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Visual feedback and self-monitoring of sign language

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Abstract

The perceptual loop theory of self-monitoring posits that auditory speech output is parsed by the comprehension system. For sign language, however, visual input from one's own signing is distinct from visual input received from another's signing. Two experiments investigated the role of visual feedback in the production of American Sign Language (ASL). Experiment 1 revealed that signers were poor at recognizing ASL signs when viewed as they would appear during self-produced signing. Experiment 2 showed that the absence or blurring of visual feedback did not affect production performance when deaf signers learned to reproduce signs from Russian Sign Language, and production performance of hearing non-signers was slightly worse with visual feedback. Signers may rely primarily on somatosensory feedback when monitoring language output, and if the perceptual loop theory is to be maintained, the comprehension system must be able to parse a somatosensory signal as well as an external perceptual signal for both sign and speech.

Keywords

American Sign Language; self-monitoring; visual feedback

Speakers monitor their speech, and when they detect an error, they interrupt themselves and repair the utterance. Speech errors can be detected either by an inner prearticulatory monitor or by an external auditory monitor (for review see Postma, 2000). Levelt (1983; 1989) proposes that overt speech errors are detected by the comprehension system, which parses auditory input from the speaker's production and feeds the results to the conceptualizer, the component of the production system involved in message preparation that can identify errors. The advantage of this proposal is that both the comprehension system and the conceptualizer are motivated independently. For example, the comprehension system is needed to parse the speech of other individuals, as well as that of the speaker.

Results from several studies indicate that speakers use auditory feedback to detect errors in production and also to monitor phonetic aspects of speech (e.g., loudness, pitch, phonetic

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realization). For example, when speakers are prevented from hearing their own voices (e.g., by wearing headphones emitting loud white noise) or when speakers silently mouth words, they are less likely to detect speech errors compared to when they can hear themselves speak (Lackner & Tuller, 1979; Postma & Noordanus, 1996). Speech volume is also monitored by auditory feedback – people talk louder when they cannot hear themselves (Lane & Tranel, 1971; Lombard, 1911), and auditory feedback is used to adjust and maintain the phonetic realization of speech sounds (Guenther, Hampson, & Johnson, 1998).

Users of sign languages also monitor their language output, interrupt themselves and produce editing expressions and repairs (Emmorey, 2002). Hohenberger, Happ, and Leuninger (2002) report that 54% of sign errors were detected and repaired in their corpus of errors from Deutsche Gebärdensprache (German Sign Language). Signers also produce editing expressions such as NO, WRONG, or a head-shake to indicate an error has occurred before making a self-correction (Emmorey, 2002).

There is also evidence that signers, like speakers, can monitor language internally and intercept errors before they are overtly uttered. Working memory experiments with ASL provide evidence for a non-overt articulatory-based system of sign rehearsal that is used during short term memory tasks (Wilson & Emmorey, 1997, 1998). This rehearsal system appears to be equivalent to subvocal rehearsal for speech and provides evidence for a type of inner signing. Like speakers, signers can monitor this internal signing, catching errors before they are actually articulated. Hohenberger et al. (2002) report that a small proportion of sign errors (8%) are detected *prior to* articulation of the intended (target) sign. For example, an incorrect hand configuration can be produced and corrected during the movement transition to the target sign. In addition, signers produce the signed equivalent of “um” (a 5 handshape with wiggling fingers), which indicates they are having production difficulty (Emmorey, 2002). Signers also sometimes stop signing and shake their head, suggesting that they have detected an error prior to articulation. Together these data support the existence of an internal monitor for sign production.

Although the internal monitor is likely to be similar for sign and speech production, the external perceptual monitor is likely to be critically affected by language modality. For example, it is not clear whether overt signed errors or misarticulations are detected by visually parsing language output using the comprehension system, as proposed for speech production. Although speakers can hear their own voices, signers cannot see their own faces (grammatical information is conveyed by distinct facial expressions), and they do not look directly at their hands while signing. Furthermore, the visual input that the comprehension system parses to understand the signing of other individuals is quite different from the visual input that the system receives from self-produced signing. Visual feedback during signing does not contain information about non-manual markers, the view of the hands is from the back, movement direction is reversed, and manual signs tend to fall within the lower periphery of the visual field, where vision is relatively poor.

To investigate the role of visual feedback during sign production, we conducted two experiments. The first experiment investigated the intelligibility of hand configurations when presented in the lower visual periphery and when viewed from the back hand orientation. Such images constitute visual feedback that could be used for visual monitoring of signed output. The goal of Experiment 1 was to discover how well the comprehension system recognizes hand configuration information perceived during sign production. The second experiment investigated whether the degradation and/or absence of visual feedback affects how well signers (and non-signers) learn to imitate novel signs. For speakers, the absence of auditory feedback impairs their ability to adjust articulation to achieve a target speech sound (Jones &

Munhall, 2003; Guenther et al., 1998). The goal of Experiment 2 was to discover whether visual feedback plays a role in fine-tuning manual sign articulation.

Experiment 1: Intelligibility of visual feedback

There are at least two factors that might make parsing of visual feedback difficult for sign language. First, the hand is viewed in an orientation that provides information with respect to the back of the hand. This view of the hand may make perception of ASL hand configurations difficult. Second, the image of one's own hand while signing often falls in the far periphery where visual acuity for detail is very poor. Our resolution of detail is sharpest in the center of vision, and falls off as an object moves away from the center, with very poor resolution in the far periphery (Anstis, 1974). Our ability to locate the entire hand in space is relatively good because our acuity for large objects is sufficient to identify the location of the hands. However, the ability to distinguish between hand configurations may be impoverished when the image falls within normal signing space, which is usually in the lower visual field (below the chin). To determine how well signers can visually identify handshapes during "self" production, these two factors, hand orientation and viewing condition, were examined in an ASL number identification task, which requires handshape discrimination.

The identification task was administered within either a Central or Peripheral *View* condition, which was crossed with an Other or Own *Hand* condition (the image of another's hand or a self-oriented hand image); see Figure 1 and Figure 2 below. The Other and Own Hand images have distinct orientations. The Own Hand image is a view of the hand from the back, which is what is normally visible during sign production, and the Other Hand image is a view of the front of the hand, which is what is canonically observed during face-to-face conversations with another signer. In the Central View condition, the hand image size and placement in the visual field matches the real-world view, as if the participant were watching another signer produce the number sign. Specifically, the Central View image is nearer central fixation, and the image size matches the size that would be viewed from approximately 1.5 meters away, falling in the viewer's left visual field (assuming all signers are right handed for simplicity). In the Peripheral View condition, the hand image is presented as if it were the viewer's own hand. That is, the hand image is far in the lower right visual field, observed at a sharp angle, and the image size is large, given a viewing distance that is very close. By crossing these two factors, we can explore how these factors (location within the visual field and view of the hand) interact and which factor plays the greater role in determining the intelligibility of ASL hand configurations.

Method

Participants—Thirteen fluent ASL signers participated in the study (4m; 9f). Eleven participants were exposed to ASL from birth or in early childhood and two acquired ASL in adolescence. Twelve participants were profoundly deaf from birth, and one participant had normal hearing and was born into a deaf signing family. ASL was the preferred and primary means of communication for the deaf participants and was used on a daily basis by the native hearing signer. All participants reported normal vision (N=10) or corrected-to-normal vision (N=3). All participants had some college level education and received monetary compensation for their participation.

Materials

Creating the Own Hand and Other Hand images: We obtained digital photographs of a native signer producing the ASL number signs SIX, SEVEN, EIGHT, and NINE. The signer's hand was shot from two angles, one representing the signer's own view of the hand and the second representing the view of another person's hand, as shown in Figure 1. In a second step, the image size of the hand stimulus was scaled to approximate viewing size at real world

distances for the Central and Peripheral View conditions. To best simulate the self view of the signer's own right hand, the photographer placed the camera behind the signer's left temple, aimed at the right hand during sign production of the numerals. Then the signer was asked to move his head slightly out of the line of the camera. This created an approximate orientation of the self view of the hand.

Determining the parameters of the viewing conditions: We obtained measurements of retinal image size and eccentricity that represent real world signing conditions, and used these measurements to create stimuli for this experiment. Retinal image size, expressed in degrees of visual angle (which is calculated as $\arctan(\text{object size/viewing distance})$), as opposed to object size, refers to how large the image is as it falls on the eye, and thus encoded by the brain. Retinal image size depends upon both object size and viewing distance, with image size of a given object increasing as viewing distance decreases. Eccentricity refers to how far from central fixation in the visual periphery an object falls. Eccentricity is calculated as $(\arctan(x/\text{viewing distance}))$ with x representing distance from central fixation.

To determine the parameters for the two viewing conditions, we first measured the hand image size for both the Central View and the Peripheral View using a live "other signer" standing 1.5 meters from our sign model, who produced the ASL sign EIGHT. One and half meters is a relatively standard, comfortable distance between two signers. Within this configuration, the hand image was calculated as 15 degrees wide in retinal size for the Peripheral View and 3.8 degrees wide in the Central view. In order to create the appropriate retinal stimulus sizes on the computer monitor during the experiment, the participant sat 35.5 cm away from the monitor, and the hand image size presented on the monitor was 9.5 cm in width for the Peripheral View and 2.5 cm wide for the Central View.

To calculate eccentricity, we measured the distance from the signer's hand while producing the sign EIGHT (specifically, using the tip of the thumb and ring finger) to the signer's nose (the bridge) for four signers. In determining viewing conditions, we took the bridge of the nose as the viewer's fixation point, because a single point must be used to calculate viewing distance of the hand from the observer's eyes. The observer's fixation will drift amongst the signer's two eyes and the mouth, but this difference from the midpoint was very small, and did not affect our stimulus parameters.

We asked each of the four signers to produce ASL numbers as if they were providing a phone number, and then asked them to freeze and hold EIGHT in its natural position and location. The distance measured between the nose and the hand (the tip of the thumb) for these four signers was 28, 35.5, 38, and 40.5 cm. We used an average of these measurements to determine which eccentricity represents a reasonable distance from the hand and the eyes. In Peripheral View, the eccentricity was 45 degrees, which represents a very large distance from central fixation. Assuming a viewing distance of 1.5 meters, the eccentricity was 13 degrees for the Central View, which represents the smaller angular distance from the Other signer's hand and fixation (i.e., the Other signer's face).

Finally, we computed the lateral peripheral eccentricities, that is, how far the hand falls vertically and horizontally from fixation, while maintaining the same viewing distance of 35.5 cm from the monitor in both conditions. For the Central View condition, the hand image was 2.5 cm in width, and participants fixated on a spot located 5 cm above and 7.5 cm to the right of the stimulus, which produced an eccentricity of 14.4 degrees, close to the real world estimate from the mean nose-to-hand value above. For the Peripheral View condition, the hand image was 9.5 cm in width, and participants fixated on a spot on the wall that fell 35.5 cm above and 23 cm to left of the stimulus, which put the stimulus 45 degrees below fixation and 33 degrees to the left of fixation. See Figure 2 for illustration of the viewing conditions.

Procedure—Participants were asked to identify the ASL number signs by pressing one of four computer keys with their right hand (V=9; B=8; N=7; M=6) (see Figure 1 for illustrations of the number signs). Each finger rested on a key such that the motorically appropriate finger pressed the correct key. For example, the index finger contacts the thumb for ASL sign NINE and rested on the “9” response key (V), while the middle finger contacts the thumb for EIGHT and rested on the adjacent “8” response key (B). Participants were asked to report which number they saw while maintaining fixation straight ahead upon a dot that was on the opposite wall (Peripheral View condition) or on the side of the computer monitor (Central View condition). Participants were instructed to focus on the fixation point while the hand images appeared on the monitor. Participants were told that during the experiment the hand images would appear in different viewing angles (i.e., from the back or from the front of the hand) and different sizes (large and small), which didn’t matter for identifying what number appeared. Participants were first familiarized with the hand images and the corresponding response keys by presenting the images centrally on the computer screen. Participants were instructed to respond as accurately as possible, and the stimulus remained on the screen until they responded.

A camera was used during the experiment to monitor participant’s eye movements to help ensure fixation. If a participant broke fixation during a trial, the data from that trial were discarded. Participants were very good at maintaining fixation, and no more than 3 trials had to be eliminated from the data for each participant.

Stimuli were presented on a 17 inch ViewSonic monitor, using SuperLab 2.0 software running on a Macintosh G3 computer. Both accuracy and response time were recorded. Participants’ head movements were stabilized using a chin rest. Testing was done in a room with dimmed lights to create maximal comfort and visibility of the computer screen. To simulate the Central View condition of perceiving another’s signing, the participant sat with the monitor to the left, such that the hand image fell within the appropriate eccentricity when viewing another signer’s hand. For the Peripheral View condition (simulating the perception of one’s own signing), the monitor was to the right of the participant and tilted 45 degrees from the participant’s line of vision, simulating one’s own view of signing (see Figure 2). Crossing the View Factor (Peripheral View, Central View) with the Hand Factor (Own Hand; Other Hand) yielded four experimental conditions, with 48 stimuli in each condition. The number signs were presented randomly, and each number appeared 12 times within a condition. The Central and Peripheral View conditions were blocked and order of presentation was counter-balanced across participants. Within each View condition, one block of Own Hand images and one block of Other Hand images were presented. Each blocked condition was tested, and then repeated a second time.¹

Accuracy and response latency were the dependent measures, and the data were analyzed using a 2 (View: Central, Periphery) X 2 (Hand: Other, Own) repeated-measures ANOVA. For all analyses, variability is reported with repeated measures 95% confidence-interval half-widths (CIs) based on single degree-of-freedom comparisons (Masson & Loftus, 2003).

Results—For accuracy, the repeated measures ANOVA revealed a main effect of viewing condition, with 17.4% more accurate responses in the Central View condition than in the Peripheral View condition (see Figure 3), $F(1, 12) = 11.52, p = .005, CI = \pm 11.18\%$. Participants also were 13.87% more accurate with the Other Hand stimuli than with the Own Hand stimuli, $F(1, 12) = 12.32, p = .004, CI = \pm 8.6\%$. Finally, Viewing condition interacted with Hand condition, $F(1, 12) = 10.67, p = .007, CI = \pm 9.31\%$. Participants were most accurate when viewing Other Hand images (80.64%) compared to Own Hand images (66.77%), but this difference was greatest in the Central View condition (see Figure 3). Response latencies were

¹Four participants did not receive the second repetition of blocks due to time limitations.

relatively slow and mirrored the accuracy results (see Table 1). However, a repeated measures ANOVA on the response latencies revealed only a significant main effect of Hand condition, with faster response latencies to Other Hand images (1353 ms) than Own Hand images (1764 ms), $F(1, 12) = 8.45$, $p = .013$, $CI = \pm 307.59$. There was no main effect of View condition, $F(1, 12) = 2.493$, $p = .140$, $CI = \pm 679.29$, and no interaction between the View and Hand conditions, $F(1, 12) = .380$, $p = .549$, $CI = \pm 515.71$.

The effects of viewing condition and hand image on identification accuracy were generally similar across the number stimuli, with the exception of SIX (see Figure 4). Unlike the other number signs, participants were more accurate for the Own Hand image of SIX, $F(1, 12) = 11.327$, $p = .006$, $CI = \pm 9.56\%$. Similar to the other number signs, participants were less accurate with the Peripheral View, $F(1, 12) = 10.171$, $p = .008$, $CI = \pm 11.35\%$, but the interaction indicates that this was true only for the Other Hand image (see Figure 4), $F(1, 12) = 9.522$, $p = .009$, $CI = \pm 17.89\%$. For SEVEN, participants were also less accurate with the Peripheral View, $F(1, 12) = 8.497$, $p = .013$, $CI = \pm 16.09\%$, and with the Own Hand image, $F(1, 12) = 15.147$, $p = .002$, $CI = \pm 10.94\%$, and there was a significant interaction, $F(1, 12) = 21.248$, $p = .001$, $CI = \pm 10.49\%$. For SEVEN, participants were most accurate with the Central View/Other Hand condition (canonically-perceived signing), and accuracy was low and similar in the other three conditions. The accuracy results for the number EIGHT were similar, with less accurate responses in the Peripheral View condition, $F(1, 12) = 4.589$, $p = .053$, $CI = \pm 18.25\%$, and with the Own Hand image, $F(1, 12) = 22.442$, $p < .001$, $CI = \pm 14.14\%$, and there was a significant interaction, $F(1, 12) = 5.851$, $p = .032$, $CI = \pm 11.43\%$. As with SEVEN, the accuracy difference between the hand images was greatest in the Central View condition. Accuracy for the number NINE was significantly lower in the Peripheral View condition, $F(1, 12) = 12.691$, $p = .004$, $CI = \pm 8.23\%$, and for the Own Hand image, $F(1, 12) = 9.959$, $p = .008$, $CI = \pm 13.71\%$, but there was no interaction for this sign, $F(1, 12) = 0.452$, $p = .514$. For all stimuli, participants were most accurate when viewing signs as they would be perceived when comprehending ASL (Central View/Other Hand) and least accurate when viewing self-produced signs (Peripheral View/Own Hand) – except for the number SIX.

Discussion—Signers were generally poor at recognizing ASL numbers signs when viewed as they would appear during self-produced signing, i.e., in the lower visual field, large image on the retina, back view of the hand. Participants had an error rate of nearly 40% in this condition, compared to only 6% when viewing number signs as they would be seen when comprehending another's signing, i.e., near the fovea, small image on the retina, front view of the hand. The results indicated that identifying signs in the low periphery was significantly worse than near the fovea and identifying ASL signs from the back image of the hand was less accurate than from the front image of the hand. This difference was greatest within the Central View condition where the back image of the hand is non-canonical. However, for the number SIX, participants were surprisingly good at recognizing the back image of the hand. Participants may have been able to identify this hand image more accurately because SIX is the only number sign for which the pinky finger is not extended, and this is particularly salient for the Own Hand image (see Figure 1). Overall, response latencies were slower when identifying ASL signs from the back image of the hand, but response latencies were not significantly affected by View condition. In general, response latencies were relatively slow and variable across participants, with some participants performing the task in under a second, while others required several seconds to identify the ASL signs.

The pattern of results provides evidence that signers are accustomed to viewing their own hands while signing. Performance with the Own Hand stimuli was relatively unaffected by the Central vs. Peripheral View manipulation (except for the number NINE; see Figure 4), whereas performance with the Other Hand stimuli was worse in the Peripheral View condition. One explanation for this pattern is that signers have more experience viewing their own hand at the

periphery of their visual field, and thus performance with the Own Hand stimuli did not drop when in the Peripheral View (unlike the Other Hand stimuli). If correct, this explanation suggests that signers do not ignore visual feedback received while signing and provides some evidence that visual feedback might be used during sign comprehension.

However, the error prone performance in the Peripheral View/Own Hand condition indicates that the sign comprehension system is not particularly good at identifying hand configuration information from the visual signal that is received from self-produced signing. In fact, during pilot testing for this experiment, we presented stimuli at farther eccentricities that nonetheless fell within normal signing space (e.g., 50 degrees eccentricity). However, participants were unable to do the task and performed at chance for this distance from the fovea. Furthermore, using motion tracking, Arena, Finlay, and Woll (2007) found that deaf signers' hands frequently fall outside their field of view (as measured by Goldman Perimetry), and thus cannot be seen. Therefore, visual feedback from signing may be frequently unavailable and when present, difficult for the comprehension system to parse.

For speakers, auditory feedback is also used to monitor phonetic aspects of speech production and may be more important for detecting phonological errors than semantic errors (Hartsuiker, Kolk, & Martensen, 2005; Postma & Noordanus, 1996; Slevc & Ferreira, 2006). In Experiment 2, we investigated whether a lack of visual feedback might impair the ability of signers to monitor phonetic aspects of language production. In addition, we explored whether visual feedback might be particularly useful for new learners who do not have a sign-based phonological system, i.e., hearing people who do not know sign language. For spoken language, such an inquiry regarding the role of auditory feedback in novel word production is impossible because all hearing individuals have acquired sound-based phonological representations. For sign language, however, we can compare the utility of visual feedback in learning to produce novel signs (e.g., signs from a foreign language) for both deaf signers who have established perceptual-motor mappings for a sign language and for hearing non-signers who do not. Visual feedback may be particularly crucial when initially establishing perceptual-motor mappings for manual language production.

Experiment 2: The role of visual feedback in imitation learning

According to the DIVA model of speech production (Guenther, 1995), speech movements are planned to achieve a sequence of auditory goals via mappings between articulations and their acoustic consequences. It is hypothesized that these mappings are acquired and maintained through the use of auditory feedback (Guenther & Perkell, 2004). Evidence supporting this hypothesis is the finding that auditory feedback improves production performance when adult speakers have to learn how to produce a "normal" /s/ while wearing a dental prosthetic that elongates their teeth (Jones & Munhall, 2003). Utterances produced when speakers could hear themselves were judged by listeners to be higher quality than productions produced when speakers' feedback was masked by noise. We explored whether visual feedback improves manual production performance when deaf ASL signers and/or hearing non-signers learn how to produce signs from Russian Sign Language (RSL) in an imitation learning task.

In Experiment 2, participants saw a videoclip of a RSL sign produced by a sign model on a computer screen and then immediately attempted to copy the sign. This procedure was repeated five times per sign, and participants attempted to improve their articulation with each successive repetition. Participants were given three sets of safety glasses: clear (normal vision), blurring, and blackened. When viewing the signs, participants raised their glasses so that the sign model could be seen, but during production, they lowered their glasses so that they either received no visual feedback, blurred feedback, or normal visual feedback as they signed. Using this paradigm, we investigated whether the production of RSL signs improved when visual

feedback was available. The blurred visual feedback condition was included to test the hypothesis that degraded visual feedback might actually lead to worse performance than no visual feedback because participants might have difficulty integrating blurred visual feedback with normal somatosensory feedback (the only type of feedback available in the “blind” condition). In addition, we examined participants’ ability to reproduce the mouth movements (“mouthings”) that accompanied the RSL signs. Mouthings could not benefit from visual feedback, and we predicted that production performance for mouthing would be unaffected by feedback condition.

Method

Participants—Forty-six adults participated in Experiment 2. Twenty-eight participants (18f; 10m) were deaf, with a mean age of 27.2 years (range: 18 – 42 years). Twenty-three participants of these participants were exposed to ASL from birth or in early childhood, and five acquired ASL in adolescence. All deaf participants used ASL as their preferred and primary language. Eighteen participants (13f; 5m) reported normal hearing and no knowledge of a signed language beyond the manual alphabet (mean = 22.3 years; range 18 – 27 years). All of the participants reported normal or corrected-to-normal vision and received monetary compensation. No participant reported any knowledge of Russian Sign Language.

Materials—Two deaf native ASL signers selected 36 RSL signs which they perceived to be difficult to produce from the following website: <http://www.stanford.edu/group/ll/data2/rsl>. The signs were judged difficult to produce because they contained non-ASL handshapes, combinations of handshapes, locations, or movements that were illegal or rare in ASL, or they contained a sequence of two or more distinct movements and handshapes. Due to digital compression, the website signs were not of a high enough quality to be used in the experiment. Therefore, we filmed a deaf native ASL signer reproducing the RSL signs, with mouthings (after extensive practice). The 36 RSL signs were edited into three separate lists of 12 signs, and the lists were counterbalanced across visual feedback conditions (blind, blurred, normal). Thus, each sign was learned by a given participant only once, and across participants, all signs appeared in each feedback condition.

Three types of safety glasses were used to create the different visual feedback conditions. For the no feedback condition, the safety glasses were covered with black electrical tape, which essentially rendered participants blind when worn. For the blurred visual feedback condition, the glasses were covered with two 20/400 Bernell amblyopia cling patches, which blurred vision to 20/800 when worn. For the normal visual feedback condition, the clear glasses were unaltered.

Procedure—Visual feedback conditions (blind, blurred, normal) were blocked, and order of condition was counterbalanced across participants. Participants were told that they would see a woman producing signs from Russian Sign Language and to closely watch each clip and then copy the woman as accurately as possible. They were asked to reproduce the mouthing component as well as the manual sign. After each clip, participants pressed the space bar to pause the video, and then put on the appropriate glasses before producing the sign. After imitating the sign, participants raised their glasses to rest on top of their head and pressed the space bar to see the target sign again. Each sign was viewed and imitated five times. Prior to each feedback condition, one practice RSL sign was presented (with five repetitions). The video camera was placed directly behind and adjacent to a 15” Powerbook G4 computer that was used to present the digital video stimuli. At the end of the experiment, a subset of 23 deaf signers and 15 hearing non-signers filled out a short questionnaire that asked whether they felt it was easier, harder, or made no difference to their performance when they wore the blackened or blurring glasses.

Coding—Each participant produced 36 signs, each of which he or she imitated five times, for a total of 180 signs per participant, with 12 signs (60 sign productions) in each feedback condition. Participants' sign productions were coded for overall manual accuracy and mouthing accuracy. For manual accuracy, each sign was assigned a point for each handshape, movement, orientation, and location in the sign. The possible sign scores ranged from 4 to 9 points (mean score = 6.58). Two deaf native ASL signers scored the 180 sign productions for each participant awarding a point for each correctly produced phonological parameter. Inter-rater agreement for sign scores was relatively high (83%, 86%, and 85% for the blind, blurred, and normal feedback conditions, respectively). Individual sign scores were divided by the total possible score for that item to arrive at a percent accuracy (where 100% indicates that the sign was reproduced completely accurately, and 0% indicates that it was reproduced with no phonological parameter correct). The dependent variable for the manual signs was percent accuracy, calculated within a feedback condition for each participant (across items) and for each item (across participants). For mouthing accuracy, each sign production was rated as 0 (no mouthing present), 1 (mouthing present, but inaccurate), or 2 (very good attempt/accurate), and these ratings served as the dependent variable. Finally, for each imitation, we noted whether participants looked at their hands during production, i.e., shifting their eyes and/or head away from the computer screen/camera and toward their hands.

Results

Manual sign imitation—For the manual sign scores, participant and item accuracy percentages were submitted to separate repeated measures analyses of variance (ANOVAs) using subjects (F1) and items (F2) as random factors, and including group (deaf signer, hearing non-signer), feedback condition (blind, blurred, normal), and repetition (1st, 2nd, 3rd, 4th, 5th) as independent variables. Figure 5 illustrates the accuracy for deaf signers and hearing non-signers across repetitions for each feedback condition.

Not surprisingly, deaf signers were significantly more accurate than non-signers (93.7% vs. 66.2% correct, respectively), $F(1,42) = 189.4, p < .001$; $F(1,35) = 240.88, p < .001$, $\text{minF}'(1,77) = 106.03, p < .001$, for the main effect of group. Both participant groups improved in accuracy across repetitions (73%, 79%, 81%, 83%, and 84% for the 1st, 2nd, 3rd, 4th, and 5th repetitions, respectively), $F(4,168) = 191.9, p < .001$; $F(4,140) = 117.74, p < .001$, $\text{minF}'(4,277) = 72.97, p < .001$, for the main effect of repetition. There was also a significant interaction between group and repetition, $F(4,168) = 65.92, p < .001$; $F(4,140) = 48.74, p < .001$, $\text{minF}'(4,291) = 28.02, p < .001$. Non-signers improved more than deaf signers across repetitions (17.8% vs. 4.7% improvement, respectively).

There was no main effect of feedback condition with the subjects analysis, $F(1,2,84) = 0.84, p = .43$, although the effect was significant by items, $F(2,70) = 4.17, p = .02$, $\text{minF}'(2,116) = .7, p = .50$ (mean percent correct for items in the blind, blurred, and normal conditions was 81.0%, 80.01%, and 78.4%, respectively). Visual feedback condition interacted with repetition, $F(1,8,336) = 2.33, p = .02$; $F(2,8,280) = 1.86, p = .06$, $\text{minF}'(8,591) = 1.03, p = .41$. Overall, improvement on manual sign production was similar for the no visual feedback and blurred feedback conditions (mean improvement = 11.71% and 12.16%, respectively), and the least improvement was observed in the condition with normal visual feedback (9.81%). There was not a significant interaction between feedback condition and participant group with the subjects analysis, $F(1,2,84) = 1.57, p = .21$, although the interaction was significant with the items analysis, $F(2,70) = 4.4, p = .02$, $\text{minF}'(2,134) = 1.16, p = .32$. Item accuracy was more affected by feedback condition in the non-signing group (mean item accuracy for blind, blurred, and normal feedback = 67.9%, 67%, and 62.8%) than in the signing group (94.1%, 93%, and 94%, respectively).

Finally, the three-way interaction between group, repetition, and condition, was significant by subjects, $F(1, 336) = 2.23$, $p = .03$, and marginally significant by items, $F(2, 280) = 1.64$, $p = .11$, $\text{minF}'(8, 581) = .95$, $p = .48$. A separate analysis for the hearing non-signers revealed a significant interaction between feedback condition and repetition, $F(1, 128) = 2.34$, $p = .022$; $F(2, 280) = 1.89$, $p = .06$, $\text{minF}'(8, 377) = 1.045$, $p = .40$. As can be seen in Figure 5, non-signers improved least in the normal visual feedback condition (15.05%), and improved more in the blind and blurred feedback conditions (19.28% and 18.93%, respectively). In contrast, deaf signers improved about equally well in all three feedback conditions (4.14%, 5.39%, and 4.55% for blind, blurred, and normal feedback conditions, respectively), $F(1, 208) = 1.01$, $p = .43$; $F(2, 280) = 1.20$, $p = .30$, $\text{minF}'(8, 462) = .55$, $p = .18$ (see Figure 5).

Mouth pattern imitation—Table 2 provides the mean ratings for mouthing accuracy for each group. Like manual accuracy, mouthing accuracy improved over repetitions for both groups, from 1.04 to 1.24 out of a possible score of 2.0, $F(1, 168) = 46.73$, $p < .001$; $F(2, 140) = 53.51$, $p < .001$, $\text{minF}'(4, 308) = 24.94$, $p < .001$. Deaf signers again outperformed non-signers, with mean scores of 1.62 and 0.70, respectively, $F(1, 42) = 57.44$, $p < .001$; $F(2, 35) = 731.98$, $p < .001$, $\text{minF}'(1, 48) = 53.260$, $p < .001$. As with manual sign accuracy, non-signers improved more than deaf signers in mouthing production, $F(1, 168) = 23.33$, $p < .001$; $F(2, 140) = 35.19$, $p < .001$, $\text{minF}'(4, 304) = 14.03$, $p < .001$, for the interaction between participant group and repetition. Unlike manual accuracy, however, mouthing accuracy was unaffected by the availability or quality of visual feedback, as revealed by no significant main effect of feedback and no significant interactions between feedback condition and participant group or repetition (all F s ≤ 1.7).

Phonological parameter effects—For the non-signer group, we examined whether visual feedback condition differentially affected the production of handshape, location (place of articulation), or movement phonological parameters. Given the high accuracy of the deaf signing group and the lack of an interaction with feedback condition for this group, we did not conduct the time-intensive phonological analyses for the deaf signers. Separate repeated measures ANOVAs were conducted for each phonological parameter for the non-signers, and the results are shown in Figure 6.

As expected from research on sign language acquisition (e.g., Conlin, Mirus, Mauk, & Meier, 2000; Siedlecki & Bonvillian, 1993; Marentette & Mayberry, 2000), non-signing participants were least accurate in learning to reproduce hand configuration (mean accuracy = 48.67%). However, non-signers improved across repetitions, $F(1, 64) = 130.94$, $p < .001$; $F(2, 140) = 86.95$, $p < .001$, $\text{minF}'(4, 197) = 52.25$, $p < .001$ for the main effect of repetition. There was no main effect of feedback condition, $F(1, 32) = .47$, $p = .62$; $F(2, 70) = 1.13$, $p = .33$, $\text{minF}'(2, 59) = .33$, $p = .72$, and no interaction between feedback condition and repetition, $F(1, 128) = 1.34$, $p = .23$; $F(2, 280) = 1.62$, $p = .12$, $\text{minF}'(8, 326) = .73$, $p = .34$.

Also predicted from sign language learning studies, non-signing participants were the most accurate in producing the target place of articulation (mean accuracy = 82.88%). Location accuracy also improved across repetitions, $F(1, 64) = 40.44$, $p < .001$; $F(2, 140) = 29.14$, $p < .001$, $\text{minF}'(4, 194) = 16.94$, $p < .001$. There was no main effect of feedback by subjects, $F(1, 32) = 1.09$, $p = .35$, although the items analysis was significant: Non-signers performed least well on items in the normal feedback condition (79.5%) compared to items in the blind and blurred feedback conditions (84.5% and 83.3%, respectively), $F(2, 70) = 4.72$, $p = .01$, $\text{minF}'(2, 47) = .89$, $p = .42$. There was no interaction between feedback and repetition, F s < 1 .

For movement, the production performance of the non-signers fell in-between that of hand configuration and place of articulation (mean accuracy = 65.23%), again following the expected pattern in sign language acquisition. Movement accuracy improved across

repetitions, $F(4,64) = 91.15$, $p < .001$, $F(4,140) = 61.59$, $p < .001$, $\text{minF}'(4,393) = 36.75$, $p < .001$. There was no main effect of feedback by subjects, $F(2,32) = .58$, $p = .57$, although (as with location), the items analysis indicates that non-signers were least accurate in the normal feedback condition (61.5%) followed by the blind and blurred feedback conditions (68% and 65.4%), $F(2,70) = 3.29$, $p = .04$, $\text{minF}'(2,44) = .49$, $p = .61$. There was no interaction between feedback condition and repetition, $F(8,128) = .85$, $p = .56$; $F(8,280) = 1.02$, $p = .42$, $\text{minF}'(8,327) = .46$, $p = .88$.

Eye gaze patterns—The analysis of gaze patterns in the blurred and normal visual feedback conditions revealed that neither group looked directly at their hands very often (see Table 3). Non-signers gazed at their hands more often than deaf signers: 12.45% vs. 5.62% of sign productions were accompanied by looks toward the hands, $F(1,42) = 6.15$, $p = .02$, $F(1,35) = 29.15$, $p < .001$, $\text{minF}'(1,58) = 5.08$, $p = .03$. Participants tended to look at their hands a similar percent of the time for the blurred and normal visual feedback conditions (9.3% and 8.8%, respectively), $F_s < 1$, for the main effect of feedback condition. There was no interaction between visual feedback condition and participant group for percent of sign productions with looks toward the hand(s), $F_s < 1$.

We next examined whether non-signing participants exhibited better production performance for signs in which they looked at their hands during at least one repetition compared to signs in which they did not. Overall, non-signers performed marginally better when they looked at their hands (71.5% vs. 65.2%), $F(1,16) = 3.91$, $p = .06$; $F(1,34) = 3.8$, $p = .058$, $\text{minF}'(1,44) = 1.93$, $p = .17$.² Examining their performance by phonological parameter, the non-signers were significantly more accurate at reproducing the target handshape when the sign was accompanied by a direct look at their hands (61.3%) versus when it was not (47.97%), $F(1,16) = 9.24$, $p = .007$; $F(1,34) = 12.60$, $p = .001$, $\text{minF}'(1,38) = 5.33$, $p = .03$. In contrast, location and movement accuracy improved only slightly when participants looked directly at their hands, and the effects were not significant. Production of place of articulation improved 2.55%, $F_s < 1$, and movement showed a 3.71% improvement, $F(1,16) = .70$, $p = .41$; $F(1,34) = 2.46$, $p = .12$, $\text{minF}'(1,25) = .55$, $p = .47$.

Questionnaire results—Finally, in response to our post-experiment questionnaire, the majority of deaf signers felt that the blackened glasses and blurring glasses had no effect on their production performance (52% and 57% of participants, respectively). A smaller percentage of participants felt that the task was harder when wearing the blackened and blurring glasses (30% and 39%, respectively), and the remainder felt that the task was actually easier with these glasses (17% and 4%, respectively). Non-signers were similar in that most (67%) felt the blurring glasses had no effect on their performance, while 20% felt the blurring glasses made the task harder, and a small percentage (13%) felt the task was easier in this condition. For the no visual feedback condition, the non-signers were roughly divided between judging the task to be harder (47%) or no different (40%) with the blackened goggles, and 13% felt the task was easier in this condition.

Discussion—Both deaf signers and hearing non-signers fine-tuned and improved their production of RSL signs with practice, although most of the improvement for the deaf signers was between the first and second repetitions (see Figure 5). However, neither group reproduced RSL signs more accurately when normal visual feedback was available to them, compared to when visual feedback was degraded or absent. The availability of visual feedback did not enable better sign production performance immediately (with the first repetition) nor did it lead to greater improvement across repetitions.

²One item was excluded from the items analysis because participants never looked their hands during its production.

In fact, there was evidence that non-signers improved *least* with normal visual feedback. One possible explanation for this finding is that non-signers may have been distracted by the visual mismatch between their own productions and those of the sign model. As discussed for Experiment 1, the view of a signer's own hand is from the back and the direction of hand movement is reversed from that of an observed sign (all participants were right-handed, as was the sign model). A few participants who indicated that the task was easier with no visual feedback (blackened glasses) explained that "I could visualize what I just saw easier without distraction" and "I feel I could sign it without any visual disturbance." Another possibility is that participants were more likely to focus on somatosensory feedback when clear visual feedback was not available. In this case, the absence of visual feedback may have improved performance by encouraging participants to fine-tune and monitor their manual production using sensorimotoric information. If phonological targets in sign language are articulatory, rather than perceptual (see Emmorey, 2005, for discussion), then concentrating on kinesthetic and proprioceptive feedback may have been beneficial in achieving the correct articulation.

The pattern of slightly worse performance with normal visual feedback was observed for each phonological parameter (see Figure 6), indicating that the presence of visual feedback did not differentially affect the production of the handshape, movement, or location of target signs. Non-signers were least accurate in producing handshape and most accurate for location, a pattern that parallels phonological acquisition by deaf children (Conlin et al., 2000; Marentette & Mayberry, 2000; Siedlecki & Bonvillian, 1993). In addition, for sign language production by adult signers (Newkirk, Klima, Pedersen, & Bellugi, 1980) and by aphasic signers (Corina, 2000), handshape production is the most vulnerable to sign errors and location is the most resistant to error. Similarly, when signers (of British Sign Language) make perceptual errors in sign recognition, handshape is misperceived much more often than location (Orfanidou, Adam, McQueen, & Morgan, 2009). These error patterns reflect the fact that handshape is the most phonologically complex parameter (Brentari, 1998; Sandler & Lillo-Martin, 2006), that location is the least ambiguous parameter and easily perceived (Orfanidou et al., 2009), and that the complex RSL handshapes were more difficult to articulate compared to reaching toward or contacting locations on the face or body.

As predicted, visual feedback condition had no effect on the production of mouthing, since one cannot see one's own mouth. When learning mouth patterns that accompany signs, somatosensory feedback is the only type of feedback available. In contrast, when learning mouth patterns associated with speech, both somatosensory and auditory feedback are present. Not surprisingly, Deaf signers outperformed non-signers when learning to produce both mouth patterns and manual signs. The deaf signers had years of experience mapping observed manual and mouth productions to their own articulations, and they also had internalized phonological representations of ASL that could serve as production aids.

The majority of sign productions (>90%) were produced while participants looked at the computer screen where the sign model appeared (or at the adjacent video camera), rather than while looking at their hands. This pattern follows normal sign production in that signers do not visually track their hands, but rather look at their addressee's face (Emmorey, Thompson, & Colvin, 2009; Siple, 1978). However, hearing non-signers, for whom the sign imitation task was particularly difficult, were more likely to look at their hands. Furthermore, their ability to produce the correct hand configuration (but not location or movement) improved when they looked directly at their hand(s). Thus, visual feedback can enhance handshape articulation when it is obtained by consciously directing gaze and attention to the hands. However, this is not the type of visual feedback that was received during the majority of sign productions in this study nor the type of visual feedback that is normally received when signing.

In sum, the results of Experiment 2 contrast with the general results from spoken language. Studies with spoken language report detrimental effects on speech production when auditory feedback is removed (e.g., Burke, 1975; Forrest, Abbas, & Zimmermann, 1986; Jones & Munhall, 2003; Lane & Tranel, 1971). In contrast, we found either no effect (for deaf signers) or a slight beneficial effect (for hearing non-signers) when normal visual feedback was removed. Nonetheless, strategic gaze toward the hands did improve handshape articulation when visual feedback was available for the non-signers.

General Discussion

The fact that signers detect overt errors and produce repairs argues for the existence of an external monitor for sign production (Emmorey, 2002; Hohenberger et al., 2002). In Experiment 1, we investigated the usefulness of visual feedback for a perception-based external monitoring system. The results indicated that signs perceived through visual feedback (Own Hand; Peripheral View) were quite difficult, although not impossible, to recognize. Recognition was above chance, and when a distinctive cue was present (i.e., no extended pinky for SIX), signers were able to identify the sign in the Own Hand condition (except when presented in the Peripheral View). Nonetheless, the low recognition performance in the visual feedback condition indicates that the visual signal from self-produced signing is quite poor. In addition, the visual signal from signs produced on the body may be even more difficult for the sign comprehension system to recognize. When signing, signers direct their gaze toward their addressee and do not look at their own bodies. Therefore signs that are made by contacting the torso with no outward movement cannot be easily seen. For example, the ASL sign POLICE is produced by tapping the left side of the chest with a “C” handshape. Although one can feel this sign being made, one cannot see the sign while gazing straight ahead.

As noted in the introduction, the sign comprehension system does not receive *any* visual feedback for non-manual linguistic markers, such as facial expressions, head nods, body shifts, etc. In ASL, as well as in many other signed languages (Zeshan, 2004a, 2004b), non-manual markers signal distinct types of interrogative and negative constructions. Conditional clauses, relative clauses, and adverbials are all also marked with non-manuals in ASL. Crucially, for some constructions, the non-manual marker is obligatory and may be the only syntactic marker for the construction. For example, conditional clauses can be marked solely by raised brows in ASL, and if the comprehension system does not perceive the raised brows, the sentence will be misinterpreted as a coordinate clause.

Together, these facts and the results of Experiment 1 indicate that visual feedback during signing is not easily recognized by the comprehension system. The comprehension system must be designed to parse the visual input from other signers, identifying non-manual markers, segmenting and identifying signs, etc. However, the visual input from self-produced signing does not appear to provide sufficient information for the comprehension system to accurately perform these computations. Such difficulty and poor performance when identifying self-produced language is not observed for spoken language. Although the sound of one’s own voice when played back on a tape recorder may be perceived as odd, one’s speech is nonetheless identifiable and recognized as easily as the speech of another person.

Also in contrast to spoken language, Experiment 2 revealed that a lack of visual feedback is not detrimental to sign articulation and may even improve articulation for novice learners (non-signers). Novice learners may have been distracted by the mismatch between the visual perception of the sign model and the visual perception of their own signing. The results of Experiments 1 and 2, in combination with other facts about the visibility of lexical and grammatical information during sign language production, indicate that the external monitoring system for sign language does not operate primarily using visual feedback.

We hypothesize that this monitor may be more sensitive to somatosensory feedback than to visual feedback. Signers receive proprioceptive and kinesthetic feedback about the position and movement of their hands and arms as they sign, and they receive tactile feedback when fingers touch each other and when the hand contacts the face or body. Evidence for the ability to detect errors based on this type of feedback is found in the self-corrections and repairs of blind signers, who rely solely on somatosensory feedback (see Emmorey, Korpics, & Petronio, 2009). In addition, novice learners may have performed better in the no visual feedback condition in Experiment 2 because they were forced to attend to somatosensory feedback when learning to produce signs.

We know of no study that specifically investigates somatosensory feedback during sign production, but there is indirect evidence suggesting an important role for sensory feedback based on proprioception. For example, Emmorey, Mehta, and Grabowski (2007) hypothesize that sign production, unlike word production, recruits the left superior parietal lobule (SPL) for the proprioceptive monitoring of language output. Lesion, neuroimaging, and TMS data all indicate a role for the superior parietal lobule in proprioception and the assessment and monitoring of self-generated movements (e.g., MacDonald & Paus, 2003; Pellijeff, Bonilha, Morgan, McKenzie, & Jackson, 2006; Wolpert, Goodbody, & Husain, 1998). Neuroimaging studies have consistently found that the left SPL is engaged during sign production (Corina, San Jose-Robertson, Guillemin, High, & Braun, 2003; Emmorey et al., 2003; Petitto et al., 2000 [supplement tables]; San Jose-Robertson, Corina, Ackerman, Guillemin, & Braun, 2004), but this neural region is not systematically activated during word production (Indefrey & Levelt, 2004). Furthermore, Corina et al. (2003) found increased activation in left SPL when right-handed signers produced signs with their left hand. It is possible that this increase in activation is due to the need for increased monitoring and assessment of the movements and hand configurations of the non-dominant hand.

In addition, evidence from deaf signers who have schizophrenia and experience “voices” provides some insight into the nature of monitoring and sensory feedback (Atkinson, 2006). A widely accepted account of auditory hallucinations in hearing people with schizophrenia attributes voice hallucinations to failures of self-monitoring, which result in subvocal speech being misinterpreted as originating externally (Frith, 1992). Atkinson (2006) argues that there are crucial differences in how hallucinations are experienced by deaf signers. While hearing people report vivid auditory imagery during voice-hallucinations, deaf people often report visual or somatic sensations. Atkinson (2006) hypothesizes that “if subvocalization is primarily a form of motor imagery, perceptual feedback may vary depending on the modality of the subvocal articulation. Thus, a hearing individual might perceive an auditory trace-ancillary to motor subvocalization of their thoughts, and the same process may result in a visual or kinaesthetic percept for signers (pg. 5).” Atkinson (2006) speculates that the raised incidence of tactile/somatic hallucinations in deaf people with schizophrenia may be attributable to the nature of the sensory feedback loop for sign language. That is, if sign language production involves somatosensory monitoring of hand and arm movements, hallucinations might result in premotor kinesthetic traces that would be experienced as somatic sensations. In a subsequent study, Atkinson, Gleeson, Cromwell, and O’Rourke (2007) found that pure tactile hallucinations were relatively rare, but “subvisual” hallucinations were often reported by prelingually deaf signers with schizophrenia. Atkinson et al. (2007) argue for an articulatory model of voice hallucinations for both deaf and hearing people and suggest that faulty source-monitoring in premotor neural circuitry may cause sign-based visual-somatic hallucinations.

What do these modality differences in perceptual feedback imply for models of language production? Models of language production that can account for monitoring of both signed and spoken language output should be favored based on parsimony. Thus, models that posit a role for somatosensory feedback for monitoring speech are supported (e.g., Lackner and Tuller,

1979). It is likely, however, that signers and speakers rely differentially on somatosensory monitoring. The fact that speakers detect fewer errors during mouthed speech than during normal speech indicates that they do not rely solely on somatosensory monitoring (Postma and Noordanus, 1996). Auditory feedback provides essential information about acoustic properties of self-produced speech that is not available through proprioception, such as voicing or nasalization. Postma (2000) hypothesizes that proprioceptive and tactile feedback may be critical for fine tuning speech motor output, but may play little role in the detection of speech errors.

Based on the data we have presented thus far, we cannot conclude that the external monitor for sign language does not utilize visual feedback at all. Although visual feedback might be distracting for adults learning to produce signs, evidence from child language acquisition suggests a role for visual feedback when learning signs. Morgan, Barrett-Jones, and Stoneham (2007) reported more hand configuration errors by a young deaf child (aged 19 to 24 months) when she produced signs with a place of articulation that fell in her visual periphery. Deaf mothers also sometimes sign on their child's own body in a way that presents a view of signing to the child as if the child were signing herself. In addition, the novice learners in Experiment 2 appeared to use strategic visual feedback (i.e., looking directly at their hands) to improve handshape articulation. Finally, deaf signers with tunnel vision due to Usher Syndrome or created by wearing tunnel vision goggles, produce signs within a more restricted signing space (Arena et al., 2007; Emmorey, Korpics et al., 2009; Emmorey, Gertsberg, Korpics, & Wright, 2009). Arena et al. (2007) and Emmorey, Korpics et al. (2009) hypothesize that visual feedback is used to calibrate the size of signing space, rather than to keep the hands within view. However, it is also possible that the external monitor for sign language assesses visual feedback as a potential source of information about sign production accuracy, but cannot rely on this visual input alone, as evidenced by the high rate of errors for recognizing self-produced signs in Experiment 1 and the lack of visibility of grammatical facial expressions and lexical signs produced in the periphery. We therefore suggest that visual feedback is not the main source of information for detecting sign errors.

Finally, there is the question of whether the comprehension system is involved in self-monitoring of overt signing, given that the comprehension system normally receives visual signed input but is unlikely to be able to efficiently use visual input from self-produced signing. One solution is to adopt a "motor theory of sign perception," as has been proposed for speech (see Galantucci, Fowler, & Turvey, 2006, for review). If perceiving signs involves access to the motor system, then it is possible that the comprehension system operates with gestural representations that are computed either from sensory-motoric input or from visual input. Mounting evidence indicates that the motor system is recruited during the visual perception of human actions (e.g., Buccino et al., 2001; Fadiga, Craighero, Buccino, & Rizzolatti, 2002), and several investigators argue that perception and action share a common coding (Goldstein & Fowler, 2003; Prinz, 1997). It is possible that external monitoring for sign (and perhaps for speech) operates upon such a common code, rather than upon a purely perceptual (visual or auditory) code. It is likely that such a common code is form-based (phonological or phonetic) and does not contain higher-level semantic or lexical information. Consistent with this hypothesis, studies by Hartsuiker et al. (2005), Postma and Noordanus (1996), and Slevc and Ferreira (2006) found that the external monitor for speech is relatively unimportant for the detection of lexical semantic errors, but important for the detection of phonological errors.

To conclude, models of human language processing should be able to account for data from both signed and spoken languages. The perceptual loop hypothesis of self-monitoring is problematic for sign language because of the difficulty that the comprehension system faces in parsing visual input from self-produced signing. If the perceptual loop hypothesis is to be maintained, we suggest that the comprehension system must be able to parse a somatosensory

signal as well as an external perceptual signal for both sign and speech. Further studies are needed to determine whether signers perhaps rely more on the internal monitor, rather than the external monitor, to detect sign errors and whether overt sign errors that are easier to feel (based on somatosensory feedback) are better detected compared to errors that might be easier to see (based on visual input).

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Figure 1. Stimuli used in the visual discrimination task were images of ASL number signs, as seen when the signs are produced by another signer (Other Hand) or as seen when produced by the signer (Own Hand).

Central View

Peripheral View

Figure 2.

Illustration of the experimental set up for presenting ASL numbers as they would fall on the retina if another signer produced the numbers (Central View) or if the participant produced the numbers (Peripheral View). For the Central View, the participant fixated on a dot affixed to right side of the computer which was 5 cm above and 7.5 cm to the right of the hand image (14.4 degrees eccentricity). For the Peripheral View, the computer was tilted 45 degrees from the participant's line of vision, and the participant fixated on a dot affixed to the opposite wall (not seen) which was 35.5 cm above and 23 cm to the left of the hand image (45 degrees eccentricity).

Figure 3.
Mean percent correct for identifying ASL number signs. Bars indicate standard error.

Figure 4.
Mean percent correct for identifying each ASL number sign. Bars indicate standard error.

Figure 5. Mean percent correct for deaf signers and hearing non-signers at each of five repetitions, as a function of visual feedback condition (blind, blurred, normal). Bars indicate standard error.

Figure 6.

Mean percent correct for each phonological parameter at each repetition, as a function of visual feedback condition (blind, blurred, normal). Data presented are for hearing non-signers only. Bars indicate standard error.

Table 1

Mean response latencies (ms) for identifying ASL number signs in each condition. Standard error is given in parentheses.

	Central View	Peripheral View
Other Hand	1056 (76)	1650 (318)
Own Hand	1570 (223)	1958 (427)

Mouthing accuracy for deaf signers and hearing non-signers as a function of visual feedback condition (highest possible score = 2). Standard deviations are given in parentheses.

Table 2

Deaf signers	Repetition				
	1	2	3	4	5
Blind	1.5 (.43)	1.6 (.44)	1.6 (.42)	1.6 (.42)	1.6 (.44)
Blurred	1.6 (.40)	1.6 (.34)	1.6 (.35)	1.6 (.37)	1.7 (.36)
Normal	1.6 (.39)	1.6 (.38)	1.7 (.36)	1.7 (.38)	1.7 (.35)
Non-signers					
Blind	.47 (.36)	.63 (.45)	.72 (.48)	.81 (.49)	.86 (.55)
Blurred	.5 (.37)	.65 (.45)	.74 (.45)	.77 (.50)	.85 (.49)
Normal	.56 (.46)	.61 (.50)	.7 (.52)	.79 (.57)	.84 (.54)

Table 3

Percent of sign productions in which participants looked at their hands (out of 60 sign productions in each visual feedback condition). Standard deviations are given in parentheses.

	Blurred Visual Feedback	Normal Visual Feedback
Deaf signers	5.62% (1.31)	5.62% (9.59)
Hearing non-signers	12.9% (1.4)	12.0% (1.3)