaningful input (visual noise) disrupted only the imagery mnemonic. This finding suggests that while the line drawings disrupted general attentional or semantic mechanisms, visual noise produced specifically visual interference. The authors conclude that incoming visual material has obligatory access to the visuospatial buffer of working memory.

Though there are many differences between that study and this one in terms of the nature of the task and in terms of the properties of the interference material, both studies converge on the conclusion that irrelevant visual input is capable of disrupting quasi-visual representations held in working memory. This raises the possibility that sign-based working memory and nonlinguistic visual working memory may share a common substrate. That is, the sign-based rehearsal system we have observed in deaf signers may be a specialized usage of working memory components that exist in the hearing population as well and are used for general purposes of visual representation.

References

Atteneave, F. (1957). Physical determinants of the judged complexity of shapes. *Journal of Experimental Psychology, 55,* 221–227.

Bellugi, U., & Fischer, S. (1972). A comparison of sign language and spoken language. *Cognition, 1,* 173–200.

Bellugi, U., Klima, E. S., & Siple, P. (1975). Remembering in signs. *Cognition, 3,* 93–125.

Ellis, N. C., & Hennelly, R. A. (1980). A bilingual word-length effect: Implications for intelligence testing and the relative ease of mental calculation in Welsh and English. *British Journal of Psychology, 71,* 43–52.

Glenberg, A. M., & Swanson, N. G. (1986). A temporal distinctiveness theory of recency and modality effects. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 12*(1), 3–15.

Hanson, V. L. (1982). Short-term recall by deaf signers of American Sign Language: Implications of encoding strategy for order recall. *Journal of Experimental Psychology: Learning, Memory and Cognition, 8,* 572–583.

Jones, D. M., Beaman, P., & Macken, W. J. (1996). The object-oriented episodic record model. In S. Gathercole (Ed.), *Models of short-term memory.* (pp. 209–237). Hove, United Kingdom: Psychology Press.

Jones, D. M., & Macken, W. J. (1993). Irrelevant tones produce an irrelevant speech effect: Implications for phonologically coding in working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*(2), 369–381.

LeCompte, D. C. (1996). Irrelevant speech, serial rehearsal, and temporal distinctiveness: A new approach to the irrelevant speech effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*(5), 1154–1165.

LeCompte, D. C., Neely, C. B., & Wilson, J. R. (1997). Irrelevant speech and irrelevant tones. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*(2), 472–483.

Marks, A. R., & Crowder, R. G. (1997). Temporal distinctiveness and modality. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 23,* 164–180.

Marschark, M. (1996). *Influences of signed and spoken language on memory span.* Paper presented to the 37th Annual Meeting of the Psychonomic Society, Chicago, IL.

Nairne, J. S. (1990). A feature model of immediate memory. *Memory & Cognition, 18*(3), 251–269.

Neath, I. (2000). Modeling the effects of irrelevant speech on memory. *Psychonomic Bulletin & Review, 7,* 403–423.

Quinn, J. G., & McConnell, J. (1996). Irrelevant pictures in visual working memory. *Quarterly Journal of Experimental Psychology, 49A*(1), 200–215.

Siple, P., & Brewer, L. G. (1985). Individual differences in coding strategies for short-term retention of signs. In W. Stokoe & V. Volterra (Eds.), *SLR '83: Proceedings of the III International Symposium on Sign Language Research* (pp. 109–116). Silver Spring, MD: Linstok Press.

Stigler, J. W., Lee, S. Y., & Stevenson, H. W. (1986). Digit memory in Chinese and English: Evidence for a temporally limited store. *Cognition, 23,* 1–20.

Wilson, M. (2001). The case for sensorimotor coding in working memory. *Psychonomic Bulletin and Review, 8,* 44–57.

Wilson, M., Bettger, J. G., Niculae, I., & Klima, E. S. (1997). The impact of language modality on the structure of working memory. *Journal of Deaf Studies and Deaf Education, 2,* 150–160.

Wilson, M., & Emmorey, K. (1997). A visual-spatial "phonological loop" in working memory: Evidence from American Sign Language. *Memory and Cognition, 25,* 313–320.

Wilson, M., & Emmorey, K. (1998). A "word length effect" for sign language: Further evidence on the role of language in structuring working memory. *Memory and Cognition, 26,* 584–590.

Wilson, M., Emmorey, K., & Iverson, A. (2003). Spatial coding in working memory for sign language: Two effects of spatial similarity. Manuscript submitted for publication.

Received April 13, 2001; revisions received November 30, 2001; accepted December 6, 2001