Is Lexical Access Driven by Temporal Order or Perceptual Salience? Evidence from British Sign Language

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Abstract

While processing *spoken* language, people look towards relevant objects, and the time course of their gaze(s) can inform us about online language processing (Tanenhaus et al, 1995). Here, we investigate lexical recognition in British Sign Language (BSL) using a visual world paradigm, the first such study using a signed language. Comprehension of spoken words and signs could be driven by temporal constraints regardless of modality ("first in, first processed"), or by perceptual salience which differs for speech (auditorialy perceived) and sign (visually perceived). Deaf BSL signers looked more often to semantically related distracter pictures than to unrelated pictures, replicating studies using acoustically-presented speech. For phonologically related pictures, gaze increased only for those sharing visually salient phonological features (i.e., location and movement features). Results are discussed in the context of language processing in different modalities. Overall, we conclude that lexical processing for both speech and sign is likely driven by perceptual salience and that potential differences in processing emerge from differences between visual and auditory systems.

Keywords: lexical access; sign language; semantics, phonology, visual world; modality

Introduction

General theories of language processing have developed on the basis of extensive data from spoken, but not signed languages, making it impossible to tease apart those aspects of language processing that are truly general from those dependent on the oral-aural language modality. While spoken language processing happens through aural perception of sounds, sign language processing occurs through visual perception which allows for more simultaneous input of information; spoken languages make use of mouth and vocal tract, while signed languages use slower manual articulators (hands, as well as eyes, mouth and body). An understanding of the processing differences that arise from these differing language modalities is critical for understanding the interaction of language processing with other cognitive systems such as perception and action. Here we take advantage of these physical differences in language processing for signed languages compared to spoken languages to investigate the nature of lexical processing and lexical access.

For spoken languages, it is generally uncontroversial that information is processed almost immediately as it comes in (e.g., Rayner & Clifton, 2009). Such *incremental* moment-by-moment language processing is likely necessary to keep up with the incredibly fast rate of speech input (estimated to be between 150-190 words per minute, Marslen-Wilson, 1973). However, during incremental processing listeners, processing even a single word, are faced with many possible alternatives that match the current acoustic-phonetic input. Empirical evidence suggests that instead of waiting until temporary ambiguities are resolved, partial activation of possible words (i.e., lexical competitors) that match current phonological information proceeds, with potential words being eliminated across time as more information becomes available (e.g., McClelland and Elman, 1986; Gaskell & Marslen-Wilson, 1997).

Evidence for incremental activation of lexical competitors during spoken language processing comes from the "visual world" paradigm (language presented simultaneously with related pictures; Allopena, Magnuson, & Tanenhaus, 1998; Altman & Kamide, 2004; Huettig & Altmann, 2005; Yee & Sedivy, 2006). For example, in Allopena et al. (1998), subjects heard an utterance like "Pick up the beaker" while viewing a display with four pictures including: 1) an object matching the noun (the target; e.g. "beaker"), 2) an object with a name beginning with the same phoneme (e.g. "beetle"), 3) an object with a name sharing the same rhyme (e.g., "speaker") and, 4) an unrelated object (e.g., carriage). The probability of fixating the target and onset competitor were identical immediately after word onset (when the two could not be distinguished from each other), and fixations to these picture types were higher than fixations to the rhyme or unrelated competitors. Immediately after reaching a phoneme differentiating the target and onset competitor, the probability of fixating the target rose sharply while the probability of fixating the related competitor fell. A weaker, but significant effect was also observed for rhyme competitors compared to unrelated competitors, indicating that activation is not restricted to words sharing onsets but is continuous (see for example McClelland and Elman, 1986).

A question of interest, then, is why words that share onsets make the strongest lexical competitors. One possibility is that strong activation of onset competitors compared to word rhymes is due to temporal considerations: i.e., word onsets occur earlier in time. This view about the activation of onset competitors can be called a 'first in, first processed' account. However, onsets also tend to be salient, particularly in languages such as English (used in the majority of visual world studies) in which stress has the effect of lengthening the first syllable as well as adding both intensity and pitch change: all of which serve to make the first part of a word more salient. Evidence that stress is important to lexical access comes from Reinisch, Jesse, and McQueen (2010). In a visual world study they found that participants use lexical stress information to direct eye gaze such that upon hearing a word with initial stress (e.g., *octopus*) fixations on printed target words with first-syllable stress (e.g., octopus) were more frequent than fixations on differently stressed competitors (e.g., *October*, with stress on the second syllable). Thus, an alternate account of the strong activation of onset competitors observed in visual world studies is that word onsets are the most auditorily salient part of a word and that auditory salience drives lexical access for processing efficiency. However, because spoken word onsets tend to be *both* temporally early and auditorily salient, it is difficult to tease apart these alternate accounts based on previous studies.

Interestingly, unlike spoken words, for visually processed signs there is evidence that the phonological features that form the onset of a sign (i.e., the first features to be formed as a sign moves through time) may not coincide with the most visually salient features (i.e., the features that can be seen most easily, for example, under visually noisy conditions). Just as in spoken languages, signed languages have sub-lexical units (phonological features) that combine in rule-governed ways to form words/signs. Signs are made up of phonological features from three major parameters (handshape, movement, and location [place of articulation]; see Sandler & Lillo-Martin, 2006 for discussion, and Figure 1 for examples of signs sharing these features). In terms of sign onsets, results from early gating studies (single frame presentation of a sign, with subsequent presentations increasing in length; Grosjean, 1981, Emmorey & Corina, 1990) suggest that handshape and location features are recognized first across time. In Emmorey & Corina (1990) subjects' initial responses tended to share the handshape and location of the target sign but differed in movement features. Once the movement of the sign was identified, the target sign also tended to be identified. The authors suggest that lexical recognition in a signed language is a two-stage process such that handshape and location are identified almost from the start of the sign (i.e., form the onset of the sign) followed by movement which coincides with sign recognition.

In terms of sign salience, Corina & Hildebrandt (2002) used a sign similarity judgement task and found that subjects preferred to pair non-signs with other non-signs sharing location and movement features more frequently than pairing non-signs with matching handshape and location features, or handshape and movement features, suggesting that they are paying attention to these feature pairings. Further support for the salience of movement and location features is found in Corina & Knapp (2006) who used a picture sign interference task (subjects named a picture in ASL while trying to ignore a superimposed image of a related distracter) and found that distracter signs sharing both movement and location with the target sign resulted in significant facilitation effects at all stimulus onset asynchronies (-130, 0, 130 ms), while signs sharing handshape and location, or handshape and movement features did not affect picture naming.

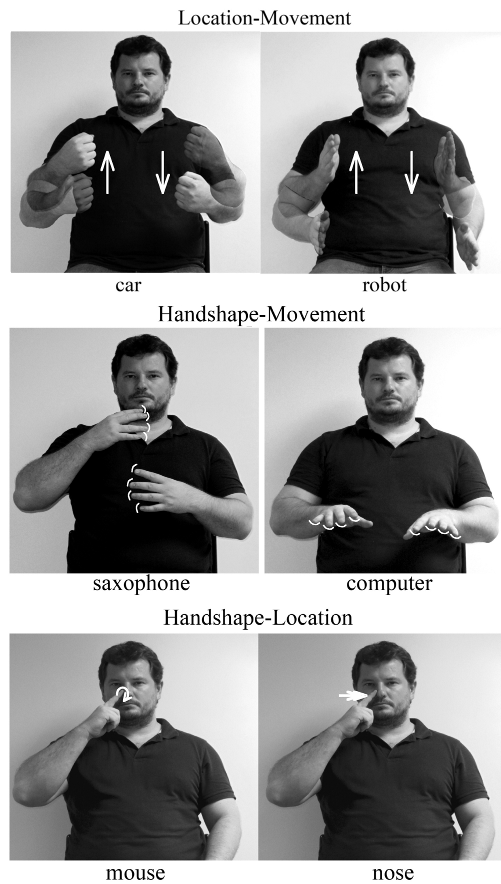

Figure 1: Examples of phonological minimal pairs in BSL. Top: *car* and *robot* share location and movement (up and down) parameters, but differ in handshape. Middle: *saxophone* and *computer* share handshape and movement (finger wiggle) features, but differ in location. Bottom: *mouse* and *nose* share handshape and location features, but differ in movement (*mouse*, with a twisting movement and *nose* with a tapping movement).

While location features are available early in sign perception, movement features only emerge later and are therefore crucial in teasing apart whether lexical access (at least for signs) is driven by temporal constraints or by perceptual salience. If temporal constraints drive lexical access in sign, signers should pay attention to handshape and location features which are available at the start of a sign and ignore movement features which emerge later. Movement features have been argued to be the most sonorous or salient part of a sign (Perlmutter, 1992). Thus, if perceptual salience is instead key to lexical access, then signers may pay attention to movement features.

Here we investigate lexical recognition in BSL using a visual world paradigm and asking whether or not the nature of access in a dynamic visual language is also incremental and graded with alternate possible words considered simultaneously over the time-course of processingFurther, we consider the nature of activation of lexical competitors (if any) and whether sign access supports a first in, first processed pattern, or a pattern driven by visual salience.

We include two critical conditions. First, a semantic condition will determine if a visual world paradigm can be a successful methodology using sign language which must be presented visually. Previously subjects have been found to look towards semantically related competitor pictures during spoken language visual world studies (Huettig, & Altmann, 2005). Here we explore whether eye movements are drawn to a semantically related object in a signed visual world in the absence of a phonological or visual relationship. The Visual World paradigm has never been used with sign language stimuli and a semantic condition (see methods) serves as our test case, under the assumption that semantic relationships should hold regardless of language. If the visual world methodology is successful with BSL, we should expect subjects to look more frequently to distracter pictures that are semantically related to a given target sign. Secondly, we examine the nature of sign recognition in real time using pictures that have phonologically related signs. If temporal information is most important, and signers process information primarily through sequential, incremental, first-in first-processed order, then signs sharing handshape and location features should be particularly salient for them. Alternatively, if perceptual salience is more relevant then signers may instead look more frequently to distracters that share movement and location features.

Method

Subjects

24 Deaf signers (13 women, 11 men, mean age 34.8) were recruited from deaf communities in England and took part in the experiment. Of these, eleven were native signers (born to deaf signing parents), four began signing by the age of five (early signers) and 9 learned BSL after age five. All subjects use BSL as their preferred and primary language.

Materials

For each trial, four pictures of objects were presented simultaneously with a centrally located video clip (see Figure 2). In each video clip, a native BSL signer produced the carrier phrase, "*I see…*", followed by the target sign. Subjects were asked to indicate (with button press, "yes" or "no") as quickly and accurately as possible whether the target BSL sign matched one of the pictures. "Target Present" trials (n= 79) in which a picture of the target sign was present constituted our fillers. On critical "Target Absent" trials (n=28), three unrelated distractor pictures with no semantic, phonological or visual relationship to the target sign were presented along with a related distracter picture. Related distracter pictures had signs that were either semantically (e.g., target: *banana*, distracter: *strawberry,* target: *zipper*, distracter: *button*) or phonologically related to the target. Phonologically related pictures were minimal pairs that shared two out of three parameters (see Figure 1 for examples). Semantically related distracter pictures were not phonologically related to the target, and phonologically related pictures were not semantically related.

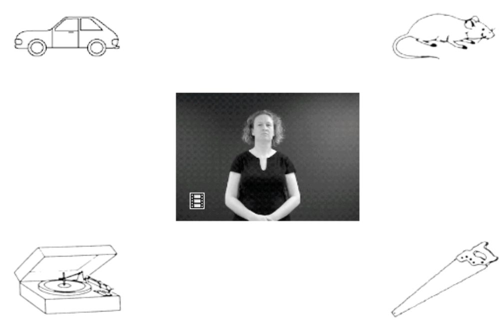

Figure 2: Example of a single trial. Areas of interest for gaze analyses were set directly around the (250x250 pixels) pictures and the (320x240 pixels) video.

Procedure

After giving consent to participate, subjects were presented with video-recorded instructions in BSL (signed by N.F., a native BSL signer) and invited to ask clarification questions. Subjects were then fitted with a head-mounted eye-tracker (SR Research, EyeLink II) and initial calibration was performed (9 fixation points). Subjects were seated 50 cm from the monitor with the tracker positioned in front of the right eye. There were four practice trials before the experiment began. Another calibration check was performed after these practice items and then again after every 36 trials (the final set had only 35 trials), at which time subjects took a self-paced break (total 107 trials, 3 sets). Additionally, drift correction on a single centrally located fixation point was performed at the start of each trial. Responses were recorded using a hand-held joypad with buttons that can be located tactilely without the need to look at keys. The entire experiment (with instructions and calibration) took approximately 20 minutes to complete. In order to ensure that all pictures were familiar to the subjects as well as to obtain naming data, subjects named all of the pictures used in the visual world experiment before we began.

The location of the pictures was balanced so that each picture type (related distracter, unrelated distracter [filler]) occurred a roughly equal number of times in each location within a given condition. Additionally, we created two sets of stimuli such that half the subjects saw any one picture in one location and half of the subjects saw it in a different location. The order of trial presentation was randomized throughout. Pictures were presented simultaneously with the sign video.

Results

First we analyzed signs produced during picture naming to ensure that signs for target and related pictures in the phonological conditions were indeed phonologically related in subjects' lexicons. Individual trials were excluded when subjects produced a sign (for either target or related pictures) that did not have the intended phonological relationship (6%). Error trials, in which participants mistakenly indicated that the target sign matched a picture on the screen (12.4%) were also excluded from analyses of response latencies and eye gaze. The number of trials by condition along with average correct response latencies and percent of correct answers across different conditions are reported in Table 1. A one-way repeated measures ANOVA by subjects revealed no significant differences for accuracy between conditions: F(3,69)=1.686, p=.178. However, a significant difference was found between conditions for response latencies ($F(3,66)$[1]=3.202, p=.029). Post-hoc tests revealed that responses were slower for handshape-movement trials than other conditions.

Table 1. Average correct response time (standard deviation by subjects in brackets) and percent correct as a function of relatedness type. Sem: related picture sharing a semantic relationship to the target; HS-MV: related picture sharing the handshape and movement of the target sign; LOC-MV: sharing the location and movement of the target sign; HS-LOC: sharing both the handshape and location of the target sign.

	Items	***RT(SD)***	***%Correct***
SEM	n=11	2792 (462)	88.3
LOC-MV	n=5	2730 (421)	91.1
HS-MV	n=6	2887 (421)	87.9
HS-LOC	n=6	2662 (446)	83.2

Five areas of interest within each time period were identified: the location of the signer in the middle of the screen (displayed as video), and one corresponding to each of the pictures displayed (coded as target, related, unrelated and matching in size to the actual pictures). The dependent measure of interest was dwell time (summed gaze duration in a given area, measured in milliseconds). Not surprisingly, across all trial types, gaze was primarily directed to the signer in the video (M=86.9%). This led to fewer looks towards pictures than would be expected in a study with auditory stimuli, so we started with a broad analysis. Specifically, for each trial, we identified two time windows. The early period, began at the start of the trial and ended when the carrier phrase "*I see…*" finished. Because the target sign was not yet produced during the early period, gaze could not yet be informed by the target. The late period was defined as the period from the start of the target sign until the button was pressed. Gaze during the late period should provide information about processing of the target sign.

In the first set of gaze analyses across the different pictures, we tested whether subjects looked longer at related pictures than unrelated pictures in the late time period, once the meaning of the target sign could be processed. We conducted hierarchical linear regressions, treating subjects and target signs as random effects, including picture relatedness (considering only related vs. unrelated pictures) and time period (early vs. late) as predictors, and dwell time (in milliseconds) as the dependent measure. Separate models were fit for each relatedness condition (semantic, location-movement, handshape-movement, handshape-location)[2]. Across all conditions there was a main effect of time period indicating longer gaze overall in the late period: semantic (95% CI [183.7, 221.1], p_{MCMC} <.001); location-movement (95% CI [134.0, 199.3], p_{MCMC} <.001); handshape-movement (95% CI [135.8, 190.0], p_{MCMC} <.001); and handshape-location (95% CI [121.3, 172.4], p_{MCMC} <.001). The main effect of picture relatedness was not significant in any of the four conditions (all p_{MCMC} >.67).

The crucial effect is the interaction between picture relatedness (related vs. unrelated) and time period (early vs. late) on dwell times, as increased looks to related pictures should only start to occur once the target sign is being produced. For semantic trials, the picture by time period interaction was significant (95% CI of relative increase for related pictures in the late period [63.5, 107.9], p_{MCMC} <.001) reflecting longer gaze to related compared to unrelated pictures in the later time period (that is, after the carrier phrase was complete and the target sign was being produced). A significant interaction of picture by time period was also observed in location-movement trials (95% CI of relative increase for related pictures in the late period [20.9, 96.6], p_{MCMC} =.001), again reflecting longer gaze to related than unrelated pictures in the later time period when information about the target sign becomes available. However, for the other two phonological conditions (handshape-movement and handshape-location) the interaction of picture and time period did not reach significance (both p_{MCMC} >.3).

We next conducted a Wilcoxon signed-rank test comparing looks to related and unrelated distracter pictures to explore possible differences in gaze across time, beginning at target sign onset. Cumulative fixations, analyzed as arcsine transformations, were grouped into

[1] Reduced df is due to empty cells for some participant/condition combinations in this analysis.

[2] We fit separate models for the different phonological relatedness conditions because a combined model revealed a significant interaction between relatedness, time period and type of phonological relation. Using location-movement as a reference condition, the 95% CI of the change in relatedness × time period interaction coefficient was (11.8, 103.8) for handshape-movement (p_{MCMC} =.040), and (-1.7, 94.3) for handshape-location (p_{MCMC} =.064).

100ms bins starting from 400 ms after the target onset and continuing until 1000 ms (see Figure 3 for time course plots). 100ms bins were used to ensure the presence of sufficient fixations to each area of interest during each time period for statistical analyses. Additionally, analyses began at 400ms after the start of the target period because during the first 300 milliseconds of the target period across all trials, subjects fixated the sign video almost exclusively. For semantic trials, cumulative gaze toward related pictures differed significantly from the unrelated pictures across all bins from 400-1000ms (range of Z from -2.20 to -3.59, all $p<.03$). This same pattern of results was observed for location-movement trials (range of Z from -2.31 to -3.63, all $p<.02$). There was no difference between related and unrelated picture gaze for handshape-location trials across all bins (all $p > .24$). However, there were significantly more looks to related pictures compared to unrelated pictures for the handshape-movement condition, but this difference was found only from 800ms-1000ms ($p<.05$, between 800-100ms; all $p>.2$ up to 800 ms).

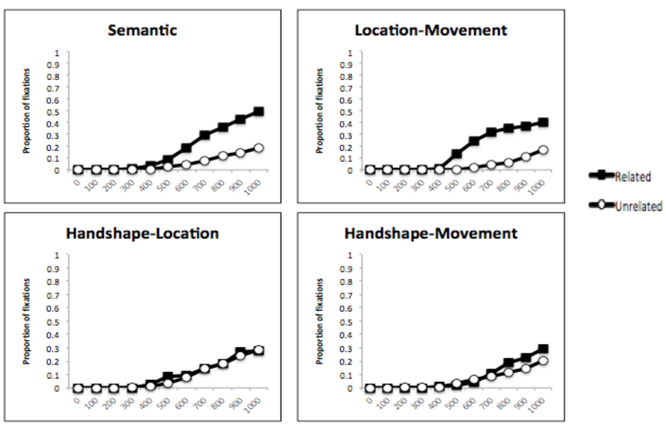

Figure 3: Time course of eye gaze from onset of the target sign for 1000ms for target-absent trials across the four conditions (from left to right: semantic, location-movement, handshape-location, handshape-movement).

Discussion

Overall, we found both semantic and phonological effects during online processing of BSL using a visual world paradigm. Once information about the target sign became available, subjects looked at related pictures longer than unrelated pictures during the semantic condition. During the production of the target sign, related pictures also attracted more looks than unrelated pictures for one phonological condition (location-movement) but not for the others (handshape-location and handshape-movement). Importantly, in the early period of each trial (i.e. before the target sign was produced), there was no difference in gaze patterns to the different picture types (related and unrelated) confirming that the results are not driven by visual characteristics of the related pictures.

In the semantic condition, subjects looked at semantically related distracter pictures more frequently than unrelated pictures, the first time such findings have been demonstrated for a signed language. This result is predicted under the view that activation of semantically related lexical competitors should not be affected by the modality in which a language occurs. The results from the semantic condition reveal that despite the need for split visual attention to both visual linguistic stimuli and pictures related to that stimuli, it is possible to investigate sign language processing using visual world and related paradigms.

The results from the three phonological conditions pairing different phonological parameters produced differing results. Phonological competitors that shared information occurring at the onset of the sign (handshape and location features) did not draw more looks either at the onset of the period in which the target sign was produced (as evidenced by our analysis of the time period from 400-1000ms after the target sign onset) or during the entire time period from the target sign onset until a button press decision was made (the late time period). This finding suggests that onsets may not be as relevant to sign language processing as has been suggested for spoken language processing (e.g., Gaskell & Marslen-Wilson, 1997).

Crucially, in the location-movement condition, subjects looked significantly more toward the phonologically related picture than unrelated pictures in the late time period. This finding parallels the Corina and Knapp (2006) study that found effects only for signs sharing location and movement features. Further, for location-movement trials, looks to the related and unrelated pictures differed significantly from 400ms after the onset of the target sign, a time comparable with that found in spoken language studies (e.g., Allopena et al, 1998). Finally, competitor pictures that shared handshape and movement features with the target did not draw more looks than unrelated pictures during the late time period. However, there was a significant, but short-lived difference such that looks to related and unrelated pictures differed between 800-1000ms after the start of a target sign. Because a difference between related and unrelated pictures was not observed in the overall late period analyses we conclude that, while subjects may be aware of the phonological similarity of signs sharing handshape and movement features, they are likely not making use of these feature pairs during online processing. Instead, looks to related pictures occurring between 800 and 1000 ms (relatively late after the onset of the target sign) appears to be a post-lexical effect in which subjects consider alternate competitor pictures before determining that the target picture is not shown. Crucially, the pattern of gaze in the handshape-movement condition differs from the location-movement condition for which gaze to the related competitor picture is early and consistent. Thus, we suggest that gaze toward related competitors in location-movement trials is indicative of active online lexical processing as has been found in spoken language studies.

In the introduction, we offered two explainations for why onsets play a special role in auditory lexical access (i.e., either temporal constraints or salience). In terms of sign language processing, if temporal constraints are driving lexical access, then signers in our study should have paid attention to handshape and location features because these features are available at the start of a sign. Instead, the sign language results suggest that sign onsets are not similarly privileged to spoken word onsets, which in turn suggests that lexical processing is not temporally driven.

Alternatively, the data support a view under which perceptual salience drives sign access. Specifically, our data show that signers pay attention to movement features which are visually salient, but which occur relatively late in sign production: only trials with related distracters that share movement features show differences between looks to unrelated filler pictures and related competitor pictures. Further, the pairing of location-movement features appears to be of greatest importance during online processing.

The nature of acoustically perceived speech in languages such as English makes it impossible to determine why word onsets seem to have privileged status in lexical access: either due to temporal characteristics (perceived first) or perceptual salience. Investigating signed languages such as BSL allows us to clearly tease these apart, because the most salient perceptual properties (e.g. movement) are not available at the onset but only become available later. Thus, increased looks towards related distracter pictures in the location-movement condition may provide insight, not only into the nature of online *sign* processing but online *speech* processing as well. It is important to note that there is no a priory reason to assume that (visual) signs and (auditory) words will be processed similarly and therefore different strategies might be used.

Overall, the results here reveal important characteristics of lexical access concerning the role of lexical variables (semantic condition) and relative time course of access to different phonological parameters (phonological condition) for sign language processing. More broadly, our current understanding of language processing is intimately tied to oral-aural modality of spoken languages. The current work clearly shows that language processing interacts with modality, and that the key to lexical access for both signed and spoken languages may be perceptual saliency, instead of temporal recency.

Acknowledgments

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