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BRIEF REPORT

Evidence for Visual Simulation During Sign Language Processing

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What are the mental processes that allow us to understand the meaning of words? A large body of evidence suggests that when we process speech, we engage a process of perceptual simulation whereby sensorimotor states are activated as a source of semantic information. But does the same process take place when words are expressed with the hands and perceived through the eyes? To date, it is not known whether perceptual simulation is also observed in sign languages, the manual-visual languages of deaf communities. Continuous flash suppression is a method that addresses this question by measuring the effect of language on detection sensitivity to images that are suppressed from awareness. In spoken languages, it has been reported that listening to a word (e.g., "bottle") activates visual features of an object (e.g., the shape of a bottle), and this in turn facilitates image detection. An interesting but untested question is whether the same process takes place when deaf signers see signs. We found that processing signs boosted the detection of congruent images, making otherwise invisible pictures visible. A boost of visual processing was observed only for signers but not for hearing nonsigners, suggesting that the penetration of the visual system through signs requires a fully fledged manual language. Iconicity did not modulate the effect of signs on detection, neither in signers nor in hearing nonsigners. This suggests that visual simulation during language processing occurs regardless of language modality (sign vs. speech) or iconicity, pointing to a foundational role of simulation for language comprehension.

Keywords: perceptual simulation, language processing, continuous flash suppression, sign languages, iconicity

Supplemental materials: https://doi.org/10.1037/xge0001041.supp

What are the mental processes that allow us to comprehend the meaning of words? The traditional view that semantic processing relies entirely on abstract, amodal representations is falling out of favor as multiple studies have demonstrated that access to the meanings of words involves sensory processes resembling those during our multimodal experience with the world (Barsalou, 2008; Meteyard et al., 2012; Ralph et al., 2017). For instance, reading action verbs like "kick" activates brain regions engaged in the execution of such actions (Hauk et al., 2004; Shtyrov et al., 2014). Importantly for the present article, there is evidence that words referring to concrete objects activate visual representations of those objects (Correia et al., 2014; Lewis & Poeppel, 2014) and facilitate the subsequent visual processing of corresponding pictures (Boutonnet & Lupyan, 2015; Lupyan & Ward, 2013; Ostarek & Huettig, 2017). The embodied theory of language makes a strong case that language is not divorced from sensorimotor systems but rather that they are tightly linked and interact when the meaning of a word is accessed.

An important gap in theories of embodiment is whether engagement of sensorimotor systems take place in all modalities of language. An important discovery in the language sciences was that sign languages, the manual communicative systems of deaf communities, are on par with spoken languages. Sign languages are unique in that they exploit the hands and body as primary articulators, and deaf signers process language through their eyes (Meier, 2002). While one could expect remarkable differences due to the different modalities (speech: oral-aural; sign: visual-manual), research has shown that both systems have considerable parallels. Speech and sign have similar linguistic organization (i.e., sublexical constitution, lexicon, syntax; see Sandler & Lillo-Martin, 2006); they are processed by overlapping brain regions (MacSweeney et al., 2008), and they follow similar developmental trajectories (Bonvillian et al., 1983). The evidence gathered over the past century leaves no room to question that despite their different

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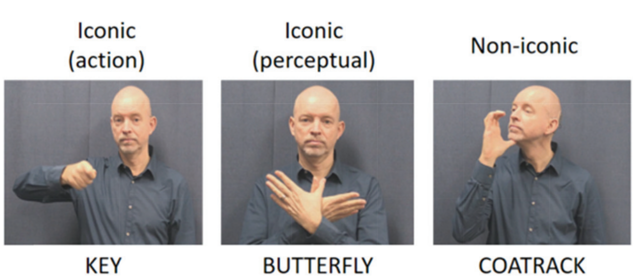
channels of expression, sign languages are fully fledged languages in their full right.

Despite their attested similarities, there is unchartered territory that may reveal important differences between speech and signs during language processing. Specifically, there is reason to question whether deaf signers show effects of visual simulation during language comprehension similar to those observed in spoken languages. Unlike spoken languages like English or Dutch, sign languages involve the visual processing of a continuous stream of body movements, the bottom-up processing of which is expected to overlap with the processes that would be activated during visual simulation. This may preclude the engagement of the visual system for language comprehension processes. That is, the processing of a sign language (through the visual system) could limit visual simulation. This contrasts not only with spoken language but also with written language that typically consists of two-dimensional symbols that differ substantially in their visual processing requirements compared to their referents. An alternative possibility is that deaf individuals are able to juggle the parallel demands of bottom-up visual processing and top-down simulation (McCullough et al., 2012; Secora & Emmorey, 2015). This feat could be facilitated by compensatory changes in the visual system that result in an increased ability to attend to multiple items in parallel (Bavelier et al., 2000; Dye et al., 2009).

Another factor that may reveal important differences between speech and sign is the high prevalence of iconicity in sign languages, understood as the direct relationship between form and meaning (Dingemanse et al., 2015). Recent developments in the languages science have convincingly demonstrated that iconic forms are not a marginal phenomenon but rather are an important component in speech and sign (Perniss et al., 2010; Perniss & Vigliocco, 2014). Sign languages are unique in that *noniconic signs* (e.g., COATRACK) coexist with iconic forms that may represent different perceptual features of the concept they denote (see Figure 1). Some iconic signs may be categorized as *action signs* because they represent an action associated with the referent (e.g., the sign KEY represents the motor action of turning a key). *Perceptual signs* tend to represent the physical shape of the referent (e.g., the sign BUTTERFLY depicts the outline of a butterfly's wings).

Figure 1

Examples of Iconic and Noniconic Signs in Sign Language of the Netherlands



Note. The sign KEY is an action-iconic sign because it depicts a bodily action associated with the referent (i.e., how the body interacts with a key). The sign BUTTERFLY is a perceptual iconic sign because the hands represent the shape of a butterfly's wings. The sign COATRACK can be classed as noniconic because it lacks an evident visual relationship with the referent. See the online article for the color version of this figure.

Most claims around embodiment have been developed on the basis of spoken/written words with noniconic links with the concepts they represent, and to the best of our knowledge, there have not yet been attempts to link iconicity with perceptual simulation. Here we explored the possibility that words that reflect more directly the motor and perceptual features of the referent (i.e., iconic) could have a stronger effect in visual simulation. Support for this prediction comes from multiple studies showing a robust processing advantage of iconic signs over noniconic ones, which has been hypothesized to arise due to more direct links of linguistic forms and the corresponding perceptual experience of the referents (Ormel et al. 2009; Vinson et al., 2015). Thus, perceptual signs, which depict the form of the referent (e.g., BUTTERFLY), could facilitate visual processing more than action and arbitrary signs. This prediction rests on the assumption that simulations activate the same sensory processes that are active during perception. In this scenario, perceptual-iconic signs should activate category-specific visual representations more strongly because both the processing of the visual form of perceptual-iconic signs and the simulation they trigger activate congruent sensory representations. Action-perceptual signs, in contrast, represent a bodily action that is not congruent with the visual representation of the object it represents.

In sum, it is currently not known whether the visual system is recruited for simulation during sign language comprehension in similar ways as has been reported in spoken languages. Further, the presence of signs with different form-meaning mappings with the referent (i.e., iconic vs. noniconic) may reveal differentiated engagement of the visual system depending on the different types of signs processed. As such, sign languages are a unique test case to further our understanding of the processes that are common to all human languages (spoken and signed) and those that are shaped by channel of expression (i.e., modality).

In order to test our claims, we used a novel paradigm (Lupyan & Ward, 2013; Ostarek & Huettig, 2017) that measures the effect of words on basic visual detection of pictures that are suppressed from awareness using continuous flash suppression (CFS; Tsuchiya & Koch, 2005). The strength of this paradigm is that detection in CFS depends on how efficiently visual features of suppressed pictures are processed (Stein et al., 2015). As such, effects of words on detection capabilities are only expected if words activate visual processes involved in the earliest stages of conscious vision (Lupyan & Ward, 2013). Thus, in contrast to previously used congruency paradigms (Zwaan et al., 2002), whose results were compatible with modal and amodal theories (Mahon, 2015), the present CFS paradigm can be considered a strong test of visual simulation (Ostarek & Huettig, 2017). We would like to refer the reader to Ostarek and Huettig (2017) as well as the supplementary materials in Lupyan and Ward (2013) for an extended discussion of how the paradigm differs from standard priming paradigms.

In the present study, a group of deaf users of Sign Language of the Netherlands (NGT) were presented with different types of signs (i.e., action iconic, perceptual iconic, noniconic), after which they had to try to detect pictures suppressed using CFS that were congruent or incongruent with the previously presented sign. We predicted that signs would activate visual simulations and therefore boost the detection of congruent compared to incongruent pictures, as has been demonstrated for spoken languages (Lupyan &

Ward, 2013; Ostarek & Huettig, 2017). Given that iconic signs have clear form-meaning mappings, we expected that they could engage in visual simulation to a higher extent than noniconic signs. In particular, the bottom-up processing of signs whose form resembles the shape of their referents (perceptual iconic signs) could preactivate visual representations that are also recruited during visual simulation and thus would be expected to give a boost to the effect of simulation on detection. However, it is also possible that all types of signs lead to the same degree of activation suggesting that words, iconic and noniconic alike, have the same evocative power to activate visual representations (Lupyan & Thompson-Schill, 2012). We also tested a group of hearing nonsigners on the same paradigm because they could potentially recognize the iconic motivation of some signs (Klima & Bellugi, 1979) or because signs could resemble the iconic gestures used by hearing speakers (Ortega et al., 2020).

Method

Participants

Two groups of participants took part in the study. The first consisted of 27 deaf users of NGT. Nine deaf participants were excluded from the experiment because of their high detection rate (mean $>$ 90%) or excessive false alarm rates ($>$ 50% or false alarm (FA) rates $>$ mean hit rate). This left a total of 18 deaf NGT signers (of whom 11 were native signers who acquired NGT from birth). The second group consisted of 19 hearing people who reported having Dutch as their mother tongue, and none of them reported knowledge of any sign language (2 additional participants were excluded due to excessive FA rates).

Stimuli

The stimuli were selected from a set of 270 lexical signs from NGT that had been previously categorized according to their type of iconicity (action, perceptual, noniconic) by two deaf research assistants (see Figure 1). Statistical analysis of their agreement in the categorization was high (kappa Cohen: .818, $p < .001$, 95% CI [.670, 0868]). In order to estimate the degree of iconicity of all signs, a group of 10 deaf NGT signers and 10 hearing adults with no knowledge of a sign language rated all signs on a 7-point scale. Both groups were presented with each sign along its translation (in Dutch), after which they had to choose a value that reflected how well the sign represented the concept (1: low iconicity; 7: high iconicity). None of the participants in the ratings task took part in the actual experiment. Once the ratings from both groups were collected, 12 signs were selected for each condition (action, perceptual, noniconic). The iconicity ratings by both groups of participants are as follows. Mean action signs: hearing = 6.2, deaf = 6.1; mean perceptual signs: hearing = 5.9, deaf = 6.1; mean noniconic signs: hearing = 2.0, deaf = 2.0. A 2 (hearing, deaf) × 3 (action, perceptual, noniconic) analysis of variance (ANOVA) revealed that the ratings across the three conditions did not differ across participants, $F(1, 66) = .464$, $p = .50$, $\eta^2 = .01$. There was no interaction, but there was a significant difference in the ratings across conditions, $F(2, 66) = 138.45$, $p < .001$, $\eta^2 = .88$. Post hoc analysis after Bonferroni corrections revealed that noniconic signs differed significantly from action, $p < .001$, 95% CI [3.84, 4.72], and perceptual signs, $p < .001$, 95% CI [3.58, 4.46], but action and perceptual signs did not differ from each other, $p = .244$, 95% CI [–.182, .696]. This shows that the stimuli in the action and perceptual conditions did not differ in their degree of iconicity but both differed from noniconic signs. Importantly, deaf and hearing participants did not differ in their judgments in iconicity ratings in the stimulus materials. Images of the full list of signs, their iconicity ratings, and the length of the videos can be found in the online supplementary materials and in the Open Access repository at https://osf.io/7s5uy/.

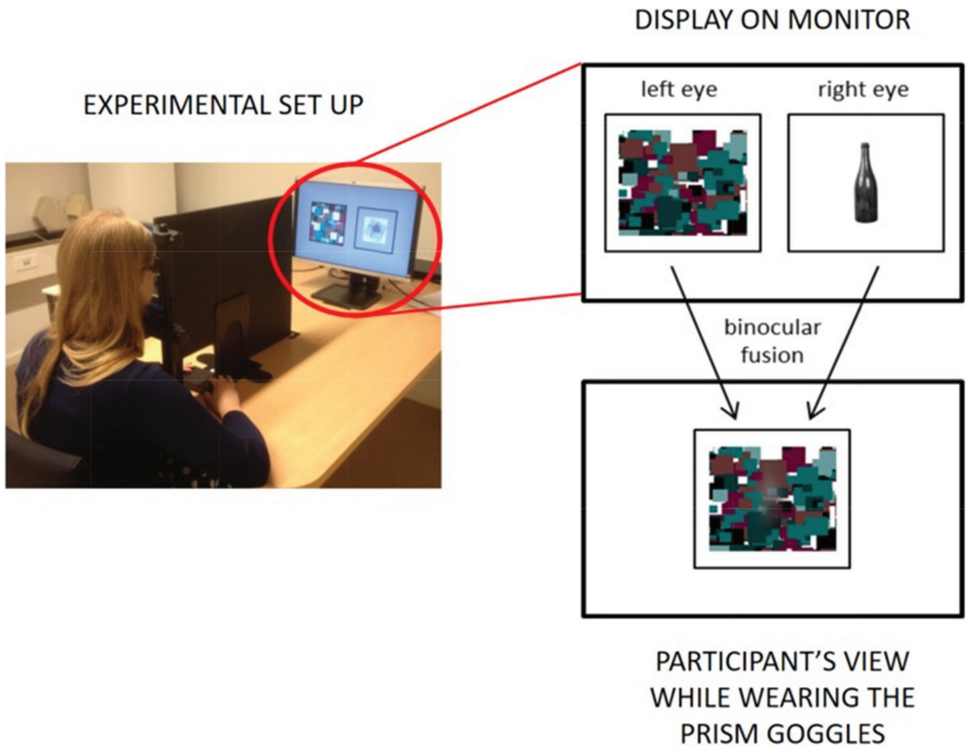
Procedure

Before the CFS experiment, signers were asked to produce their favored sign for the concepts used in the experiment. When the signs did not match the stimulus materials, they were excluded from analysis, which was only necessary in 17 cases in total (see online supplemental materials). After receiving instructions about the detection task, participants were asked to put on custom-made prism goggles (prism diopter: 10 Δ) and place their head on a chinrest 80 cm from the screen (resolution: 1,900 × 720, refresh rate: 60 Hz). There was a separator from the nose toward the center of the screen to ensure that each eye only saw the ipsilateral half of the screen. CFS was achieved by presenting rapidly changing (at a rate of 10 Hz) masks consisting of rectangles of random sizes and colors (similar to Hesselmann et al., 2011) to one eye and a grayscale and slightly blurry (Gaussian blur, 3-pixel radius) picture to the other (see Figure 2).

Suppression strength was adjusted before the main experiment such that without the influence of preceding signs, pictures would be detected about half of the time and remain completely invisible the other half. To that end, participants first performed a staircase procedure aimed at determining individual detection thresholds (96 trials), where each hit resulted in a slight reduction of the image contrast and each miss resulted in a slight increase. This avoids ceiling and floor effects and, in most cases, leads to hit rates of approximately 50% in the main experiment. Stimulus presentation and response-logging were done using Presentation Software (Version 16.2; www.neurobs.com).

In the main experiment, participants were presented with short videos of 36 signs (12 action iconic, 12 shape iconic, 12 noniconic) and 36 corresponding pictures. The pictures were taken from the De Groot et al. (2016) database. They were repeated eight times across the experiment (total of 288 picture-present trials). In an additional 144 trials, no picture was present, resulting in a total of 432 trials. Critically, in half of the picture-present trials, signs were congruent versus incongruent with the pictures. Incongruent images were fixed per participant (e.g., for a given participant, in incongruent trials where the sign for BALL was presented, it would always be followed by a picture of a battery). Trials were presented in random order. Each trial began with a central fixation cross (500 ms). Then, a short video of a sign was displayed. Based on the previous finding from spoken language that effects of words on detection in CFS are specific to the first hundreds of milliseconds after word onset (Ostarek & Huettig, 2017), we displayed the signs only for as long as absolutely necessary to be recognized (preparations and retraction of the sign were not part of the sign videos). There were two versions per sign, which were used in two blocks (the order was counterbalanced across

Figure 2
Experimental Setup of the Continuous Flash Suppression (CFS) Paradigm



Note. Participants sat in front of a computer with their head on a chin rest while wearing custom-made prism goggles. A separator from the nose toward the center of the screen was located on the table to ensure that each eye only saw the ipsilateral half of the screen. The computer screen displayed the visual noise on the left side, and on the right side, the picture was displayed, which was congruent or incongruent with the sign shown before. The intensity of the pictures was adjusted such that detection rates approximated 50% (i.e., pictures remained invisible about half of the time). See the online article for the color version of this figure.

participants). In one version, the video was stopped as soon as the movement of retraction of the sign began. The second version lasted an additional 200 ms. As this did not affect any of the results, the data from both versions were collapsed. The signs were immediately followed by the CFS masks (and a picture when applicable) that were displayed for 600 ms. Finally, a screen appeared asking the participant to indicate by button press whether there was a picture or not (see Figure 3).

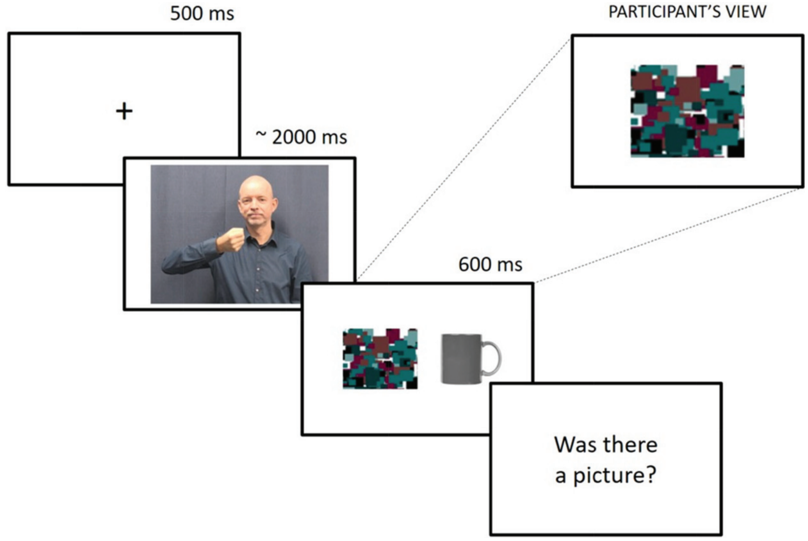
Analysis

We determined exclusion criteria before data collection according to which participants with detection rates higher than 90% or lower than 10% on average, as well as participants with higher false alarms than detection rates or false alarm rates higher than 50%, were not used for analysis. This led to the exclusion of nine signers (two due to ceiling effects, seven due to excessive false alarm rates) and two nonsigners (both due to excessive false alarm rates), suggesting that there are differences in how strongly deaf signers versus controls are affected by CFS (see online supplemental materials for further information). One item (clock) was excluded in the control group due to a ceiling effect ($>$ 90% detection).

To analyze detection rates, we used a logistic mixed-effects model (as implemented in the R package lme4; Bates et al., 2014). The first analysis tested whether the congruency between signs and targets influenced detection rates and whether signers and nonsigners differed. To this end, a logistic mixed-effects model was run with congruency and group as well as their interaction as fixed effects, by-participant and by-item random intercepts, and by-participant and by-item random slopes for the effect of congruency. To test for effects of iconicity, this factor was added as a fixed effect, as well as random intercepts and by-participant random slopes. Follow-up within-group analyses were run with congruency and iconicity as well as their interaction as fixed effects and random by-participant intercepts and slopes for the effect of congruency and iconicity and their interaction, as well as by-target item intercepts and slopes for the effect of congruency. For models including factors with more than two levels, we calculated main and interaction effects using Type II Wald chi-square tests (see Baayen et al., 2008). Planned follow-up comparisons of the effect of congruency at the three different types of iconicity were done using pairwise tests of estimated marginal means.

Note that the different iconicity conditions refer to the signs associated with the targets, not the signs that participants saw on a given trial. At first sight, this seems counterintuitive, but it is preferable because this way, the targets are exactly the same in the

Figure 3
Structure of Each Experimental Trial



Note. A fixation cross was presented for 500 ms, and this was followed by a Sign Language of the Netherlands sign that played automatically in its entirety. The sign was immediately followed by the continuous flash suppression masks along with a congruent or incongruent picture for 600 ms (note that participants viewed only the visual nose due to the prism goggles). Participants were then required to press a button to indicate whether they had seen or not a picture. See the online article for the color version of this figure.

congruent and incongruent conditions. This allowed us to evaluate whether detection of a given picture was influenced by whether a congruent sign was presented and whether the iconicity status of the corresponding sign mattered. The alternative, where performance is compared for a sign with a given iconicity status followed by (a) the congruent picture or (b) an incongruent (and hence different) picture, is less desirable because in that case for each sign, different conditions display different pictures for which baseline detection rates likely differ.

Second, we conducted equivalent analyses on d' scores. We calculated d' scores per participant per condition, which were then submitted to a repeated-measures 2 (congruency; congruent vs. incongruent) by 2 (group; signer vs. nonsigners) ANOVA to analyze the data across groups, as well as to a 2 (congruency; congruent vs. incongruent) by 3 (prime type; action iconic vs. shape iconic vs. noniconic) ANOVA for within-group analyses. Paired-samples t tests were used to test the effect of congruency at the three levels of prime type.

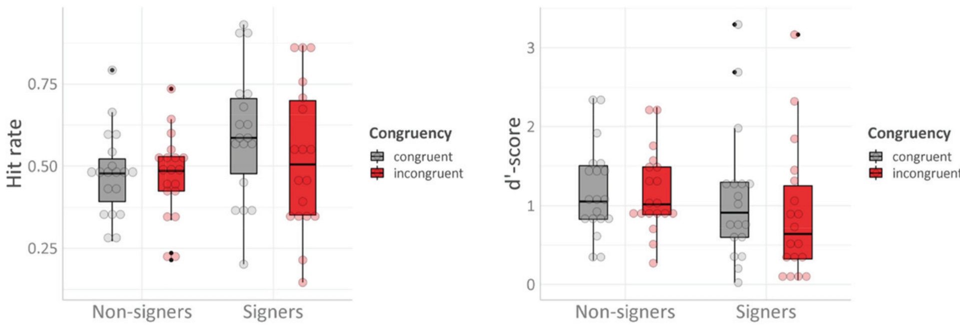
Results

The main result (see Figure 4) is that for deaf signers, detection rates and sensitivity were higher in the congruent condition (hit rate: M = .59, SE = .011; d': M = 1.091, SE = .17) compared to the incongruent condition (hit rate: M = .52, SE = .011), whereas for nonsigners, there was virtually no difference between the congruent (hit rate: M = .477, SE = .011; d': M = 1.197, SE = .165) and incongruent condition (hit rate: M = .472, SE = .011; d': M = 1.174, SE = .161). The logistic mixed-effects and d' analyses revealed a main effect of congruency, with higher scores in the congruent condition (hit rate: estimate = .1, SE = .032, z = 3.077, p = .002; d': $F(1, 35)$ = 8.44, p = .006), and crucially, this detection boost for congruent pictures was stronger for deaf signers than for hearing nonsigners (Congruency × Group interaction for hit rates: estimate = .085, SE = .029, z = –2.879, p = .006; d': $F[1, 35]$ = 5.291, p = .028). Follow-up per-group analyses confirmed that detection was enhanced for congruent targets in deaf signers (hit rates: estimate = .180, SE = .060, z = 3.021, p = .003; d': $F[1, 17]$ = 8.353, p = .010, χ^2 = .329) but not in hearing controls ($z < 1$).

We next explored whether the congruency effect in deaf signers was modulated by age of first exposure to a sign language. Only around 5–10% of deaf children learn a sign language natively from their signing caregivers (Mitchell & Karchmer, 2004), with delay to sign exposure having an effect in sign processing (Mayberry, 2007). We ran a model with congruency and nativeness as well as their interaction as fixed effects, random by-participant intercepts and slopes for the effect of congruency, and random by-target intercepts and slopes for the effects of congruency and nativeness. There was no evidence that nativeness modulated the congruency effect ($p > .3$). However, we would like to note that the statistical power for this analysis was insufficient to draw firm conclusions on the effect of nativeness.

We now turn to the role of iconicity. There was some evidence for a main effect of iconicity (hit rates: χ^2 = 2.6, p = .27, d': $F[2, 70]$ = 13.612, $p < .001$) and an interaction between iconicity and group (hit rates: χ^2 = 5.42, p = .066, d: $F[2, 70]$ = 3.669, p = .031), likely due to slightly better detection of targets associated with noniconic signs, especially for nonsigners (see Figure 5). Note that these tentative effects reflect baseline detection differences regardless of the congruency between signs and target images.

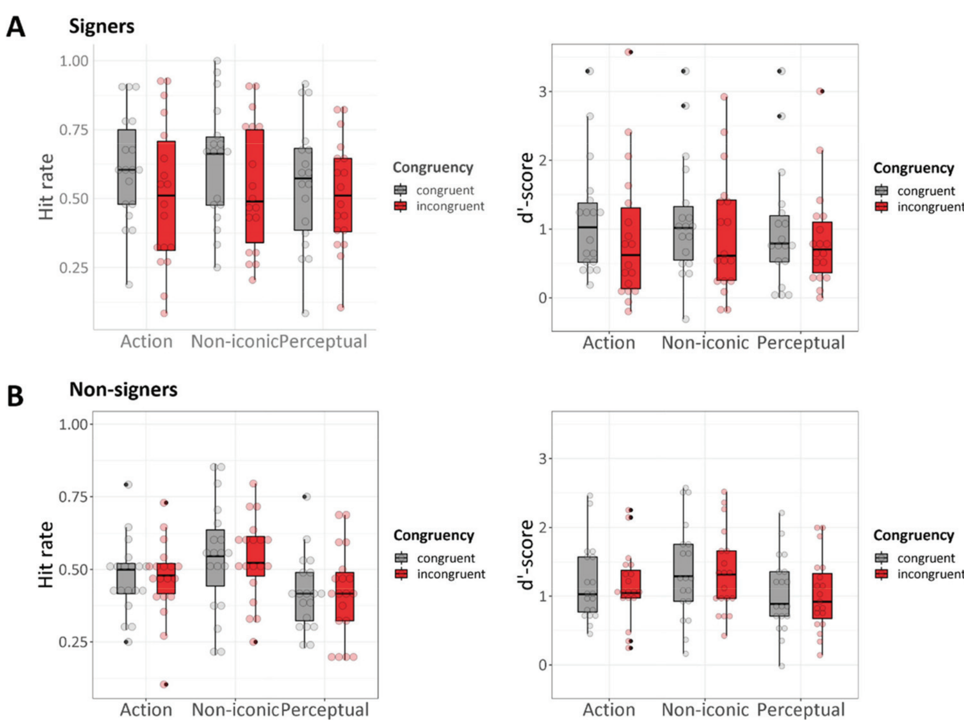
Figure 4
Boxplots of Hit Rates (Left) and d′ Scores (Right) of Signers and Nonsigners in the Congruent and Incongruent Trials



Note. The solid horizontal lines indicate the medians, the upper and lower ends of the boxes indicate the 75th and 25th percentiles, and dots indicate individual participants' means. See the online article for the color version of this figure.

Importantly, there was no evidence that iconicity modulated the congruency effect for either group; the interaction between congruency and iconicity ($p > .3$) and the interaction between congruency, group, and iconicity ($p > .3$) were not significant. Nevertheless, as this directly pertains to the prediction that the congruency effect would be boosted in the perceptual-iconic condition, we report the corresponding post hoc analyses. For signers, the interaction of congruency and iconicity was not significant (hit rates: $\chi^2[2] = 3.770$, $p = .152$; d': $F[2, 34] = .977$, $p = .387$). Planned pairwise contrasts indicated congruency effects in the action-based iconic (hit rates: estimate [log-odds ratio] = .485, $SE = .149$, $z = 3.248$, $p = .001$; d': $t[17] = 2.718$, $p = .015$) and the

Figure 5
Hit Rates (Left) and d′ Scores (Right) of (A) Signers and (B) Nonsigners for Congruent Versus Incongruent Pictures Whose Corresponding Signs Are Action-Based Iconic, Noniconic, or Perceptual-Based Iconic



Note. The solid horizontal lines indicate the medians, the upper and lower ends of the boxes indicate the 75th and 25th percentiles, and the dots indicate individual participants' means. See the online article for the color version of this figure.

noniconic condition (hit rates: estimate [log-odds ratio] = .425, *SE* = .155, *z* = 2.734, *p* = .006; d': $t[17] = 2.088$, *p* = .052), but not in the perceptual-based iconic condition (hit rates: estimate [log-odds ratio] = .178, *SE* = .149, *z* = 1.197, *p* = .231; d': $t[17]$ = 1.376, *p* = .187). Nonsigners did not reveal an effect of congruency for any type of sign (see Figure 5).

Finally, false alarm rates were higher (χ^2 [1] = 5.231, *p* = .022) for signers (action iconic: *M* = .235, *SE* = .017; perceptual iconic: *M* = .223, *SE* = .017; noniconic: *M* = .214, *SE* = .017) than for nonsigners (action iconic: *M* = .145, *SE* = .013; perceptual iconic: *M* = .135, *SE* = .013; noniconic: *M* = .125, *SE* = .013). There was no evidence for an effect of iconicity ($p > .3$) or an interaction effect ($p > .9$) on false alarm rates.

Discussion

Research has shown that semantic processing engages our perceptual systems (Meteyard et al., 2012) and that words activate perceptual features of objects via perceptual simulation (Lewis & Poeppel, 2014; Ostarek & Huettig, 2017). These claims, however, have been made around spoken languages, which are primarily expressed through speech/text and whose words have an arbitrary relationship between the form of a word and the concept they represent (i.e., noniconic). As such, there is limited evidence whether the processing of sign languages of deaf communities also engages in this form of perceptual simulation and whether iconicity contributes to simulation. While there is no doubt that speech and sign have the same underlying linguistic structure, it is unclear whether both modalities (i.e., speech and sign) operate under similar processes. Here we entertained the possibility that the processing of a sign language may not lead to visual simulation because of excessive demands to the visual system. That is, we could find differences in the effect of spoken versus signed language processing in visual simulation due to the visuospatial nature of signs.

To address this question, we probed visual simulation in the processing of signs in a group of deaf users of NGT. We capitalized on a novel application of CFS to test whether signs activate visual simulations of the objects they refer to and therefore boost the detection of congruent objects. Our results show that the evocative properties of words can be extended to lexical labels expressed in the manual modality (i.e., signs). Despite important physical differences between words and signs that could result in differences in language processing, we observe that signs have similar knock-on effects on visual processing. Specifically, we found that when viewing signs referring to objects, deaf signers activate visual representations of these objects, which in turn influence detection sensitivity to congruent pictures suppressed with CFS. Signs also activate sensory representations in deaf people at similar rates as spoken words do in hearing people (Lupyan & Ward, 2013; Ostarek & Huettig, 2017). Importantly, the processing of a manual-visual language does not disrupt (visual) simulation processes. As has been shown for motor simulation through motion perception (in MT+ areas), (McCullough et al., 2012) and semantic compatibility (Secora & Emmorey, 2015), our results add to the growing body of evidence that deaf signers can juggle the parallel demands of bottom-up visual processing and top-down simulation. Our data provide empirical evidence that signs and words alike hold a unique place in human cognition in that both have the capacity to modulate processes across perceptual systems with striking parallels. A core property of the human capacity for language, regardless of whether it is expressed through speech or sign, seems to be the penetration of perceptual systems.

A result worth highlighting is that sign iconicity did not increase visual sensitivity in deaf signers. There is a growing body of evidence showing a processing advantage of iconic signs over noniconic signs in deaf signers because of the close links between the form of a sign and the concept it represents (Thompson et al., 2009; Vinson et al., 2015). A possible mechanistic account of how the iconicity advantage arises is that the physical form of a sign preactivates processes that are subsequently recruited top-down during simulation. Based on this, we predicted that perceptual-iconic signs (those representing the shape of the object) could show stronger effects on visual sensitivity because the form of these signs could facilitate visual simulation processes. This was not the case, suggesting that the locus of the iconicity advantage lies at higher levels of processing.

Embodied theories are typically not very specific about the exact representations or processes predicted to be activated during simulation but generally claim that at some level, simulations activate the same processes that are active during perception. If so, one would expect bottom-up processing of the visual form of perceptual-iconic signs and the ensuing visual simulation to have additive effects (as they would both be expected to preactivate shape-specific representations in the visual system). We did not obtain evidence for such additive effects. The present results indicate a dissociation between bottom-up sensory and top-down (simulation) signals. We propose that this dissociation arises because simulations specifically reflect diagnostic features of an object's category (e.g., the general features of a bottle), whereas bottom-up processing of an object involves a unique exemplar with idiosyncratic low-level features (e.g., the specific features of a given bottle). A similar mechanism has been suggested for featural (David et al., 2008) and categorical attention (Çukur et al., 2013), whereby attention to particular features or semantic categories during natural vision leads to increased tuning to relevant features, with stronger effects in high-level compared to low-level retinotopic visual cortex (Çukur et al., 2013). Further elucidating the neurocognitive mechanisms that underlie the dissociation between simulation and perception is an important challenge for future research.

Iconicity had no effect in hearing nonsigners either. Sign-naive participants can guess the meaning of some iconic signs thanks to their resemblance to their referent (Klima & Bellugi, 1979; Pizzuto & Volterra, 2000). They also have exposure to manual iconicity thanks to the iconic gestures that are commonly produced accompanying speech in face-to-face interactions (Kita, 2000; Özyürek et al., 2007). However, whereas hearing nonsigners can identify the meaning of some iconic signs when they resemble gestures (Ortega et al., 2020), they typically can only identify accurately a small proportion of iconic signs (Klima & Bellugi, 1979; Pizzuto & Volterra, 2000; Sehyr & Emmorey, 2019). Our data suggest that iconicity in signs did not lead to the efficient retrieval of information from the visual system. Thus, whereas hearing nonsigners are perceptive to some extent of sign iconicity (Klima & Bellugi, 1979; Ortega et al., 2020), it is not sufficient to activate specific visual representations. This suggests that the ability to retrieve diagnostic conceptual features from the sensorimotor systems in signs requires a fully fledged linguistic system in the manual modality.

The human capacity of language has the potential to be expressed not only in speech but also with the body, as in the case of the sign languages of deaf communities. The contribution of our study is that both words and signs display unique referential properties through links with our sensorimotor experiences. While objects can be referred to through a wide array of cues (e.g., pictures, sounds), words and signs stand out for their capacity to efficiently activate diagnostic conceptual features that capture the essence of a concept. Our data suggest that the retrieval of sensorimotor features involves mechanisms that modulate surprisingly basic visual processes, namely, those involved in the earliest stages of conscious vision. Linguistic labels have the power to transgress other cognitive domains and stimulate representations across systems. This new evidence can help us move toward a more complete picture of the cognitive architecture of language that is not confined to the communicative channels of spoken language.

Context Paragraph

There is increasing evidence that comprehending words that refer to physical objects involves the activation of sensory processes that would be activated if the object was actually perceived. So far, this process called *perceptual simulation* has only been studied in the domain of spoken languages, and it is currently not known whether it is used in sign languages, the manual languages used by deaf communities. Here, we adapted a recently developed strong test of perceptual simulation that measures the effect of language on participants' ability to detect pictures that are suppressed from awareness. Our results suggest that signs, similar to spoken words, trigger visual simulations that can make otherwise invisible objects visible. This suggests that perceptual simulation is a general property of language regardless of mode of communication (i.e., speech vs. sign).

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