VIOLATING THE PHONOTACTIC PROPERTIES OF AMERICAN SIGN LANGUAGE TO CREATE ILLEGAL PSEUDOSIGNS

by

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I humbly dedicate this work to the members of the ASL community in Nova Scotia, especially those I treasure as friends.

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ABSTRACT

This study aimed to develop a set of visual-manual stimuli that varied in structure, phonotactic permissibility, and lexicality, to be used in future brain imaging studies of sign language learning. By developing a set of illegal pseudosigns as part of these stimulus sets, we also the first steps towards validating some of the hypothesized phonotactic constraints for American Sign Language. Possible phonotactic constraints and violations were identified with a group of native ASL signers and cross-referenced with published inventories of ASL. These violations were systematically applied to a set of real ASL signs. English speaking non-signing participants rated these illegal pseudosigns — along with a set of legal pseudosigns, a set of emblematic gestures, and a set of ASL signs — on a scale of meaningfulness and decided if each stimulus was ASL, yes or no. Interestingly, participants perceived some ASL signs and pseudosigns as meaningful, which may reflect that they interpreted these stimuli as pantomime or emblems. Overall, participants gave lower average meaningfulness ratings to illegal pseudosigns than legal pseudosigns, and were more likely to rate legal pseudosigns than illegal pseudosigns as ASL, suggesting that illegal pseudosigns are perceived as less plausible forms even to those naïve to signed languages. This suggests that the rules governing the formation of ASL appear to respect visual-manual patterns that are inherently interpreted as potentially meaningful or communicative.

LIST OF ABBREVIATIONS USED

ASL	American Sign Language
BSL	British Sign Language
DC	Dominance condition
ERP	Event related potential
fMRI	Functional magnetic resonance imaging
FPC	Finger Position Constraint
FPC1	Finger Position Constraint violation type 1
FPC2	Finger Position Constraint violation type 2
HSC	Handshape Sequence Constraint
ISL	Israeli Sign Language
PC	Place Constraint
rSFC	Revised Selected Finger Constraint
SC	Symmetry Condition
SHCC	Syllable-level Hand Configuration Constraint
SMC	Secondary Movement Constraint
STC	Syllable Timing Constraint
STSp	Superior temporal sulcus (posterior)

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"It is well known that a vital ingredient of success is not knowing that what you're attempting can't be done." - Terry Pratchet

CHAPTER 1 INTRODUCTION

American Sign Language (ASL) is a naturally arising communication system which fulfills all criteria of a natural human language (e.g., Valli & Lucas, 2000). Comparing the structure of naturally-arising signed languages to the types and range of linguistic structures documented for spoken languages reveals many similarities, leading to a general consensus that signed and spoken languages can be considered to rely on the same underlying linguistic capacities, in spite of their different sensory and motor modalities. At the same time, signed languages have inherent differences from spoken languages, arising from a language constructed in the visual-manual (as opposed to the aural-oral) modality (see Sandler and Lillo-Martin, 2006 for a comprehensive review). A full review of these differences is beyond the scope of this work. Here I focus on the basic components of ASL — the framework for understanding how ASL signs are constructed and how they can be manipulated.

Phonology, morphology, and the syllable in American Sign Language

In spoken languages, the phoneme is generally defined as the smallest unit of sound that can distinguish one word from another (Valli & Lucas, 2000). The words *cat* and *bat* are distinguished by their initial phoneme, /k/ and /b/ respectively. Phonemes can also be found in signed languages. Broadly, the basic phonemic categories of ASL are: *hand configuration*, including the position of the fingers (handshape) and the orientation of the entire hand; the *location* the sign is performed on the body or in the space surrounding the body; the *movement* performed by the hand or hands, which can either be a path movement with a clear direction, or secondary movement (e.g., finger wiggling) which is contained to the hand itself; and *non-manual signals* such as facial expression and movement of the torso (Brentari, 2012). It is worth noting that hand orientation has been proposed as a separate phonemic category (Stokoe, 1960/2005; Battison, 1974) but is most often considered a feature of the hand configuration category (Sandler, 2012). Like spoken phonemes, the number of individual units in ASL is limited and small compared to the number of fully realized signs, although the specific units depend on which model of ASL phonology is considered (Stokoe, 1960/2005; Brentari, 1998; Liddell & Johnson, 1986; Vogler & Metaxas, 2004). While phonemes in spoken languages must occur sequentially, these signed phonemes may — and often do — occur simultaneously. Just as words in spoken languages can be distinguished on the basis of a single phoneme, there exist minimal pairs in ASL that are distinguished on the basis of a single phoneme (e.g., RED[1] and SWEET contrast only in handshape).

Phonemes can be combined to form morphemes, which are defined as the smallest possible unit of meaning in any language. *Free morphemes* can stand alone to function as words, while *bound morphemes* must be combined with other morphemes to form meaningful words. For example, in English the word *disqualified* is composed of the bound morpheme *dis-*, the free morpheme *qualify*, and the bound morpheme *-ed*. In ASL, morphemes can also be free or bound, however unlike in spoken languages bound morphemes can be realized simultaneously as well as sequentially. Morphemes in ASL may be entire signs, or may be smaller units such as specific hand configurations (e.g., classifiers) or locations (e.g. subject/verb agreement) (Wilbur, 2011). The sign ARRIVE contains a single morpheme, while the sign GIVE-YOU contains the morpheme GIVE

[1] When glossing a sign to English, it is conventional to write the gloss in capital letters. Images of signs glossed in this manuscript can be found in Appendix A: Glossary of ASL Signs

with the specific final location of the sign indicating YOU, comprising a second morpheme.

Morphemes in sign language are composed of one or more syllables. Syllables in spoken languages are defined by a vowel nucleus, with or without initial (onset) or final (coda) consonants. For example, the word *hotel* has two syllables, *ho* and *tel*. In ASL, syllables are defined by movement (Liddell & Johnson, 1989). The general rule is that a path movement forms the nucleus of a syllable, and can be used to count the syllables in a sign (Brentari, 1990; Perlmutter, 1992). In signs that lack a path movement — such as YELLOW, which is signed by rotating the wrist — internal movement may be considered to define the syllable. When path and internal movement occur simultaneously, the number of syllables is defined by the path movement alone. For example, the sign FRIENDLY contains a path movement with simultaneous wiggling of the fingers, and is considered to have one syllable (Brentari, 2012). However, signs can also occur without lexical movement, such as the sign MOTHER, which is signed with a stationary handshape in a single location. In these cases, it has been proposed that the transitional (epenthetic) movement to bring the hand/hands toward or away from the target location can be considered as the syllabic movement feature (Brentari, 1998).

The vast majority of lexical signs (up to 93%) fit the phonological template of location-movement-location, thus containing a single path movement and therefore a single syllable (Sandler & Lillo-Martin, 2006). However, all of the sign forms which occur in ASL are described in Table 1. Bimorphemic, monosyllabic signs are commonly signs containing a suffix, or compound signs that have been reduced to a single syllable.

Bimorphemic, disyllabic signs are predominantly compound words (Sandler & Lillo-Martin, 2006).

Table 1.
Attested morpheme and syllabic structure combinations in ASL

Morphemes (#)	Syllables (#)	Example
Monomorphemic (1)	Monosyllabic (1)	ARRIVE
Monomorphemic (1)	Disyllabic (2)	DESTROY
Bimorphemic (2)	Monosyllabic (1)	BELIEVE
Bimorphemic (2)	Disyllabic (2)	LUNCH

ASL phonotactics

While ASL phonology is widely studied, relatively little is known about ASL phonotactics, or the constraints on the formation of the language at the word, syllable, and morpheme level. So far, most of what is known about ASL phonotactics comes from descriptive inventories of ASL, and observation of what does and does not occur in this language (e.g., Stokoe, 1960/2005; Klima & Bellugi, 1979; Battison, 1974, 1978; Brentari, 1998; Liddell & Johnson, 1989; Valli & Lucas, 2000). For example, based on detailed observations of two-handed signs in ASL, Battison (1978) proposed the Symmetry Condition, which states that signs in which each hand moves independently always have identical or mirrored handshape, location, and movement. Many researchers have proposed constraints on the formation of ASL signs over the last three decades (Sandler & Lillo-Martin, 2006; Mandel, 1981; Wilbur, 1993; Uyechi, 1996; Brentari, 1998; Battison, 1978), but as yet, these proposed constraints have not been validated with empirical evidence. The following section provides a brief overview of the proposed phonotactic constraints on ASL.

Proposed phonotactic constraints on ASL

Finger Position Constraint. The Finger Position Constraint (FPC; Mandel, 1981) states that in any hand configuration there are only two groups of fingers: selected fingers, which are all in the same position and can be in any position but closed; and unselected fingers, which can be only all extended or all closed, creating maximum contrast between the two groups of fingers. For example, for the handshape V, the index and middle fingers are fully extended (selected) while the ring and pinky fingers are curled under the thumb (unselected). Further, the FPC states that unselected fingers do not make contact with the body or location the sign is performed, do not move, and do not point.

Handshape Sequence Constraint. The Handshape Sequence Constraint (HSC; Sandler, 1989; Brentari, 1990) states that if there are two finger positions in a sign, then *one* of these finger positions must be open or closed, where open indicates full finger extension and closed indicates contact with the thumb.

Revised Selected Finger Constraint. The Revised Selected Finger Constraint (rSFC; Sandler, 1989; Mandel, 1981) states that there can be only one specification for selected fingers in a morpheme, i.e., within a morpheme, changes in handshape are limited to those that do not change the selected fingers. Fingerspelling, as well as compound signs, are considered exceptions to this constraint.

Place Constraint. The Place Constraint (PC; Battison, 1978) states that there can be only one major body area specified in a sign. Sandler (1989) proposed a revision to this constraint, stating that only one major body area can be specified within a morpheme rather than a full sign. Compound signs are exceptions to this constraint.

Syllable-level Hand Configuration Constraint. Operating under the assumption that both handshape and orientation are included in hand configuration, the Syllable-level Hand Configuration Constraint (SHCC; Wilbur, 1993; Uyechi, 1996; Brentari, 1998; Sandler & Lillo-Martin, 2006) states that within a syllable, handshape may change or orientation may change, but not both. Further, handshapes and orientations are limited to a maximum of two within a syllable (again, fingerspelling is an exception to this constraint).

Syllable-timing Constraint. The Syllable-Timing Constraint (STC; Sandler & Lillo-Martin, 2006) states that any changes in handshape or orientation in a syllable with a path movement must be aligned with the start or end of the path movement. For example, the sign FORGET contains a handshape change from B to A, and this change occurs at the end of the path movement across the forehead.

Secondary Movement Constraint. The Secondary Movement Constraint (SMC; Perlmutter, 1992; Sandler & Lillo-Martin, 2006) states that secondary movement features can only occur on the nucleus of a syllable. Examples of secondary movement include rapid repetition of handshape changes or finger wiggling. As defined in the previous section, secondary movement can define the nucleus of a syllable only if there is no path movement within the sign. If there is secondary movement within a sign that contains a path movement, the secondary and path movements must occur simultaneously (Sandler & Lillo-Martin, 2006).

Symmetry condition. The Symmetry Condition (SC; Battison, 1978) states that if both hands of a sign move independently, then both hands must use the same handshape, perform the same movement (either simultaneously or in alternation), be in the same location (identical or mirror image location), and the orientation of each hand must be either identical or symmetrical relative to the line of bilateral symmetry. A more detailed analysis of four different symmetry conditions (reflection, rotation, translation, and glide reflection) was presented by Napoli and Wu in 2003. However, Battison's original description of the SC is still widely accepted (Sandler & Lillo-Martin, 2006).

Dominance condition. The Dominance Condition (DC; Battison, 1978) states that if the hands of a two-handed sign do not match in handshape, then one hand must be passive while the dominant hand articulates the movement, and the configuration of the passive handshape is restricted to be one of: A, S, B, 5, G (or 1), C, and O (traditionally considered the unmarked — or most common — handshapes). Napoli and Wu (2003) proposed an expansion to this condition to permit the passive handshapes H, L, and V. This condition was further revised by Sandler & Lillo-Martin (2006), who specified that the DC is applicable to two-handed signs where the passive hand does not move, and that in these signs the passive hand must either match the dominant handshape *or* be restricted to the set of handshapes listed above.

Phonotactics of other signed languages

Unsurprisingly, other signed languages (e.g. British Sign Language [BSL], Israeli Sign Language [ISL]) are also governed by constraints on well-formed signs (Orfanidou et al., 2009; Sandler & Lillo-Martin, 2006). Although relatively little research has been conducted in this area on languages other than ASL, the available evidence suggests some overlap, but also some differences, in the phonotactic constraints of other sign languages relative to ASL. Orfanidou and colleagues (2009, 2010) manipulated phonotactic constraints on BSL to investigate the contribution of different phonemes to sign recognition as well as the influence of well-formedness in segmenting sign sequences. Although the authors reported that there is no defined set of phonotactic rules for BSL, the authors violated some of the proposed constraints described for ASL to create meaningless pseudosigns in BSL, stating that these constraints "seem to hold for BSL as well" (Orfanidou et al., 2009, p.304). They also identified a violation of a main principle of BSL as a sign with movement from the head to the non-dominant hand (Orfanidou et al., 2009). This type of location change is, however, permissible in ASL (e.g., REMEMBER), indicating that phonotactic constraints on signed language may be at least partially language-specific.

Pseudosigns

One way of determining what the phonotactic constraints are in a language is by empirically testing how people react to pseudowords (or pseudosigns). In the study of spoken languages, pseudowords can be defined as meaningless strings of letters or phonemes. Creating pseudowords often involves rearranging or substituting one or more letters of a lexical word (e.g., frog to *freg*). Pseudowords can either be permissible or 'legal' in the language of study (e.g., *snarp*), or 'illegal' in that they violate the rules of the language (e.g., *lpsee*). Legal and illegal pseudowords are fundamental to psycholinguistic studies of language processing independent of meaning, and can serve important functions as control stimuli in language learning studies. Pseudowords minimize lexical biases in perceptual tasks (Ganong, 1980), and can be used to investigate factors influencing memory and comprehension of linguistic material (e.g., Heim et al., 2005). Comparing the perception of legal and illegal pseudowords allows researchers to investigate how language processing is influenced by phonotactic knowledge of a certain language (e.g., Mikhaylova, 2009).

The more word-like a pseudoword appears, the more difficult it is to determine if it is a true word or a meaningless form. In a lexical decision task, where participants are presented with strings of letters or sounds and must decide if they form existing words, legal pseudoword stimuli take longer to reject than illegal pseudowords (e.g., Coltheart et al., 1977, cited in Yap et al., 2015; Keuleers & Brysbaert, 2010). It has been demonstrated that a larger N400 response (an event related potential — ERP — negative deflection associated with lexical-semantic processing) is evoked during the auditory presentation of legal pseudowords than illegal pseudowords. Likewise, in functional magnetic resonance imaging (fMRI) studies the left hemisphere language processing network shows greater activation for legal pseudowords than illegal (Friederici, 2006; Rossi et al., 2011; Price et al., 1996), despite the fact that both types of pseudowords are meaningless. In a study during which participants were asked to identify if pseudowords presented aurally were mono- or disyllabic, Berent and colleagues (2007) demonstrated that native English speakers misidentified monosyllabic illegal pseudowords (e.g., *lbif*) as disyllabic legal pseudowords (e.g., *lebif*), while participants who spoke Russian, a language which tolerates onset clusters such as *lb*, did not. This indicates that knowledge of the phonotactics of a particular language can influence how pseudoword forms are perceived (Berent et al., 2007). To summarize, legal and illegal pseudowords differ both in how they are perceived and how they are processed by the brain, and these differences are influenced by a person's phonotactic knowledge.

Similar to pseudowords, many studies in sign language linguistics make use of pseudosigns, which are manual gestures based on the properties of a signed language such as ASL (e.g., Emmorey et al., 2011; Best et al., 2010; Pa et al., 2008; Wilson and Emmorey, 2003; Orfanidou et al., 2009, 2010; Grosvald et al., 2012; Hildebrant & Corina, 2002; Neville et al., 1998; Bavelier et al., 1998; Kovelman et. al, 2014; Buchsbaum et. al, 2005). Pseudosigns serve many of the same research functions as pseudowords, and just like pseudowords, pseudosigns can vary in how well they conform to the rules of the language. Legal pseudosigns have been used to gain insight on modality-specific or -independent language processing (e.g., Petitto et al, 2000); to investigate the organization of linguistic short term memory in different modalities (e.g., Pa et al., 2008); to examine the effect of irrelevant visual input on working memory for sign language and English (Wilson & Emmorey, 2003); to compare the processing of linguistically structured material to the processing of unstructured gesture (e.g., Emmorey, 2010) and contrast the perception of meaningful and meaningless gesture between ASL signers and spoken language users (e.g., Emmorey et al., 2011). Illegal pseudosigns for ASL, on the other hand, are relatively unexplored in the literature, often being filtered out during the development of legal pseudosign stimuli (e.g., Petitto et al., 2000; Kovelman et al., 2010; Pa et al., 2008). However, illegal pseudosigns have important applications in the study of signed languages and gesture perception. Comparing the perception and processing of legal and illegal pseudosigns by fluent signers would allow researchers to validate the proposed phonotactic constraints on ASL, and potentially uncover previously uncharacterized constraints on this language. Examining how new learners of sign language perceive illegal pseudosigns would help inform on how signers acquire knowledge of these phonotactic properties, and how perception of other gesture stimuli is influenced by this knowledge.

Sign language and the brain

Although spoken and signed languages have radically different forms and input/output modalities, extensive research has demonstrated that, when sensory differences are accounted for, both types of languages engage the same network of brain regions for production and comprehension (Neville et al., 1998; MacSweeney et al., 2002, 2008; Campbell et al., 2008; Newman et al., 2002, 2010, 2015). That is, when brain activation during spoken and signed language processing are compared after subtracting activation due to matched (but non-linguistic) acoustic or visual control stimuli, the same core regions of the left cerebral hemisphere are activated for specific linguistic tasks such as retrieving the meanings of words or parsing the grammar of a sentence. These areas include the inferior frontal gyrus (Broca's area), the temporal-parietal junction (Wernicke's area), and the superior temporal sulcus. These findings are in accord with a large literature in linguistics demonstrating that signed and spoken languages have comparable organizational properties and structures, suggesting that there are modality-invariant, universal properties of natural human languages (see Sandler and Lillo-Martin, 2006 for review).

In contrast, non-linguistic gestures have been shown to activate a neural network that is largely distinct from that engaged during language processing. Perception of any human movements (termed *biological motion*) primarily activates a region of the posterior superior temporal sulcus (STSp) bilaterally, but generally with a right hemisphere dominance (Grossman & Blake, 2001; Grossman et al., 2005). Pantomimed actions (e.g., acting out brushing one's teeth or chopping wood) and emblems (culturallyspecific hand gestures that convey meaning independently of speech; e.g., creating a circle with the thumb and forefinger to indicate *OK*) activate STSp along with the right anterior temporal lobe, and regions of the superior parietal lobe and the left premotor cortex (Newman et al., 2010; Husain et al., 2012). These latter two regions are often referred to as the *mirror neuron system* based on findings that these areas are similarly active when people perceive actions or perform the actions themselves.

Interestingly, in one study where descriptions of the same events were communicated either through sign language or gesture (Newman et al., 2015), knowledge of sign language was shown to influence brain activation for *both* sign language and gesture: native ASL signers showed activation of the language network for both types of stimuli (though significantly more strongly for ASL), whereas non-signers activated the STSp and mirror neuron system for both gestures and ASL (which they did not know as a language, and so interpreted like other gestures). Similar results were obtained in other studies by Malaia et al. (2012) and Husain et al. (2012). This suggests that experience with a visual-manual language affects how people process not only that language, but non-linguistic gesture as well. However, the degree of proficiency or fluency in sign language required to affect processing of visual-manual stimuli, or whether factors such as phonotactic permissibility, lexicality, or linguistic structure of the visual-manual stimuli has an impact on how they are perceived and processed by new learners of sign language, is not known.

To begin to investigate how much exposure to sign language is necessary to trigger a shift in how visual-manual communication is processed, a possible research paradigm could use fMRI to examine how brain activation in response to both sign language and non-linguistic gesture changes before and after a semester (12 weeks) of ASL instruction, in people previously naïve to sign language. Previous work in spoken language research has demonstrated that significant changes in neural activity related to word recognition can been seen after as little as 14 hours of second language instruction (McLaughlin et al., 2004); the results of this study would inform the design of future studies, which could look serially over shorter intervals (e.g., MRI scans every 4 weeks) or longer intervals, depending on the degree of change and amount of variability observed across individuals. This research program would improve our understanding of how language, a heavily structured and rule-governed system, differs from other forms of visual-manual communication that lack linguistic structure. It would also provide an important complement to the existing literature on the neural bases of second language acquisition, which up until now have been studied almost exclusively using spoken languages.

Purpose

To investigate the factors influencing how new learners of ASL perceive and process visual-manual stimuli, we propose employing four different types of stimuli, which vary in structure, phonotactic permissibility, and lexicality: ASL signs, which are highly structured and phonotactically permissible with lexical meaning; emblems, which do not have linguistic structure, do not violate phonotactic constraints, but do convey symbolic meaning; legal pseudosigns, which are linguistically structured, do not violate phonotactic constraints, but are meaningless; and illegal pseudosigns, which are linguistically structured, but do violate the phonotactic constraints of ASL and are meaningless. Table 2 describes how we would expect these different types of stimuli to be perceived by English speaking non-signers before and after they receive ASL instruction. As new learners of ASL acquire phonotactic and lexical knowledge of this language, the brain areas recruited to process these types of stimuli may change as well. However, in order to elucidate these potential differences in perceptual processing, it is crucial to carefully develop and select stimuli with the specific properties outlined above.

Table 2.
Predicted perception of different stimulus categories pre- and post-ASL instruction

	ASL signs	**Emblems**	**Legal Pseudosigns**	**Illegal Pseudosigns**
Pre-instruction	Meaningless	Meaningful	Meaningless	Meaningless
Post-instruction	Meaningful	Meaningful	Meaningless	Meaningless

The purpose of the present study was to develop a set of visual-manual stimuli that varied in structure, phonotactic permissibility, and lexicality to be used in future brain imaging studies of sign language learning. The main goals of this study were to first use a rating task to examine how these stimuli (ASL signs, emblems, legal pseudosigns, illegal pseudosigns) were perceived by English speakers with no sign language experience, and secondly to use specific rating criteria to select exemplar stimulus items in each category for use in future studies. By developing a set of illegal pseudosigns as part of these stimulus sets, we have taken the first steps towards validating some of the hypothesized phonotactic constraints for ASL.

To create illegal pseudosigns, we discussed possible phonotactic constraints and violations of these constraints with a group of native ASL signers. We cross-referenced these violations with the proposed phonotactic constraints in the established literature (Sandler & Lillo-Martin, 2006; Mandel, 1981; Wilbur, 1993; Uyechi, 1996; Brentari, 1998; Battison, 1978), and systematically applied the selected violations to a set of real

ASL signs. The resulting illegal pseudosigns were practiced and performed by a native ASL signer and video-recorded, along with a set of legal pseudosigns (from Grosvald et al., 2012), a set of ASL signs (Smith et al., 2008), and a set of emblems (gestures which carry meaning independently of speech) commonly used by North Americans (Zaini et al., 2012; Matsumoto & Hwang, 2009).

To explore how these stimuli were perceived by English speakers naïve to sign, we designed a rating study based on procedures described by Emmorey et al. (2011) and by Petitto et al. (2000). English speaking non-signing participants were presented with all four types of stimuli in random order, and were asked to rate each item on a scale of meaningfulness, and provide a brief description or guess at the meaning. Further, participants were asked to decide whether each item viewed was ASL, in a yes/no forced decision task. The goal of this rating procedure was to identify the best exemplars of each stimulus category, based on pre-determined criteria of meaningfulness and how likely the items were to be rated as ASL.

We predicted that overall, basic ASL items would be perceived as meaningless and identifiable at chance level as ASL since our participants had no knowledge of this language. Items in the emblem category were predicted to be perceived as highly meaningful, and less likely to be mistaken for ASL. Both legal and illegal pseudosigns were predicted to be perceived as meaningless, and we expected that our participants would be equally likely to classify both types of pseudosigns as sign language, based on their lack of knowledge of the phonotactic rules of this language. Based on these predictions, we established average rating thresholds for items in each category, and eliminated any items that did not meet these criteria. Items in the ASL category that were guessed correctly by any participant, and any legal or illegal pseudosign with multiple similar guesses across participants were also eliminated. A final 40 stimulus items were selected for each category, for use in future brain imaging studies of sign language learning.

CHAPTER 2 METHODS

Participants.

Eleven self-identified fluent English speakers with no ASL experience, ages 18-65, were recruited from various locations through email and advertising on social media. Participant demographics are described in Table 3. Interested participants contacted the researcher through email, and were screened for eligibility (Appendix B). The eligibility questionnaire confirmed English proficiency and ensured that these participants had no prior knowledge of any signed language, no hearing or uncorrected visual impairments, and no neurological conditions or pathology that could affect performance on the study task.

Table 3.
Participant demographics

N	Gender	Age (mean, SD)	Native language (n)
11	M =2 F = 9	27.5, 8.5	English (9) Polish (1) Arabic (1)

Stimuli

This study employed four types of stimuli, which varied in predicted meaningfulness depending on the participant's knowledge of ASL (signer versus non-signer): ASL signs, emblems, legal pseudosigns, and illegal pseudosigns. The different stimulus types also varied in their structure and well-formedness, as detailed below.

American Sign Language. Basic ASL signs (n = 343) were selected from Signing Naturally Units 1-6 (Smith et al., 2008). These included both one-handed and two-handed signs, and comprised a variety of nouns, verbs, and adjectives. To maintain simplicity, disyllabic signs with alternating or repeated path movement (e.g., BABY in which the arms move back and forth twice) were accepted; disyllabic signs with affixes (e.g., TEACHER: TEACH + PERSON affix) or compound forms were not. Fingerspelling or signs based on alphabetization (e.g, HIGHSCHOOL, signed using the handshapes H and S) were not used.

Emblems. Recognizable emblems (n = 77) commonly used by English speakers were sourced from previously published works (Zaini et al., 2012; Matsumoto et al., 2009). These stimuli were not linguistically structured but carried concrete meaning independent of speech.

Legal pseudosigns. Legal pseudosigns (n = 84), which were formed using combinations of hand conformations, movements, and locations that follow the phonotactic rules of ASL but do not currently exist in that language, were used with permission from work by Grosvald et al. (2012). These stimuli were meaningless, highly structured and well-formed according to the phonotactic rules of ASL.

Illegal pseudosigns. Potential constraints on well-formed ASL signs were identified through a review of published inventories of ASL (Brentari,1998; Mandel, 1981; Sandler & Lillo-Martin, 2006) and with input from a sign language linguist (David Corina, University of California, Davis). Identified constraints and possible violations were then brought to round-table discussions with a volunteer group of native signers (n=3) and an interpreter, to evaluate their permissibility.

Not all proposed constraints were used in the development of the illegal pseudosigns for this study. For the purposes of developing stimuli for use in future brain imaging studies, we aimed to have our stimuli match our criteria for each category as closely as possible. For illegal pseudosigns, this meant choosing proposed phonotactic constraints that had clear violations which were identified as ill-formed by our group of native signers. Some proposed constraints were eliminated because they had many exceptions identified by both the literature and the group of native signers (i.e., the Place Constraint [Battison, 1978], the Dominance Condition [Battison, 1978], Revised Selected Finger Constraint [Sandler, 1989; Mandel, 1981]). The Handshape Sequence Constraint (Sandler, 1989; Brentari, 1990) was eliminated because violations of this constraint (e.g., a sign with two finger positions in which neither position is open or closed) did not appear entirely ill-formed to the group of native signers who helped develop the stimuli. We also tried to avoid patterns in our stimuli that could be learned by our participants as the completed this study as well as future brain imaging studies. The Secondary Movement Constraint (Perlmutter, 1992; Sandler & Lillo-Martin, 2006) was eliminated because it had limited possibilities for violation: violating this constraint would involve selecting signs with a path movement and inserting secondary movement either directly before or directly after the path movement. This would create a subset of very similar-looking pseudosigns following a pattern that participants could learn to identify over the course of the study. We also avoided violations that were implausible because of physical awkwardness (e.g., twisting the wrist or elbow in a difficult way) or impracticality (e.g., a sign performed on the back of the head where it is all but invisible). To summarize, we chose proposed constraints and violations that did not have easily identifiable exceptions, appeared ill-formed to the group of native signers, and could create a sufficiently varied set of pseudosigns while not appearing physically or perceptually impossible. The following section briefly revisits the proposed constraints and describes the identified violations for each. Example videos of these illegal pseudosigns can be found with this thesis manuscript in the Dalhousie University DalSpace archives (www.dalspace.library.dal.ca); see Appendix C for more information.

Finger Position Constraint. The FPC (Mandel, 1981) states that in any hand conformation there are only two groups of fingers: selected fingers and unselected fingers. To violate this constraint, we created a set of hand conformations that contained a "half-selected" finger or group of fingers, in an intermediate position between allowable selected and unselected positions. These "illegal" handshapes are described in Table 4; images of these handshapes can be found in Appendix D. These handshapes were then substituted into ASL signs to create illegal pseudosigns in the subcategory Finger Position Constraint violation type 1 (FPC1).

Table 4.
Illegal handshapes created by violating the Finger Position Constraint

Finger grouping	**Name**
Selected + half-selected + unselected	X-middle open
	K-index bent
	U-ring open
	7-index bent
	I-middle open
Selected + half-selected	K-ring&pinky open
	3-ring&pinky open
	T-pinky bent
Unselected + half-selected	Ring open
	E-index open

Further, the FPC states that unselected fingers do not make contact, do not move, and do not point. To violate this constraint, we created pseudosigns where the unselected group of fingers in a hand conformation performed the action of touching the body or place of articulation, forming the subcategory Finger Position Constraint violation type 2 (FPC2).

Syllable-level Hand Configuration Constraint. The SHCC (SHCC; Wilbur, 1993; Uyechi, 1996; Brentari, 1998; Sandler & Lillo-Martin, 2006) states that within a syllable, handshape may change or orientation may change, but not both. To violate this constraint, we created pseudosigns which included a change in handshape AND a change in orientation within a syllable. The SHCC also states that handshapes and orientations are limited to a maximum of two within a syllable; however, creating pseudosigns with three or more handshape changes or orientation changes within a syllable simply made the pseudosigns appear to be either a) fingerspelling, an allowable exception to this constraint, or b) disyllabic, with one or two handshape/orientation changes per syllable. Therefore, this aspect of the SHCC was not applied to our pseudosigns.

Syllable-timing Constraint. The STC (Sandler & Lillo-Martin, 2006) states that any changes in handshape or orientation in a syllable with a path movement must be aligned with the start or end of the path movement. To violate this constraint, we created pseudosigns where handshape or orientation changed in the *middle* of a path movement.

Symmetry Condition. The SC (Battison, 1978) states that if both hands of a sign move independently, then both hands must use the same handshape, perform the same movement (either simultaneously or in alternation), be in the same location (identical or mirror image location), and the orientation of each hand must be either identical or symmetrical relative to the line of bilateral symmetry. To violate this constraint, we created a set of two-handed pseudosigns in which the hands were symmetrical in location, orientation, and movement, but did not match in handshape. We chose to mismatch handshape rather than the other conditions of symmetry because it was more natural for a native signer to perform, and could produce a large variety of pseudosigns by simply switching one hand's handshape for another in the ASL inventory.

Applying violations. The above violations were systematically applied to basic mono- and disyllabic signs from a standard beginner ASL curriculum (Signing Naturally, Units 1-6). Similar to the signs used for the ASL category, disyllabic signs with affixes, compound forms, and signs using fingerspelling were not selected. These stimuli were highly structured and well-formed with clearly defined meaning in ASL.

Signs selected from the curriculum were listed in a table by unit number and were broken down into components: handshape (including number of hands, orientation, use of symmetry/dominance); location; and type of movement, both path and internal. Violations were applied based on these components and their possible combinations (e.g., a symmetrical two handed sign could have the SC violation applied; a sign with a change in orientation could have a handshape change added to violate the SHCC, etc.). Base signs were taken from all six curricular units. Using this method, 88 illegal pseudosigns were created. These stimuli were highly structured, but both meaningless and ill-formed according to the proposed constraints on ASL.

Video recording.

Each stimulus was practiced and performed by a native signer and video-recorded. Videos were recorded against a black backdrop using a Sony digital video cassette recorder, linked to a Firestore FS-4 DTE recorder which digitized the recording. The signer was instructed to keep his face neutral during all videos to reduce any overt perceptual clues to the meaning of the stimuli. Each video was reviewed for accuracy, clipped, and edited using Adobe Premiere Pro™. Videos were matched for colour and contrast using Adobe Speedgrade™. Video duration ranged from two to seven seconds across all stimuli. All videos were exported in AVI format using the NTSC DV preset, at 720p, 29.97 fps, 48000 Hz.

Rating Task.

The rating study was designed in Psychopy (v. 1.82.02; Pierce, 2007) and executed on a computer in the NeuroCognitive Imaging Laboratory at Dalhousie University. Participants were seated quietly in front of the computer, and were presented with videos of each of the four types of stimuli in random order. For each video, participants were asked to:

1. Rate the video's meaningfulness using a 7-point Likert scale (adapted from Emmorey et al., 2011). Details of this scale are in Table 5.
2. Type a word or a short phrase describing the perceived meaning or their best guess
3. Decide if the stimulus presented was ASL (forced choice YES/NO)

Table 5.
Meaningfulness rating scale

Rating	Description
1	Completely unrecognizable – does not look like anything I have ever seen before
2	No meaning – cannot begin to guess at meaning
3	Unclear meaning – fairly unsure of the meaning and probably could not describe
4	Undecided – could or could not have meaning
5	Weak meaning – might be able to guess
6	Fairly clear meaning – fairly certain of the meaning and probably could describe
7	Absolute clear meaning – definitely know what this means and could define

Before beginning the main task, participants were given the opportunity to practice these steps. Each video played only once, and replays were not permitted. Participants proceeded at their own pace, and were allowed to take breaks at any time. Completion of the entire study took two to three hours. Participants were reimbursed with $20 for their participation, or they could choose to waive this reimbursement.

Data analysis.

Each stimulus item's average rating and 95% confidence interval was calculated using R statistical software (version 3.3.0). Acceptable stimuli for each category were then selected based on their meeting of expected criteria:

a) Selected ASL signs were not meaningful to non-signers (average rating no higher than 3, and confidence interval ≤ +/- 1) and were highly meaningful to native signers (average rating 6, and confidence interval ≤ +/- 1)
b) Selected emblems were highly meaningful to both groups (average rating 6, and confidence interval ≤ +/- 1)
c) Selected legal and illegal pseudosigns were not meaningful to non-signers nor to native signers (average rating no higher than 3, and confidence interval ≤ +/- 1)

Further, sign stimuli whose meaning was correctly guessed by any participant, or any pseudosign stimuli with multiple similar guesses across participants were eliminated. Using this method, each category was narrowed down to 40 exemplar stimuli for a total of 160 stimuli, a reasonable number based on how long it would take participants to complete future fMRI studies.

CHAPTER 3 RESULTS

Meaningfulness ratings

Average rating and 95% confidence interval for each stimulus category are shown in Figure 1: ASL = 3.9; Emblem = 6.2; Legal pseudosign = 3.1; Illegal pseudosign = 2.8. We analyzed the effect of category on rating with linear mixed-effect modeling, using the lme4 package in R statistical software (version 3.3.0). Subjects were specified as a random factor. We found a significant effect of category, $F(3,10) = 994.9$, $p < 0.001$. Fixed effects pairwise comparisons revealed significant differences in average rating between all categories. The results of all pairwise comparisons are visualized in Figure 1.

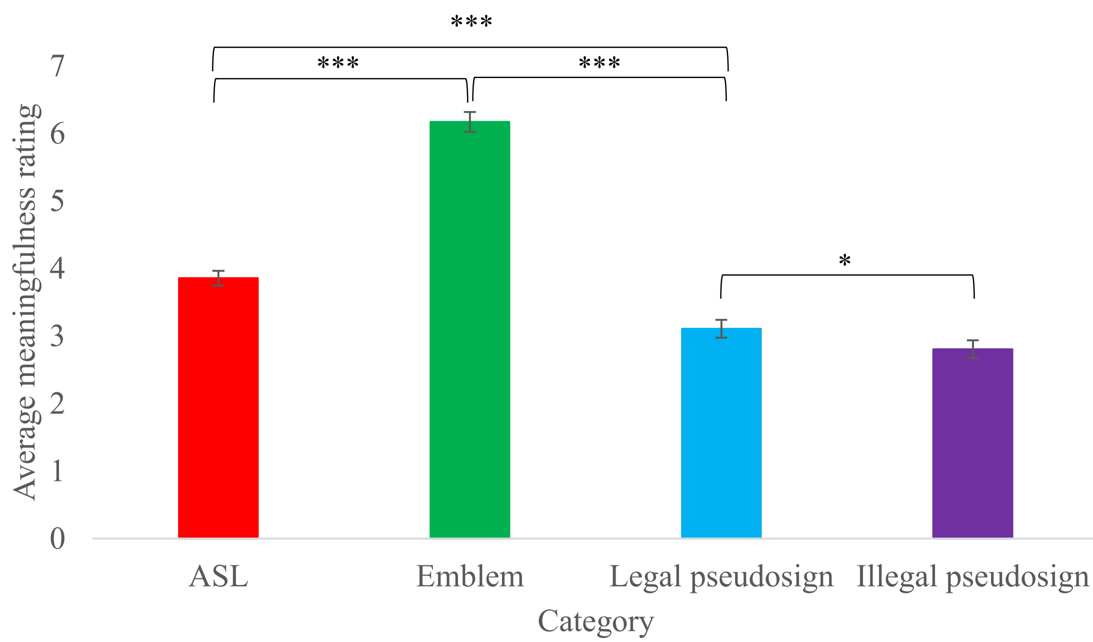

Figure 1. Average meaningfulness rating for each stimulus category. Vertical bars represent 95% confidence intervals. Significant category comparisons are indicated with brackets; * p<0.05, ** p<0.01, *** p<0.001.

American Sign Language. The average rating and 95% confidence interval per item in the ASL category can be seen in Figure 2. The items in the ASL category were rated across the range of the meaningfulness scale, with average ratings ranging from 1.6 to 7 (median: 3.75; mode: 3). Applying our rating criteria threshold (non-signers: mean ≤ 3, and confidence interval ≤ +/- 1) reduced possible items from 343 to 82. Stimulus items were further narrowed down based on meaningfulness guesses: any ASL items whose meaning was correctly guessed by a non-signer, or for which multiple people made similar guesses to the meaning, were removed (n = 13). The remaining stimulus items were sorted by average rating, and the 40 lowest rated items were selected for the final set. Although not a strict criterion, we also aimed for a balanced distribution of items across Units 1-6 of the Signing Naturally curriculum where possible. Average ratings of each of the final stimulus sets are visualized in Figure 8.

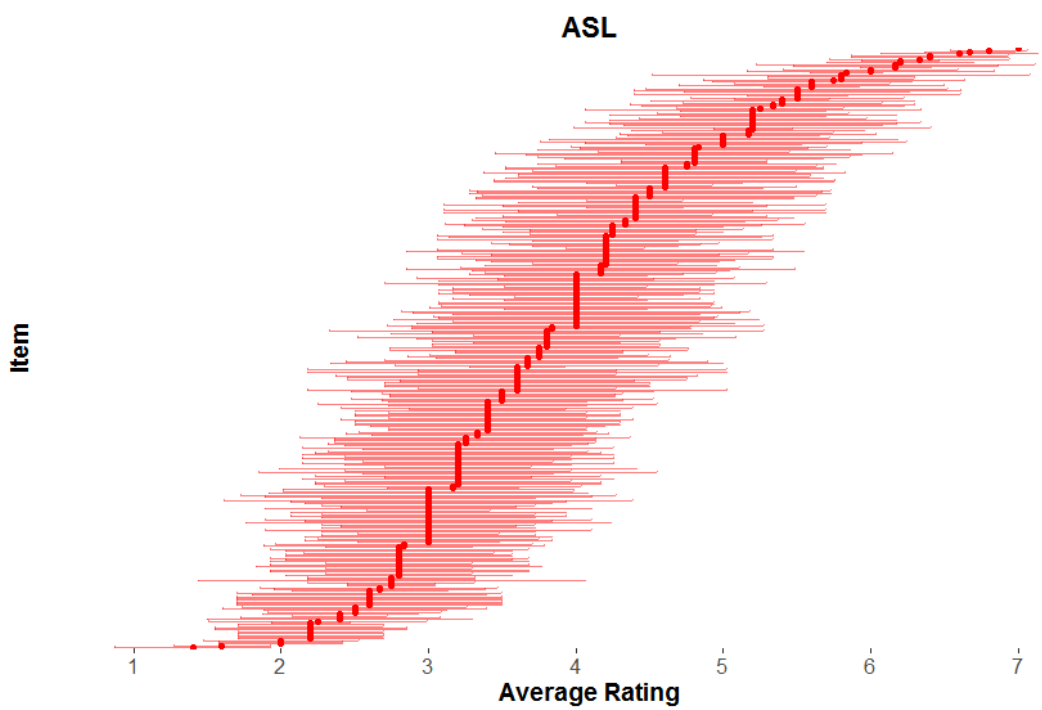

Figure 2. Average meaningfulness rating by English-speaking non-signers for stimulus items in the ASL category. Horizontal errors bars indicate 95% confidence intervals. On this scale, 1 indicates the least meaningful and 7 indicates the most meaningful.

Emblems. A total of 77 emblems were viewed and scored by participants. The average rating and 95% confidence interval per item in the Emblem category can be seen in Figure 3. Items in the Emblem category had average ratings of 3.6 or higher (median: 6.3; mode: 6). Applying the rating criteria threshold (mean ≥ 6 and confidence interval ≤ +/- 1) reduced possible items to 57. These items were sorted by average rating, and the 40 highest rated items were selected for the final set, visualized in Figure 8.

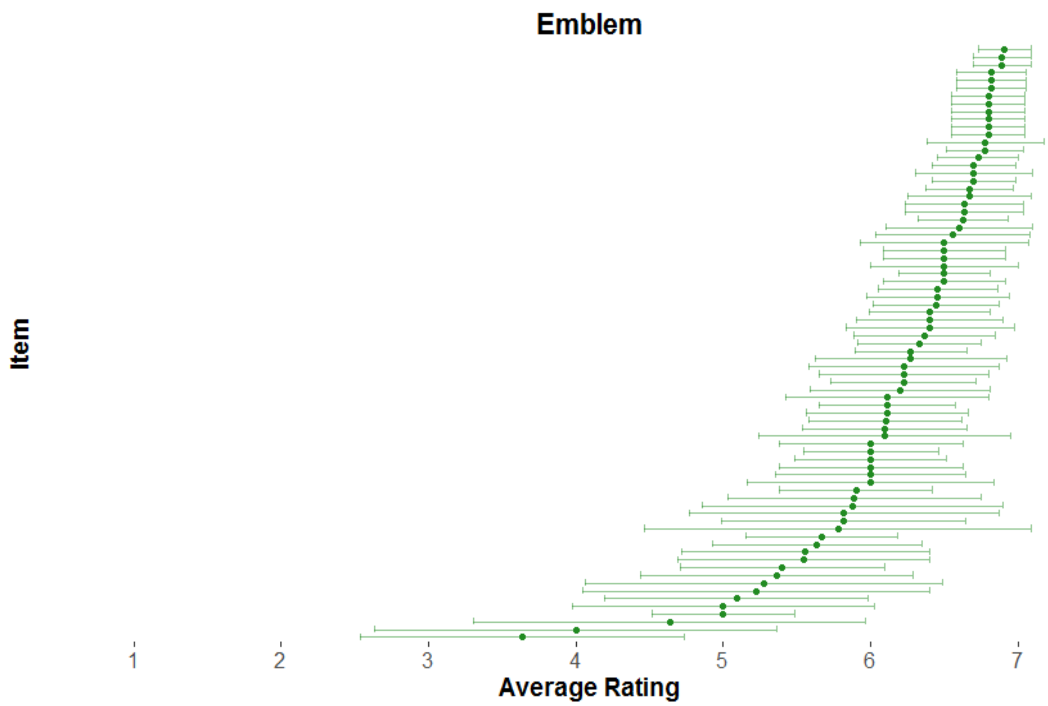

Figure 3. Average meaningfulness rating by English-speaking non-signers for stimulus items in the Emblem category. Horizontal error bars indicate 95% confidence intervals. On this scale, 1 indicates the least meaningful and 7 indicates the most meaningful.

Legal pseudosigns. A total of 84 Legal Pseudosign items were viewed and scored by participants. The average rating and 95% confidence interval per item in the Legal Pseudosign category can be seen in Figure 4. Average ratings for items in this category ranged from 2 to 5 (median: 3; mode: 3). Applying the rating criteria threshold (mean ≤ 3 and confidence interval ≤ +/- 1) reduced possible items to 45. Of these, five items had multiple similar guesses across participants and were eliminated. The remaining 40 items were selected for the final set, visualized in Figure 8.

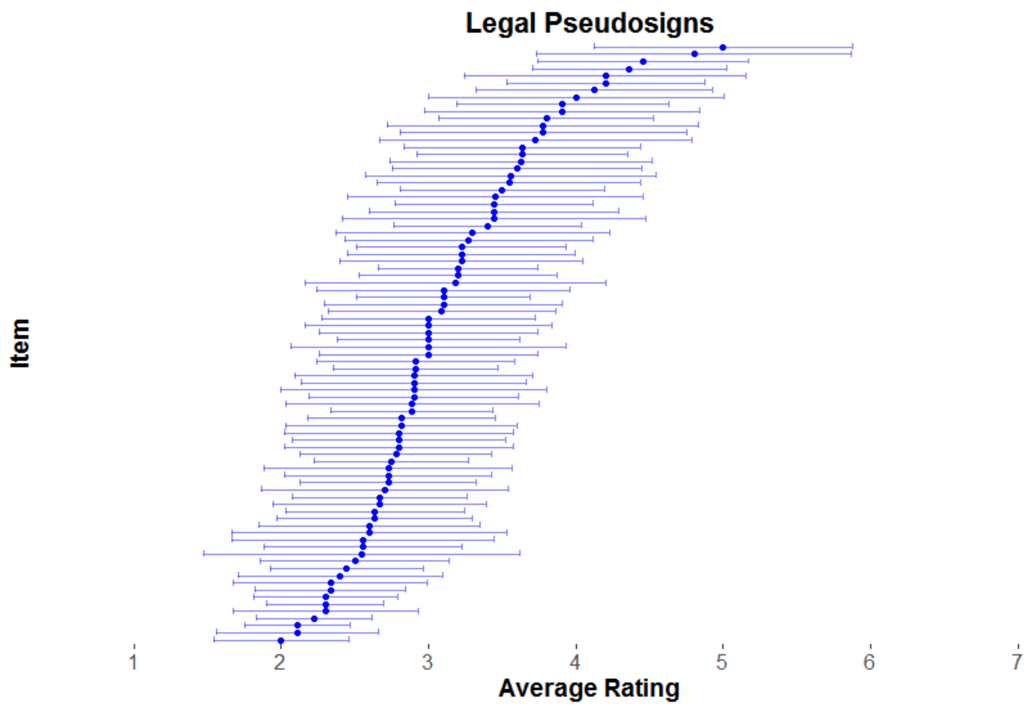

Figure 4. Average meaningfulness rating by English-speaking non-signers for stimulus items in the legal pseudosign category. Horizontal error bars indicate 95% confidence intervals. On this scale, 1 indicates the least meaningful and 7 indicates the most meaningful.

Illegal pseudosigns. Figure 5 shows the average rating and 95% confidence interval for the 93 items in the Illegal Pseudosign category. Average ratings for items in this category ranged from 1.5 to 4.5 (median: 2.7; mode: 3). Applying the rating criteria threshold (mean ≤ 3 and confidence interval ≤ +/- 1) reduced possible items to 61. Fifteen items elicited multiple similar guesses across participants and were eliminated. The remaining 46 items were sorted by average rating, and the 40 lowest rated items were selected for the final set, visualized in Figure 8.

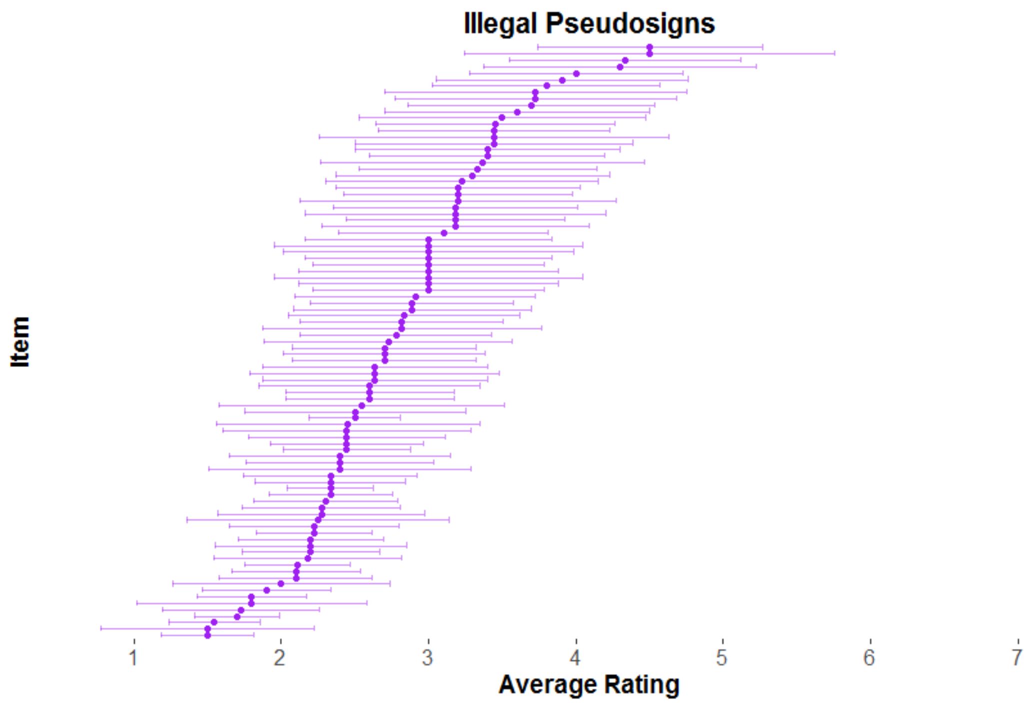

Figure 5. Average meaningfulness rating for stimulus items in the illegal pseudosign category. Horizontal error bars represent 95% confidence intervals. On this scale, 1 indicates the least meaningful and 7 indicates the most meaningful.

To examine whether average meaningfulness ratings differed across subcategories of illegal pseudosign, we sorted the illegal pseudosign stimulus items by type of violation and used boxplots to visualize the distribution of ratings in each subcategory, presented in Figure 6. Average rating and 95% confidence interval for each subcategory are shown in Figure 7. We analyzed the effect of subcategory on rating with linear mixed-effect modeling, using the lme4 package in R statistical software (version 3.3.0). Subjects were specified as a random factor. We found no significant effect of subcategory ($F[4,10]=1.52$, $p>0.1$), indicating that average meaningfulness ratings for illegal pseudosigns were similar across violation types.

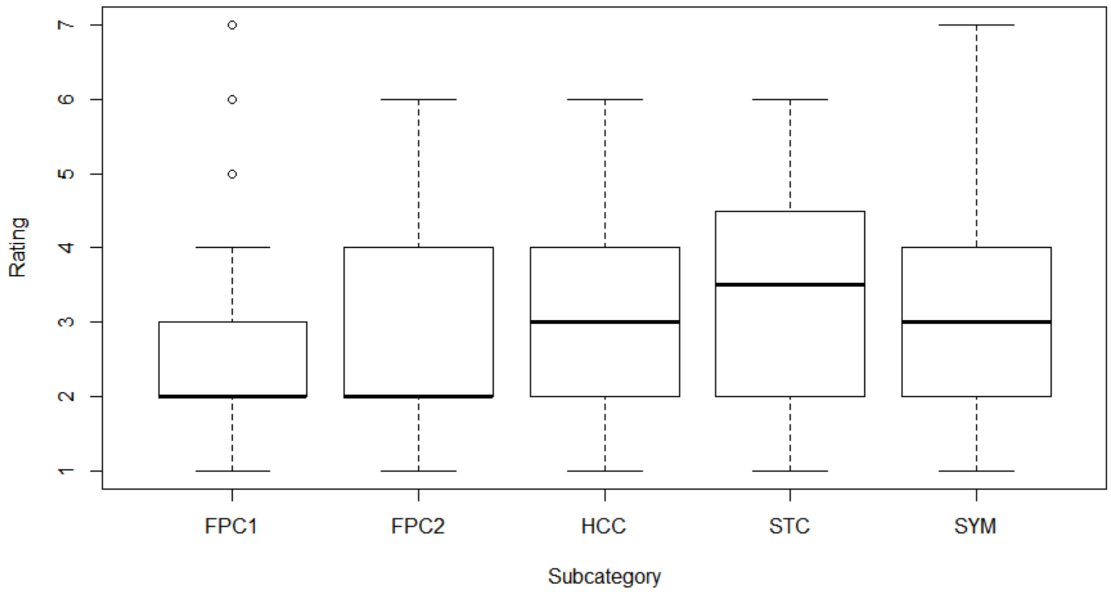

Figure 6. Distribution of meaningfulness ratings by English-speaking non-signers for subcategories of illegal pseudosign. The top fence of each box plot indicates the upper limit of the range of meaningfulness ratings for that subcategory; the bottom fence indicates the lower limit of the range. Each box area indicates the range in which 50% of the ratings for that subcategory are contained. The bold line contained within each box indicates the median rating for that subcategory. Outliers are indicated by points outside the fences of a boxplot. FPC1=Finger Position Constraint violation type 1 (n = 10); FPC2=Finger Position Constraint violation type 2 (n = 17); SYM=Symmetry violation (n = 22), HCC=Hand Configuration Constraint violation (n = 10); STC=Syllable Timing Constraint violation (n = 3)

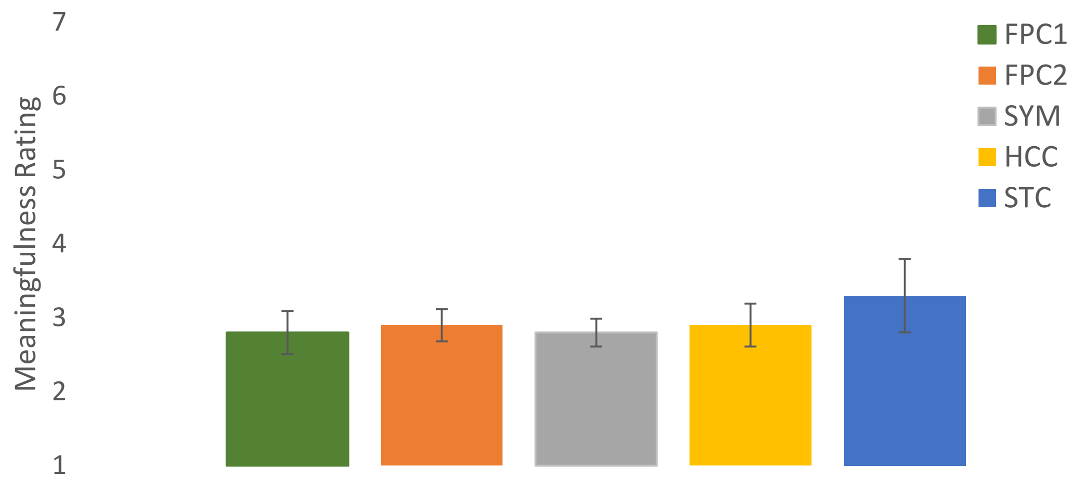

Figure 7. Average meaningfulness rating by English-speaking non-signers for subcategories of illegal pseudosign. Vertical bars represent 95% confidence intervals. No significant difference was found between subcategories using linear mixed effects modeling ($F(4,10) = 1.52$, $p > 0.1$). FPC1=Finger Position Constraint violation type 1 (n = 10); FPC2=Finger Position Constraint violation type 2 (n = 17); SYM=Symmetry violation (n = 22), HCC=Hand Configuration Constraint violation (n = 10); STC=Syllable Timing Constraint violation (n = 3)

Rating criteria.

Figure 8 shows the distribution of average meaningfulness ratings per stimulus item in all four categories after applying our rating criteria. After applying our rating criteria, the average meaningfulness rating and 95% confidence interval for each stimulus category after rating criteria were recalculated and are shown in Figure 9: ASL = 2.7; Emblem = 6.5; Legal pseudosign = 2.7; Illegal pseudosign = 2.4. We re-analyzed the effect of category on rating using the same linear mixed-effect modeling as described above. Subjects were specified as a random factor. We found a significant effect of category ($F[3,10]=2126$, $p<0.001$). Fixed effects pairwise comparisons revealed that the average meaningfulness rating for the emblem category was significantly different from the average meaningfulness ratings for the remaining three categories; no significant difference in average meaningfulness rating was found between the ASL, legal pseudosign, and illegal pseudosign categories. The results of all pairwise comparisons are visualized in Figure 9.

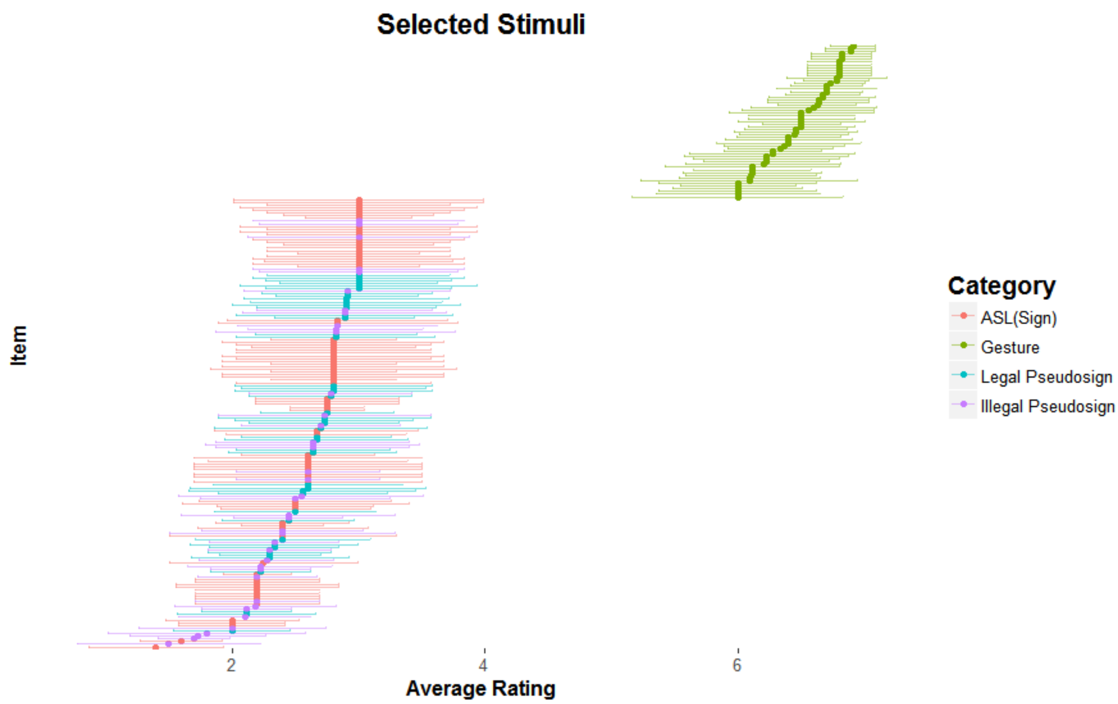

Figure 8. Average ratings for stimuli in all four categories which meet rating threshold criteria for English-speaking non-signers. Horizontal bars indicate 95% confidence intervals.

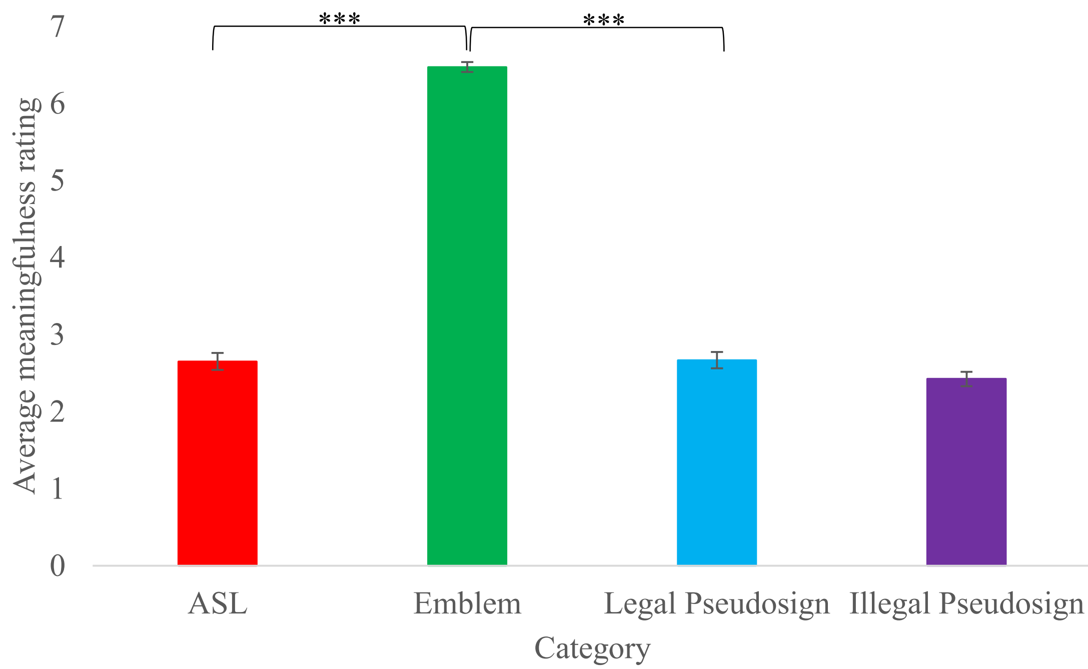

Figure 9. Average meaningfulness ratings for each stimulus category after rating criteria were applied. Vertical bars indicate 95% confidence intervals. Significant category comparisons are indicated with brackets; *** p<0.001.

ASL Classification

A single-predictor logistic model was fitted to the classification data from English-speaking non-signers for all stimulus items to examine the relationship between the likelihood that an item was classified as ASL and the category to which that item belonged. The logistic regression was carried using the Generalized Linear Mixed Effects model in R (version 3.3.0), with log odds back-transformed to probabilities.

Table 6.

Probability of items in each stimulus category being rated as ASL

Category	**Probability ASL (Yes)**
ASL	0.789
Legal Pseudosign	0.799

Category	Probability ASL (Yes)
Illegal Pseudosign	0.678
Emblem	0.307

As shown in Table 6, participants were less likely to rate emblems as ASL than not, with a probability under 0.5. Participants were more likely to rate ASL, legal pseudosign, and illegal pseudosign items as ASL than not, with probabilities greater than 0.5. Pairwise comparisons revealed that non-signers were significantly less likely to rate illegal pseudosign than legal pseudosign items as ASL. There was no significant difference in probability between legal pseudosign and ASL, indicating that non-signers were equally likely to rate items in these two categories as ASL. These results and the results of all pairwise comparisons are shown in Figure 10.

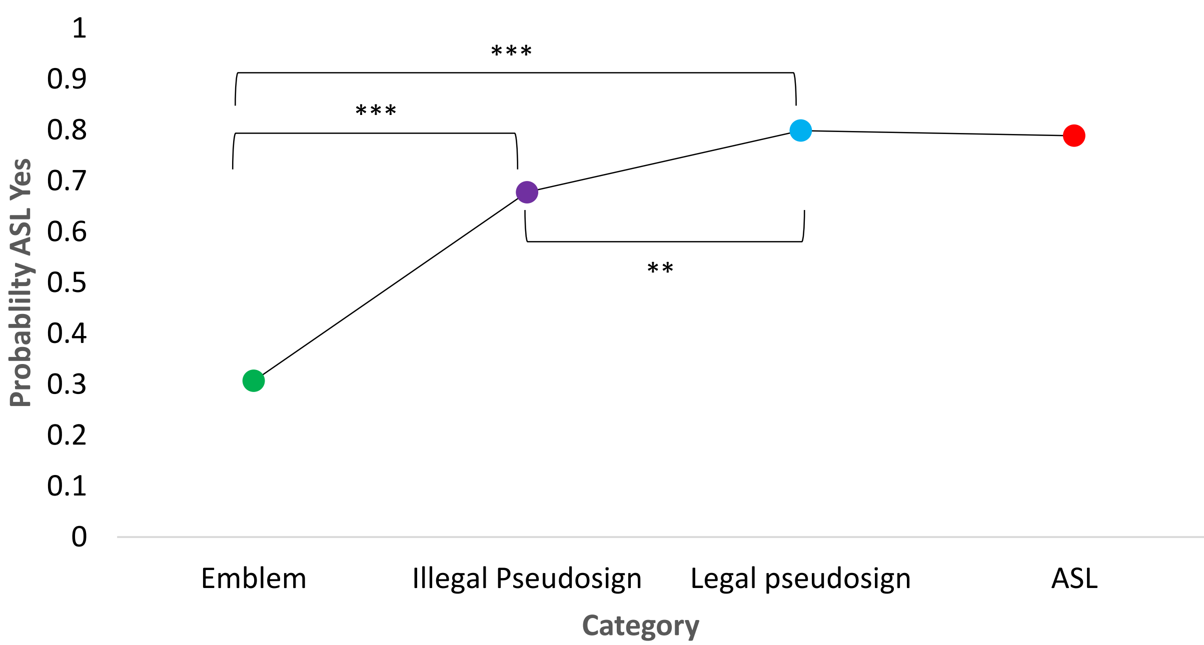

Figure 10. Probability of each stimulus category being rated ASL, where y=1 indicates 100% probability of being rated as ASL in the ASL Yes/No forced choice task. Significant category comparisons are indicated with brackets; ** $p<0.01$, *** $p<0.001$.

CHAPTER 4 DISCUSSION

Perceived meaningfulness

American Sign Language. We predicted that non-signing participants would perceive ASL signs as meaningless, since these participants had no knowledge of ASL. While the average meaningfulness rating for the ASL category (3.8) was on the meaningless end of the scale and lower than that of the emblem category, it was higher than the average meaningfulness rating for both legal and illegal pseudosigns. As seen in Figure 2, individual ASL items were given average ratings across the entire range of meaningfulness. Some ASL signs were rated as highly meaningful while others were rated as completely meaningless, as well as across the levels in between. This may reflect that some ASL signs have iconic features — meaning that even though they follow ASL phonotactics, aspects of the handshapes or movements represent visual features of their referents. To determine if iconicity is a factor in how meaningful our sign stimuli are to non-signers, future work might investigate the iconicity of our stimulus items by providing non-signers with a set of ASL signs and their English gloss, and having the non-signers describe the relation between the visual features of the sign and its meaning (Klima & Bellugi, 1979). The items with high agreement among non-signers as to the relation between the sign's form and its referent would be considered iconic. We might expect that ASL items with high iconicity would be assigned high meaningfulness ratings and also be correctly guessed by non-signers; of the 14 ASL items assigned an average rating of 6 or higher by non-signers, eight were correctly guessed by more than one participant. However, Klima and Bellugi (1979) found that the meaning of ASL signs with high iconicity (as evaluated by the previously described procedure) were still unlikely to be correctly guessed by non-signers, even in a multiple choice test. Therefore, it is perhaps more likely that the more highly rated ASL items in our study were those that contained features that could be interpreted by non-signers as literal pantomime, whether they were guessed correctly or not. For example, common guesses for FORGET (average rating 6.4), which involves drawing a flat hand across the forehead, were “relief”, “phew”, and “sweaty”, all plausible definitions that could be assigned to the action of drawing a hand across the forehead. Future work could examine participant guesses to determine whether these highly rated signs were being interpreted as pantomimes or emblems, and use these guesses and the rating data to create a subset of ASL signs that are perceived as meaningful by non-signers before ASL training. A set of “meaningful” ASL signs and a set of “meaningless” ASL signs, as perceived by non-signers, could allow us to explore the impact that perceived meaningfulness, regardless of accuracy, has on how these stimuli are processed by the brain.

Emblems. We predicted that our group of non-signing participants would perceive emblems as highly meaningful. Consistent with this prediction, the average meaningfulness rating for this category was 6.2, significantly higher than all other stimulus categories. All but three of the emblem stimuli had average ratings of five or higher, indicating that participants perceived these stimuli as meaningful. The intended meaning of these stimuli were also guessed correctly by almost all participants.

Legal Pseudosigns. The average meaningfulness rating for the legal pseudosign category (3.1) was significantly lower than the average meaningfulness rating for the ASL category, and in contrast with the ratings obtained for ASL signs, legal pseudosigns consistently received average ratings of four or less, indicating that participants perceived these stimuli to be of ambiguous meaning or meaningless. Only seven legal pseudosign items received average meaningfulness ratings greater than four, indicating they were perceived as having more than ambiguous meaning. This was consistent with our predictions for legal pseudosigns, based on the fact that these stimuli were artificially fabricated to convey no real meaning even to fluent signers. However, we had expected that our participants would perceive these legal pseudosigns similarly to ASL signs, as they have no lexical knowledge of ASL and the legal pseudosigns conform to the same formational parameters as ASL. We must consider then, that there may be key differences in the features of the ASL signs that received high meaningfulness ratings and the features of items in the legal pseudosign category. It is possible that in creating these legal pseudosigns, Grosvald et al. (2012) selected base signs or phonological parameters that were the least recognizable or transparent. Careful examination of the stimulus items and further discussion with Grosvald et al. could help clarify this difference in the distribution of ratings between ASL signs and legal pseudosigns.

Illegal pseudosigns. The average meaningfulness rating for the illegal pseudosign category (2.8) was consistent with our predictions that participants would find these stimuli to be meaningless, and items in the illegal pseudosign category consistently received average ratings of four or less, indicating that participants perceived these stimuli to be of ambiguous meaning or meaningless. However, the average meaningfulness rating for the illegal pseudosign category was found to be significantly lower than the average meaningfulness ratings for both the ASL category and the legal pseudosign category, which was not expected. Although these illegal pseudosigns were based on ASL signs taken from the same curriculum as the items in the ASL sign category, adding a phonotactic violation seemed to make these items appear less meaningful to our participants. It is especially interesting that participants rated illegal pseudosigns as less meaningful than legal pseudosigns, even though they had no knowledge of ASL or its phonotactic parameters. This suggests that there is some inherent implausibility to a phonotactically illegal pseudosign that is detectable even to those naïve to signed language. This possibility is discussed in further detail in the following section.

It is worth noting that participants rated all illegal pseudosigns similarly, regardless of type of violation. While it was not necessarily expected that one violation would appear more ill-formed than another, it would be interesting to see whether this finding differs for future participants who are learning ASL, which could indicate that knowledge of ASL phonotactics has an influence on how different violations are perceived.

ASL classification

We predicted that our participants would be least likely to classify emblems items as ASL, since these stimuli were recognizable and commonly used by English speakers in North America. As expected, the items in the emblem category were significantly less likely than the other stimulus categories to be classified as ASL.

We predicted that our participants, as non-signers, would classify ASL items as ASL at chance level, since they had no knowledge of ASL and would simply be guessing. We also expected that participants would be equally likely to classify both types of pseudosigns as sign language, based on their lack of knowledge of the phonotactic rules of this language. However, we found that ASL, legal pseudosign, and illegal pseudosign items were more likely to be classified as ASL than not. Given that the nature of the task itself required participants to look for ASL-like items, it is possible that these results indicate a bias from our participants to classify items they felt certain were not ASL as ASL-NO, and all other items as ASL-YES. We also found that ASL and legal pseudosign items were equally likely to be classified as ASL, while illegal pseudosign items were significantly less likely than ASL and legal pseudosign items to be classified as ASL. Taken together with the differences in average meaningfulness ratings between stimulus groups, this indicates that the non-signers perceived illegal pseudosign items as different from ASL or legal pseudosign in some way, even though they were naïve to the phonotactic constraints on ASL.

There are a few possible explanations for this difference in perception and classification of illegal pseudosigns. Perhaps the most parsimonious is that participants were able to perceive differences from the native signer's performance of the illegal pseudosigns; the native signer reported having to concentrate more intensely when performing illegal pseudosign items, which contained unfamiliar handshapes and phoneme combinations, and this unnaturalness could have been conveyed by his facial expression or other body postures or movements. Although during filming we gave feedback on the native signer's neutral face, and re-filmed some stimuli where the face was deemed over-expressive, it is quite possible that there were enough perceptual cues on the signer's face to give some indication of the different categories of stimuli. In future work, it would also be interesting to have a non-signer learn and perform our stimuli from all categories, to examine whether meaningfulness ratings were affected by the stimulus model's knowledge of ASL phonotactics. Using a post-production effect to blur the signer's face could also remove that variable, or even having the signer wear something that blocks the eyes and eyebrows could also minimize the perceptual cues conveyed by the face.

Statistical learning and the ability to perceive and identify patterns in the environment has been argued to be the foundation of language acquisition both in infants and in adult second-language learners (Mattson, 2014; Saffran, 1996; Romberg & Saffran, 2010). By observing up to 600 videos, it is possible that our non-signing participants were able to implicitly or even explicitly identify patterns in the stimuli, allowing them to perceive the illegal pseudosigns as 'different' from ASL, legal pseudosign, or emblems. If this is the case, it is interesting that these patterns seemed to be used as clues that particular stimuli were less likely to be ASL, even though these participants were naïve to sign language and its phonotactic constraints. Although we tried to avoid constraint violations that were physically or perceptually implausible, if we consider languages and their constraints to evolve towards simplicity and away from forms that are difficult to produce or comprehend (Brighton, 2003; Schrementi & Gasser, 2010), it is possible that illegal pseudosigns, which violate these constraints, would intrinsically look less plausible than ASL or legal pseudosign items. This is supported by our finding that illegal pseudosign items were, on average, given lower meaningfulness ratings than legal pseudosign items.

Stimulus selection

Rating thresholds. As shown in Figure 8, applying our rating thresholds to select acceptable stimuli in each category resulted in a clear separation between predicted meaningful/predicted meaningless stimulus types for English-speaking non-signers. As seen in Figure 9, applying our rating thresholds resulted in no significant difference in the average meaningfulness ratings for the ASL, legal, and illegal pseudosign categories, while the average meaningfulness for the emblem category remained significantly higher than all other categories. Based on this successful separation of our stimulus categories, we now have a set of 40 exemplar stimulus items from each category for use in future studies. However, further investigation of the differences between items in different categories, as described above, may be necessary before these exemplar lists are finalized.

Classification criteria. Our non-signing participants were less likely to classify illegal pseudosigns as ASL than legal pseudosigns. From a psycho-physical point of view, it would be ideal if the categories of legal and illegal pseudosign were indistinguishable to those participants who are naïve to sign languages. As explained above, illegal pseudosigns may intrinsically look less plausible than legal pseudosigns by their very nature, since they violate constraints that are likely driven by simplicity and ease of production. It is also possible that participants are picking up on cues conveyed by our native signer's performance of the stimuli, but investigation of these particular factors will have to wait until future stimulus development. We could attempt to circumvent this issue with the stimuli we have already developed by eliminating illegal pseudosigns that have been rated as ASL by less than 50% of participants. However, this would eliminate exactly half of our illegal pseudosign items, leaving us with only 16 acceptable illegal pseudosign stimuli. In future studies, we will continue to examine this issue, but selecting a set of illegal pseudosigns that are indistinguishable from legal pseudosigns may not be a realistic goal.

Future directions

This study marks the first stage of exploring the validity of the proposed phonotactic constraints on ASL and the development of a robust set of visual-manual stimuli for use in future research. A clear limitation of this study is its small sample size (11), which lacks statistical power and limits our ability to interpret our findings or draw solid conclusions. To improve our ability to recruit participants, future work could develop an online version of this study, allowing participants to complete the study from anywhere in North America. In addition to more non-signing participants, recruiting a group of fluent signers to complete the study would improve our ability to investigate the phonotactic violations used to create illegal pseudosigns, and add robustness to the rating data used to select exemplar stimuli. Additional criteria would be added for each category to accommodate the differences in predicted meaningfulness of the stimulus items depending on sign language experience. We would expect that overall, basic ASL items would be highly meaningful and easily identifiable as ASL by fluent signers; we would expect emblems (which are associated with North American culture) to be highly meaningful to fluent signers as well but less likely to be mistaken for ASL. We would expect both legal and illegal pseudosigns to be meaningless to fluent signers, but that legal pseudosigns would be more likely to be mistaken for ASL.

Once we have established a set of illegal pseudosign stimuli that fulfill our meaningful/meaningless criteria with both non-signers and fluent signers, further studies could continue to investigate the validity of the proposed constraints and identified violations of these constraints. Firstly, developing additional pseudosign stimuli is recommended, to balance the (currently unequal) number of items in each violation subcategory. We could then begin to validate the proposed constraints and violations by having a group of fluent signers sort pseudosigns into legal/illegal (or well-formed/ill-formed) categories. Another method of ensuring that the identified violations are on target would be to train a group of fluent signers on the proposed constraints on ASL, and then ask them to identify which constraint each illegal pseudosign appears to violate. These methods would validate the proposed constraints on ASL by verifying that pseudosigns that violate these constraints are perceived as illegal or ill-formed by fluent signers, and by ensuring that each pseudosign clearly violates a proposed constraint without inadvertently creating other unspecified violations.

The current study did not investigate all proposed constraints on ASL, and did not include all possible violations of the constraints that were investigated. Future studies could explore these and other constraints in more detail, with further collaboration from native signers and sign language linguists. For example, future research could examine how violations of the Symmetry Condition using location or movement rather than handshape affect how these particular illegal pseudosigns are perceived. Each proposed constraint included in this study, along with the constraints not included in this study, could be investigated and validated individually.

Conclusion

Using a perceptual task and strict selection criteria, we have developed a set of visual-manual stimuli that vary not only in structure, phonotactic permissibility, and lexicality, but in how they are perceived by English speaking non-signers. These stimuli are to be used in future brain imaging studies of sign language learning. By developing a novel set of illegal pseudosigns based on some of the proposed phonotactic constraints on

ASL, this study has taken the first steps towards exploring these proposed constraints. ASL items were rated by non-signing participants across the entire range of meaningfulness, although meaningfulness rating was not necessarily indicative of the participants' ability to correctly guess the meaning of an ASL item. Further exploration of the influence of iconicity or recognizable features of ASL signs on meaningfulness ratings is warranted. Our non-signing participants perceived both legal and illegal pseudosigns as generally meaningless, but on average gave lower meaningfulness ratings to illegal pseudosigns than legal pseudosigns, and were less likely to rate illegal pseudosigns than legal pseudosigns as ASL. This indicates that non-signers perceived illegal pseudosign items as different from ASL or legal pseudosign in some way, a surprising finding which may indicate that our stimuli need to be refined, or that illegal pseudosigns are intrinsically implausible by the nature of their phonotactic violations. Future studies will aim to increase participant numbers and recruit a group of fluent signers to complete the study as well, which will further the development a robust set of gesture-based stimuli that vary in structure, well-formedness, and perceived meaningfulness dependent on sign language experience.

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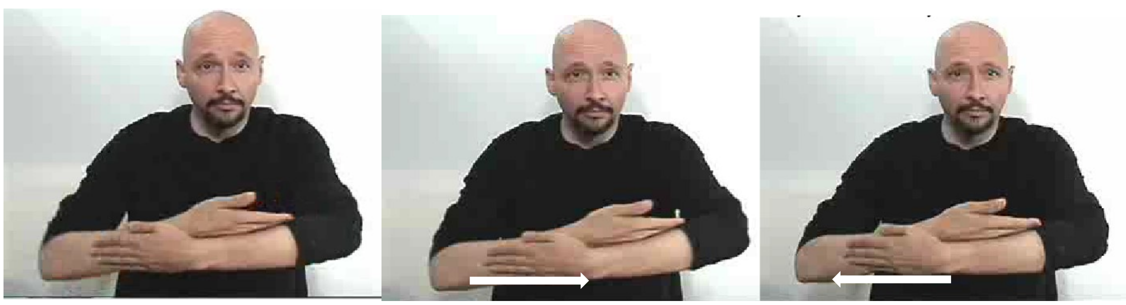
APPENDIX A   Glossary of ASL Signs

All material courtesy of Dr. Bill Vicars and www.lifeprint.com

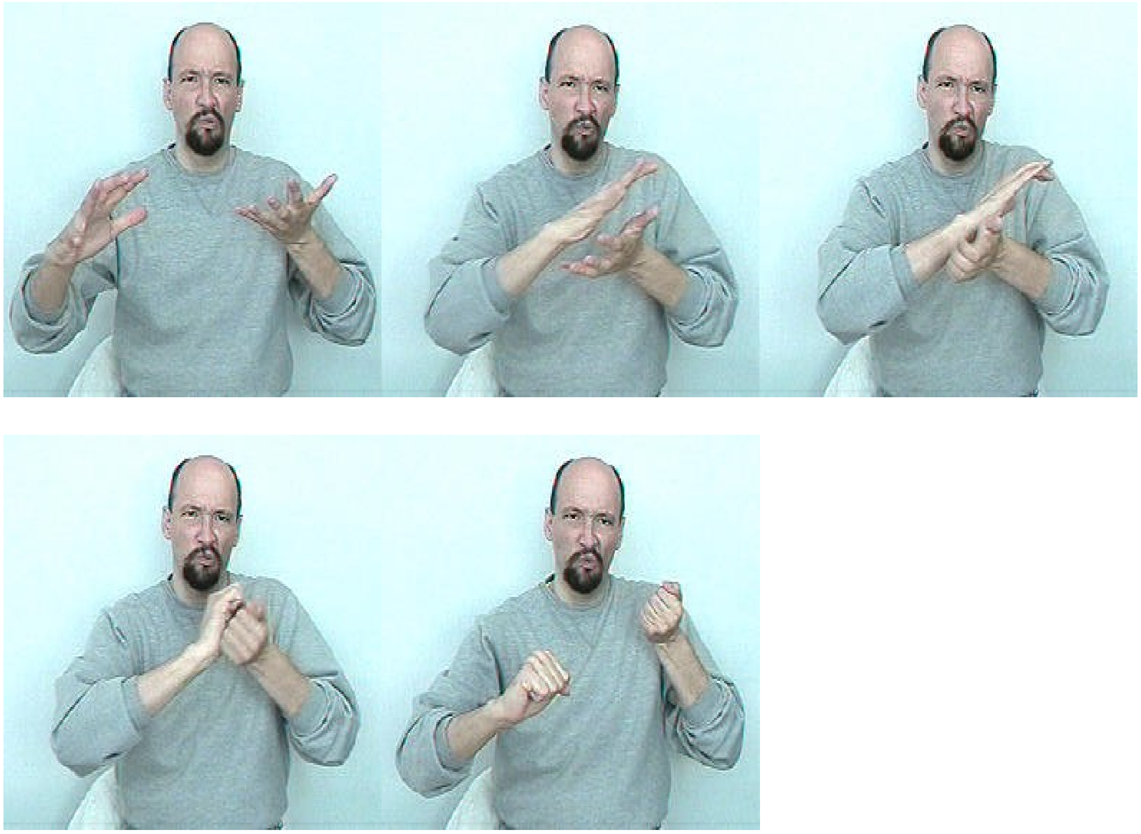
ARRIVE

BABY



BELIEVE

DESTROY



FAMILY

FRIENDLY

FORGET

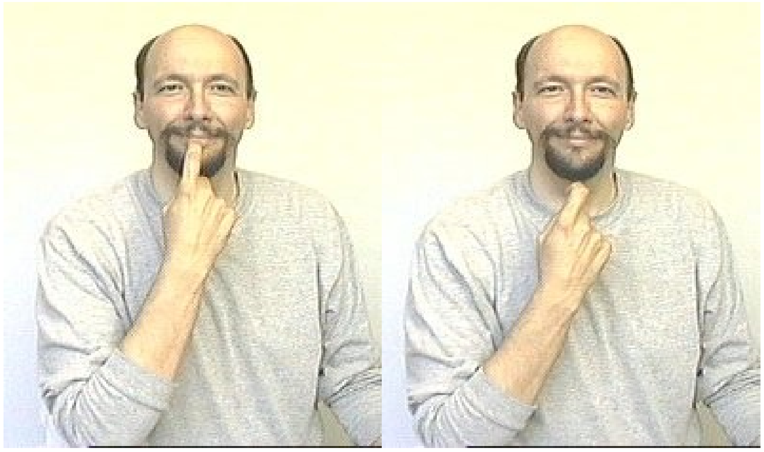
GIVE-YOU

HIGH SCHOOL

LUNCH

MOTHER

RED



REMEMBER

SWEET

TEACHER

YELLOW

APPENDIX B Eligibility Screening Form

Meaningfulness of Hand Gestures

Research Eligibility Screening Form

In order to determine whether you may participate in this research study, please answer all questions honestly and to the best of your ability.

Your age: _____________ Are you: ☐ right or ☐ left handed?

	YES	NO
Is English your first language?	☐	☐
If no, what is your first language? :		
Do you have any neurological conditions?	☐	☐
If yes, please describe:		
Do you have any conditions that may affect your emotions or mood? (including claustrophobia)	☐	☐
If yes, please describe:		
Do you have any other medical conditions that may affect your performance or alertness?	☐	☐
If yes, please describe:		
Are you taking any medications?	☐	☐
If yes, please describe:		

Do you wear: Glasses ☐ or Contact Lenses ☐?

	YES	NO
Do you have any other vision problems?	☐	☐
If yes, please describe:		
Do you have any hearing impairment?	☐	☐
If yes, please describe:		
Have you used sign language before?	☐	☐

If "yes":

When did you first begin to use sign language?

When did you last use sign language?

What type of sign language have you used? (ex: ASL, LSQ, MSL, etc.)

Check off all that apply

I have used finger spelling ☐

I have used signs ☐

APPENDIX C Electronic Supplements

Example videos of illegal pseudosigns can be found with this thesis manuscript in the Dalhousie University DalSpace archives (www.dalspace.library.dal.ca).

A) Finger Position Constraint violation type 1: The ASL sign COLLEGE performed using the phonotactically illegal handshape *7-index bent*.

B) Finger Position Constraint violation type 2: The ASL sign GIRL performed using the legal handshape *F*, with unselected fingers touching the face.

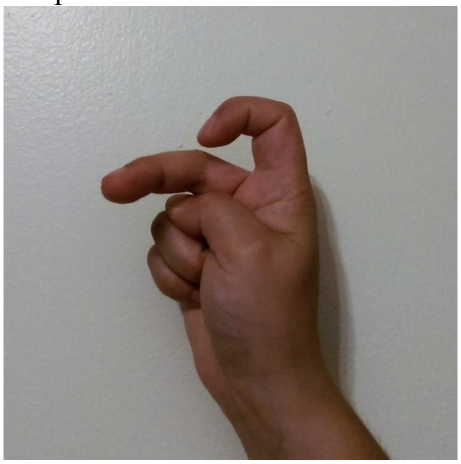
C) Syllable-level Hand Configuration Constraint violation: The ASL sign COOK, which contains a change in orientation, performed with a handshape change (from *flat-B* to *L*).

D) Syllable Timing Constraint violation: The ASL sign HUNGRY performed with a change in orientation (from palm up to palm down) in the middle of the path movement down the torso.

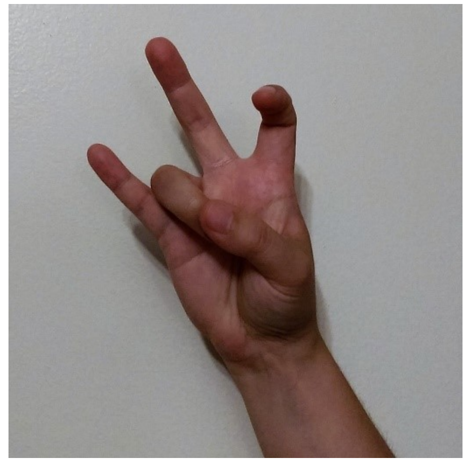
E) Symmetry Condition violation: The ASL sign FAMILY performed with the mismatched handshapes *F* and *C*.

APPENDIX D   Illegal Handshapes

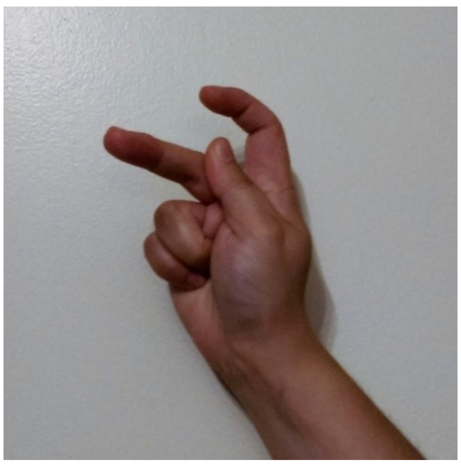
X-middle open



7-index bent



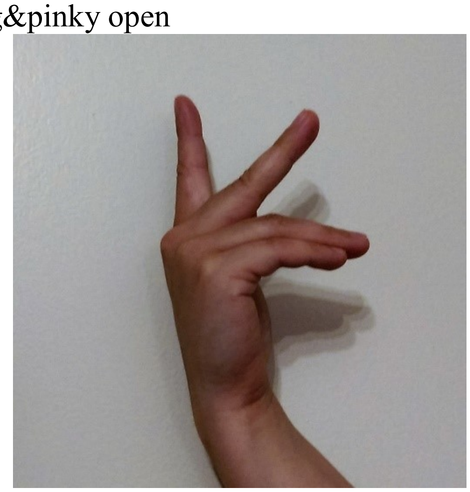
K-index bent



I-middle open

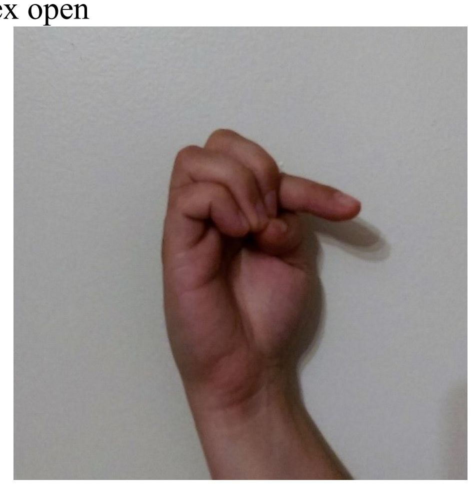
U-ring open

K-ring&pinky open



3-ring&pinky open

E-index open



T-pinky bent

Ring open