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REPETITION REDUCTION ACROSS THE LEXICON OF AMERICAN SIGN LANGUAGE

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ABSTRACT

In this dissertation, I examine how fingerspelled words and core signs in American Sign Language (ASL) reduce as they are repeated. This investigation is motivated by theories of language production that posit that reduction may be shaped not only by reducing articulatory effort, but also by accommodation to an interlocutor's understanding of the linguistic signal. However, the distinct articulatory constraints of different linguistic systems, like those of fingerspelling and core signs in ASL, may allow for different possibilities to reduce articulatory effort. This, in turn may have a distinct impact on an interlocutor's perception of reduced forms. I first focus on reduction patterns in fingerspelling, using a corpus of fingerspelled words to test not only how gradient reduction in word duration proceeds as fingerspelled words are repeated, but also whether this is accompanied by the deletion of fingerspelled letters. The analysis shows fingerspelling reducing considerably, across multiple mentions, with letter deletions increasing with repetition. In my second analysis, I examine how core signs in ASL reduce across repeated mentions, with results showing not only duration reduction across multiple mentions, but also other types of reduction, including the deletion of movements and the centralization of the location of signs articulated on the body. I then directly compare these two systems, using fingerspelled words and signs from the same corpus to determine whether reduction patterns differ between the two categories. The findings from the language production analysis show strikingly similar patterns in duration reduction between fingerspelling and core signs. Finally, I compare how reduction in each of these systems impacts the perception of reduced forms. Contrasting with the results from the analyses of language production, findings from the perception experiment suggest an unequal impact of reduction in the fingerspelling and core sign systems on how signers of ASL perceive reduction. Together, this adds detail to our understanding of how different articulatory systems influence reduction, as well as shows a disconnect between patterns in the production and perception of reduced forms.

CHAPTER 1

INTRODUCTION

Variation in language is commonplace. However, patterns in this variation from across linguistic modalities can provide clues about the constraints that shape how language is produced. One process that provides particular insight into this is that of *reduction*. Through much of the history of scholarship on language production, reduction has been associated not only with ways that people change the way they produce language to be more efficient but also ways that language producers do, and do not, take their audience into account as they communicate. By using an investigation of reduction processes in two linguistic systems within the lexicon of American Sign Language (ASL), this dissertation asks how the structural and articulatory constraints inherent to different linguistic systems contribute to predictable variation in language production. It does this by analyzing reduction processes in fingerspelling and core signs in ASL, focusing not only on their differences but also their similarities. This comparison is then used to determine what the properties of reduction processes in these systems can tell us about the mechanisms influencing the way that language is produced. This approach will use a particular context in which reduction commonly occurs, that of the repetition of a form within discourse, to probe these reduction processes in ASL.

Reduction is a term that refers to phenomena in which there is a decrease in the articulated material and prominence of a form. The term has been applied to instances of shortening of a word or sign, segment deletion, and other types of prominence loss. Empirical findings for spoken languages have shown that an increase in a word's predictability, part of which is determined by whether it has been mentioned before, corresponds to increased reduction (Fowler and Housum, 1987; Baker and Bradlow, 2009; Bell et al., 2009; Aylett and Turk, 2004; Kahn and Arnold, 2015; Turnbull, 2015; Vajrabhaya and Kapatsinski, 2011). Increased predictability provides a context in which language producers can be more efficient in production, minimizing articulatory effort and resulting in reduction. This reduction corresponds in spoken languages to a decrease in the intelligibility of reduced forms when they are presented outside of their context of increased predictability (Fisher and Tokura, 1995; Fowler and Housum, 1987; Hunnicutt, 1985; Samuel and Troicki, 1998).

As a result, some linguistic theories posit that reduction processes are shaped, at least in part, by a language producer balancing the understanding of their interlocutor, reducing in ways that retain comprehension based on information available in the discourse context (Fowler and Housum, 1987; Aylett and Turk, 2004; Jurafsky et al., 2001). This connection between reduction, the contexts in which forms reduce, and the effect of reduction on intelligibility has been used in support of theories positing the mechanisms behind reduction, with mixed support for theories that do and do not argue for language producers taking their interlocutors into account as they reduce (Turnbull, 2015). A more complete understanding of language production theories like these requires cross-modal support, as differing articulators as well as perceptual channels can impact not only what constitutes efficiency in language production, but also how these differences are perceived. Here, this is approached through reduction processes in ASL, with this investigation appealing not only to the properties of the manual-visual modality, but also to the differing linguistic structures present within ASL itself.

Although research on sign languages has addressed the phenomena of reduction broadly, less attention has been afforded to how reduction processes occur in ASL in the context of higher predictability, such as under the context of increased discourse mentions, or how this type of reduction impacts how interlocutors perceive reduced forms. ASL fingerspelling and core signs have unique articulatory and structural properties that, when interacting with pressures from language production and perception, may result in patterns of reduction that are distinct. The pressures that have been theorized to shape reduction are hypothesized to interact in different ways with the articulatory constraints of each system, providing a more detailed picture of reduction processes in sign languages as well as the forces that shape them. This investigation ties together previous work on reduction in sign languages, showing different reduction processes occurring across the lexicon, with theoretical research positing the mechanisms behind reduction. By studying reduction in these contexts, looking at patterns in both core signs and fingerspelling in ASL, the dissertation will probe how structural and articulatory differences in the ASL lexicon contribute to differences in reduction processes and how this might impact the perception of these forms, providing further multi-modal insights into theories of language production.

1.1 Repetition reduction and theories of language production

Repetition reduction is a phenomenon where repeated forms in a discourse exhibit reduction, bringing together both the contextual predictability that arises within communication and the changes that result from the pressures that act on articulation. By focusing on reduction processes within ASL, we can investigate the various forces that shape language production across linguistic modalities. However, framing the reasons why repetition reduction can contribute to our understanding of the mechanisms behind language production relies on previous scholarship not only on reduction in sign languages, but also on a clearly delineated definition of reduction and an explanation of its connection to broader theories.

1.1.1 Defining reduction

This investigation is concerned with reduction phenomena within ASL, both in language production and perception. At its broadest, cross-modally, *reduction* encompasses linguistic processes which involve the minimization of material or loss of prominence of a linguistic unit. This includes processes ranging between the full deletion of a unit to partial, gradient changes in production across linguistic domains. Reduction processes occur across multiple levels of linguistic structure, encompassing the deletion of full syntactic units to finer-grained phonetic processes. However, for the purposes of this dissertation, the types of reduction that are considered will be limited to reduction within the phonological and phonetic domains and, unless otherwise specified, *reduction*, as used in the present work, will exclude anything above the level of phonological processes.

Reduction processes are set in contrast to processes of hyperarticulation, in which forms are articulated clearly and distinctly (Johnson et al., 1993). Contrasting with hyperarticulation, many reduction processes have been argued to occur due to language producers expending less effort in articulation (Lindblom, 1990), resulting in forms not reaching their more clearly articulated targets. From a gestural standpoint, reduction has been considered to result, in part, from decreased magnitude of the gestures made by the articulators in production (Browman et al., 1990). Although what constitutes less effort in articulation is difficult to define, this has been assumed to be due to reduction involving less energy than the increased precision and size of gestures involved in hyperarticulating forms.

Although this formulation of reduction is applicable cross-modally, the realization of reduction across different modalities is modulated by the properties of the linguistic signal and the articulators. In speech, reduction processes are typically considered to encompass the acoustic processes of segmental deletion (Ernestus, 2014) or vowel shortening, word duration, changes in F0, and the centralization of vowels (Turnbull, 2015; Clopper and Turnbull, 2018). In contrast, reduction processes in sign languages, elaborated in §1.2.2, only partially overlap with those in speech as they share some, but not all temporal and articulatory characteristics with spoken words. These include not only reduction in duration, but also reduction along the multiple articulatory parameters that form ASL signs.

1.1.2 Reduction and predictability

Repetition reduction processes are tied to models of language production that posit several mechanisms as driving these processes. These models of language production have emerged as explanations for empirical findings from studies, largely on spoken languages, showing that an increase in a word's predictability, part of which is determined by whether it has been previously mentioned, corresponds to an increase in reduction. For spoken languages, this relationship between reduction and predictability has been probed from a number of different angles, including probability-based measures and the newness of a word within a discourse. Under the probability-based measures, words with higher probability had shorter duration. This was found in studies looking at cloze probability (Liu et al., 1997), as well as frequency and the joint probability, conditional probability, and the mutual information of a word with the previous or following words (Jurafsky et al., 2001; Aylett and Turk, 2004; Bell et al., 2009). Other reduction effects associated with the probability of a word also include a decrease in vowel duration, as well as devoicing and segment deletion (Coetzee and Kawahara, 2013; Turnbull, 2015). Studies have also examined how the newness of a word to a discourse influences word duration, arguing that as the redundancy of a token increases as it is repeated, it becomes more predictable.

This research is built on early studies, such as that of Fowler and Housum (1987), which found repeated mentions of a word to be reduced in duration in relation to the duration of their first mentions. In Fowler and Housum (1987), initial and repeated tokens from a radio monologue were analyzed for duration, F0, and amplitude. Repeated words in the discourse were distinguished by their shortened duration and reduced amplitude. Shortened, more redundant words were also found to be less intelligible when presented in isolation.

A series of studies on repetition reduction following this confirmed these early findings (Pluymaekers et al., 2005; Bell et al., 2009; Lam and Watson, 2010; Jacobs et al., 2015; Kahn and Arnold, 2015; Turnbull, 2015). For example, Bell et al. (2009) conducted a study using data from *The Switchboard Corpus* to test how duration was influenced by frequency, conditional probability, and repetition. They found that the effect of repetition reduction remains even when accounting for reduction effects that are attributable to word frequency and to the conditional probability of a word, showing that repetition makes a contribution to word reduction separate from that of other probability based-effects that contribute to a word's predictability. Within this study, repeated words reduced, on average, to 4.5% less of the duration of their first mention. While this repetition effect has been examined most frequently for English, research on other languages[1] has shown a similar effect. This effect can also been seen in across age ranges, with repetition reduction effects being reported as early as age two (Tendera et al., 2022), demonstrating its pervasiveness in communication.

1.1.3 Theories of reduction

These empirical findings are tied to theories of language production that attribute repetition and other probability-based effects on duration, such as conditional probability and frequency, to several different causes[2]. Fowler and Housum (1987)'s early results on repetition reduction framed reduction as being related to a word's givenness within the discourse context. Repeated, given tokens were argued to show reduction in duration because they have support within the discourse context and, as a result, can be articulated more efficiently without a loss in comprehension. Subsequent theoretical models intended to explain repetition reduction effects, as well as predictability effects more generally, expand on this result and explanation, positing different mechanisms to explain reduction, often varying in the role the interlocutor plays in this process.

The first set of these theories, like in Fowler and Housum (1987)'s early explanation, rely on the contextual information that is available to an interlocutor to explain why words reduce, although they differ in the role this information plays in the realization of differences in

1. See Wiener et al. (2012) for a study on repetition reduction in Mandarin, Rodriguez-Cuadrado et al. (2018) for Spanish, Vajrabhaya and Kapatsinski (2011) on Thai, Kaland and Himmelmann (2020) for Papuan Malay, and Hoetjes et al. (2014) for signs in the Sign Language of the Netherlands (NGT).

2. This discussion should be taken with the caveat that reduction itself is not necessarily a unified phenomena, as different patterns of reduction in spoken languages have been shown to arise under distinct conditions. For example, Turnbull (2017) found that while some measures of predictability correspond to a reduction effect in F0, this does not extend to increased predictability as a result of increased discourse mention, which did not exhibit F0 reduction.

articulation. Here I will term these *interlocutor-oriented* theories[3]. The Probabilistic Reduction Hypothesis of Jurafsky et al. (2001), one theory within this category, posits that words are reduced when they have a higher probability because higher probability words provide more signal-independent information about their identity. Because other contextual factors within the discourse already provide some information about what is going to be articulated, this allows the producer to expend less energy in clearly articulating each linguistic item. Another similar but distinct theory, the Smooth Signal Redundancy Hypothesis (Aylett and Turk, 2004; Turk, 2010), argues that in the process of language production speakers try to maintain a smooth linguistic signal in which a consistent amount of information is available to their interlocutor. This means that as redundancy increases, increasing the information content available to the interlocutor indicating a word's identity, the effort expended in articulation decreases, allowing speakers to maintain a constant level of information in articulation.

Contextual information assists listeners in recognizing reduced variants, in contrast to unreduced variants (Brouwer et al., 2013), indicating that interlocutors rely on this context to understand reduced forms. Framed in terms of repetition reduction, this class of explanations of reduction predicts that, in an effort to maintain a consistent level of comprehensibility, reduction is mediated by how much a word can reduce while remaining intelligible[4] given information available from whether or not it has already been given in the discourse.

In an explanation that attributes reduction to a different mechanism, other accounts like that of Bell et al. (2009), argue that word level activation for the language producer, which is determined by a word's predictability, drives articulatory planning. Within this

3. In much of the scholarship on theories explaining reduction, this class of theories is termed "listener-oriented" (as in Turnbull (2015); Clopper and Turnbull (2018)). However, here I opt for the term *interlocutor*, as this more appropriately encompasses multiple modalities.

4. This should be taken with the caveat that reduction in some contexts can facilitate comprehension, such as in cases where reduction within words with high lexical frequency supports their recognition (see Mitterer and Russell (2013)).

theory, words that are more redundant and predictable are retrieved more quickly, leading to quicker articulation. Here, these accounts will be termed *producer-oriented*[5]. In contrast to the interlocutor oriented theories of word reduction, reduction is not mediated by speaker's accommodations for their interlocutor, instead arising only due to mechanisms internal to the speaker. This makes the prediction that only factors that influence a word's activation will influence patterns in reduction, rather than the intelligibility of a form.

Yet another category of theoretical explanations for reduction effects has been proposed, built on exemplar-based frameworks (Pierrehumbert, 2001), where reduction processes are seen as the result of passive evolutionary processes. Within these frameworks, reduction processes that accompany predictability effects occur due to passive processes that accumulate over generations of language users. Easily understood words, like high frequency, albeit reduced, words or difficult to understand words that are acoustically prominent are preferred for retention across generations of language use, while unclear language use is dispreferred and falls out of use (Silverman, 2012). More predictable words, while reduced, are easier to understand due to their predictability. Their reduced forms are then added to their respective exemplar clouds and, due to their high frequency, are produced more, resulting in their retention over time. As discussed in Turnbull (2015), this set of theories does not easily account for reduction effects that occur as a result of increased discourse predictability, although it accounts for lexical predictability effects connected to word frequency and neighborhood density. For this reason, they will not be the focus of the present investigation, but deserve mention, as they often best account for other predictability related reduction effects (Turnbull, 2015; Clopper and Turnbull, 2018). Instead, the listener and producer oriented theories will provide the primary backdrop to the current analysis.

In determining which of these theories best explain reduction effects, there has been mixed evidence in support of the interlocutor and producer oriented theories of reduction.

5. This terminology will be used here instead of the more commonly used "talker oriented" (as used in Turnbull (2015); Clopper and Turnbull (2018)).

There is evidence that people take their interlocutors into account while communicating. For example people modify their speech to be clearer when speaking with non-native speakers of their language (Uther et al., 2007) and infants (Cristià, 2010; Kuhl et al., 1997). In addition, speakers lengthen their words depending on whether their listeners are paying attention or are distracted (Rosa et al., 2015), as well as adjust the extent to which they modulate production of a form based on its predictability depending on whether they can see that they have an interlocutor.

However, there is contrasting evidence indicating that language users might not always take their interlocutors into account. For example, in a task manipulating whether a speaker knew that their audience had or had not changed when producing repeated references during a map task, Bard et al. (2000) showed that reduction still occurred in repeated mentions with an interlocutor who had not been present previously. This occurred even though repeated mentions were less intelligible to their new interlocutor, who lacked previous context. Providing additional support for the producer-oriented perspective, Baese-Berk and Goldrick (2009) found that speakers modulate their speech when hyperarticulating words with minimal pairs regardless of listener context, hence not changing their speech just to avoid listener confusion. This mixed support then leaves open questions about ways people may or may not take their interlocutor into account in language production.

1.1.4 The 'given vs. new' distinction

When accounting for the phenomenon of repetition reduction, both interlocutor and producer oriented theories rely, at least in part, on the *givenness* of a form within a discourse to explain reduction effects.The effect of repetition within these theories has typically been treated as binary. Whether a word was already given within the discourse, regardless of the number of times it had appeared, was treated as the primary factor in determining reduction. However, this question, whether the repetition effect is a binary or a scalar one, was addressed in Bell et al. (2009). While Bell et al. (2009) found a general effect of repetition on duration, the difference in the effect of the third and subsequent mentions on repetition, when compared to the effect of the second mention, was not significant. This supports an argument that the only relevant effect word repetition contributes to the discourse context draws from whether it is already given in the discourse, regardless of the number of times it has been mentioned. This argument was supported by further research on repetition reduction on additional languages, like in Vajrabhaya and Kapatsinski (2011)'s study of Thai, which found a robust first-mention lengthening effect, but which failed to find an effect of subsequent repetitions on increased reduction. From these findings, the contribution of word mention in models of language production could be framed as predicted entirely by whether a word is 'given' or 'new' in the discourse.

This conceptualization of the contribution of the information provided in a word's repetition fits within frameworks of common ground and their impact on communication. Information that has not yet been mentioned, and is thus not yet part of the common ground, is considered *new* (Clark, 1977; Kess, 1992). In contrast, information that has become part of the common ground within a particular discourse is termed *given* (Clark, 1977, 1992). Used commonly outside of the realm of phonetic and phonological variation, this framework has also been used to explain other changes that occur depending on the given or new status of a particular discourse referent, encompassing syntactic reduction, including phrase length and complexity (Jaeger and Levy, 2006) or pronoun versus full noun phrase use (Gundel et al., 1993). This framing of a referent's contribution to the discourse context is a binary one, where *given* and *new* are the relevant categories in predicting communicative changes in the form of a referent.

While repetition has been treated as a binary effect, research has also addressed whether the time between repetitions influences reduction, with findings showing conflicting results. The early study of Fowler and Housum (1987) predicted that when a word was more temporally distant from its previous mention it may reduce less, as the word may be remembered less well, decreasing its givenness within the discourse. Contrary to their predictions, when looking at the effect of distance between mentions, measured in terms of number of words, they found no effect of distance on duration. In contrast, in a later study examining differences in reduction effects between native and non-native speakers of Spanish, results showed that repetition reduction effects were stronger, with a larger decrease in duration, when there was a shorter temporal distance between mentions (Rodriguez-Cuadrado et al., 2018). This effect was attributed to increased priming for words that were temporally closer to one another, suggesting that word activation is higher for temporally closer mentions.

This reduction effect will be tested here through the lens of repetition reduction in ASL for both fingerspelling and signs. This is not only to provide additional insight into the mixed findings on the effect of the distance between mentions and the binary nature of the repeated mention effect, but also to further situate theories of language production within evidence from multiple modalities.

1.1.5 Common ground, audience, and communicative pressure

Although evidence for the effect of the role of an interlocutor and the discourse status of a referent on reduction have received mixed empirical support in research on phonetic variation in speech production, other aspects of communication have been shown to be sensitive to audience and the status of a referent. A referent's status within the common ground of a conversation, which constitutes the information shared between interlocutors within a conversation (Gerwing and Bavelas, 2004) influences linguistic and paralinguistic communication, like that of gesture.

Expanding outside of the realm of linguistic form, the role of a referent's contribution to the common ground is also evident in non-linguistic, gestural communication. The information status of a referent can be seen in people's co-speech gestures articulated when discussing given versus new referents. When gesturing about referents that are already given within the common ground, gestures tend to be smaller and less precise (Gerwing and Bavelas, 2004; Holler and Stevens, 2007). This is accompanied by a shortened duration of the articulated gesture as repetitions increase (Masson-Carro et al., 2016; Holler et al., 2022). People have also been shown to be sensitive to their audience in gesturing about given information, even when this is not clear in their speech. In instances in which speakers do not change their speech, maintaining the same number of referents regardless of audience knowledge, people do modulate their accompanying gestures, indicating sensitivity to audience status in communication, but not necessarily in oral language use (Hilliard and Cook, 2016). This cross-modal influence of redundant information in the discourse context on articulation, and its interaction with audience, points to the need to continue probing these questions across modalities.

1.2 Reduction in American Sign Language

This dissertation uses the context of increased predictability offered by repetition to examine distinct reduction processes that occur across the ASL lexicon, focusing on the fingerspelling and core sign systems. Reduction processes are predicted to occur due to similar pressures acting on different linguistic systems within the lexicon. The impetus for examining repetition reduction in ASL stems from the properties of the different parts of the ASL lexicon, with the distinct structural and articulatory systems in core signs pointing to different ways that similar pressure on linguistic systems can result in differences in production and perception. To build appropriate hypotheses about how processes of reduction will occur in the context of repetition, this investigation must be informed by wider scholarship on the realization of reduction in sign languages.

1.2.1 Scope of this research within ASL

Reduction processes have been studied for sign languages from a number of different angles in language production, with a smaller amount of attention given to the perception of reduced forms. Although scholarship on predictability-based reduction often leaves out processes that occur as a result of changes conditioned by the phonological or prosodic context (Clopper and Turnbull, 2018), such as stress, prosodic structure, and surrounding phonological context, this investigation will rely on findings from previous work looking into reduction processes more broadly. This will allow the current project to narrow in on what kinds of processes might occur in the context of the increased predictability offered by repetition. Because they are more frequently repeated in discourse, this work focuses on repetition reduction in fingerspelling and core signs in ASL, to the exclusion of classifier forms, which comprise the remainder of the ASL lexicon but are repeated exactly at a lower frequency.

In studies of reduction as it pertains to sign languages, patterns of reduction in fingerspelling systems and in core signs have been examined separately. In distinguishing between and comparing these categories, I follow the model of the lexicon of ASL adapted from Brentari and Padden (2001), where the lexicon is divided into two components, the native lexicon component and the non-native lexicon component, whose overlap comprises the core lexicon. The core lexicon consists of signs that are highly standardized in their form. Within a core sign, any change in hand configuration is limited to the same set of selected fingers. Although core signs can be articulated with a wide range of different movements and locations, they are also limited in the number of distinct sequential movements they can contain, with core signs limited to two movements (Brentari, 1998).

Under this model of the lexicon, fingerspelled words fall within the non-native lexicon and have their own set of distinct structural and articulatory properties. Fingerspelled words consist of the sequential articulation in the neutral signing space of fingerspelled letters, representing characters from the English alphabet. These fingerspelled letters are articulated through a distinct set of handshapes, as well as a limited set of palm orientations and movements (Keane and Brentari, 2016). The sequential nature of fingerspelling segments, as well as its lack of variation along the dimensions of movement and location, set it apart from core signs.

1.2.2 Reduction processes in fingerspelling and core signs

The different properties of each part of the lexicon lend themselves to distinct processes of reduction, as both their relationships to sequentiality and the parameters involved in their articulation offer different possibilities for reduction. These are reflected in the reduction processes that have been identified in previous scholarship, within and outside of the context of repetition, and inform the predictions of the current work.

Research on reduction in fingerspelling in ASL has demonstrated a set of reduction patterns that overlap, but are not completely shared, with those of core signs. As fingerspelled words, like signs, include a temporal dimension, research on reduction in fingerspelling has shown these words to undergo considerable reduction, with their duration decreasing not only between first mentions and the following repetitions, but also continuing as words are subsequently repeated (Wager, 2012; Lepic, 2019; Thumann, 2012). Previous studies on fingerspelling, while using relatively small corpora, suggest that fingerspelling shows a pattern in reduction that is distinct from that in speech, wherein reduction continues after second mentions. These findings suggest that the given-new distinction is inadequate to predict patterns of production within this system and point to the need for further study into the exact trajectory of repetition reduction across mentions of fingerspelled words.

Properties of the fingerspelling system, as well as the ways that individual parts of this undergo reduction, provide some insight into why this might be the case. For example, as fingerspelling involves the rapid, sequential articulation of handshape segments, requiring considerable articulatory effort, there is substantial coarticulation between fingerspelled letters, which continues to increase up to a word's third mention (Brentari, 1998). This increased coarticulation between handshapes, as well as loss of fingerspelled letters within each word that occurs in the context of repetition (Wager, 2012; Brentari, 1998), also suggests that the articulatory complexity of articulating these handshapes quickly in sequence provides allowances for considerable changes in form that might contribute to the patterns seen in duration reduction.

Core signs, due to their temporal properties, as well as greater number of parameters, have been shown to undergo reduction processes in a number of ways that are distinct from fingerspelling. The location parameter for signs provides a dimension along which they can undergo reduction, wherein they can undershoot or not reach their citation location. This has been noted along many of the locations at which signs are articulated, including in neutral space as well as signs articulated on and around the head. Core signs signed in faster signing rates are more likely to be lowered, or undershoot their location, if they are higher in the signing space, while signs articulated lower in the signing space are more likely to raise in their location at faster signing rates (Mauk, 2003). Signs articulated at or near the head tend to lower at faster signing rates (Tyrone and Mauk, 2010) and in casual signing (Lucas et al., 2002; Liddell and Johnson, 1989), as well as more generally shift their location in a central direction in the signing space (Tyrone and Mauk, 2012). In another form of undershoot, Parkensonian signers undershoot location through loss of contact with the body (Brentari and Poizner, 1994; Brentari et al., 1995; Poizner et al., 2000).

Reduction also occurs along the parameter of handshape, and has been observed in a number of contexts. Handshape reduction has been documented in cases where handshapes undershoot their articulatory targets at higher signing rates (Mauk, 2003). It has also been noted in the signing of Parkensonian signers, whose articulation of signs exhibits the laxing of handshapes, blending of adjacent segments, and loss of phonetic contrasts (Loew et al., 1995; Brentari et al., 1995; Tyrone et al., 1999; Poizner et al., 2000). Handshape reduction, while

Table 1.1: Summary of reduction effects documented for American Sign Language

Category	Measure	Effect
Fingerspelling	Duration	Reduction in duration across 2+ mentions
	Letter deletion	Increased letter deletion under repetition
	Coarticulation	Increased coarticulation of letters under repetition
Core signs	Duration	Reduced duration when repeated
	Location	Centralization and lowering at faster signing rates
	Location	Loss of body contact for Parkinsonian signers
	Handshape	Undershoot in articulation at faster signing rates
	Handshape	Loss of contrasts, blending, and laxing for Parkinsonian signers

not the focus of the present investigation, shows another dimension along which articulatory pressures shape variation in the articulation of signs.

Core signs, like spoken words and fingerspelling, also have a temporal dimension which exhibits reduction. This reduction, while a gradient measure, can encompass deletion, undershoot in location, and faster signing. For Swedish Sign Language, it was found that the global frequency of a sign correlated with its duration, with more frequent signs tending to be shorter (Börstell et al., 2016). Repeated signs have been shown to exhibit duration reduction in the context of repetition (Hoetjes et al. 2014 for the Sign Language of the Netherlands (NGT) and Grosjean (1979) for ASL). However, it remains to be tested how the number of repetitions of a sign impacts its duration (ie. whether the decrease in duration is only significant between first and second mentions or continues past this). A summary of reduction processes in fingerspelling and signs can be found in Table 1.1.

As the present research seeks to inform theories of language production that also posit a connection between patterns in reduction and how reduced forms are perceived, an improved understanding of how reduced forms are perceived in sign languages can inform our understanding of how both perception and production shape reduction processes. While little work has specifically addressed the intelligibility of reduced fingerspelled words and core signs, related work has looked at the influence of repetition reduction on the perceived precision of signing, as well as how the rate of presentation of signing and fingerspelling impacts comprehension. Work examining the perceived precision of reduced forms, comparing them to their unreduced variants, has proved inconclusive, with Hoetjes et al. (2014) finding that native signers of the Sign Language of the Netherlands (NGT) perceive no significant difference between repeated forms and their first mentions. However, scholarship on fingerspelling has noted it to be particularly difficult to understand (McKee and McKee, 1992; Geer, 2016, 2019), in comparison to signs, suggesting that reduction has the potential to impact the understanding of fingerspelling in a greater way, as understanding these forms is already more difficult for perceivers.

This hypothesis is supported by evidence from the impact of changing the rate of presentation on the intelligibility of signs and fingerspelled words in ASL. A comparison of studies on the impact of presentation rate on comprehension shows that, when presentation rate is artificially increased the same amount, fingerspelling (Reed et al., 1990) shows a greater decrease in levels of comprehension than ASL signs (Fischer et al., 1999). Further investigation into any disconnect between the perception of reduced and unreduced forms will clarify this, providing more direct evidence of how reduction processes impact the perception of these forms.

1.3 Research questions and outline

Through the lens of repetition, this investigation into reduction processes in ASL, comparing patterns in language production in different parts of the lexicon, will provide new insights into how shared and differing structural and articulatory properties shape processes of reduction. It will approach this topic largely from the perspective of language production, while supplementing it with a preliminary study testing the impact of reduction on perception. Although the production results themselves will inform our understanding of how pressures on language production shape reduction, the corresponding impact of reduction on perception could then have implications for broader theories of language production by providing new perspectives into different ways reduction might impact the intelligibility of fingerspelled words and signs. Any alignment between similarities or differences between reduction processes in production and their impact on perception would suggest a link between how language producers modulate reduction. Misalignment might indicate that language producers do not take their interlocutors into account when they reduce, with reduction patterns driven mostly by producer-internal mechanisms.

The two primary areas of inquiry driving the questions within this investigation are:

1. *Articulatory constraints on the production of ASL*: What are the processes of reduction that occur in the context of repetition for fingerspelling and core signs in ASL, and what does this tell us about the articulatory constraints that shape language production in sign languages?

2. *Language production models:* How does our understanding of the production and perception of processes of reduction in ASL, revealing a connection or disconnect between the production and perception of reduced forms, inform broader theories of language production that are intended to explain trends in production cross-linguistically?

By answering these questions, this dissertation aims to make descriptive, methodological, and theoretical contributions. Descriptively, I will use a corpus approach to detail the different processes of reduction that are seen in fingerspelling and core signs, comparing them to reduction processes outside of this context and in speech. Methodologically, the perception of reduced forms has received little attention in previous scholarship, and so the perception study will contribute to this through a preliminary experiment while discussing methodological challenges faced in approaching this. In testing how reduction processes are perceived, the present work will use a novel experimental set-up, utilizing naturalistic stimuli in new ways. With regard to linguistic theory, these processes of reduction will provide new insights into ways that signers may or may not take their interlocutors into account while reducing, as well as detailing ways that articulatory pressures shape language production.

These questions and contributions will be approached, to different degrees, through the following chapters:

- *Chapter 2:* Chapter 2 focuses on how repetition reduction is realized in the production of fingerspelling in ASL. It employs a corpus approach, using a corpus of naturalistic online videos by signers of ASL, to test how several processes of reduction are realized in fingerspelling. It analyzes the gradient process of duration reduction, targeting the trajectory of duration reduction across mentions, as well how the more categorical process of letter deletion occurs in the context of repetition. Findings suggest that fingerspelled words continue to reduce in duration past their first repetition, presenting a disconnect with previous results on processes in speech. Building on previous work on fingerspelling, results also show fingerspelled letters increasingly undergoing deletion as words are repeated.

- *Chapter 3:* Chapter 3 examines different ways that signers reduce core signs in the context of multiple repetitions in ASL. Relying on data from two corpora, this analysis tests how duration reduction proceeds across multiple repetitions of signs, as well as how this interacts with the loss of repeated movement segments within signs. In addition, it tests how the context of repetition results in reduction within other domains, including the repeated internal movements of signs, as well as the location of signs articulated on the body. The results from this show signs reducing in their duration across multiple repetitions. Accompanying this duration reduction is a deletion in the repeated movements internal to signs, as well as systematic centralization of signs articulated on the body.

- *Chapter 4:* Chapter 4 directly compares the trajectory of repetition reduction between fingerspelled words and core signs in ASL, analyzing both categories alongside one another to determine whether there are considerable differences in reduction between the two systems. Combining data from the corpora used in chapters 2 and 3, it tests the prediction that fingerspelled words will reduce to a greater degree than signs. However, contrary to study predictions, findings show strikingly similar patterns in repetition reduction between the two systems wherein duration reduction proceeds across similar trajectories for both fingerspelling and signs.

- *Chapter 5:* Chapter 5 examines the impact of repetition reduction on language perception by comparing people's ability to differentiate between reduced and unreduced forms through a discrimination task, comparing this ability for fingerspelling and for core signs. Using a novel methodology that utilizes naturalistic data sourced from the production study corpora as stimuli, it tests whether signers are able to distinguish unreduced forms from reduced ones, providing first insights into the perception of reduced forms in ASL. Findings from the study show a disconnect between the perception of fingerspelling and core signs, wherein highly reduced fingerspelled forms, those that exhibit letter deletions, are distinguished from unreduced forms at a higher rate. In addition, results showed signers responding most slowly to reduced signs in comparison to fingerspelling, with a slight decrease in response time when signs exhibited an additional, categorical reduction process.

- *Chapter 6:* Chapter 6 concludes the dissertation by synthesizing the findings of each study, bringing them together to provide a fuller picture of reduction process in ASL, as well as discussing their implications for cross-modal theories of language production. It then elaborates on the limitations of the present approach and points to future directions for this work as ways to further address how the mechanisms behind language production can be revealed by the linguistic structures present in sign languages.

CHAPTER 2

REPETITION REDUCTION IN FINGERSPELLING PRODUCTION

2.1 Introduction

In linguistic discourse, words are frequently repeated and, in studies on spoken and signed languages, the repetition of these words has been shown to correspond to a decrease in the duration of the repeated word, as well as an increase in segment deletion and coarticulation. Within theories of language production, this repetition effect has been used as evidence to further understand the mechanisms behind language production. While these theories have been built on evidence from findings from spoken languages, differences in findings from research on repetition reduction in spoken languages and previous studies on fingerspelling in American Sign Language (ASL) indicate that the relationship between repetition and reduction may not be uniform across modalities, suggesting that the role of repetition in language production should be reexamined. In this chapter, I use data from ASL fingerspelling, a system in ASL where strings of letters are represented in the manual-visual modality, to further probe the relationship between fingerspelled word reduction and repetition. I test not only how this repetition reduction is realized across multiple repetitions of fingerspelled words, focusing on decreases in duration and internal deletions of letters within these words, but also on how this interacts with other factors that influence word duration, including the time between repeated mentions. This analysis is conducted with the goal of providing a more detailed view of repetition reduction in fingerspelling, while situating fingerspelling reduction within wider theories of language production.

Repetition reduction is couched within language production theories, elaborated more at length within Chapter 1, that argue that contextual information available about a word's identity affects its production, with more available contextual information corresponding to reduced articulation. If contextual information about an upcoming word's identity is available, for example if the word has been mentioned previously, then according to different theories, the referent might be retrieved faster in production resulting in faster articulation (Bell et al., 2009) or, according to other theories, less effort is expended in articulation to articulate a clear referent for an interlocutor (Jurafsky et al., 2001; Aylett and Turk, 2004). Crucially, these theories differ with regard to whether or not interlocutors are taken into account by the language producer in mediating reduction processes. These reduction effects occur in both the phonetic and phonological domain, and are seen not only for gradient measures like word or segment duration, but also for the full deletion of segments (Coetzee and Kawahara, 2013; Turnbull, 2015).

Previous scholarship on the effects of repetition on word reduction in spoken languages has shown that whether or not a word has been mentioned in a discourse influences its duration, with words that have already been given in discourse showing a reduction in their duration with respect to their previous mention. These studies have shown the effect of repetition to occur between the first and second mentions of a word (Fowler and Housum, 1987; Pluymaekers et al., 2005; Lam and Watson, 2010; Jacobs et al., 2015; Kahn and Arnold, 2015; Turnbull, 2015), with findings indicating no significant effect on duration of subsequent mentions after a word's second mention (Bell et al., 2009; Vajrabhaya and Kapatsinski, 2011). As such, the effect of word repetition has been treated as binary and insofar as token duration is influenced by repetition, this is determined by whether the word has or has not been mentioned previously in the discourse.

However, small-scale studies on fingerspelling in ASL (Brentari, 1998; Thumann, 2012; Wager, 2012; Lepic, 2019) have show reduction continuing in repeated fingerspelled words past their second mention, suggesting that a binary conceptualization of the effect of repetition on duration is not sufficient. Fingerspelling is system in ASL in which words are formed through the sequential articulation of different handshapes which each represent a letter in the English alphabet (Keane and Brentari, 2016). When fingerspelled words are repeated, they exhibit not only a shortening in duration to a degree greater than that seen in spoken languages, but also exhibit a considerable increase in the degree of coarticulation and fingerspelled letter segment deletion. While findings on fingerspelling reduction are from studies that rely on relatively small sample sizes, they suggest that repetition effects may not be limited to second mentions, although this requires testing from a larger dataset and controlling for other factors that might influence duration. This more magnified reduction effect in fingerspelling then provides another way to examine the ways that previous mentions of a form in discourse influences duration.

Data from a naturalistic corpus drawn from online videos of fingerspelled words in ASL are used in this chapter to examine the effect of repeated mentions on fingerspelled word reduction. Word duration and fingerspelled letter deletion are the primary metrics of reduction used in this analysis. These were chosen to encompass both gradient and categorical reduction processes in fingerspelling. The inclusion of duration reduction also has the advantage of providing a measure of reduction that can be compared to other systems in ASL, such as core signs, and other modalities. The effect of repetition is examined not only through how many times a word has previously been mentioned, but also through the amount of time between a word and it's previous mention. Distance between mentions has been shown to effect word duration, with Rodriguez-Cuadrado et al. (2018) showing repetition reduction effects to be smaller when there is more time between mentions in a study on Spanish, suggesting that distance also has a relevant contribution to the contextual information used in language production. Research on word duration in spoken and sign languages, outside of the realm of fingerspelling, has also shown prosodic position within the phrase (Nespor and Sandler, 1999; Brentari and Crossley, 2002) to influence word duration, and the length of a word in segments has been shown to influence the likelihood of deletion (Turnbull, 2015). These factors are included within the present analysis as the effect these factors have not been explored for ASL fingerspelling, and each of these factors can potentially influence variability in the duration of repeated fingerspelled words.

2.2 Background

This investigation is set at the intersection of findings from research on spoken languages that have been used in support of different models of language production and research on ASL fingerspelling showing both distinct structural properties and reduction processes within this system. Together, these motivate this analysis and inform study predictions about how reduction will be realized in fingerspelling.

2.2.1 Properties of ASL Fingerspelling

Fingerspelling in ASL, the focus of this chapter, is distinct not only from spoken languages, but also from the rest of the ASL lexicon in its configurational properties, its temporal properties, and its domains of use. Within the ASL fingerspelling system, the letters of the English alphabet are represented through a set of handshapes, as well as a limited number of orientations and movements (Keane and Brentari, 2016). The ASL fingerspelled alphabet can be seen in Figure 2.1[1].

ASL uses a one-handed system in which each of the 26 letters of the English alphabet are represented through a unique configuration of the hand, comprising its handshape, the orientation of the palm and, occasionally, the movement of the hand in space, as is the case for the letters 'J' and 'Z'. This one-handed system contrasts with some of the other fingerspelling systems around the world, including British Sign Language (BSL) and Australian Sign Language (Auslan), which employ two-handed fingerspelled alphabets (Cormier et al., 2008). The handshape configurations used within the ASL fingerspelling system overlap with

1. This figure was created Jon Keane using a freely available font created by David Rakowski. This figure is licensed under a Creative Commons Attribution-ShareAlike 3.0 Unported License and as such can be reproduced freely, so long as it is attributed appropriately.

those used in the rest of the ASL vocabulary, although they are partially distinct from those in the core vocabulary of the ASL lexicon, to the exclusion of initialized core signs (Brentari and Padden, 2001).

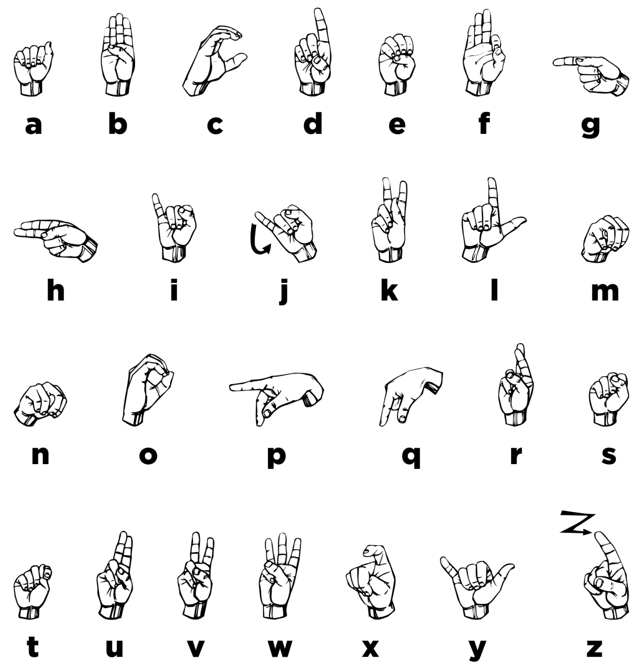

Figure 2.1: The ASL fingerspelling alphabet

Within the fingerspelling system, fingerspelled letters are combined to represent strings of letter sequences which commonly correspond to English words or phrases. Within these sequences, fingerspelled letters are typically articulated in rapid succession. This rapid, sequential articulation of fingerspelled letters is notable not only because of its potential contribution to the articulatory and processing difficulty of these sequences, but because it is distinct from the articulatory patterns of core signs[2]. Fingerspelling distinguishes itself through its inventory of handshapes used within this system of the lexicon and also employs complex handshapes at a greater frequency than those used in the rest of the ASL lexicon (Brentari and Padden, 2001). Handshape complexity, within the context of this analysis, is

2. Further discussion of these differences will be found in Chapter 4.

determined by age of acquisition and articulatory difficulty, with the set of least complex, unmarked handshapes being those that both are acquired earliest (Braem, 1990) and those that co-occur with the two-handed signs in ASL with the most complex movements (Battison, 1978). The least complex set of handshapes, by this metric, encompasses the 'B', '5', 'A', '1', 'C' handshapes[3]. In an analysis of a 1000 word corpus of signs, Henner et al. (2013) found that the 'B', '5', 'A', and '1' handshapes were the most common, comprising at least 50% of the handshapes in the corpus.The distribution of these unmarked handshapes in the ASL lexicon contrasts with fingerspelled words, which employ a greater range of handshapes and do not include the highly frequent '1' and '5' handshapes.

Although distinct from the other systems in the ASL lexicon, fingerspelling is a common feature of ASL discourse. Often discussed as a contact phenomenon, either in the form of borrowing (Battison, 1978; Brentari, 2001; Brentari and Padden, 2001) or code-mixing (Montemurro and Brentari, 2018), fingerspelling is commonly used to fill gaps in the lexicon, including for technical vocabulary, personal and proper names, brands, acronyms, as well as months and holidays (Wilcox, 1992). In addition to filling lexical gaps, fingerspelling is used for emphasis and in compounding (Padden and Gunsauls, 2003), as well as to contrast and emphasize information in discourse (Montemurro and Brentari, 2018), even in situations in which there is a core sign available in ASL.

While fingerspelling is commonly employed in ASL, estimates of its rate of usage vary. On the lower end, some scholarship reports fingerspelling to comprise approximately 10% of signed discourse (Morford and MacFarlane, 2003), while other research reports it to comprise 15-39% of ASL discourse (Padden and Gunsauls, 2003). Crucially, individuals have also been shown to vary in the amount that they fingerspell, with the variation in the frequency at which individuals fingerspell corresponding to many factors, including age of ASL acquisition

3. Metrics of handshape complexity with additional levels of detail have been proposed in, for example, Brentari et al. (2017), but this degree of differentiation between levels of complexity is not necessary for the present analysis.

and years of schooling (Padden and Gunsauls, 2003).

Rates of fingerspelling also vary considerably. Fast fingerspelling has been reported to occur at anywhere between 3.33 letters a second (Wilcox, 1992) and 8 letters a second (Quinto-Pozos, 2010). This misalignment between empirical findings indicates that there is likely a large degree of variation in rates of fingerspelling production. Additionally, Keane (2014) shows that variation in fingerspelling rate can be partially explained by a number of factors, including word type and intersigner variation. Keane (2014)'s study reports that non-English words are fingerspelled at a slower average rate than English words and that one of the main factors explaining variation in fingerspelling rates is differences in rates between individual signers. This suggests that, to effectively study the effect of repetition reduction across ASL Fingerspelling, it is important to control for individual and word level variation.

As a manual way to represent English words, ASL fingerspelling is also unique due to its relationship to English orthography. Accounts theorizing the connection between fingerspelled letters and orthography differ in the ways that this applies to the production and perception of fingerspelled words. Within one framework, fingerspelling is conceptualized as sequences of letters which retain their identity as distinct letters, with particular sets of distinguishing features that can be analyzed and perceived separately, although they overlap with one another (Battison, 1978; Wager, 2012). In contrast, other accounts emphasize that within fingerspelled words, fingerspelled letters themselves are not analyzable as separate units and instead comprise overlapping articulatory gestures. Crucially, under this perspective, it is the fingerspelled word as a whole, rather than strings of isolated letters, that is produced and recognized by signers (Wilcox, 1992). The fingerspelled letters together form a "movement envelope" that is processed and produced as a whole word unit where there are smooth transitions in and out of each letter, rather than static handshape sequences that follow one another (Akamatsu, 1985). Here, I take a middle approach, like that of Keane (2014) and Keane and Brentari (2016), where fingerspelled words are considered to be comprised of individual letters that are articulated and processed as overlapping articulatory gestures.

2.2.2 ASL fingerspelling and reduction

Reduction in fingerspelling has been approached from various angles, including, but not limited to, reduction in the context of repetition. Types of reduction analyzed for fingerspelled words include letter deletion (Battison, 1978; Brentari, 1998; Patrie and Johnson, 2011; Wager, 2012; McDonald et al., 2017), increased coarticulation between fingerspelled letters (Keane et al., 2012; Keane, 2014; Brentari, 1998; Battison, 1978; Wager, 2012; Lepic, 2019; Thumann, 2012), and a decrease in word duration (Lepic, 2019; Wager, 2012; Thumann, 2012).

Outside of the context of repetition reduction, letter deletion has received attention as a reduction phenomenon in fingerspelling. In a comparison of careful versus rapid fingerspelling of ASL interpreters, McDonald et al. (2017) found that deletions increased in rapid fingerspelling. Of these deleted letters, that most frequent deletions comprised vowel letter segments[4] (McDonald et al., 2017). Although letter deletion is commonly cited as a reduction phenomenon in fingerspelling, a great deal of variation has been reported in accounts of fingerspelling deletion. For example, Wager (2012)'s analysis found that 44% of the fingerspelled words analyzed in her study exhibited deletions, while McDonald et al. (2017) found that deletion occurred in 12% of the words in their corpus. Although, in their experimental methodologies, both of these studies determined deleted letters to be those in which no trace of a letter was deemed present, there is a striking degree of difference between these two findings. This difference might be attributable to differences in the corpora used for the two different studies, as one encompassed a signed speech by a Deaf signer (Wager, 2012) and the

4. This finding should be taken with the caveat that letter frequency was not controlled for in the corpus itself, and so it is not clear whether this finding is a result of corpus frequency or the properties of the letters themselves.

other an elicited corpus of signing produced by ASL interpreters (McDonald et al., 2017), and points to the need for further study.

Although the present approach examines fingerspelling reduction as it occurs within discourse, reduction has been approached from not only a synchronic perspective, but a diachronic one as well. Early analyses of ASL fingerspelling focused on how fingerspelling changed over time, analyzing the way that high frequency forms were incorporated into the lexicon of ASL during the process of language change. Fingerspelling reduction was first addressed in the wider context of lexicalization. Battison (1978) notes that a number of high frequency fingerspelled words have become incorporated into the lexicon. These lexicalized forms are often characterized by deleted letters, a high degree of coarticulation, and the addition of internal movement that is otherwise not typically seen accompanying fingerspelled words.

This conceptualization of lexicalization was then focused more locally to particular instances of fingerspelling within discourse by Brentari (1998) in her analysis of what was termed the "local lexicalization" of fingerspelled words. In this analysis, Brentari (1998) notes that as fingerspelled words are repeated in a discourse, they appear to undergo a process of lexicalization. Brentari reports that over repetitions of a word, coarticulation and letter deletion increase as the words are locally lexicalized. These words are reported to, by their third production, reach a stable, reduced form.

Subsequent studies on repetition and reduction in sign languages have continued to focus on fingerspelling. Previous research on the topic (Thumann, 2012; Wager, 2012; Lepic, 2019) has addressed fingerspelling reduction using small case-studies based on a single word, or multiple words from a single signer. These studies addressed reduction at a general level, and the interaction between repetition reduction and other factors, such as coarticulation and word frequency. For example, Thumann (2012) looks at how the duration of a fingerspelled word changes over the course of a conversation between two signers. The fingerspelled word examined, M-O-B-I-L-E, is repeated 23 times through the conversation. Across the conversation, as an overall trend, the duration of the fingerspelled words shows a decrease in duration from the first to the 23rd mention, along with increased coarticulation across the 23 mentions. In another study, using data from a signed presentation, Wager (2012) looks at durational differences in eight repeated, fingerspelled words using data drawn from a speech given by a Deaf native signer. Wager found that signing rate increased across repetitions, with second mentions averaging 71% of the duration of first mentions. Wager also found that the proportion of words with dropped letters increased across repeated mentions, going from 38% to 67% by third mentions. Fingerspelling reduction and its interaction with frequency is addressed by Lepic (2019), who analyzes four repeated words (two low frequency and two high frequency) from videos of *The Daily Moth*, a video newscast in ASL. Lepic found that the high frequency words do not show any differences in duration as they are repeated. In contrast, the low frequency tokens continued to reduce across multiple repetitions becoming more coarticulated and routinized, with, for example, the duration of one word reducing to less than half of the duration of its first mention by the time it had been repeated four times.

Although the previous studies on ASL suggest that repetition effects continue across multiple word mentions in ASL fingerspelling, it is unclear if and how these effects are realized across larger datasets encompassing a wider range of lexical items and individual signers. Additional sources of variability in word duration also need to be accounted for in analyzing patterns in reduction across repetitions. Here, the potential sources of variation included are variation due to phrasal position, the presence of a deleted letter, and time between repeated mentions. Prosodic position has been shown to influence sign duration in ASL, with, for example, phrase final position being associated with phrase final lengthening in duration (Nespor and Sandler, 1999; Coulter, 1993; Brentari and Crossley, 2002). While the influence of phrasal position on the duration of fingerspelled words has not been studied, this factor should be included to control for this potential source of variation, with the prediction that fingerspelled words will pattern like core signs and exhibit phrase final lengthening. Letter deletions, which have been attested as reduction processes under repetition, also have the potential to influence word length, as this categorical deletion of segments could then correspond to increased amounts of duration reduction.

Lastly, while the effect of the binary, given vs. new contrast has been the main focus within studies on repetition reduction, there is some evidence from Rodriguez-Cuadrado et al. (2018) that suggests between-mention-distance might also influence the duration of repeated words. This effect is in the opposite direction of the repetition reduction effect, with words that are farther apart exhibiting less reduction. If results are consistent with the prediction that increased temporal distance[5] between mentions is associated with less reduction, this also complicates the conceptualization of how a word's givenness in discourse contributes to reduction.

Given findings from previous work on fingerspelling, it is also important to analyze not only whether or not a word had been mentioned, but also how many times it had been mentioned previously and how much time had passed since its previous mention. In line with the findings from previous studies on fingerspelling that show length reduction occurring past second mentions (Brentari, 1998; Wager, 2012; Thumann, 2012; Lepic, 2019), I predicted that fingerspelled words will show reduction in their duration continuing past their second mention.

Letter deletions, in addition to duration, can also be analyzed on their own as a reduction phenomenon that interacts with word mention across multiple repetitions. For letter deletion, previous work on lexicalization (Battison, 1978), local lexicalization (Brentari, 1998), and repetition reduction (Wager, 2012) in ASL motivates the prediction that fingerspelled letters are more likely to be deleted in contexts of repeated discourse mentions. Studies of

5. Although distance has also been measured through number of words between mentions, for the present study, time will be the chosen measure of distance to build on the more recent Rodriguez-Cuadrado et al. (2018) study.

Table 2.1: Summary of predictions for fingerspelled word reduction in the context of repeated discourse mentions

Variable	Predictor	Prediction
Duration	Mention number	Duration will decrease over multiple mentions
	Distance	Duration will increase as distance increases
Deletions	Mention number	Deletions will increase in the context of repetition
	Word length	Shorter fingerspelled words will exhibit fewer deletions

spoken languages have also shown categorical, segmental deletion effects to interact with word length, with longer words being more likely to exhibit deletions (Turnbull, 2015). This leads to the additional prediction that shorter fingerspelled words will exhibit fewer deletions.

These predictions, if borne out, support a richer conceptualization of the previously binary given vs. new distinction, as they would suggest that language producers take detailed information about the degree of an item's presence in discourse including the number of times it was mentioned, as well as how long it has been since it last occurred. They would also suggest that fingerspelling reduction may not be mediated to the same extent as reduction in speech, continuing past second mentions. Lastly, these findings could enrich our picture of reduction processes for fingerspelling by adding providing a more detailed description of how categorical processes like deletions occur in the context of repeated discourse mentions.

2.3 Methodology

2.3.1 Corpus data

The data used in this analysis comprise a corpus of repeated fingerspelled sequences collected from online videos in ASL. The dataset of repeated tokens includes a total of 616 individual fingerspelled sequences, from 116 separate words. These sequences are from a total of 32 different signers. The dataset used in the present corpus study is drawn from a wider, 35,000 token database of fingerspelling annotations. The wider database is a crowd-sourced set of videos and fingerspelling annotations that was created for a separate project focused on automatic fingerspelling recognition (Shi et al., 2019). Video data in the original database were drawn from various Youtube channels and other Deaf social media websites (ex. https://www.deafvideo.tv). The videos within this represent a variety of genres and encompass a wide range of topics, including vlogs (video blogs) about politics, cooking, and health, as well as news and educational videos in ASL. Due to the variety of genres, the signing in the corpus ranges from semi-scripted (i.e. from the news videos) to spontaneous (i.e. from ASL vlogs). These videos were annotated for the temporal boundaries and letter content of the fingerspelled words within the videos by annotators on Amazon's Mechanical Turk.

The motivation for the use of a corpus drawn from online videos from ASL users stems from the more naturalistic nature of the data, the amount of data available, and the wider swath of the signing community represented in the sample. This is additionally supported by the argument that data from this platform is more naturalistic and unconstrained by biases and constraints introduced when gathering data in a controlled laboratory setting (Hou et al., 2020) and is aimed primarily at a deaf audience. To address any privacy concerns associated with using online data and to ensure that no violations of privacy occur, only publicly available videos will be used in the analysis.

A subset of the original dataset, targeting repeated sequences, is used for the present analysis. The subset used for the reduction analysis was taken from videos in which fingerspelled sequences are repeated multiple times, targeting those that are repeated between 3 and 6 times by a single signer. Lexicalized sequences were excluded from the data. Lexicalized fingerspelling was excluded as some of its articulatory properties differ from that found otherwise in fingerspelling. Lexicalized fingerspelled sequences can include additional movement in their articulation and different locations not used in typical fingerspelling (Battison, 1978), and so any fingerspelled word with an additional movement or location outside of the typical fingerspelling space was excluded from the corpus. Lepic (2019) also demonstrated that reduction may not occur in high frequency fingerspelled words, which are more likely to have undergone lexicalization. High frequency fingerspelled words in ASL encompass function words like ‘all’, ‘if’ and ‘but.’ Not only do many of these have features of grammaticalization (Battison, 1978), but they have also been shown in analyses of speech to not demonstrate the same reduction patterns as content words (Bell et al., 2009). For this reason, function words, which are typically high frequency, were excluded from the corpus used for analysis.

2.3.2 Signers

The fingerspelled sequences included in the corpus are from a total of 32 different signers. Due to the nature of the metadata available for the videos in the corpus, it was not possible to extract exact demographic information about the signers within the videos. However, signers in the videos were from a variety of locations, encompassing various locations in the United States, as well as Canada. 28 of the signers were right hand dominant (ie. primarily fingerspelled with their right hand), while 4 of the signers were left hand dominant.

2.3.3 Annotation

Data annotation, completed in ELAN (Lausberg and Sloetjes, 2009)[6], captured the timing properties and letter content of the target fingerspelled tokens. Although the original crowd-sourced corpus of fingerspelling annotations encompassed the fingerspelled words included in the reduction-study corpus, each of these required additional annotation to more precisely capture the timing properties of each fingerspelled sequence. The fingerspelled tokens within the reduction dataset were re-annotated by the researcher to include precise information about the timing and fingerspelled letters spelled for each of the fingerspelled words.

6. Elan is a multimedia annotation tool developed at Max Planck Institute for Psycholinguistics, The Language Archive, Nijmegen, the Netherlands (https://tla.mpi.nl/tools/tla-tools/elan/).

Annotations are included for the target fingerspelled sequence, the letters spelled by the signer in the video, and the duration of each fingerspelled token. Annotations are also included for each fingerspelled token's position in the phrase, distinguishing between phrase-final words and words in other positions within the phrase. The inclusion of phrasal position in the analysis is to account for any variation in the data that could be attributed to phrase-final lengthening, an effect that has been documented previously for core signs in ASL (Coulter, 1993; Brentari and Crossley, 2002), albeit not for fingerspelled words. Phrasal position was determined by a token's adjacency to a phrasal boundary, as indicated by a significant pause, dropping the hands, or the beginning of a new phrase.

The temporal boundaries of each fingerspelled word span the duration of the entire fingerspelled word, beginning when the hand settles into the initial handshape of the first letter and ending as the hand relaxes out of the handshape of the final letter. In cases where the initial or final handshape did not provide a reliable cue for the temporal boundaries of the fingerspelling annotation, for example, in cases where a final fingerspelled letter was held while the other hand began to form another sign, other cues, such as the lowering of the hand from its position in neutral space or a shift in non-manual markers, were used. The duration of each fingerspelled token was calculated in milliseconds. Letter deletion was judged through a conservative measure where a letter is considered deleted when there were no features remaining from the handshape of the letter being spelled. This conservative measure was adopted due to the gradient nature of processes like coarticulation, where judging deletion by degree of coarticulation could present annotation inconsistencies. A summary of all of the annotated properties can be seen in Table 2.2.

Annotation was completed by the researcher and annotation reliability calculated by comparing the annotations to those of a trained research assistant at the University of Chicago. After training the research assistant on the annotation schema, annotation reliability was calculated by having the research assistant annotate 10% of the dataset, which was then used to calculate reliability. Reliability was calculated for annotations encompassing fingerspelled word identity, phrasal position, mention number, and the deletions present. The Cohen's Kappa was 0.91 between annotators.

Table 2.2: Variables under investigation annotated for fingerspelling production analysis

Variable	**Measure**
Duration	Duration (milliseconds)
Letter deletion	Number of deletions & identity of deleted letters
Phrasal Position	Phrasal position (final or non-final) determined by adjacency to a boundary

2.4 Analyses & results

This investigation examines reduction in ASL both as seen in the trajectory of duration reduction across mentions and in the deletion of letter segments across mentions. It focuses first on the trajectory of duration reduction and then on reduction through deleted letters. The duration analysis is conducted in two parts. The first part of this analysis, *Duration analysis 1: Mention number*, tests whether mention number, phrasal position, and the presence of deleted letters influence fingerspelled word duration, looking at word mentions 1 through 6. The second part of the analysis, *Duration analysis 2: Distance between mentions*, is conducted to look at the influence of the distance between mentions on word duration. Distance between mentions is not applicable for the first mention of words within the dataset and so a subset of the data, comprising data from mentions 2 through 6, is used for this analysis. In the third part of the results, *Letter deletions*, to provide additional analysis of a categorical, deletion reduction process, I examine trends in the deletion of fingerspelled letters across repeated mentions, looking at how this is influenced by the length of fingerspelled words.

2.4.1 Duration analysis 1: Mention number

The first part of the analysis tests whether there is a significant difference between the duration of each mention of a word and the following mention, as well as tests the effects of phrasal position and the occurrence of letter deletions on duration. Trends in duration reduction are tested using mixed effects regression models, using *lmer()* in the *lme4* R package (Bates et al., 2015). A summary of the descriptive statistics for mean duration across each of the factors examined in the first part of the analysis can be seen in Table 2.3. The data for duration were positively skewed (skewness = 1.473, kurtosis = 5.7384) and so duration values were log transformed for the regression analysis to normalize their distribution.

Table 2.3: Average duration values (in milliseconds) for fingerspelled word duration at each mention number. These descriptive statistics show means along with standard deviations in parenthesis. Averages are separated into each of the factors analyzed in the analysis (phrasal position, presence of deleted letters).

	Mention	1 [n=116]	2 [n=116]	3 [n=116]	4 [n=100]	5 [n=91]	6 [n=75]
Total		990.793	787.228	662.370	628.110	623.483	545.853
		(507.144)	(446.055)	(338.252)	(358.626)	(346.827)	(255.639)
Position	Final	1126.629	882.519	736.1400	712.162	734.928	537.791
		(575.0507)	(502.352)	(391.106)	(412.261)	(381.927)	(263.123)
	Non-final	834.833	712.151	606.4848	578.746	573.952	549.647
		(362.077)	(383.596)	(282.4123)	(316.208)	(320.917)	(254.610)
Deletions	Absent	989.106	788.921	666.187	625.161	616.983	559.770
		(490.281)	(458.901)	(348.176)	(328.368)	(341.218)	(260.608)
	Present	1004.153	782.034	653.888	632.921	635.468	521.111
		(649.135)	(411.700)	(319.687)	(407.824)	(362.161)	(249.466)

Trends in duration differences between mentions 1 and 6 were examined using linear mixed effects regression models, testing the influence of each of the factors of interest by comparing the performance of the models as each factor was added as a fixed effect. To test whether mean duration significantly decreased following each mention, mention number was coded using Helmert Contrast Coding. This coding system compares the means of an ordered variable by comparing the mean of the variable at each level, which here is mention number, with the mean of the combined subsequent levels. The present analysis uses a five level coding contrast, comparing the mean word duration of mentions 1 though 6. Each of the remaining factors included in the analysis was treatment-coded. Phrasal position had a two way contrast, phrase-final or other, with phrase-final as the baseline. The presence of letters deletions was also coded as a two way contrast, with deletions coded as present or absent, where present was treated as the baseline.

The contribution of each of these factors in accounting for variation in token duration was tested by comparing the performance of the regression models that incrementally added each factor as a fixed effect. The model comparison was constructed by first using a base model looking at the effects on token duration with mention number included as a fixed effect, with random effects included for individual signer and fingerspelled word (Model 1a). The *lme4* formula for the base model is as follows:

$$\textsc{duration} \sim \textsc{repetition number} + (1|\textsc{signer}) + (1|\textsc{word})$$

Each factor was then added to the model incrementally as a fixed effect to see if its addition improved model performance[7]. Phrasal position was first added as a fixed effect (Model 1b) to see if the fit of the model improved and then deletion presence was added (Model 1c). The model summaries can be seen in Table 5.2

Table 2.4: Model structures, presented as the *lme4* formula, used to compare the effect of mention number, phrasal position, and the presence of deletions on the duration of fingerspelled words.

Model 1a:	DURATION ∼ MENTION NUMBER + (1|SIGNER) + (1|WORD)
Model 1b:	DURATION ∼ MENTION NUMBER + PHRASAL POSITION + (1 | SIGNER) + (1|WORD)
Model 1c:	DURATION ∼ MENTION NUMBER + PHRASAL POSITION + DELETION PRESENCE + (1|SIGNER) + (1|WORD)

7. Interaction terms between the fixed effects were also tested, but did not improve model fit, and so they are excluded from the present analysis

The estimates for each of the predictors included as fixed effects in the analyses for each of the models can be seen in Table 2.5[8]. Table 2.5 also shows the results of the model comparison, in which the performance of each subsequent model is compared with an ANOVA. Model 1c best accounted for variance in the data and will be used to discuss the results of significant factors included in the model.

Looking at the estimates for Model 1c, results show that the difference between the first mention and subsequent mentions is significant (*Estimate*=0.089, SE=0.015, T(616)=11.006, p<0.001), as well as the difference between the second and subsequent mentions (*Estimate*=0.051, SE=0.015, T(616)=5.250, p<0.001), with the value of the estimate decreasing between the two comparisons. The difference between the durations of the third and subsequent mentions was not significant in the model. This effect of mention number on mean duration can be seen in Figure 2.2.

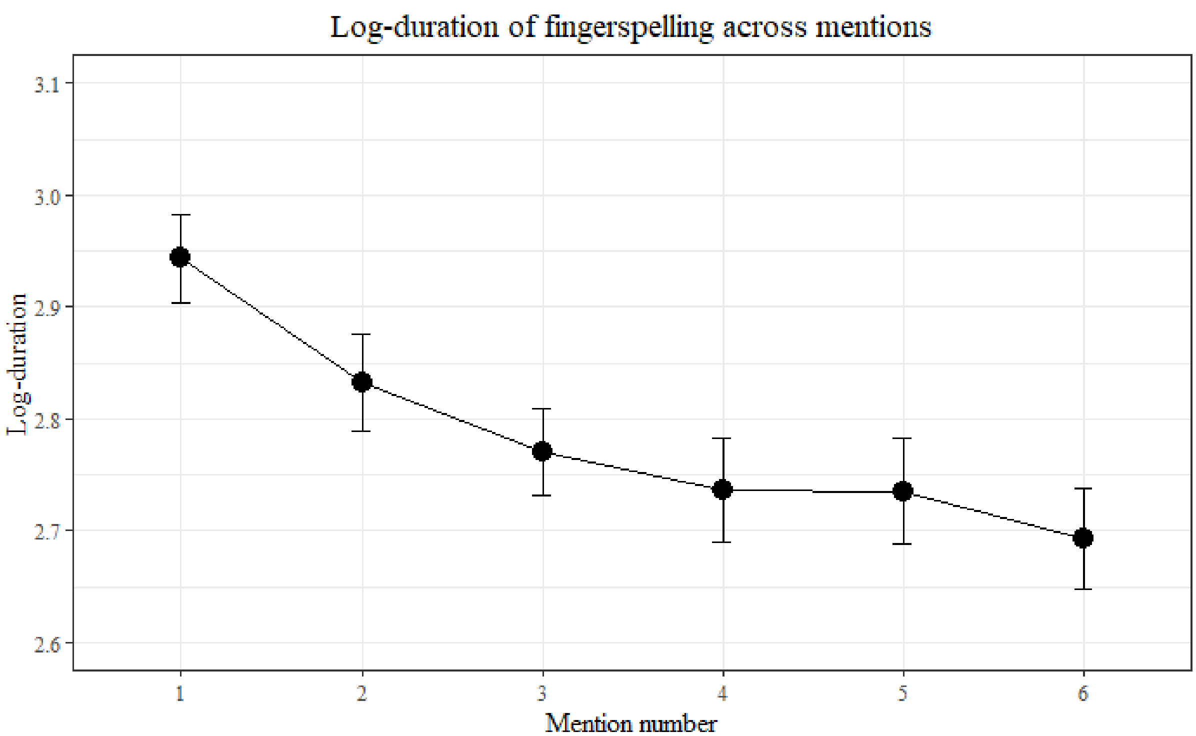

Figure 2.2: Mean duration of fingerspelled words at each mention number (mentions 1-6)

8. Regression tables were created using the R package Stargazer (Hlavac, 2015)

Table 2.5: Model comparison for Duration analysis 1 - Model comparison was conducted using mentions 1 through 6. Estimates are provided with their standard error in parenthesis. Results of an ANOVA comparing model performance are included at the bottom of the table.

	Dependent variable:		
	Duration (log transformed)		
	Model 1a	Model 1b	Model 1c
Constant	2.807***	2.776***	2.815***
	(0.025)	(0.026)	(0.028)
Mention>1	0.181***	0.168***	0.141***
	(0.014)	(0.013)	(0.013)
Mention >2	0.087***	0.081***	0.066***
	(0.014)	(0.013)	(0.013)
Mention >3	0.036**	0.029**	0.021
	(0.015)	(0.014)	(0.013)
Mention>4	0.008	0.004	0.006
	(0.017)	(0.016)	(0.015)
Mention>5	0.012	0.014	0.010
	(0.020)	(0.020)	(0.018)
Phrasal Position: Final		0.080***	0.072***
		(0.012)	(0.012)
Deletion Presence: Present			−0.121***
			(0.015)
Observations	616	616	616
Log Likelihood	246.756	266.755	294.886
Akaike Inf. Crit.	−475.512	−513.510	−567.772
Bayesian Inf. Crit.	−435.703	−469.278	−519.116
Chi-squared		39.999	56.262
p-value		p<0.001***	p<0.001***
Note:			*p<0.1; **p<0.05; ***p<0.01

The addition of phrasal-position significantly improved model performance, accounting for variation in fingerspelled word duration, as did the addition of information about the presence of deleted letters. Results from Model 1c show a significant positive effect of fingerspelled words in final positions (*Estimate*=0.072, SE=0.012, T(616)=6.210, p<0.001) and a significant negative effect of letter deletions (*Estimate*=-0.122, SE=0.015, T(616)=-7.971, p<0.001). This revealed that words with deleted letters were shorter in length. This also confirms a significant phrase-final lengthening effect for fingerspelled words in ASL. The mean duration of tokens across mentions, separated by phrasal position ('final' vs. 'non-final') can be seen in Figure 2.3[9].

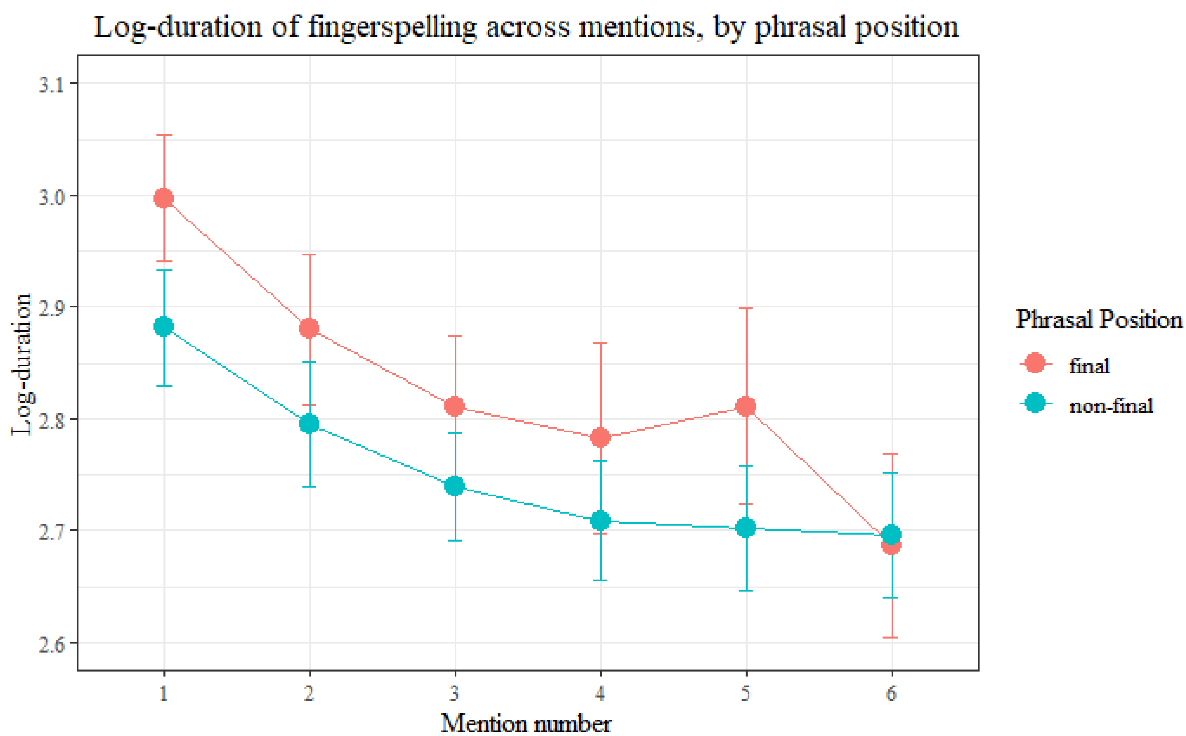

Figure 2.3: Mean duration of fingerspelled words at each mention number by phrasal position (mentions 1-6)

9. It should be noted that the difference between phrase-final and other positions appears to disappear at the sixth mention. However, because there were fewer data points for the sixth mentions of fingerspelled words, as well as even fewer in phrase-final position, this is likely an artifact of the smaller number of data points, rather than a loss of the effect overall.

2.4.2 Duration analysis 2: Distance between mentions

The influence of the temporal distance between mentions on the duration of tokens was examined by looking at mentions 2 through 6 of the repeated fingerspelled words. The values in the dataset for the distance between repeated words were positively skewed (skewness = 3.342, kurtosis = 16.231) and so the values for distance between mentions were log transformed in the analysis to normalize their distribution. Figure 2.4 shows the relationship between duration and the distance between mentions. The plot shows a positive relationship between duration and distance between mentions, with an increase in the time between mentions corresponding to an increase in token duration. A linear regression revealed that this trend was significant, showing a positive relationship between duration and distance between mentions (Estimate=0.082, SE=0.016, $T(500)=5.102$, $p<0.001$).

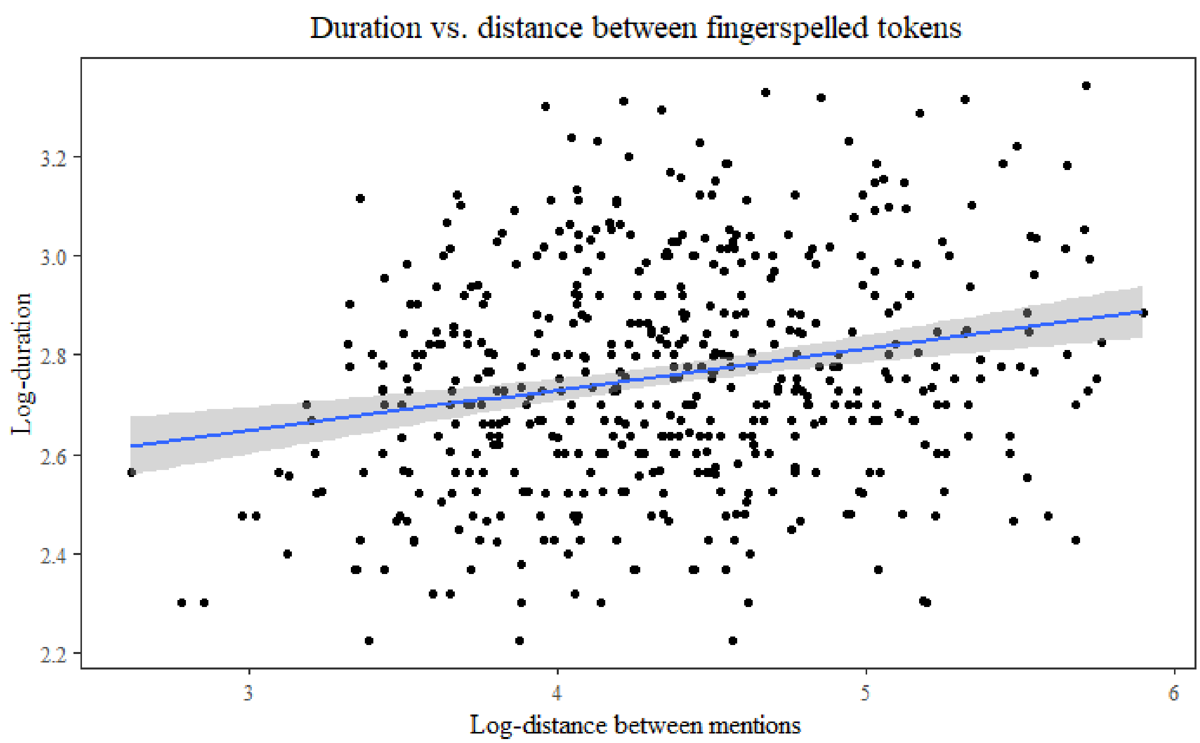

Figure 2.4: Scatter plot comparing fingerspelled token duration and distance from preceding mention (mentions 2 through 6)

This relationship, along with the change in token duration across mentions, was further probed by comparing mixed effects regression models to see if the addition of distance between mentions improved model performance. As this analysis only looks at mentions 2 through 6, the variable of mention number was coded through four level Helmert Contrast Coding.

The base model for this comparison, using data from mentions 2 through 6, included the mention number contrast as a fixed effect, with individual signer and word as random effects (Model 2a). Phrasal position was added as a fixed effect (Model 2b) as well as the presence of deleted letters (Model 2c), to see if their inclusion continued to improve the model when applied to a smaller dataset. Lastly, distance between mentions was added as a fixed effect (Model 2d). The formulas for each of the models can be seen in Table 2.6.

Table 2.6: Model structure used to compare the effect of mention number, position, and time between mentions on fingerspelled word duration.

Model 2a:	DURATION ~ MENTION NUMBER + (1|SIGNER) + (1|WORD)
Model 2b:	DURATION ~ MENTION NUMBER + PHRASAL POSITION + (1|SIGNER) + (1|WORD)
Model 2c:	DURATION ~ MENTION NUMBER + PHRASAL POSITION + DELETION PRESENCE + (1|SIGNER) + (1|WORD)
Model 2d:	DURATION ~ MENTION NUMBER + PHRASAL POSITION + DELETION PRESENCE+ BETWEEN-MENTION-DISTANCE + (1|SIGNER) + (1|WORD)

The results of the model comparison and estimates for each fixed effect can be seen in Table 2.7. The performance of each of the models, as factors are added, is compared using an ANOVA. These results show that the addition of phrasal position significantly improved the fit of the model, as did inclusion of the presence of deleted letters and the distance between mentions. This result indicates that variability in the duration of fingerspelled tokens, excluding data from the first mentions of fingerspelled words in the data, can be accounted for by a token's position in the phrase, the presence of letter deletions, as well as the distance between a token and its previous mention.

The best performing mode, Model 2d, with fixed effects for mention number, phrasal

Table 2.7: Model comparison for Duration analysis 2 - Model comparison was conducted using data from mentions 2 through 6. Estimates are provided with their standard error in parenthesis. Results of an ANOVA comparing model performance are included at the bottom of the table.

	Dependent variable:			
	Duration (log transformed)			
	Model 2a	Model 2b	Model 2c	Model 2d
Constant	2.775***	2.747***	2.443***	2.514***
	(0.025)	(0.026)	(0.053)	(0.052)
Mention>2	0.088***	0.082***	0.079***	0.064***
	(0.014)	(0.014)	(0.013)	(0.012)
Mention>3	0.038**	0.031**	0.038***	0.028**
	(0.015)	(0.015)	(0.014)	(0.013)
Mention>4	0.010	0.005	0.009	0.010
	(0.017)	(0.016)	(0.016)	(0.014)
Mention>5	0.013	0.015	0.007	0.003
	(0.021)	(0.020)	(0.019)	(0.018)
Phrasal Position: Final		0.080***	0.076***	0.069***
		(0.014)	(0.014)	(0.013)
Deletion Presence: Present				−0.123***
				(0.016)
Distance			0.070***	0.064***
			(0.011)	(0.010)
Observations	500	500	500	500
Log Likelihood	179.286	194.510	214.887	239.204
Akaike Inf. Crit.	−342.573	−371.019	−409.773	−456.407
Bayesian Inf. Crit.	−308.856	−333.088	−367.627	−410.047
Chi-squared		30.447	40.754	48.634
p-value		$p<0.001$***	$p<0.001$***	$p<0.001$***
Note:				*p<0.1; **p<0.05; ***p<0.01

position, letter deletions, and distance between mentions, was used to further examine the directionality of the trends and significance of each of the factors included as fixed effects. The model again showed a significant between-mention effect, with a significant difference between the second and subsequent mentions (*Estimate*=0.044, SE=0.015, Z(500)=5.210, $p<0.001$). The analysis also showed a positive relationship between duration and phrasal position (*Estimate*=0.069, SE=0.013, T(500)=5.429, $p<0.001$) and a significant negative relationship between duration and deleted letters (*Estimate*=-0.125, SE=0.016, T(500)=-7.553, $p<0.001$), with significantly longer phrase final tokens and shorter tokens with deleted letters. Lastly, Model 2d also showed significant positive relationship between duration and distance between tokens (*Estimate*=0.064, SE=0.010, T(500)=6.433, $p<0.001$).

Together, looking at both parts of the analysis, results show fingerspelled words continuing to reduce past their second mention, with variability in the data accounted for by including phrasal position, the presence of deleted letters, and distance between repeated mentions.

2.4.3 Letter deletion

The relationship between letter deletions and mention number was tested by looking at how many words contained letter deletions at each repeated mention, as well as how this was influenced by the length of the word. The change in the likelihood of letter deletions between each mention number was tested for mentions 1-6. Within this analysis, I examine trends in whether or not a word contained a deleted letter, as well as how many letters were omitted from the fingerspelled word. Trends in reduction through deleted letters are tested using generalized linear mixed effects regression models, using *glmer()* in the *lme4* R package (Bates et al., 2015).

The differences in the likelihood of letter deletions occurring between each mention number were examined using a logistic regression within a generalized linear mixed effects model.

As with the duration analysis, to test whether the likelihood of letter deletions changed between each mention, the variable of mention number was coded via Helmert Contrast Coding and deletions were treatment coded as present or absent. The base model (Model 3a) for this comparison included mention number as a fixed effect, with individual signer and word as random effects. Word length (in letters) was added as a fixed effect (model 3b) to see if its inclusion improved the performance of the model. The formulas for these models can be seen in Table 3.8.

Table 2.8: Model structures, presented as the *glme4* formula, used to compare the effect of mention number and word length (in letters) on the likelihood of letter deletion within fingerspelled words

Model 3a:	DELETION PRESENCE ~ MENTION NUMBER + (1 | SIGNER) + (1 | WORD)
Model 3b:	DELETION PRESENCE ~ MENTION NUMBER + LENGTH IN LETTERS + (1 | SIGNER) + (1 | WORD)

The results of the model comparison for the logistic regression models and estimates for each fixed effect can be seen in Table 2.9. The performance of each of the models was compared using an ANOVA, with results showing that the addition of word length as a factor significantly improved the performance of the model.

The analysis for the best fitting model, 3b, also showed a significant relationship between the likelihood of deletions and mention number, with a significant difference between the first and subsequent mentions (*Estimate*=2.618, SE=0.451, Z(616)=5.803, $p<0.001$), as well as between the second and subsequent mentions (*Estimate*=1.184, SE=0.352, Z(616)=3.359, $p<0.001$). Figure 2.7 shows the trends in the frequency of letter deletions from mention numbers 1-6. This figure shows shows which percentage of words at each mention contained letter deletions, revealing a trend wherein the percentage of words that include deleted letters increases as mention numbers increase, reaching a steadier level around mention 3.

Model 3b also showed a significant effect of the length of the fingerspelled word, in letters, with longer words being more likely to show letter deletions (*Estimate*=-0.650, SE=0.139, Z(616)=-4.665, $p<0.001$). A visualization of the trend in which longer words are more likely

Table 2.9: Logistic regression model comparison for analysis of the presence of letter deletions, using data from mentions 1 through 6. Estimates are provided with their standard error in parenthesis. Results of an ANOVA comparing model performance are included at the bottom of the table.

	Dependent variable:	
	Presence of letter deletion	
	Model 3a	Model 3b
Constant	2.050***	5.839***
	(0.478)	(1.019)
Mention >1	2.600***	2.618***
	(0.450)	(0.451)
Mention >2	1.161***	1.184***
	(0.352)	(0.352)
Mention >3	0.638*	0.660*
	(0.350)	(0.350)
Mention >4	−0.164	−0.116
	(0.379)	(0.379)
Mention >5	0.214	0.266
	(0.470)	(0.470)
Letter length		−0.650***
		(0.139)
Observations	616	616
Log Likelihood	−277.307	−264.611
Akaike Inf. Crit.	570.613	547.221
Bayesian Inf. Crit.	605.999	587.030
Chi-squared		25.392
p-value		p<0.001***
Note:	*p<0.1; **p<0.05; ***p<0.01	

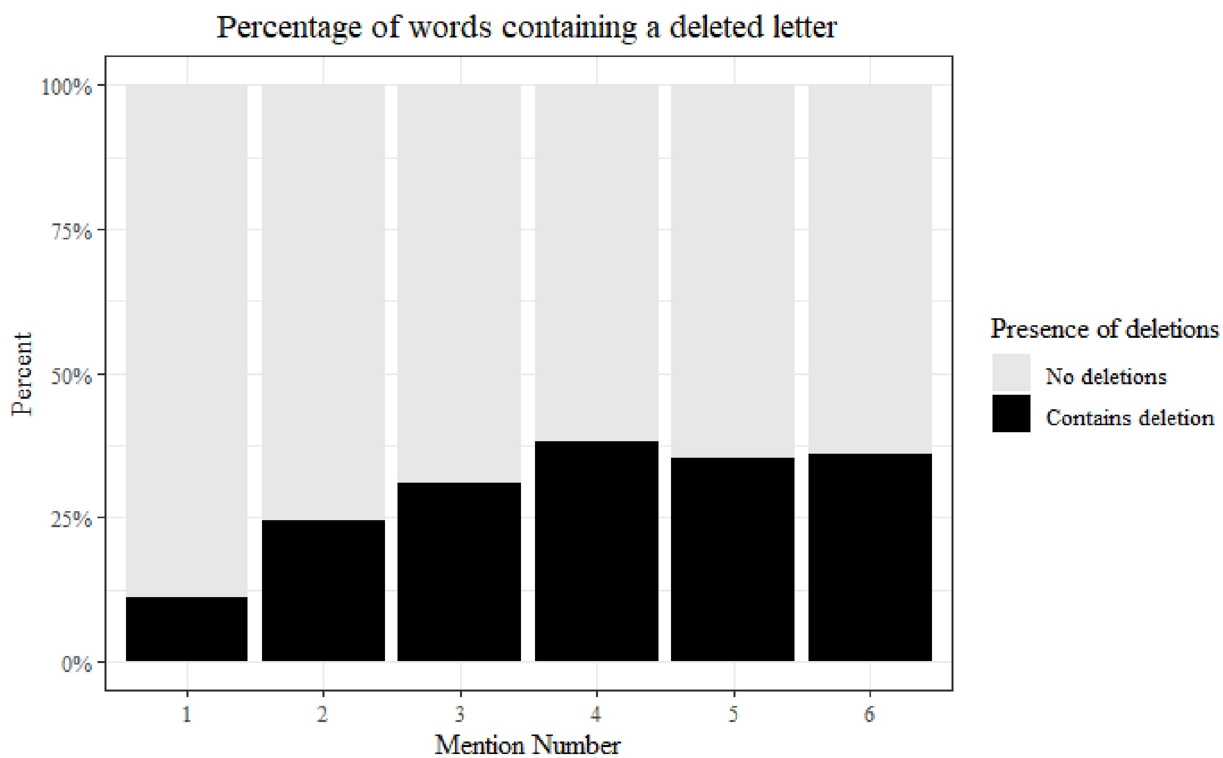

Figure 2.5: Percentage of words that contained at least one letter deletion, by mention number

to show letter deletions can be seen in Figure 2.6[10].

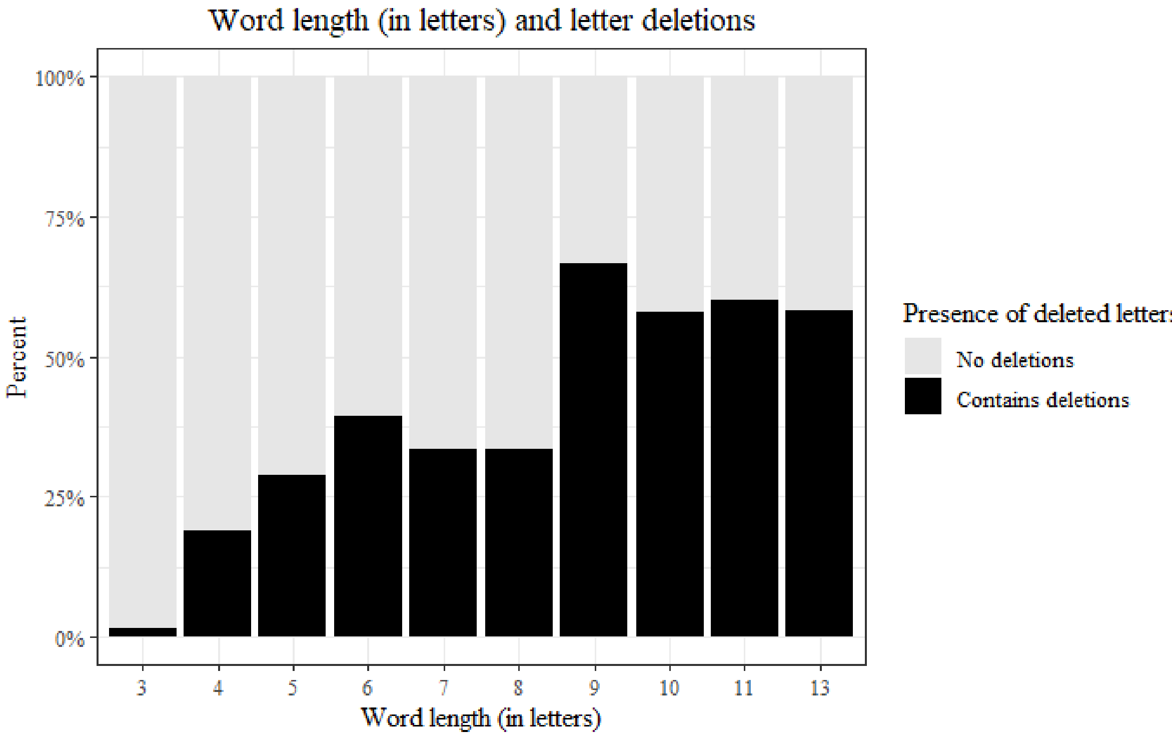

Figure 2.6: Percentage of words with letter deletions, by word length in letters

For a more granular analysis of the relationship between letter deletion and mention number, the relationship between mention number and the number of deletions per fingerspelled word was also analyzed. Differences in the number of letter deletions per word at every mention number were analyzed using a negative binomial regression within a generalized linear mixed effects model. The factors included in the model include mention number and length in letters. The base model (Model 4a) for this comparison included mention number as a fixed effect, with individual signer and word as random effects. Word length (in letters) was added as a fixed effect (model 4b) to see if its inclusion improved the performance of the model. The formulas for these models can be seen in Table 2.10.

10. It's important to note that there are far fewer long words in the dataset (with upwards of 8 letters) and so these frequencies are less robust than those for words of shorter lengths. See the Table A.1 in the appendix for a table with the frequency counts and percentages for distributions of tokens of different word lengths in the dataset

Table 2.10: Model structures, presented as the *glme4* formula, used to compare the effect of mention number and word length (in letters) on the number of deleted letters.

Model 4a:	NUMBER OF DELETIONS ~ MENTION NUMBER + (1|SIGNER) + (1|WORD)
Model 4b:	NUMBER OF DELETIONS ~ MENTION NUMBER + LETTER LENGTH + (1|SIGNER) + (1|WORD)

The results of the model comparison for the regression models and estimates for each fixed effect can be seen in Table 2.11. The performance of each of the models is compared using an ANOVA, with results showing that the addition of word length as a factor significantly improved the performance of the model.

The analysis of the best performing model, Model 4b, showed a significant relationship between the number of deleted letters and mention number, with a significant difference between the first and subsequent mentions (*Estimate*=-1.324, SE=0.270, Z(616)=-4.874, $p<0.001$), and a significant difference between the second and the subsequent mentions (*Estimate*=-0.793, SE=0.194, Z(616)=-3.833, $p<0.001$), as well the third and the subsequent mentions (*Estimate*=-0.396, SE=0.172, Z(616)=-2.281, p=0.022). This result can be seen in Figure 2.7, showing that fingerspelled words more likely to exhibit a greater number of deletions as mention number increases. Model 4b also showed a significant effect of the length of the fingerspelled word, in letters, on letter deletions (*Estimate*=0.335, SE=0.463, Z(616)=5.972, $p<0.001$), wherein longer words have more deletions.

Together, the deletion analyses shows that letter deletion itself is a robust reduction trend that occurs in the context of repeated fingerspelled word mentions. Not only does the likelihood of fingerspelled words exhibiting a deleted letter increase as mention numbers increase, but so does the likelihood that more letters will be deleted. This trend is influenced by word length, wherein longer words, with more substance that can be targeted for deletion, are more likely to exhibit letter deletions.

Table 2.11: Negative binomial regression model comparison for the analysis of the number of deleted letters across mention numbers, using data from mentions 1 through 6. Estimates are provided with their standard error in parenthesis. Results of an ANOVA comparing model performance are included at the bottom of the table.

	Dependent variable:	
	Number of deleted letters	
	Model 4a	Model 4b
Constant	-1.779^{***}	-3.724^{***}
	(0.252)	(0.463)
Mention>1	-1.313^{***}	-1.324^{***}
	(0.267)	(0.270)
Mention>2	-0.729^{***}	-0.749^{***}
	(0.194)	(0.194)
Mention>3	-0.374^{**}	-0.396^{**}
	(0.173)	(0.172)
Mention>4	-0.050	-0.080
	(0.174)	(0.175)
Mention>5	-0.070	-0.121
	(0.211)	(0.213)
Letter length		0.335^{***}
		(0.059)
Observations	616	616
Log Likelihood	-426.235	-409.962
Akaike Inf. Crit.	870.469	839.925
Bayesian Inf. Crit.	910.278	884.157
Chi-squared		32.545
p-value		$p<0.001^{***}$
Note:	$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$	

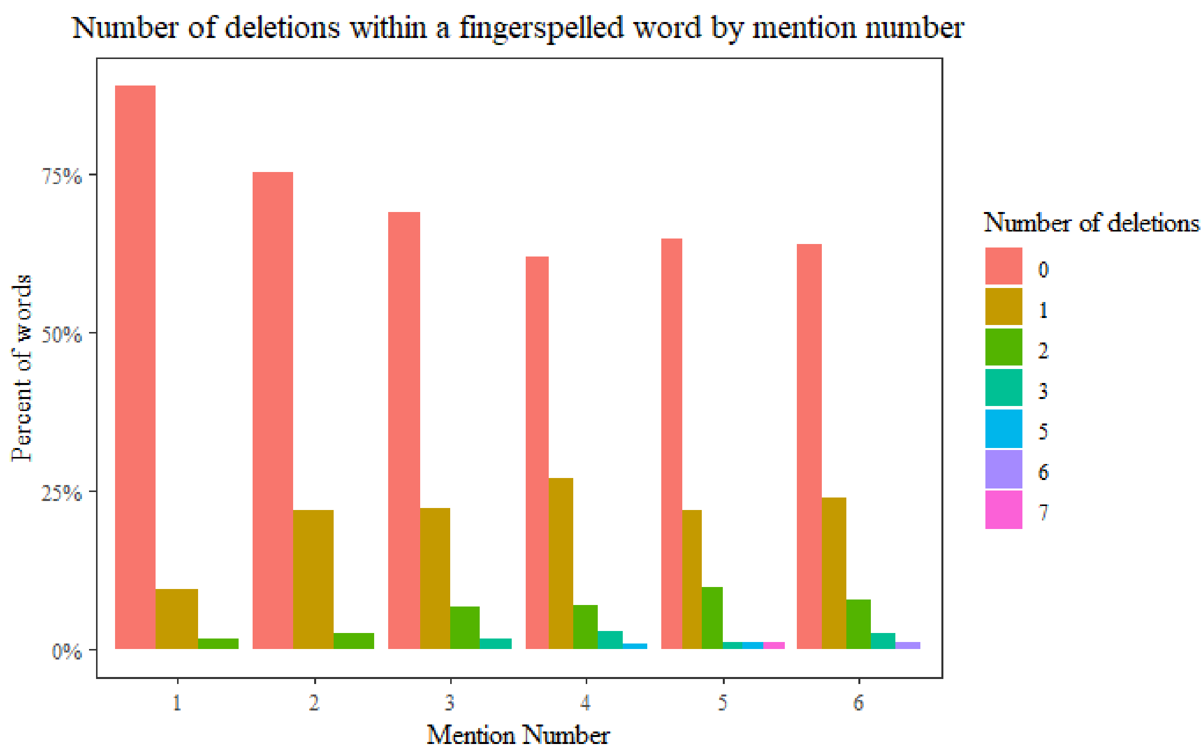

Figure 2.7: Number of letter deletions at each mention, as a percent of the total number of fingerspelled word tokens at each mention (mentions 1-6)

2.5 Discussion

The goal of this chapter was to contribute a more comprehensive view of repetition reduction processes in fingerspelling, while refining our understanding of the factors that shape language production cross-modally. The analyses in this chapter suggest that both gradient and categorical reduction processes occur when fingerspelled words are repeated, changing over increased repetitions. Not only do they add more detail to our understanding of reduction processes in ASL fingerspelling, but the contribution of mention number and between mention distance on duration reduction in fingerspelling also provides new insights into language production models that have been posited to explain reduction processes.

2.5.1 Toward a fuller picture of reduction in fingerspelling

Within the present analysis, reduction processes in the context of repeated mentions were observed along both gradient and categorical variables, with significant reduction seen both in fingerspelled word duration and for letter deletions. The present findings not only confirm trends seen in previous scholarship, but also account for additional types of variation that influence trends in reduction.

Focusing first on trends in duration, the factors that significantly influenced fingerspelled word duration included mention number and the distance between mentions, as well as phrasal position and the presence of letter deletions. Within the analysis, not only did the duration of fingerspelled words significantly decrease across multiple mentions, but mentions that were closer together exhibited a greater degree of duration reduction. This adds detail to the contribution of mention number in accounting for how reduction in duration occurs for fingerspelled words, which in previous scholarship was shown to continue across multiple mentions (Wager, 2012; Lepic, 2019; Thumann, 2012). This also points to the need to study repetition reduction across multiple mentions in other parts of the ASL lexicon, like for core signs (Chapter 3 of the present work) to determine if this magnified reduction effect is a property of the manual-visual modality or of the fingerspelling system. The present results also provide additional insight into the trajectory of repetition reduction, as the degree of reduction did not remain consistent as repetition continued. This is seen in how the effect of individual mention on duration reduction is strongest for early mentions, with no significant additional effect on duration of later mentions (i.e. 3 through 6).

The relationship between mention and duration in fingerspelling is shown to be even more complex when considering the additional dimension of between-mention-distance. The results showed that the degree to which a fingerspelled word reduces in duration is also mediated by the time since it was previously mentioned. This follows findings like those of Rodriguez-Cuadrado et al. (2018), who found this effect for Spanish, but this effect had not yet been documented for fingerspelling.

Additional variation in the duration of fingerspelled words can be accounted for through other factors, including phrasal position and letter deletions. For phrasal position, phrase final tokens showed a significant lengthening effect, a result that is consistent with predictions following from previous research on phrase final duration lengthening in ASL (Brentari and Crossley, 2002; Coulter, 1993; Nespor and Sandler, 1999). While earlier research on the influence on prosodic position on duration in ASL showed this phrase final lengthening effect for core signs, the finding in the present study shows that this effect extends to fingerspelled words. Letter deletion also contributed to the duration patterns in the data, with the presence of letter deletions corresponding to shorter duration. This suggests a relationship between categorical and gradient reduction processes, with full segmental deletion resulting in a greater degree of duration reduction.

Letter deletion, the categorical form of reduction measured in this analysis, was also shown to be a process that occurs in the contexts of repeated word mentions. Within the analysis, deletions were more likely in the context of repeated mentions, with not only the occurrence of deletions increasing, but also the number of the deleted letters themselves increasing at higher mention numbers. This letter deletion effect was shown modulated by word length, where longer words were more likely to exhibit letter deletions, aligning with the finding from Turnbull (2015) on segment deletion and word length in spoken English. This finding is unsurprising, given that longer words have more segmental material that can be deleted and are articulatorily more difficult.

2.5.2 Fingerspelling reduction and language production

Together, the findings on the effect of repetition number and between-mention distance also complicate the role repetition plays in models of language production, suggesting that the binary given versus new distinction assumed in previous accounts (Fowler and Housum, 1987; Bell et al., 2009) is not sufficient in specifying how repetition affects duration cross-linguistically. These results show that word production can be sensitive to not only how many times a word has been mentioned, but also how close it is to its previous mention in discourse.

Focusing on the contribution of mention number to duration reduction, while results show reduction continuing past the second mention, subsequent repetitions do not have the same size of effect on word duration, as the size of the effect contributed by each subsequent repetition decreases as fingerspelled words continue to be repeated. Trends in the deletion of fingerspelled letters also showed that the likelihood of a word containing a letter deletion did not continue to increase at later mentions. The theories of reduction that explain limits in word reduction as due to accommodations for an interlocutor (Jurafsky et al., 2001; Aylett and Turk, 2004) could provide one explanation for why the reduction effect is limited. If the point at which words stop reducing is the same point at which no amount of information in the signal is enough to retrieve the word's identity, then this would indicate that the decrease in duration reduction across mentions is as a result of the signer's accommodation for their interlocutor in order to maintain a comprehensible signal.

Another explanation for these trends can be drawn from theories of word reduction that rely on the amount of contextual information available to determine the predictability of a token (Fowler and Housum, 1987; Jurafsky et al., 2001; Aylett and Turk, 2004; Bell et al., 2009), which in turn determines how much a word reduces. The decrease in the degree of reduction that occurs as repetitions increase could indicate that there is a limit to how much additional repetitions contribute to the predictability of a word. This could be coupled with the effect of distance between repeated mentions, where a larger distance between mentions renders a word less predictable. Another explanation for the effect of distance between repeated mentions can be drawn from Bell et al. (2009)'s theory of reduction where word level activation drives articulatory planning and, following this, speed of articulation. If lexical activation decreases over time, then this provides another potential explanation for the slower articulation of mentions thatare farther from their antecedent. While the present findings do not provide clear answers as to what mechanisms drive the effect of mention number and between mention distance on duration, although a number of explanations have been offered, they provide a more enriched conceptualization of repetition's contribution within models of language production.

From a cross-modal perspective, the findings from the fingerspelling production analysis also complicate the role of mention number in contributing to reduction. Regardless of the exact mechanisms posited within the theoretical explanation, the duration results suggest that the conceptualizations of the contribution of given versus new information to linguistic models of the factors that influence word reduction should be made richer, including more detail than whether a word has or has not been mentioned. Although research on speech shows reduction occurring only between first and second word mentions (Bell et al., 2009; Vajrabhaya and Kapatsinski, 2011), duration reduction was found to continue past second mentions in the current study. These findings then suggest that language users can utilize a more complex set of information relating to mention number than was previously assumed.

Rather than simply the given-new binary, discourse mention's contribution to a word's predictability within discourse includes not only how many times it has been mentioned, but also the length of time since the previous mention.

The present analysis has shown that language users have the capacity to use detailed information about word mentions, like number of mentions and distance between mentions, in language production. The difference between some of these findings and those from research on spoken languages could be attributed to a variety of factors, including the articulatory complexity of fingerspelled words or their articulation in the manual-visual modality. Comparison to reduction patterns in core signs (Chapter 4 of this dissertation) as well as to reduction patterns across modalities, for example, in gesture, could provide additional insights into the factors shaping this difference.

2.6 Conclusion

The present chapter's findings confirm previous work on fingerspelling reduction in ASL, while providing additional insights into the trajectory of reduction across mentions and letter deletions. At the broadest level, they show that the tendency for repeated fingerspelled words to continue to reduce past their second mention, noted in previous smaller studies, appears to be robust, as does the tendency for letters to be deleted within the context of repetition. The analysis also shows that the variation in token duration across mentions can at least partially be accounted for through phrasal position, the presence of deletions, and that increased distance between mentions modulates duration reduction effects.

Together, this presents an even more detailed picture of fingerspelled word reduction: one in which gradient and categorical reduction processes both occur in the context of discourse mentions and are influenced by a variety of factors. This not only confirms, but expands upon previous findings on repetition reduction and local lexicalization that showed categorical processes, like deletion (Brentari, 1998; Wager, 2012) and gradient processes, like a decrease in duration (Wager, 2012; Thumann, 2012; Lepic, 2019), as features of repetition reduction. This analysis also provides a more complex cross-modal picture of what information is available to language producers in production.

Although the present study has noted differences in the degree to which words reduce in fingerspelling when compared to spoken English, it is not clear how much of this difference is an effect of modality (spoken vs. signed) or is an effect of the properties of the fingerspelling system itself. This can begin to be addressed by comparing fingerspelling reduction to how reduction is realized in core signs. Additionally, improved understanding of which models best explain reduction patterns cross-linguistically can be gained through expanded study of reduction effects in ASL, looking not only at the production but also the perception of these reduced forms, as this could provide insight into the degree to which language production is mediated by accommodation to an interlocutor. While these questions remain, the present study has provided a starting point from which to explore other ways repetition reduction is realized in fingerspelling, as well as how properties of fingerspelling or modality contribute to the repetition reduction effect.

CHAPTER 3

REPETITION REDUCTION IN CORE SIGN PRODUCTION

3.1 Introduction

This chapter examines repetition reduction processes for core signs in ASL, with the goal of addressing not only the different ways that these signs reduce when repeated, but also beginning to explain the factors that shape the realization of reduction in core signs. It forms part of a wider effort to describe systematic phonetic and phonological variation in sign languages, while contributing to knowledge about the pressures that shape linguistic systems across modalities.

Core signs, the focus of this chapter, are comprised of a distinct set of temporal and articulatory properties which allow for multiple dimensions where reduction can occur. Although in sign language research, reduction processes have been identified for core signs, spanning a number of the articulatory parameters, minimal attention has been given to repetition reduction in particular. Examining reduction patterns for this part of the ASL lexicon through the context of increased predictability offered by repetition can then lead to additional insight into how the articulatory characteristics of a linguistic system shape reduction processes.

Core signs in ASL are composed of multiple parameters articulated simultaneously (Stokoe, 1960). Variation in the articulation of core signs can exist along each of these articulatory dimensions, encompassing their duration, handshape, movement, and location[1]. While previous research on phonetic and phonological variation in sign languages has shown patterned ways that various factors influence the phonetic and phonological shape of signs, this chapter will specifically focus on how repeated mentions in discourse impact reduction patterns along

1. Although non-manual markers are often considered one of the parameters of core signs, this investigation will be focusing on variation along the manual articulators, leaving reduction in non-manuals to future work.

a number of these different dimensions.

Here, reduction is discussed as a form of reduced prominence or articulation that can encompass smaller or shorter articulatory movements that may not fully reach their citation form or may disappear entirely. While reduction arises in a number of different contexts, this chapter narrows in on how the increased predictability offered by repeated discourse mentions influences reduction. This, in turn can contribute to our understanding of the mechanisms behind language production. Specifically, if reduction is driven by pressure to produce language more efficiently, but is also influenced by the way that reduction processes impact comprehension[2], as is argued in some accounts (Lindblom, 1990; Aylett and Turk, 2004; Fowler and Housum, 1987), then by examining these reduction patterns we can gain further insight into how these pressures shape linguistic systems across modalities.

I examine how discourse mention influences reduction in core signs through a corpus analysis, using repeated sign mentions from two corpora in ASL. The properties of the core signs investigated here encompass sign duration, the movement repetitions present in some signs, and sign location. Studying reduction for each of these properties of signs will provide new perspectives on both gradient and categorical forms of reduction, providing a more comprehensive picture of reduction in core signs by looking at multiple dimensions of their structure. Also tested is the way that these variables interact with other factors that can influence patterns along these dimensions, including phrasal position and the temporal distance between repeated mentions.

3.2 Background

Although, in ASL, simultaneous organization is a property of many parts of the lexicon, this chapter will only be focusing on reduction processes as they occur for core signs in ASL, also

2. For more elaborated discussion of theories positing general mechanisms behind reduction processes, see Chapter 1.

referred to as the frozen lexicon (McDonald, 1985; Brentari and Padden, 2001). Core signs are defined here as those that are standardized in their form and their meaning. They have a relatively stable citation form and are typically those that can be found in a dictionary. This is in contrast to classifier constructions, which which vary considerably in their form and have no single, canonical use. It is also in contrast to fingerspelling, which is restricted in its domains of use and articulation.

Signs are comprised of several temporal and articulatory properties that can undergo reduction, including their duration in time and their configuration along each of the phonological parameters. The phonological structure of signs is typically described as comprising a distinct handshape, location, and movement[3] (Stokoe, 1960). The handshape of a sign is the configuration of the manual articulator or articulators, for two handed signs. Movement describes the way that the articulators move in space, encompassing both larger path movements, in which the proximal joints closer to the body articulate movements of the arms through space, and smaller local movements, where more distal joints articulate changes in the orientation or configuration of the hand. (Brentari, 1998). Movements within a sign can also vary in the number of times they are repeated during the articulation of a single sign. The location of a sign is the area where a sign is articulated, whether this is on the body, head, face, non-dominant hand, or in the neutral space in front of the signer. While many of these dimensions can exhibit reduction, only a subset of these will be the focus of the present analysis, encompassing the duration of signs, sign movement, and sign location.

Although the focus of the present investigation is specifically on repetition related reduction, this form of reduction is related, within wider framings of reduction processes, to reduction in contexts of higher predictability. As elaborated in more detail in Chapter 1, there is a cross-linguistic trend in which more predictable elements in language exhibit increased reduction (Aylett and Turk, 2004; Jurafsky et al., 2001; Fowler and Housum, 1987;

3. Some signs are additionally specified for a non-manual component

Bell et al., 2009; Turnbull, 2015; Lam and Watson, 2010; Hoetjes et al., 2014; Vajrabhaya and Kapatsinski, 2011; Rodriguez-Cuadrado et al., 2018). While the present analysis will focus on the context of increased predictability offered by repetition, which has received considerably less attention in scholarship on reduction in sign languages, reduction processes outside of repetition may provide a starting point for investigations into repetition reduction for core signs in ASL. Previous findings from research about both predictability-based reduction and reduction more broadly in sign languages will be used to motivate the study of the particular properties of signs that are central to this analysis, as well as inform predictions regarding how reduction might be realized in the context of repetition.

3.2.1 Duration variation in core signs

Sign duration was selected as one of the primary metrics for reduction studied in this analysis, as this measure encompasses other types of reduction, such as increased speed of articulation, smaller articulatory movements, as well as any coarticulation[4] and deletions. It also provides a gradient measure of reduction that can be analyzed for signs that vary across a range of their articulatory properties. A number of factors have been shown to influence variation in the duration of signs. Previous studies of sign duration have addressed how sign duration and rate compares to speech (Grosjean, 1979; Bellugi and Fischer, 1972), the relationship between duration and signing rate (Wilbur, 2009a; Grosjean, 1979), the effect of stress on sign duration (Wilbur and Nolen, 1986; Wilbur and Schick, 1987), the relationship between phrasal position and signing rate (Brentari and Crossley, 2002; Nespor and Sandler, 1999; Coulter, 1993; Grosjean, 1979), the impact of frequency (Börstell et al., 2016), and the impact of repetition (Grosjean, 1979; Hoetjes et al., 2014). While not all of these variables can be controlled for in the present analysis, they provide an idea of the types of factors that influence sign duration and can inform the design of the present analysis of duration

4. For coarticulatory processes along the dimension of handshape, see Cheek (2001), on ASL, and Ormel et al. (2017), on NGT.

variation in the context of repeated discourse mentions.

The properties of sign duration that have received attention outside of the realm of predictability-related effects are found in the context of signing rate, linguistic stress, and phrasal position. Sign duration is subject to rate variation, wherein for example, signs are shorter at faster signing rates and longer at slower signing rates (Grosjean, 1979; Wilbur, 2009a). There is also considerable evidence from previous scholarship showing that signs in ASL lengthen phrase finally. This was shown in early work, like that of Grosjean (1979), as well as confirmed in later studies (Brentari and Crossley, 2002; Nespor and Sandler, 1999; Coulter, 1993) that showed a robust phrase-final lengthening effect. Lastly, although stress impacts other features of core signs and might be predicted to influence duration, it has been shown that the duration of sign syllables is not significantly impacted by linguistic stress (Wilbur and Nolen, 1986; Wilbur and Schick, 1987).

Predictability-based reduction effects on duration, such as those related to sign frequency and repetition reduction, while not addressed extensively for ASL, have been tested in research on other sign languages. One of the well-studied predictability based-reduction effects relates to the frequency of a form, wherein more frequent forms are more predictable. These more frequent forms, in turn, have been shown to be shorter in length than less frequent forms (Zipf, 1949; Bybee and Hopper, 2001; Bybee and Scheibman, 1999). Although frequency effects on duration have not been tested extensively for ASL, looking outside of ASL, reduction as it relates to sign frequency was studied for Swedish Sign Language (Börstell et al., 2016). Using a corpus study, Börstell et al. (2016) tested the relationship between the duration, frequency, and parts of speech of the signs in a corpus. Results showed that the global frequency of a sign correlated with its duration, where more frequent signs were shorter (Börstell et al., 2016). Additionally, they found that function signs were significantly shorter than content signs.

Sign duration and repetition have also been shown to be related, with previous work showing duration reduction in the context of repetition. The relationship between sign duration and repetition was examined for the Sign Language of the Netherlands (NGT). Hoetjes et al. (2014) examined duration differences between the first and third mentions of signs in NGT using a picture matching task. Within the study, participants were tasked to describe a picture grid to an interlocutor, which elicited repeated productions of signs referring to the images within the grid. Their results showed that the duration of signs at their first mention was significantly longer than at their third mention, demonstrating that repeated core signs exhibit duration reduction. Although not the focus of its analysis, an early study on the temporal properties of signs in ASL within Grosjean (1979) also found that signs are shorter on their second occurrence within narrative retellings of a story, but only when controlling for phrasal position (i.e. whether a sign was within a sentence or at the end). Neither of these studies tested how mention number itself impacted sign duration, only looking at length differences between two different mentions namely first vs. third mentions (Hoetjes et al., 2014) and first vs. second mentions (Grosjean, 1979).

Studying whether multiple mention numbers have a distinct impact on sign duration, accounting for the influence of factors like phrasal position and distance between repeated mentions, will provide a more complete picture of how sign duration is mediated by other properties of discourse. Following findings from Hoetjes et al. (2014) and Grosjean (1979), showing repetition reduction effects for core signs, I predict that core signs will reduce in their duration when repeated in the present corpus analysis of ASL.

3.2.2 Movement repetitions

Movement repetitions, or the internal repetitions of signed syllables[5], were selected as a variable for study within this analysis that might exhibit reduction. Movement repetitions[6] are one aspect of the structure of core signs that can occur sequentially and are integral to the phonological make-up of many ASL signs. Although only a subset of signs in the ASL lexicon are articulated with sequential repeated movements, these provide an area to test segment deletion for core signs, providing a comparison point to reduction processes involving categorical deletion across the ASL lexicon (ie. to ASL fingerspelling) and across modalities (ie. to speech). For example, there is a tendency for fingerspelled letters to delete as fingerspelled words are repeated (Brentari, 1998; Channer, 2012; Wager, 2012) and segmental deletion in spoken English has been shown to be more likely in contexts of higher predictability (Turnbull, 2015). Repeated movements can provide, in addition to redundancy that might support sign comprehension, morphological information, and so studying reduction along this dimension of sign structure may indicate ways that reduction impacts information available in the linguistic signal.

Phonological movement repetition is also related to processes of reduplication in sign languages, and there exists some degree of terminological variation encompassing phenomena in sign languages where the entirety or part of a sign is repeated. For example, Borstell (2011, p.8) defines reduplication as “a morphological process in which there is a repetition of phonological content within a word/sign." Because reduplication and repetition are closely related but distinct in terms of their relationship to linguistic structure, it is crucial to carefully define the distinction between the two. The approach I take here defines *repetition* as the process occurring at the phonetic and phonological levels in which phonetic material

5. Here, I am referring to syllables as movements, but consider the two terms to be interchangeable in the context of this analysis.

6. These have also been discussed as movement cycles (Klima and Bellugi, 1979), wherein syllables within a sign are repeated. Terminologically, they share the same meaning, at least for the purposes of this analysis. “Movement repetition" will be used for the sake of consistency within the present dissertation.

is articulated multiple times. In contrast, I define *reduplication* as a morphological process in which repetition is employed in articulating differences in meaning. As such, all reduplication involves repetition, but not all repetition involves reduplication. The present analysis will focus on the repetition of movements in ASL.

Phonetic repetition within a sign varies in how it is realized articulatorily depending on the phonological properties of the sign itself. Repetition occurs along a sign's movement, which changes depending on the structure of a particular sign and influences the size of the movement and joints used in articulation. For example, a path movement, such as a full circular or straight movement, can be fully repeated, employing movements of the shoulder and elbow joints. Smaller, local movements can also be repeated[7], such as changes in aperture involving the finger joints or a radio-ulnar movement resulting in an orientation change. Attested forms of repetition have been shown to be restricted by the phonological form of a particular sign where, for example, if signs are comprised of two distinct movements, repetition in the context of reduplication can only apply to the second movement of the sign (Sandler, 1989).

In ASL, repetition is a feature of some lexical items that can also occur in the context of morphological reduplication. The citation forms for a subset of core signs in the lexicon involve repetition, where the repetition is part of the sign's lexical entry, without which it would be ill-formed. For example, within the ASL lexicon, movement repetition marks the difference between some noun-verb pairs, with a repeated movement characterizing the noun (Supalla and Newport, 1978). Within the realm of morphology, reduplication is also commonly employed to convey aspectual information (Klima and Bellugi, 1979), and it has been analyzed as indicating aspectual information, such as durative and interative meaning (Anderson, 1982). In addition, the plural form of nouns can be formed through the reduplication of the form of a sign (Fischer, 1973; Wilbur, 2009b). This use of repetition expands

7. Trilled movements, involving small, uncountable movements of the manual articulators will not be considered repetitions within this analysis due to their uncountable nature.

outside ASL, as cross-linguistic descriptions of reduplication tend to show it to be iconic in its usage, often expressing repetition of an action or plurality of a referent (Borstell, 2011; Wilbur, 2009b)[8]. As such, any phonetic or phonological changes that impact the articulation of this reduplication have the potential to result in a change in the information available within the linguistic signal.

The relationship between internal repetitions and reduction has received little attention in scholarship on sign languages, but research has addressed some of the factors that do effect movement repetition-related variation. As one example, Wilbur and Schick (1987) and Wilbur and Nolen (1986) noted a pattern in which signers would increase the number of repetitions within signs as a cue for stress[9]. There is some variation reported in this strategy as a cue to mark stress, dependent in part on the type of movement, wherein signs without a path movement were more likely to increase the number of internal repetitions when stressed. While in the opposite direction of a reduction process, this shows that signers modulate the number of movements within a sign in patterned ways within linguistic discourse. Although movement repetition reduction in the context of repeated discourse mentions has not been investigated[10], this demonstrates that discourse factors can shape tendencies in sign-internal repeated movements.

Outside of research on sign languages, findings from spoken languages have shown that segments are more likely to delete in contexts of higher predictability (Turnbull, 2015). This finding, combined with results from Wilbur and Schick (1987)'s research showing patterned variation in cyclic movements in different contexts, lead to the prediction that, for signs with internal repetitions, the number of internal repetitions will decrease in the context of

8. See Wilbur (2009b) for a more elaborated discussion of the uses and history of scholarship on morphological reduplication in ASL

9. It is notable that although repetitions increased in the context of linguistic stress, it was not the case that individual syllables in these stressed forms were consistently longer than in unstressed forms.

10. To my knowledge, there have been no previous studies on repetition reduction as it applies to internal movement repetitions, but if so this will provide additional empirical insights into this phenomenon.

repeated sign mentions. Additionally, I predict an interaction between discourse mention effects on duration and the reduction of repeated internal movement segments. Because words that have internal repetitions can lose entire movement segments, this leads to the additional prediction that these words will show a greater loss in duration in comparison to signs that lose no internal movement repetitions.

3.2.3 Location variation and reduction

Reduction in sign languages also occurs along the parameter of location, providing another variable that will be analyzed in the present analysis. Previous work on location variation can provide insights into what types of reduction patterns in location might surface in the context of repeated discourse mentions. Variation in location has been analyzed in the context of signing rate, increased frequency, and linguistic stress. This work is not only suggestive of the conditions that are conducive to reduction, but also indicates which articulatory properties might be targeted by reduction in the context of repetition.

Like with duration, the relationship between sign frequency and reduction has been examined for location. Schembri et al. (2009) examined location variation in Australian Sign Language (Auslan) and New Zealand Sign Language (NZSL) through a large corpus study. Focusing on signs articulated at or above the forehead level, results from their study suggested that sign frequency influences the likelihood of sign lowering, with more frequent signs being more likely to appear in lower, non-citation forms. Similarly, for ASL, Lucas et al. (2002) found an effect of lexical category on the likelihood of sign lowering in a sociolinguistic corpus study targeting signs articulated on the forehead. In their study, focusing on the sociolinguistic factors that influence sign location, Lucas et al. (2002) found that, in ASL, function signs are more likely to be lowered than content signs like nouns and verbs. This suggests a frequency effect on sign location, as function signs tend to be more frequent. In another corpus study, specifically examining gradient and categorical variation in signs articulated at the head, face, and neck, Russell et al. (2011) found that lexical frequency effected the vertical displacement of signs, with more frequent signs articulated in lower locations.

Phonetic variation in location has also been shown to be modulated by signing rate. A series of studies using motion capture technology (Mauk, 2003; Tyrone and Mauk, 2010, 2012) have examined signing rate effects on phonetic variation in sign location. Sign reduction along the dimension of location was shown in Mauk (2003), who found that signs signed in faster signing rates were more likely to be lowered, or undershoot their location, if they were higher in the signing space, while signs articulated lower in the signing space were more likely to raise in their location at faster signing rates. Studies that followed this examining reduction in sign location showed that signs articulated at the locations on the head, such as at the forehead level, tend to lower at faster signing rates (Tyrone and Mauk, 2010), as well as more generally shift their location in a central direction in the signing space (Tyrone and Mauk, 2012).

While much work on sign lowering and reduction has specifically focused on signs articulated at higher locations on the head, expanding beyond forehead located signs, Russell et al. (2011) found that lowering occurred the most in signs articulated at the forehead, with less lowering occurring for signs articulated at lower locations on the face, including the nose, mouth, chin, and neck. Although signs articulated on the forehead were those where the most lowering occurred, a significant amount of lowering was seen for signs articulated at the mouth and neck also showed lowering tendencies. This difference was attributed in part to the pressure towards undershoot in order to reduce the articulatory effort involved in moving an articulator greater distances. This could have driven more sizeable reduction processes in the locations articulated farther away from the center of the signing space. It was also attributed to articulatory planning on the part of the signer, taking into account somatosensory feedback that might constrain how reduction can occur (ie. a sign articulated on the forehead will not lower to obscure or contact the eyes). Within their study, Russell et al. (2011) also compared categorical and continuous reduction processes, finding gradient variation in location, rather than full changes in phonological sign location, to be more common.

Loss of contact between the manual articulators and locations on the body has also been treated as a form of reduction. Studies looking at reduction in the context of the signing of Parkensonian signers has shown reduced signing appearing as both the distalization of the joint articulating a sign's movement and loss of contact with the body (Brentari and Poizner, 1994; Brentari et al., 1995; Poizner et al., 2000). Loss of contact with the body, as a form of reduction, was also mentioned in early work on the topic from Liddell and Johnson (1989) who suggest that sign lowering in casual signing may occur along with a loss of contact with the head. Although loss of contact will not be the focus of the present analysis, it demonstrates another way that signs can undershoot their location by not reaching their citation form. This supports predictions that reduction processes may involve minimizing articulatory effort in such a way that less movement is required, resulting in processes of reduction wherein signs do not reach their citation location specification.

As location is a variable that has been shown to reduce across a number of contexts, the higher predictability environment of repetition can provide a fuller picture of the situations in which location will vary in a semi-predictable way. Although sign reduction in location has been shown in the contexts of higher signing rates, it remains untested whether signs are more likely to exhibit reduction in location in the context of repetition. Given that reduction in location has been seen in many other contexts, it might be assumed that location reduction may occur in the context of repetition as well. However, work by Turnbull (2017) has demonstrated that reduction processes are not always uniform across distinct contexts and different types of predictability correspond to overlapping but not necessarily uniform types of reduction. Analysis of location variation as a result of repeated mentions will then test

Table 3.1: Summary of predictions for sign reduction in the context of repeated mentions

Variable	Predictor	Prediction
Duration	Mention number	Duration will decrease in the context of repetition
	Distance	Duration will increase as distance increases
Movements	Mention number	Deletion will be more likely in the context of repetition
Location	Mention number	Repeated signs articulated lower on the body will raise

whether sign reduction in location extends to the context of repetition.

Given that much of the empirical work on location reduction has focused on signs articulated at or near the head, the present investigation will focus on signs articulated on the body. The motivation for studying this variable follows from the work on changes in sign location as an effect of signing rate (Tyrone and Mauk, 2010, 2012; Mauk, 2003), showing signs centralizing rather than only lowering. When compared to their first mentions, I predict that repeated signs articulated on the body will centralize, with those articulated lower on the body raising. This prediction, along with those for the other variables targeted in this analysis, can be seen in Table 3.1.

3.3 Methodology

3.3.1 Corpus data

Data for the analyses of repetition reduction in core signs is drawn from two sources: an online corpus and a corpus of narratives elicited in a lab setting. The corpus of narratives was selected to allow for the comparison of the same lexical items across signers and to target signs that have the relevant properties of the variables that will be studied in the core sign analysis, including repeated movements and locations on the body. In addition, it allows for an examination of repetition reduction processes in a more controlled setting.

In contrast, the online corpus comprises a set of publicly available online videos. The motivation for the use of a corpus drawn from online videos from ASL users stems from the more naturalistic nature of the data, the amount of data available, and the wider swath of the signing community represented in the sample. This is additionally supported by the argument that data from this platform is more naturalistic and unconstrained by biases and constraints introduced when gathering data in a controlled laboratory setting (Hou et al., 2020). The videos in the online corpus are the same as those used in the fingerspelling analysis (Chapter 2) and thus provide not only a point of comparison to reduction patterns in the more controlled narrative corpus to see if they remain robust outside of a lab setting, but also will also be used to compare reduction patterns in signs to those in fingerspelling in Chapter 4 of the present work.

Tweety corpus: Composition and signers

The Tweety corpus is a video corpus of narratives in ASL, collected in a laboratory setting. In eliciting the narratives for the corpus, signers of ASL were asked to recount the Tweety cartoon “Canary Row." Canary Row is a cartoon that includes multiple short scenes in which a cat, Sylvester, attempts to catch the bird Tweety. In recounting the Canary Row narratives, signers produce different sets of repeated core signs across their descriptions of the video vignettes. The dataset includes narrative retellings of seven vignettes, resulting in seven distinct narratives per signer. The narrative responses vary in length, ranging from 30 seconds to 2 minutes. In total, the signs annotated for this dataset include 879 tokens of 75 different signs, used by multiple signers in different narrative recountings of the Tweety vignettes.

The corpus comprises narratives from 14 adult signers of ASL, collected in two different data elicitation sessions in the years 2006 and 2012. 11 of the signers acquired ASL before the age of five, while 3 of the signers acquired ASL after this age. 13 of the signers were right hand dominant while one signer was left hand dominant. There were 7 female and 7 male signers.

Online Corpus: Composition and signers

The online corpus comprises a set of naturalistic videos, drawn from publicly available videos on online platforms such as *Youtube.com* and *DeafVideo.tv*. The videos in the online corpus were selected from those used previously from the study of fingerspelling in Shi et al. (2019), and comprise a subset of these. The videos within the corpus encompass a variety of genres and a wide range of topics, including vlogs (video blogs) about politics, cooking, and health, as well as news and educational videos in ASL. Additionally, they included a range of signing styles, from semi-scripted to conversational. This dataset encompasses 1009 individual tokens of 184 signs. Motivated by previous findings from speech (Bell et al., 2009) and fingerspelling (Lepic, 2019) showing high-frequency, function words (ex. IF, BUT) to be less likely to undergo reduction, only content words, encompassing a variety of nouns and verbs, were selected for inclusion in the corpus.

Signs from 30 different signers are included in the corpus. 26 of the signers were right hand dominant (ie. signed primarily with their right hand), while 4 of the signers were left hand dominant. Due to the nature of the online videos, metadata regarding demographics (gender, race, geographic distribution) of the signers was not available.

3.3.2 Annotation

Data annotation, completed in ELAN[11] (Lausberg and Sloetjes, 2009), captured the timing and structural properties of repeated signs within the dataset. Annotations encompassed the targeted dependent variables including sign duration, the number of internal movements, sign location, and phrasal position. The same annotation schema was used for each corpus. The ELAN annotation schema used to annotate these variables can be seen summarized in Table A.2 within the appendix. To simplify the annotation schema, and because the present study

11. Elan is a multimedia annotation tool developed at Max Planck Institute for Psycholinguistics, The Language Archive, Nijmegen, the Netherlands (https://tla.mpi.nl/tools/tla-tools/elan/).

makes no predictions about differing behaviors between the dominant and non-dominant hands, annotations only capture the configuration and movement of the dominant hand.

The temporal boundaries of each sign in the dataset span the duration of the entire sign, beginning when the hand settles into the initial handshape of the sign and ending as the hand relaxes out of the final handshape. In cases where the initial or final handshape did not provide a reliable cue for the temporal boundaries of the sign, other cues, such as the lowering of the hand from its position of articulation or a shift in non-manual markers, were used. This occurred in cases where a sign was held while the other hand articulated a new utterance or if the handshape remained tense, but began moving into another sign. The duration of each sign token was calculated in milliseconds. For each sign in the dataset, the presence and number of internal movements was annotated. Internal movements included repeated path and local movements, although uncountable internal movements such as finger wiggles were not annotated within the present analysis.

The location coding system captures specific distinctions in the articulation location of the sign. Annotations specify not only the major location (the head, body, arm, hand, and neutral space), but also the minor location for the major location of interest (body located signs). Location specifications were made to be as small as possible while still reliably located and measured in a comparable way across sign tokens and signers. Location was determined from the point when the dominant hand and passive location were nearest to one another. For body-located signs, annotations captured distinctions in location height, encompassing the neck, shoulder, chest, torso, and lower torso[12]. As such, this system captures categorical, but not continuous, location differences. Annotations were included for the starting and ending locations for each sign.

Annotations were also included for the phrasal position of each sign, distinguishing between phrase-final signs and sign in other positions within the phrase. The inclusion of

12. Annotations do not specify horizontal distinctions in body location, such as ipsi- and contralateral setting distinctions.

Table 3.2: Table summarizing the variables annotated within the corpus of core signs.

Variable	**Criteria for inclusion** (citation form)	**Measure**
Duration	All	Duration (milliseconds)
Repetitions	Has repeated path or local movement	Number of repetitions, movement type (path, local)
Location	Articulated on the body	Place and setting distinction
Phrasal Position	All	Phrasal position (final or non-final) determined by adjacency to boundary

phrasal position in the analysis was to account for any variation in the data that could be attributed to phrase-final lengthening, an effect that has been documented previously for core signs in ASL (Coulter, 1993; Brentari and Crossley, 2002; Wilbur, 1999; Grosjean, 1979). Phrasal position was annotated by a token's adjacency to a phrasal boundary, as indicated by a significant pause, dropping the hands, or the beginning of a new phrase. A summary of all of the annotated properties can be seen in Table 3.2.

Annotation was completed by the researcher and annotation reliability calculated by comparing the annotations to those of a trained research assistant at the University of Chicago. After training the research assistant on the annotation schema, annotation reliability was calculated by having them annotate 10% of the dataset, which was then used to calculate reliability. Reliability was calculated for annotations encompassing sign identity, phrasal position, mention number, and the number of internal repetitions. The Cohen's Kappa was 0.96 between annotators.

3.4 Analyses & Results

The present analysis focuses on repetition reduction as it applies to a gradient measure, sign duration, and to two categorical measures, including the number of internal movements and categorical variation in sign location. The current analysis is divided into three sections: The first section of the analysis analyzes how the duration of core signs varies across repeated mentions, as well as how this is influenced by the distance between discourse mentions and the loss of internal movement segments. The second section of the analysis focuses on reduction in the number of repeated mentions within signs, looking directly at how the likelihood of a loss in movements and patterns in the number of movements change across mention numbers. The third part of the analysis looks at variation in location in the context of repeated mentions, focusing on locations articulated on the body, and presents a case study of one sign to exemplify how this is realized.

3.4.1 Duration reduction analyses

Sign duration analysis 1: Reduction over mentions 1-6

The first part of the duration analysis for core signs tests the trajectory of duration reduction across multiple mentions, as well as how this is influenced by phrasal position. Because duration differences could also potentially result from differences between the datasets and conditions under which the data was collected, I data source (the online corpus or the Tweety corpus) was also included as a factor in the analysis.

A summary of the descriptive statistics, showing mean duration across each of the factors examined in the first part of the analysis, can be seen in Table 3.3. The duration values in the data were positively skewed (skewness = 1.658, kurtosis = 7.212) and so duration values were log transformed for the statistical analyses to normalize their distribution.

Trends in duration differences between signs over repeated mentions 1 through 6 were analyzed using linear mixed effects regression models. The influence of each of the factors of interest was tested by comparing the performance of the models as each factor was added as a fixed effect. To test whether mean duration significantly decreased after each mention, mention number was coded using five level Helmert Contrast Coding. The five level coding contrast compares the mean core sign duration of mentions 1 though 6, comparing the mean

Table 3.3: Average duration values (in milliseconds) for sign duration at each mention number. The descriptive statistics show means along with standard deviations in parenthesis. Averages are separated into each of the factors analyzed in the analyses (data source, phrasal position, and presence of a decrease in movements with respect to first mentions).

Mention #		1 [n=516]	2 [n=516]	3 [n=358]	4 [n=248]	5 [n=158]	6 [n=104]
Total		423.817	317.070	311.251	299.732	310.892	305.154
		(230.113)	(171.622)	(153.525)	(139.014)	(141.442)	(151.515)
Source	Online	486.731	365.579	349.123	325.237	322.290	314.168
		(255.416)	(181.635)	(164.493)	(138.291)	(147.044)	(151.138)
	Tweety	376.738	279.975	256.020	252.827	278.365	269.523
		(196.862)	(153.844)	(116.0131)	(128.392)	(119.812)	(151.330)
Position	Final	625.706	510.313	443.637	424.446	415.718	456.500
		(283.673)	(202.832)	(163.142)	(156.859)	(141.256)	(172.037)
	Non-final	364.294	270.523	279.200	270.425	284.269	259.750
		(172.434)	(124.674)	(132.796)	(116.897)	(129.040)	(110.760)
Movement decrease	Absent		334.175	333.3254	323.300	334.708	338.291
			(172.944)	(149.489)	(131.844)	(138.436)	(146.496)
	Present		266.023	256.715	232.343	251.088	230.593
			(157.522)	(150.410)	(137.898)	(132.239)	(137.236)

of each level with the combined means of the subsequent levels. The additional factors included in the analysis were treatment coded. Phrasal position was coded with a two way contrast, final or non-final, with final as the baseline. Data source was also coded with a two way contrast, Tweety or Online, with Tweety treated as the baseline.

The model comparison was constructed by first using a base model that looked at the effect of mention number, included as a fixed effect, on sign duration. Random effects were included for individual signer and sign (Model 1a). The *lme4* formula for the base model is as follows:

$$\textsc{duration} \sim \textsc{mention number} + (1 \mid \textsc{signer}) + (1|\textsc{sign})$$

Each factor was then added to the model incrementally as a fixed effect to see if its addition improved model performance. The source of the data was first added as a fixed effect (Model 1b) to see if the fit of the model improved and then phrasal position was added (Model 1c). The model summaries can be seen in Table 3.4.

Table 3.4: Model structures, presented as the *lme4* formula, used to compare the effect of mention number, data source, and phrasal position on the duration of signs.

Model 1a:	DURATION ~ MENTION NUMBER + (1|SIGNER) + (1|SIGN)
Model 1b:	DURATION ~ MENTION NUMBER + SOURCE + (1|SIGNER) + (1|SIGN)
Model 1c:	DURATION ~ MENTION NUMBER + SOURCE + PHRASAL POSITION + (1|SIGNER) + (1|SIGN)

.

For the first analysis of the duration of core signs, using data from mentions 1-6, the estimates for each of the predictors can be seen in Table 3.5[13]. Table 3.5 also shows the results of the model comparison, in which the performance of each subsequent model is compared with an ANOVA. Model 1c best accounted for variance in the data and will be used to discuss the results of the factors included in the model.

Focusing on Model 1c, results show that the difference between the first mention and subsequent mentions of core signs is significant (*Estimate*=0.148, SE=0.009, T(1887)=16.245, p<0.001), as well as the difference between the second and subsequent mentions (*Estimate*=0.032, SE=0.010, T(1887)=3.263, p=0.001). The value of the estimate decreased between the two comparisons. The difference between the duration of the third and subsequent mentions, the fourth and subsequent mentions, and the fifth and subsequent mentions were not significant in the model.

The addition of information about the source of the dataset,online or Tweety, significantly improved model performance, accounting for variation in the duration of signs, as did the addition of the phrasal-position contrast. Results from Model 1c show a significant negative effect of data source (*Estimate*=-0.071, SE=0.025, T(1887)=-2.878, p=0.006), indicating that signs in the Tweety dataset were significantly shorter. This difference can be seen plotted in Figure 3.1.

The analysis also showed a significant positive effect for signs in final positions (*Estimate*=0.194, SE=0.010, T(1887)=18.959, p<0.001), confirming a significant phrase-final

13. Regression tables were generated using the R package Stargazer (Hlavac, 2015).

Table 3.5: Regression model comparison for analysis of sign duration using data from mentions 1 through 6. Estimates are provided with their standard error in parentheses. Results of an ANOVA comparing model performance are included at the bottom of the table.

	Dependent variable:		
	Duration (log transformed)		
	Model 1a	Model 1b	Model 1c
Constant	2.479***	2.508***	2.455***
	(0.015)	(0.016)	(0.015)
Mention>1	0.155***	0.156***	0.148***
	(0.010)	(0.010)	(0.009)
Mention>2	0.033***	0.035***	0.032***
	(0.011)	(0.011)	(0.010)
Mention>3	0.017	0.018	0.019
	(0.013)	(0.013)	(0.012)
Mention>4	0.002	0.003	0.007
	(0.016)	(0.016)	(0.015)
Mention>5	0.022	0.023	0.030
	(0.022)	(0.022)	(0.020)
Phrasal Position: Final			0.194***
			(0.010)
Source: Tweety		−0.086***	−0.071***
		(0.027)	(0.025)
Observations	1,887	1,887	1,887
Log Likelihood	459.077	463.657	627.920
Akaike Inf. Crit.	−900.154	−907.315	−1,233.841
Bayesian Inf. Crit.	−850.269	−851.887	−1,172.870
Chi-squared		9.160	328.525
p-value		p=0.002***	p<0.001***
Note:			*p<0.1; **p<0.05; ***p<0.01

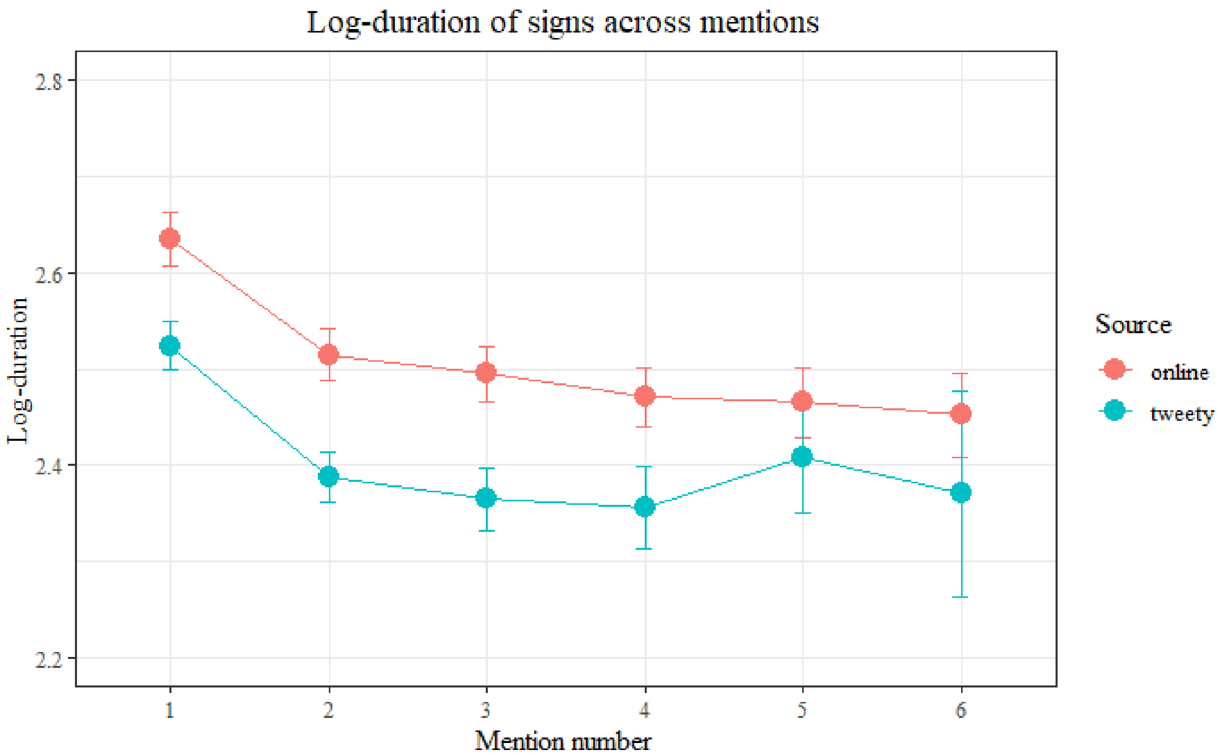

Figure 3.1: Mean duration of signs at each mention number by data source (mentions 1-6)

lengthening effect for signs. The mean duration of tokens across mentions, separated by phrasal position ('final' vs. 'non-final') can be seen in Figure 3.2.

Sign duration analysis 2: Reduction over mentions 2-6

A second duration analysis was conducted to analyze not only the effect of the distance between repeated mentions on sign duration, but also to test the impact of a decrease in internal repetitions on the duration of signs. The values in the dataset for distance between repeated words were positively skewed (skewness = 1.2534, kurtosis = 5.151) and so, as in the previous analysis, the values for distance between mentions were log transformed to normalize their distribution. Analysis was conduced using data from mention numbers 2 through 6[14]. To determine if the number of internal movements decreased, the number of

14. First mentions are excluded because they have no mention preceding them with which to compare them, both for distance between mentions and the decrease in repeated movements.

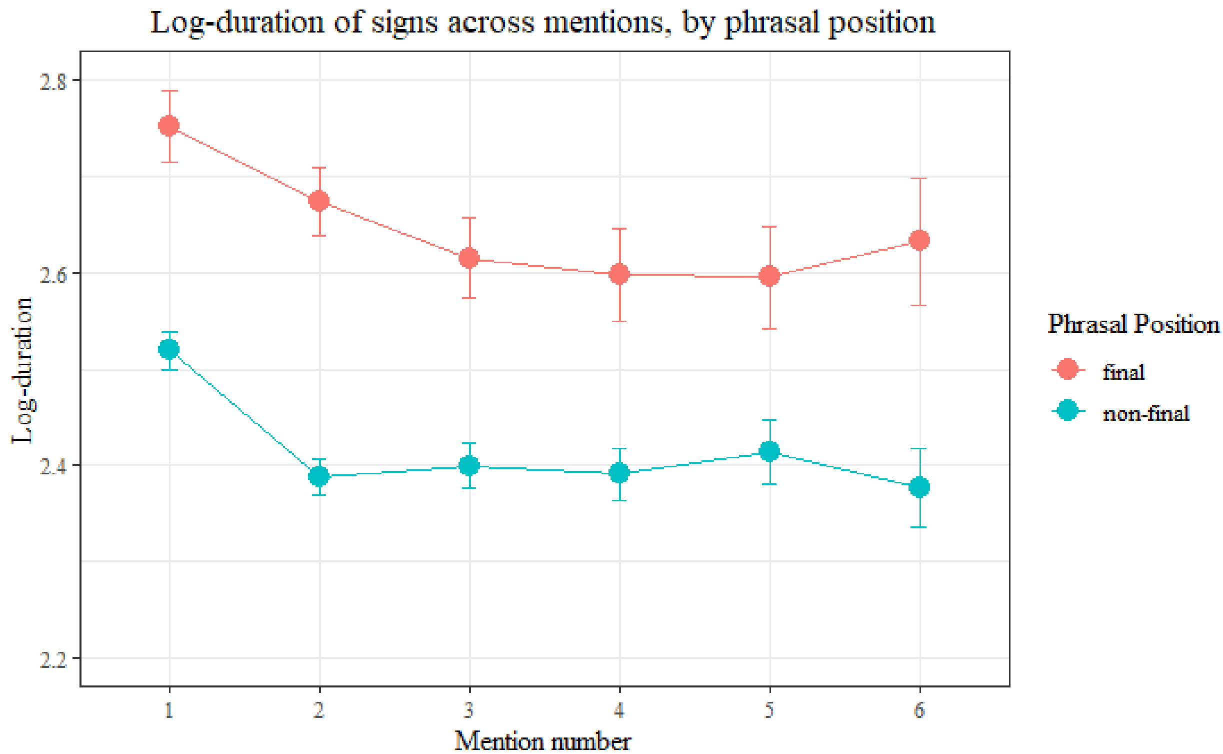

Figure 3.2: Mean duration of signs at each mention by phrasal position (mentions 1-6)

movements at each mention was compared to the number of movements at the first mention. They were coded then as 0 (no loss in movements) or 1 (loss in movements).

Figure 3.3 shows the relationship between duration and the distance between mentions for core signs. The plot shows a positive relationship between duration and distance between mentions, where an increase in the time between mentions corresponds to an increase in sign duration. A linear regression revealed that this trend was significant, showing a positive relationship between duration and distance between mentions (Estimate=0.066, SE=0.009, $T(1373)=7.098$, $p < 0.001$).

The relationship between distance between mentions and duration, as well as the effect of a decrease in movements, was tested by comparing mixed effects regression models to see if the addition of distance between mentions and the presence of a decrease in movements improved model performance. As this analysis only looks at mentions 2 through 6, the

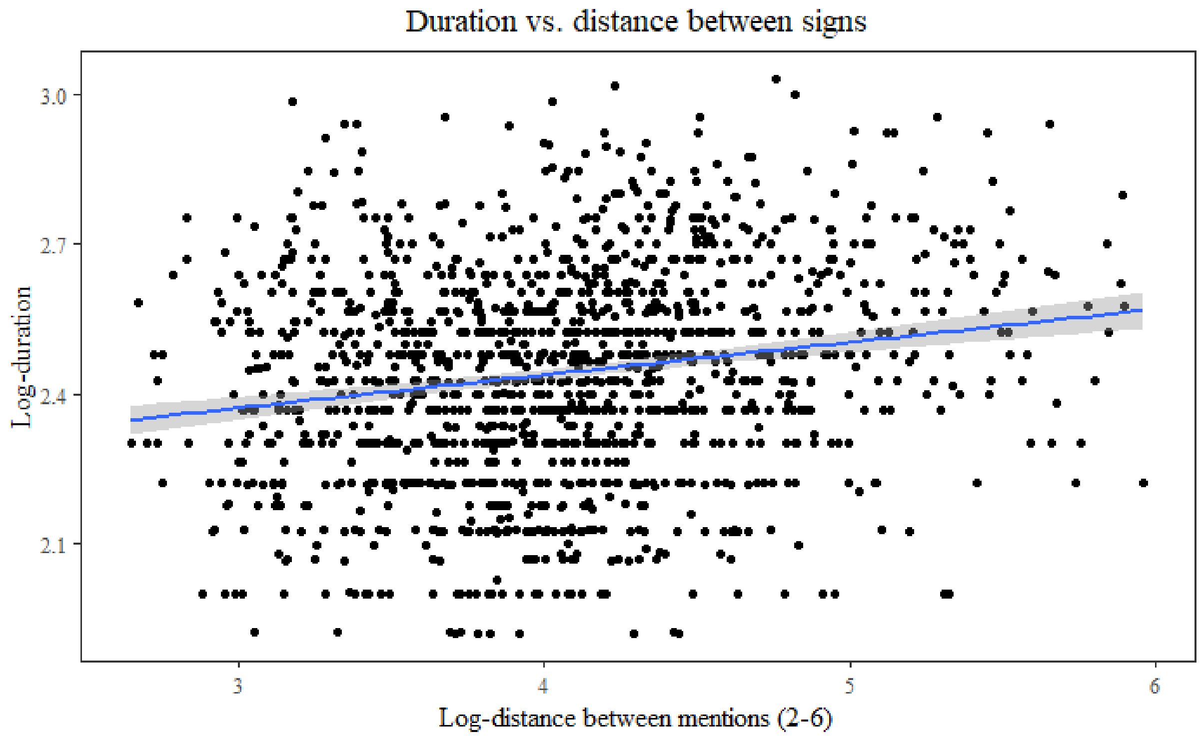

Figure 3.3: Scatter plot showing duration and distance from preceding mention for core signs (mentions 2-6)

variable of mention number was coded through four level Helmert Contrast Coding. The loss of internal movements was treatment coded, with signs without a decrease in mentions coded as the baseline.

The base model for this comparison, using data from mentions 2 through 6, included mention number as a fixed effect, with individual signer and word as random effects (Model 2a). Data source was added as a fixed effect (Model 2b) as well as phrasal position (Model 2c), to see if their inclusion continued to improve the model when applied to a smaller dataset. The presence of a movement deletion was then added as an interaction effect with mention number (Model 2d). Lastly, distance between mentions was added as a fixed effect (Model 2e). The formulas for each of the models can be seen in Table 3.6.

The results of the model comparison and estimates for each fixed effect can be seen in Table 3.7. The performance of each of the models, as factors were added, was compared

Table 3.6: Model structures, presented as the *lme4* formula, used to compare the effect of mention number, data source, phrasal position, occurrence of a decrease in number of movements, and distance between signs on the duration of signs.

Model 2a:	DURATION ~ MENTION NUMBER + (1 | SIGNER) + (1|SIGN)
Model 2b:	DURATION ~ MENTION NUMBER + SOURCE + (1 | SIGNER) + (1|SIGN)
Model 2c:	DURATION ~ MENTION NUMBER + SOURCE + PHRASAL POSITION + (1 | SIGNER) + (1|SIGN)
Model 2d:	DURATION ~ MENTION NUMBER * MOVEMENT DECREASE + SOURCE + PHRASAL POSITION + (1 | SIGNER) + (1|SIGN)
Model 2e:	DURATION ~ MENTION NUMBER * MOVEMENT DECREASE + SOURCE + PHRASAL POSITION + DISTANCE BETWEEN + (1 | SIGNER) + (1|SIGN)

using an ANOVA. These results show that the addition of data source and phrasal position significantly improved the fit of the model, as did inclusion of the occurrence of a decrease in movements, as an interaction term with mention number, and the distance between mentions.

The best performing mode, Model 2e, was used to further examine the directionality of the trends and significance of each of the factors included in the model. The model's regression showed a marginally significant between-mention effect, with a significant difference between the second and subsequent mentions (*Estimate*=0.019, SE=0.011, T(1373)=1.769, p=0.077). The analysis also showed a positive relationship between duration and phrasal position (*Estimate*=0.184, SE=0.012, T(1373)=15.957, p<0.001) and a marginally significant relationship between data source and duration (*Estimate*=-0.047, SE=0.026, T(1373)=-1.750, p=0.085), wherein signs in the Tweety corpus were shorter. Model 2e also showed significant positive relationship between duration and distance between tokens (*Estimate*=0.034, SE=0.008, T(1373)=4.294, p<0.001). In addition, it also showed a negative relationship between duration and a decrease in movements (*Estimate*= -0.148, SE=0.012, T(1373)=-11.933, p<0.001), wherein signs with a deletion were shorter in duration. Lastly, results showed an interaction between mention number and the presence of a deletion, although this was only significant between second and subsequent mentions (*Estimate*=0.045, SE=0.021, T(1373)=2.154, p=0.031). The relationship between duration and the occurrence of a decrease in move-

Table 3.7: Regression model comparison for analysis of sign duration using mentions 2 through 6. Estimates are provided with their standard errors in parentheses. Results of an ANOVA comparing model performance are included at the bottom of the table.

	Dependent variable:				
	Duration (log transformed)				
	Model 2a	Model 2b	Model 2c	Model 2d	Model 2e
Constant	2.455***	2.483***	2.429***	2.472***	2.326***
	(0.015)	(0.016)	(0.015)	(0.016)	(0.038)
Mention>2	0.033***	0.037***	0.035***	0.016	0.019*
	(0.011)	(0.011)	(0.010)	(0.011)	(0.011)
Mention>3	0.018	0.020	0.021*	0.015	0.015
	(0.013)	(0.013)	(0.012)	(0.013)	(0.013)
Mention>4	0.001	0.002	0.007	0.001	0.004
	(0.016)	(0.016)	(0.015)	(0.016)	(0.016)
Mention>5	0.021	0.021	0.029	0.017	0.015
	(0.022)	(0.022)	(0.021)	(0.023)	(0.023)
Movement Decrease: Present				−0.152***	−0.148***
				(0.012)	(0.012)
Phrasal Position: Final			0.203***	0.184***	0.184***
			(0.012)	(0.012)	(0.012)
Source: Tweety		−0.086***	−0.077***	−0.065**	−0.047*
		(0.027)	(0.025)	(0.026)	(0.026)
Distance					0.034***
					(0.008)
Mention>2*Movement Decrease				0.047**	0.045**
				(0.021)	(0.021)
Mention>3*Movement Decrease				0.019	0.020
				(0.024)	(0.024)
Mention>4*Movement Decrease				−0.001	−0.001
				(0.031)	(0.031)
Mention>5*Movement Decrease				0.031	0.034
				(0.042)	(0.042)
Observations	1,373	1,373	1,373	1,373	1,373
Log Likelihood	307.125	311.663	435.713	513.170	522.102
Akaike Inf. Crit.	−598.250	−605.325	−851.426	−996.340	−1,012.205
Bayesian Inf. Crit.	−556.452	−558.302	−799.178	−917.969	−928.609
Chi Sq.		9.075	248.100	154.914	17.865
p-value	p =0003	p<0.001	p<0.001	p<0.001	p<0.001
Note:			*p<0.1; **p<0.05; ***p<0.01		

ments can be seen in 3.4. This figure, accompanied by the results of the analysis, suggest that the presence of a decrease in movements is what is driving duration reduction past second mentions in core signs.

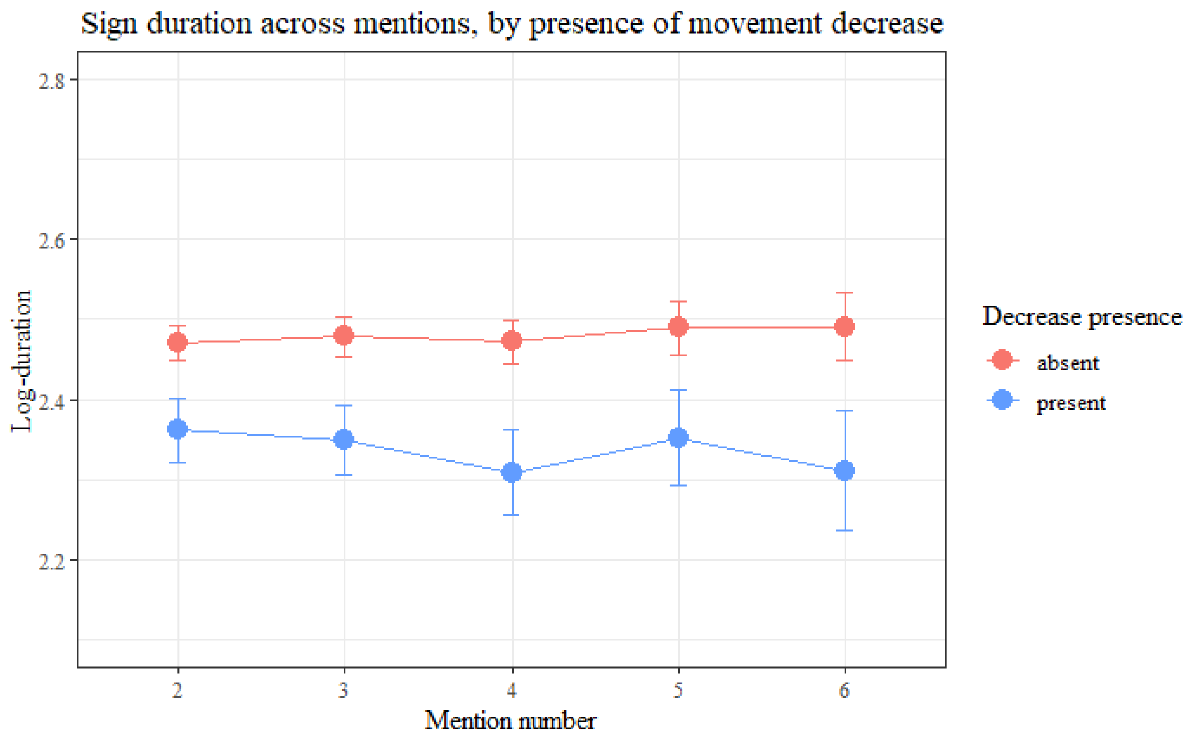

Figure 3.4: Mean duration of signs at each mention number by presence of a decrease in movements (mentions 2-6)

3.4.2 Repeated movement deletion

The next part of this analysis focuses on the effect of repeated mentions on variation in the number of repeated movements internal to some core signs. First, for a broad strokes analysis, I examined the effect of mention number on the likelihood of a decrease in the number of deleted mentions. To provide a more fine grained picture of variation in internal movements over repetitions, I then analyzed how the number of movements themselves changed over repeated mentions. This analysis is conducted on a subset of the data, comprising only signs that have multiple repeated movements in their citation form.

In the first part of the repeated movement analysis, I look at the effect of mention number on the likelihood of a decrease in the number of internal movements from the first mention, examining trends in the occurrence of a decrease in internal movements[15] across mentions 2-6. Within this part of the analysis, the number of internal movements at each mention of a sign was compared to the number of movements at the first mention. If the number was less than at the first mention, this was coded as “decrease" and if it was the same or greater than the first mention, this was coded as “no decrease".

The differences in the likelihood of a decrease in internal movements occurring between each mention and the subsequent mentions was analyzed using a mixed effects logistic regression. As with the duration analysis, to test whether the likelihood of letter deletions changed between each mention, the variable of mention number was coded via four level Helmert Contrast Coding and changes in number of movements were coded as “no decrease" (0) or “decrease" (1). The base model (Model 3a) for this comparison included mention number as a fixed effect, with individual signer and sign as random effects. Phrasal position (final vs. non-final) was added as a fixed effect, and then distance between mentions was added as a fixed effect. The formulas for these models can be seen in Table 3.8.

Table 3.8: Model structures, presented as the *glme4* formula, used to compare the effect of mention number, phrasal position, and between-mention distance on the likelihood of a decrease in the number of a sign's repeated movements

Model 3a:	DECREASE ∼ MENTION NUMBER + (1 |SIGNER) + (1|SIGN)
Model 3b:	DECREASE ∼ MENTION NUMBER + PHRASAL POSITION + (1|SIGNER) + (1|SIGN)
Model 3c:	DECREASE ∼ MENTION NUMBER + PHRASAL POSITION + BETWEEN MENTION DISTANCE + (1| SIGNER) + (1|SIGN)

The results of the model comparison for the logistic regression models for the analyses of the effect of mentions on the likelihood of a decrease in internal movements, and the estimates for each fixed effect, can be seen in Table 3.9. The performance of each of the models was

15. See Table A.3 in the appendix with the frequency counts and percentages for distributions of signs with decreases in internal movements in the dataset.

compared using an ANOVA, with results showing that the addition of phrasal position and the distance between repeated mentions improved the performance of the model.

Table 3.9: Logistic regression model comparison analyzing the decrease in repeated movements. Model comparison was conducted using data from mentions 2 through 6. Estimates are provided with their standard error in parenthesis. Results of an ANOVA comparing model performance are included at the bottom of the table.

	Dependent variable:		
	Presence of a decrease in movements		
	Model 3a	Model 3b	Model 3c
Constant	0.312^{*}	0.055	-2.910^{***}
	(0.163)	(0.183)	(0.689)
Mention>2	0.344^{**}	0.373^{**}	0.446^{**}
	(0.173)	(0.177)	(0.180)
Mention>3	0.015	0.061	0.107
	(0.204)	(0.208)	(0.210)
Mention>4	0.190	0.237	0.278
	(0.257)	(0.262)	(0.265)
Mention>5	0.074	0.091	0.132
	(0.353)	(0.360)	(0.365)
Phrasal position: Final		1.021^{***}	1.036^{***}
		(0.239)	(0.243)
Distance			0.725^{***}
			(0.162)
Observations	888	888	888
Log Likelihood	−578.467	−568.692	−558.384
Akaike Inf. Crit.	1,170.935	1,153.383	1,134.769
Bayesian Inf. Crit.	1,204.458	1,191.695	1,177.870
Chi-squared		19.552	20.614
p-value		$p<0.001^{***}$	$p<0.001^{***}$
Note:			*p<0.1; **p<0.05; ***p<0.01

The analysis for the best fitting model, 3c, showed a significant relationship between the likelihood of a decrease in internal movements and mention number, with a significant difference between second and subsequent mentions (*Estimate*=–0.446, SE=0.180, Z(888)=2.515, p=0.011). This can be seen in Figure 3.5, which shows the percentage of signs that contain a decrease in movements at each mention.

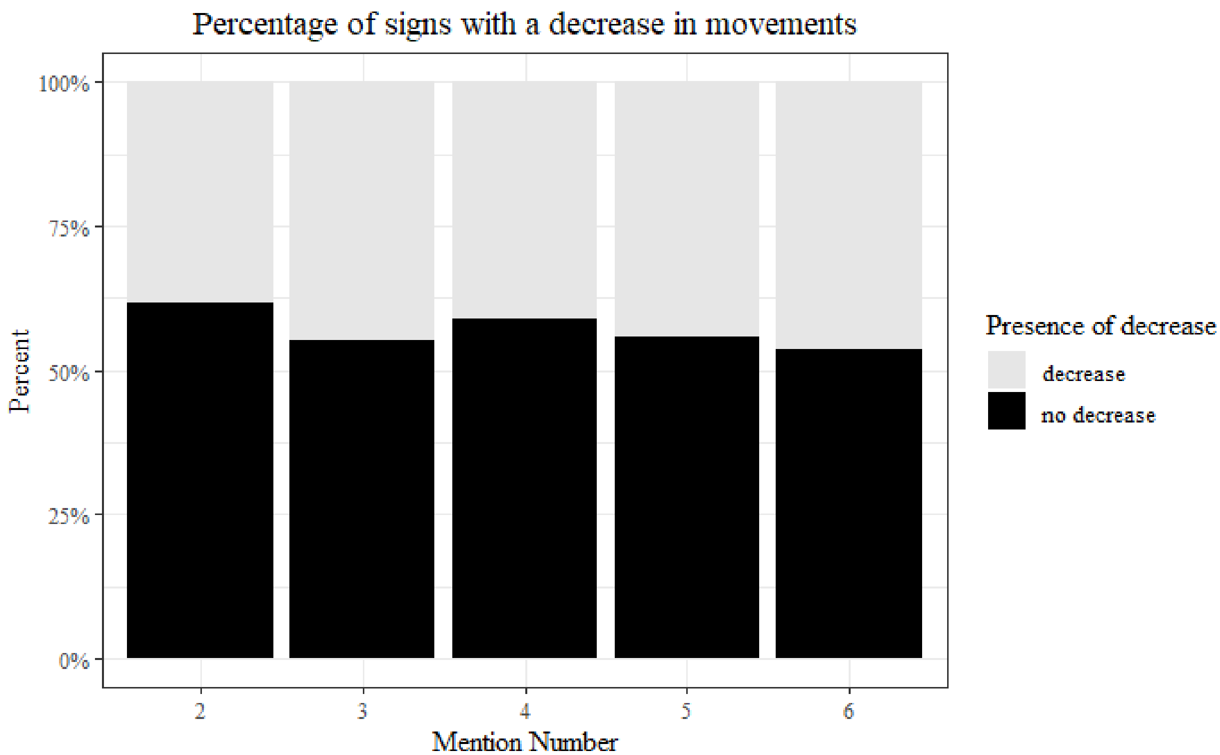

Figure 3.5: Percent of signs that exhibit a decrease in internal movements with respect to the first mention, by mention number (mentions 2-6)

The results also showed a significant effect of phrasal position, with phrase final positions being more likely to exhibit no decrease in internal movements (*Estimate*=1.036, SE=0.243, Z(888)=4.418, p<0.001). This trend can be seen exemplified in Figure 3.6. There was also a significant effect of distance between mentions, with increased distance between repeated signs corresponding to an increased likelihood that signs would not decrease in their number of movements (*Estimate*=0.725, SE=0.162, Z(888)=4.565, p<0.001).

In the next part of the analysis of repeated movement reduction, I look at the impact

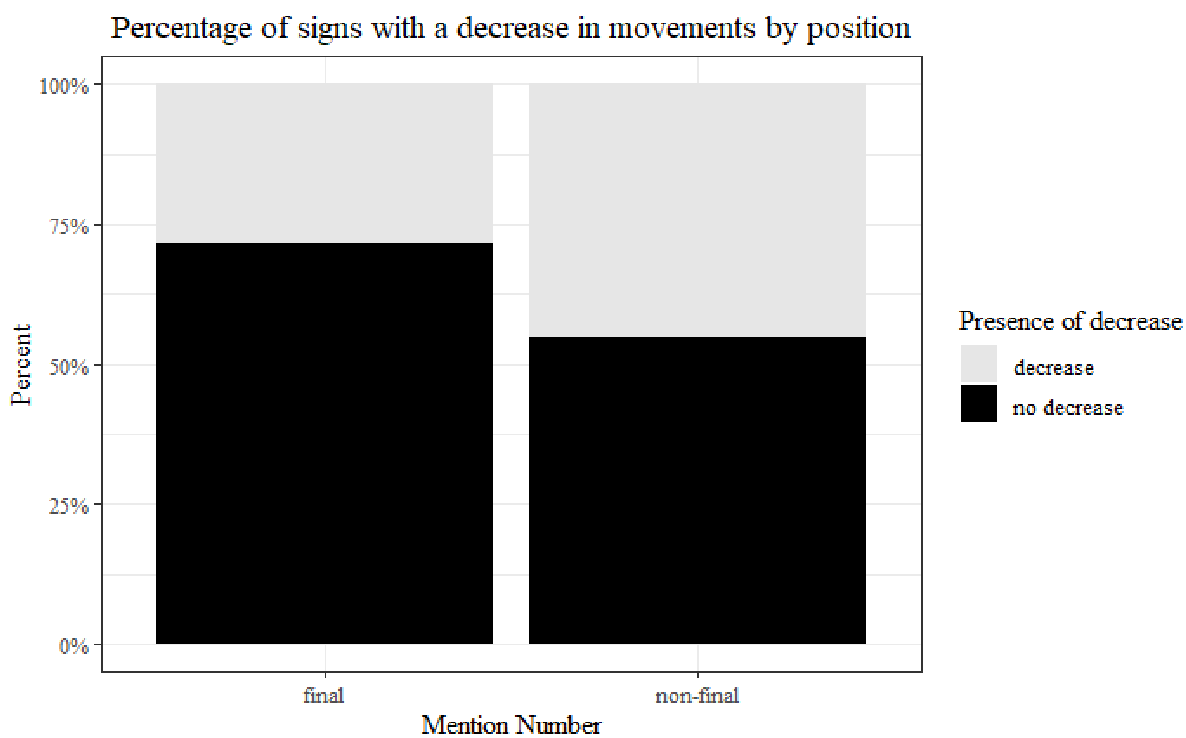

Figure 3.6: Percent of words, by phrasal position, that exhibit a decrease in their internal movements with respect to their first mentions (mentions 2-6)

of mention number on the number of movements themselves, using data from mentions 1 through 6. The effect of mention number on the count of the number of internal repetitions was analyzed using a negative binomial generalized linear mixed effects model. To test whether the average number of internal movements changes across mentions, mention number was coded with five level Helmert Contrast Coding while the number of internal movements was coded as a numeric count variable. The base model for this comparison (4a) included mention number as a fixed effect and included signer and sign as random effects. Phrasal position was added as a fixed effect to see if this improved the performance of the model (model 4b). The formula for these models can be seen in Table 3.10.

Table 3.10: Model structures, presented as the *glme4* formula, used to compare the effect of mention number and phrasal position on the number of movements in each sign

Model 4a:	# OF INTERNAL MOVEMENTS ~ MENTION NUMBER + (1 | SIGNER) + (1|SIGN)
Model 4b:	# OF INTERNAL MOVEMENTS ~ MENTION NUMBER + PHRASAL POSITION + (1 | SIGNER) + (1|SIGN)

.

The results of the model comparison testing the factors that influence the number of movements can be seen in Table 3.11. The performance of each of the models was compared using an ANOVA, with results showing that the addition of information about phrasal position improved model performance.

Results of the best performing model, 4b, show a significant effect of mention number and phrasal position on the number of movements. More specifically, the average count of internal movements changes significantly between first and subsequent mentions (Estimate = 0.256, SE = 0.047, Z(1224)=5.479, p<0.001), as well as between second and subsequent mentions (Estimate = 0.107, SE = 0.054, Z(1224)=2.015, p=0.044). The proportion of signs with each number of movements at each mention number can be seen in Figure 3.7. This graph shows the trend reflected in the results, wherein the percent of signs at each mention with just one movement increases across mentions, levelling off around mention 3. It also

Table 3.11: Negative Binomial regression model comparison analyzing the number of movements, modeling data from mentions 1-6. Estimates are provided with their standard error in parenthesis. Results of an ANOVA comparing model performance are included at the bottom of the table.

	Dependent variable:	
	Number of repeated movements	
	Model 4a	Model 4b
Constant	0.617***	0.538***
	(0.029)	(0.031)
Mention>1	0.264***	0.256***
	(0.047)	(0.047)
Mention>2	0.105*	0.107**
	(0.054)	(0.054)
Mention>3	0.059	0.066
	(0.066)	(0.066)
Mention>4	−0.0002	0.007
	(0.086)	(0.085)
Mention>5	0.009	0.019
	(0.119)	(0.113)
Phrasal position: Final		0.290***
		(0.049)
Observations	1,224	1,224
Log Likelihood	−1,719.405	−1,702.688
Akaike Inf. Crit.	3,456.809	3,425.376
Bayesian Inf. Crit.	3,502.798	3,476.475
Chi-squared		33.434
p-value		p< 0.001
Note:		*p<0.1; **p<0.05; ***p<0.01

shows the number of signs with multiple movements, 2 and 3+, decreasing across mentions. Together, this demonstrates how the average number of movements decreases across mention numbers.

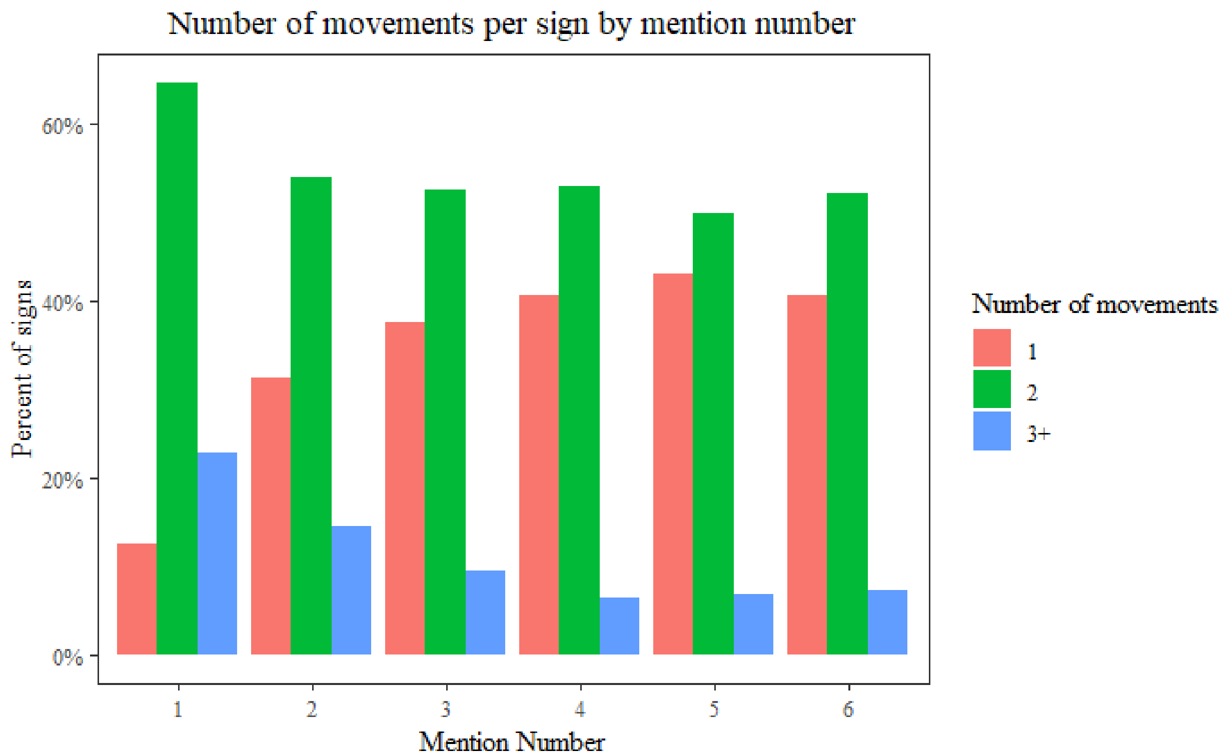

Figure 3.7: Percentage of signs with each number of movements across mentions (mentions 1-6)

Similar to previous analysis, there was also a significant effect of phrasal position, where phrasal position significantly influenced the number of internal movements (Estimate = 0.290, SE=0.049, Z(1224)=5.976, p<0.001), with phrase final signs being more likely to exhibit a higher number of internal movements.

3.4.3 Location variation

The final part of the analysis of reduction in core signs examines variation in the location of core signs. It targets variation in the locations of signs articulated on the body, focusing not only on how repetition but also the initial location of a sign impacts the ways that location varies across repeated mentions. This location analysis, while exploratory and based on a small number of tokens, provides a preliminary picture of reduction strategies used by signers in the context of repetition for body-anchored signs. This is approached first through an examination of trends in location variation throughout the study datasets and then through a case study of a single sign.

The impetus for focusing on body located signs is drawn from the distribution of scholarship about reduction along the dimension of location. The focus in previous scholarship on location variation has largely been centered on the lowering of signs articulated on or near the head (Tyrone and Mauk, 2012; Johnston and Schembri, 2010; Lucas et al., 2002; Schembri et al., 2009; Russell et al., 2011), with the caveat that Tyrone 2012 found centralization via lowering and horizontal movement inwards. Outside of this, studies on location variation have also examined undershoot and coarticulation in neutral space locations (Mauk, 2003), but few have addressed locations on the body. This analysis attempts to add breadth to our understanding of variation in location by focusing on signs articulated on the body.

Motor control and effort reduction have been theorized to be some of the primary driving forces shaping the physical articulation of reduction processes. For this reason, for body anchored signs, we predict to see signs that are farther towards the peripheries of the signing space reducing by moving towards more central locations. From these locations, signers will not need to move as far to articulate adjacent signs and, in not needing to reach their target locations, can make their movements less precise, facilitating articulation.

Repetition reduction and location variation

This analysis examines trends in variation for body-located signs in the context of repetition, focusing on how the initial location of a sign influences the likelihood that a sign's location will vary in a consistent manner. In particular, I test the prediction that body anchored signs will shift upwards to a more central position in the signing space. For this analysis, I focus on a subset of the dataset comprising only signs articulated on the body[16], encompassing a total of 61 individual signs, each repeated between 2 and 6 times (231 tokens total).

Examining the distribution of the body locations articulated within the datasets shows an unequal distribution of the locations of signs, with most signs articulated on the chest. Table 3.12 shows the total number of body-located signs and the percent of the body-located signs in the dataset they encompass.

Table 3.12: Frequency of different locations of signs articulated on the body

Location	**Count**	**Percent**
chest	170	73.59%
lower-torso	10	4.33%
neck	11	4.76%
shoulder	13	5.63%
torso	27	11.69%

The distribution of body-located signs in the analysis sample show that the large majority of body signs are articulated on the chest, comprising roughly 74% of these signs. This is followed by signs articulated on the torso (∼12%) and then signs on the neck, shoulder, and lower-torso, each of which make up less than 6% of the signs analyzed.

To analyze variation in the location of signs across mentions, I then compared the location of each repeated mention of a sign to the location of its first mention, using the first mention as a baseline. I then noted the directionality of any change in movement with respect to the first mention. For example, for a sign articulated at the torso for its first mention, if the repeated mention was articulated at the chest, this would be categorized as a shift up. If the repeated mention was articulated at a lower location, such as the lower-torso, this would be categorized as shift down. This analytic choice means that the subset of signs used for this analysis only encompasses signs mentions 2-6 (171 tokens total). This sample excludes first

16. Only the sign-initial location setting was analyzed, rather than the initial and final locations, as there is no clear reason to predict that these would yield different results. Locations only included those articulated by the dominant hand.

mentions as they have no mention preceding them with which to compare them.

Of all of the repeated signs in the dataset, only 19% changed in their location. Of the signs that changed location, they moved both in an downwards and upwards direction, with the upward shifts occurring more frequently. 13% of the signs shifted upwards, while 6% shifted downwards.The large majority of the signs that changed in their location were articulated at their first mention at the more peripheral body locations, such as the lower-torso or shoulder. Trends in location[17] shifts, divided into location on the body for the first mentions of signs, can be seen in Figure 3.8.

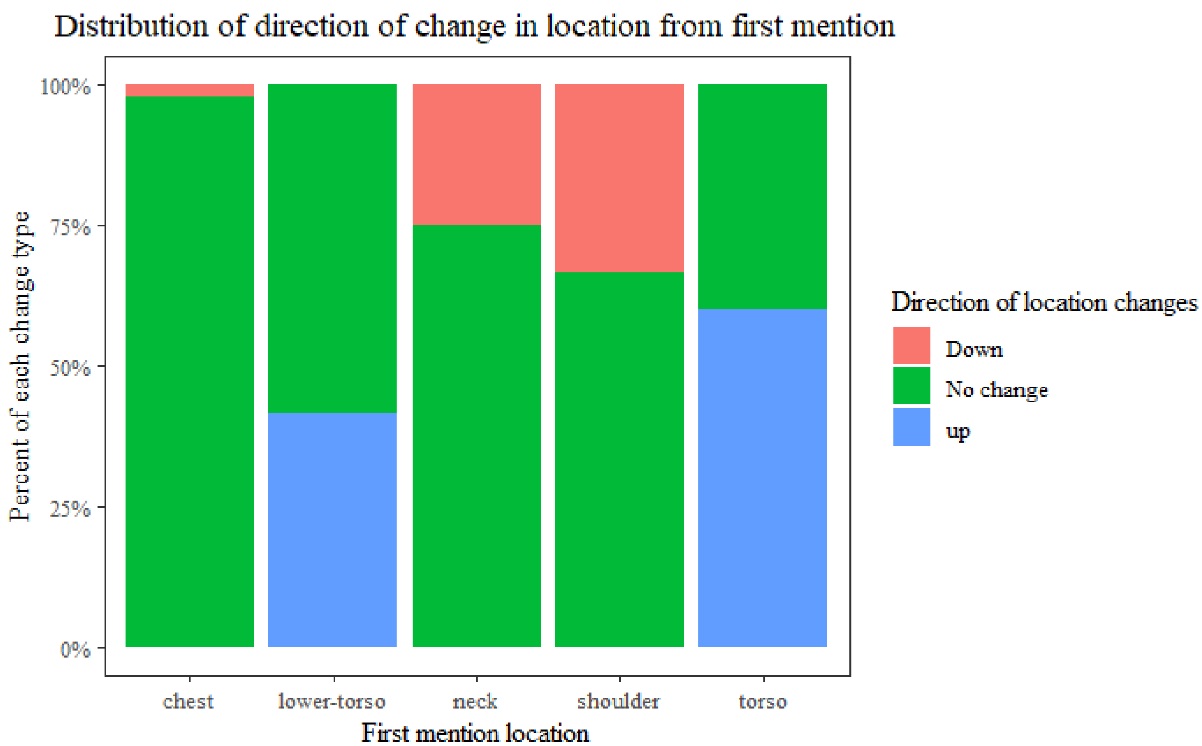

Figure 3.8: Percentage of repeated signs with each type of change in direction, categorized by the location of their first mention (data from mentions 2-6)

Overall, this study of shifts in location show body located signs either remaining at their initial location or shifting towards a chest location. This is exemplified by how the large

17. A full set of exact percentages and token counts, reflecting the numbers in Figure 3.8 can be found in the appendix (Table A.4)

majority of signs articulated at the chest for their first mentions did not shift their location over subsequent mentions (97%). In contrast, signs articulated below the chest at their first mention, at both torso and lower-torso locations, showed a tendency to shift upwards, with close to 50% of signs at each of these locations shifting upwards. Sign articulated above the chest showed a tendency in which, if they were to change in location from their first mention, they shifted downwards. Signs articulated at the shoulder shifted downwards 33% of repeated mentions. Signs at the neck also only exhibited variation from their first mentions in a downwards direction, changing locations in 25% of signs initially articulated at the neck. Together, these trends indicate a pressure to move to more central locations on the body itself, rather than simply towards more central locations in the signing space.

A case study in location variation: MONKEY

The Tweety dataset allows for the comparison of the same core signs not only across multiple mentions, but across multiple signers, and so I take advantage of this here by presenting a case-study of location variation as it occurs for a single sign to exemplify the realization of a reduction processes in location. Here, I consider the case of the sign MONKEY, a sign which, in its citation form, is articulated on the torso or the lower torso for the first part of the sign, and then moves upwards in location for its final location setting. Figure 3.9 shows an image of the citation form of MONKEY.

Reduced forms of MONKEY are predicted to move upwards on the body from their initial torso locations, moving to positions higher on the torso or chest. This is because, not only does movement in this direction centralize the location of the sign, but this decreases the size of the movement between the initial and final location settings of the sign.

14 of the signers in the dataset produced repeated versions of the sign MONKEY, comprising a total of 72 tokens of MONKEY in the dataset. While many of the signers articulated MONKEY at its initial, citation location, this was not the case for all of the signers in the

Figure 3.9: Image of the citation form of MONKEY. Image is from Valli (2006), used with permission from Gallaudet University Press.

dataset. In fact, the majority of the signers in the dataset articulated MONKEY at a location on the chest for the first mention of the sign. This included 8 out of 14 signers. An example of what this looks like can be seen in Figure 3.10.

An initial location on the chest leaves less opportunity for reduction in an upward direction on the body, as would be predicted for signs articulated at lower body locations. The articulation of MONKEY at chest locations for first mentions suggests that either these signers have an alternative form of MONKEY within their lexicon which is articulated at a location higher than the dictionary entry for the form or suggests that they are already producing reduced forms at their first mentions. If the latter, the elicitation strategy and setting, via elicited narratives before a camera in a lab environment, or other contextual factors may drive the production of an already reduced form of MONKEY in first mentions.

For those signers who articulated MONKEY at a lower location, the sign was articulated at either the torso or lower-torso. These signers aligned with the expected citation form in their first mentions. An example of initial locations for a first, unreduced mention and then

Figure 3.10: Image of MONKEY's first mention initial location (chest) for one signer narrating a Canary Row vignette.

its third mention can be seen in Figure 3.11.

For the signers who articulated monkey at the torso and lower, although repeated mentions were often articulated in the same location as their first mentions (6 out of 17 - 33%), the large majority shifted upwards (18 out of 27 - 67%). All of the upward location shifts from the torso moved to the chest, while the signer whose initial location was at the lower torso shifted upwards to the torso.

In addition to sign raising, MONKEY exemplified other reduction strategies used by signers. In particular, some signers, in addition to raising the location of the sign MONKEY, dropped the non-dominant hand in articulating repeated mentions. An example of this can be seen in Figure 3.12. While not reflected in the annotation or data analysis schema used in this particular analysis, this strategy was used by multiple signers in the articulation of repeated mentions.

By looking at reduction strategies used for a single sign, as well as the range of variation

Figure 3.11: Image of the initial locations for a first mention (torso) and third mention (chest) of MONKEY within a Canary Row narrative.

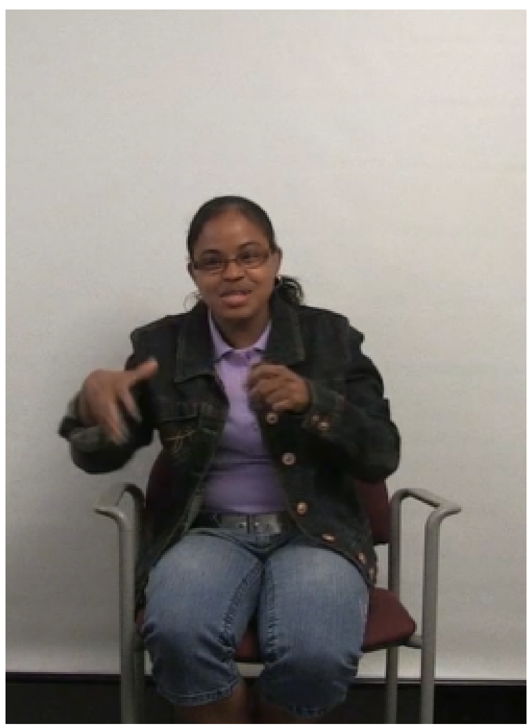

Figure 3.12: Image of a repeated mention of MONKEY in which a signer used an the alternative reduction by articulating MONKEY with one hand.

in articulation across mentions, we can gain a more nuanced picture as to what the numeric data and wider trends from the previous analyses in this chapter reflect in the production of individual signers. This sign exemplifies a case where signs articulated at lower locations on the body, like the torso and lower-torso, have a tendency to shift upwards in contexts of increased predictability. However, while the strategy of using repetition reduction as a lens through which to view reduction strategies does reveal reduction trends, as shown by the signs that were articulated at their citation locations in their first mentions, this does not tell the whole story. The prevalence of either non-citation or, potentially, already reduced forms at first mentions points to the continued need for future work to test the other factors that drive variation and reduction in core signs, in addition to repetition.

3.5 Discussion

When taken together, results from these analyses show reduction in the context of repeated discourse mentions to be a robust trend, with reduction processes occurring along several dimensions for ASL and encompassing categorical and gradient variables. Significant reduction was seen both in the duration and number of repeated internal movements for core signs. For sign location, reduction patterns were also observed through the centralization of signs articulated on the body. Building on earlier scholarship showing reduction occurring for each of these categories, although not necessarily in the context of repetition, this analysis confirms and expands upon findings of earlier work. Additionally, it expands upon descriptions of duration reduction in the context of repetition by adding the contribution of individual mention number, analyzes reduction in repeated movements, and describes location variation for a location area that has received less attention within previous scholarship.

Focusing first on the analysis of duration reduction, the current results confirm previous findings on duration reduction in signs from other sign languages and provide a more detailed understanding of how the duration of signs varies across multiple mentions. As with

Hoetjes et al. (2014) and Grosjean (1979)'s findings about NGT and ASL showing that core signs reduce in the context of repetition, the present analysis showed significant reduction between first and repeated mentions for ASL core signs. The analysis of duration showed not only an effect of mention number on the duration of signs in ASL, but also showed that duration, while decreasing across multiple mentions, does not continue to reduce indefinitely, as the amount of reduction decreased across mentions and was only significant for earlier mention numbers. This suggests a limit to which signs can reduce, either due to the limited contribution of mention number on a sign's predictability or limits on reduction driven by a need to retain a comprehensible signal.

Duration was not solely impacted by repetition, as results also showed a range of other factors that influenced duration reduction, including time between repeated mentions, phrasal position, and a decrease in the number of internal movements. Results showed that the distance between mentions themselves influenced reduction, with more temporally distant mentions reducing more. Duration was also impacted by phrasal position, with longer phrase final tokens. This follows work a considerable body of previous work (Grosjean, 1979; Brentari and Crossley, 2002; Nespor and Sandler, 1999; Coulter, 1993) showing phrase final lengthening for signs. The occurrence of a decrease in internal movements between first and repeated mentions also impacted duration across repeated mentions, with shorter durations for signs that exhibited a decrease in the number of their internal movements. This relationship interacted with mention number, indicating that some of the duration decrease for repeated mentions is driven by the loss of internal movements. This is a striking finding, as it suggests that signs with multiple movements, and thus the potential to reduce in their movements in the context of repetition, are those that are driving the duration-reduction effect following second mentions. More broadly, it also suggests that duration reduction is not a unified phenomenon, even in one part of the ASL lexicon.

Focusing specifically on reduction in repeated movements within signs and the relationship between this variable and mention number, the present analysis showed both the likelihood of deletion and likelihood of a change in the number of repeated movements differing significantly across repeated mentions. Specifically, signs with repeated internal movements were significantly more likely to decrease in the number of internal movements in the context of repeated mentions. The presence of deleted movements interacted with phrasal position, where phrase final tokens were more likely to retain internal repeated movements. The number of movements in a sign also changed significantly across repeated discourse mentions, with the total number of movements decreasing across mentions. While the number of movements internal to a sign have been studied in the context of stress (Wilbur and Nolen, 1986; Wilbur and Schick, 1987), the present work shows that movement repetition is a property of core signs that also undergoes reduction in the context of repeated discourse mentions. Expanding beyond work on sign languages, this finding also aligns with finding on spoken languages showing that segments are more likely to delete in higher predictability contexts (Turnbull, 2015; Coetzee and Kawahara, 2013).

Considering how reduction processes change the type and quality of information available in the linguistic signal, changes that can could impact the comprehension of these signs, the reduction of internal movement repetitions has implications for not only the signer, but also the interlocutor within signed discourse. First, reducing the repeated movements articulated within a sign removes some amount of redundancy from the signal. More, albeit redundant, information could be beneficial for maintaining comprehension, and so any loss of this additional redundant information in the articulation of signs, as provided by repeated movements, has the potential to render signs more difficult to understand. In addition, a decrease in internal movements could potentially remove some amount of morphological information conveyed in the signal itself, like in the case of noun-verb pairs that are distinguished through repetition. The loss of this morphological information would then force the interlocutor to rely more on context to retrieve a sign's meaning, context that has been provided if a sign has been mentioned in the discourse previously.

The last part of the analysis, focusing on variation in sign location under repeated discourse mentions, showed trends wherein location reduction for body anchored signs is realized as movement towards more central locations on the body. Results showed signs articulated at more peripheral body locations centralizing when they were repeated. Patterns noted within the preliminary analysis showed signs articulated below the chest raising in their location and signs articulated above the chest lowering in their location, although the lowering trend was not as strong. In contrast, signs already articulated at a central location showed little tendency to vary.

It is important to note that, unlike analyses like that of Mauk (2003), this study did not control for the locations of nearby signs, which could additionally impact variation in location in systematic ways within the dataset analyzed here. Further study with larger sample sizes, controlling for the locations of adjacent signs, will determine the extent to which these trends hold. However, patterns seen in the current analysis suggest that location reduction in signing is not defined just by a tendency to lower, as might be argued if gravity were the only factor driving sign reduction in location. The case study of the sign MONKEY exemplified this, while showing the limitations of the current analytic approach. The case study of MONKEY showed that, although the primary location reduction strategy used by signers was to raise from lower locations to higher ones, many signs did not undergo reduction at all, as they exhibited non-citation or already reduced forms in their first mentions. Although the context of increased predictability offered by repetition allows for the comparison of repeated mentions of sign forms, this approach is limited in the types of reduction it might capture as first mentions may already be reduced to some degree.

This expands our understanding of location reduction by demonstrating another dimension along which location reduction occurs, while showing some of the limitations of the repetition-reduction approach. Using the increased predictability of repeated discourse mentions, the tendency to centralize locations articulated on the body provides a body-counterpart to complement to studies that previously focused on the head (Tyrone and Mauk, 2012; Russell et al., 2011; Lucas et al., 2002; Schembri et al., 2009). Together, this adds support indicative of a pressure to decrease articulatory effort by minimizing the distance travelled by the articulators in signing.

3.6 Conclusion

Together, this analysis uses repetition, which conditions reduction processes by providing a context of increased predictability, to test how reduction is realized for multiple properties of ASL signs, encompassing not only multiple parameters, but also categorical and continuous variables. The simultaneous structures involved in the production of signs each have affordances that can be taken advantage of in minimizing effort in articulation. This encompasses not only movement and location, but also the temporal properties of signs. The present analysis shows how the affordances of some of the different parameters, a feature of the distinct articulatory system of core signs, allow for many different types of reduction, including categorical processes that influence more gradient types of reduction like reduction in sign duration. These processes, in turn, have an even wider impact due to their potential to influence the processing of these signs, changing the quality and type of information available in the linguistic signal.

CHAPTER 4

COMPARING REDUCTION BETWEEN FINGERSPELLING AND CORE SIGNS

4.1 Introduction

A more comprehensive view of how articulatory and structural differences influence variation within linguistic systems requires comparison of variation between these systems. The present chapter addresses this by focusing on how fingerspelled words and core signs in American Sign Language (ASL) reduce in their duration, comparing patterns in reduction across these two parts of the ASL lexicon to discern whether their differing structural and articulatory constraints result in distinct patterns in reduction. Previous work has shown fingerspelling in ASL to reduce considerably, decreasing in duration across multiple repeated mentions, exhibiting coarticulation between letters and even the deletion of full letter segments (Brentari, 1998; Wager, 2012; Lepic, 2019). This contrasts with research on spoken English which shows a significant reduction effect for second but not subsequent mentions of repeated words (Bell et al., 2009). Previous work on sign languages has also shown that repeated core signs reduce in duration (Hoetjes et al., 2014; Grosjean, 1979), but it remains to be tested, excluding the present work, whether repeated signs in ASL reduce on a similar trajectory as that of fingerspelling, for example showing reduction effects past a sign's second mention, or if reduction patterns instead mirror those found in spoken English. Although previous work has addressed duration reduction in fingerspelling, and to a limited extent, in core signs, a direct comparison between the two will shed light on how the properties of the fingerspelling and core sign systems might shape patterns in reduction.

The rapid, sequential articulation of handshapes involved in fingerspelling led to the hypothesis that fingerspelled words would reduce to a greater degree and show continued reduction over more repeated mentions than core signs. This hypothesis was tested through a corpus analysis using annotated corpora of publicly available videos from online sources, consisting of a subset of those used in chapters 2 and 3. The analysis then examined patterns in duration reduction for these two categories of the lexicon, testing whether duration reduction followed a different trajectory across multiple mentions for core signs and fingerspelled words. Contrary to the initial hypothesis, results showed core signs and fingerspelled words exhibiting similar patterns in duration reduction. These similarities have implications for the ways that pressure on both the shared and differing properties of these two parts of the lexicon shapes the trajectory of duration reduction across mentions.

4.2 Background

The conclusions drawn from this comparison of reduction patterns in fingerspelled words and core signs necessarily rely not only on assumptions about what forces shape reduction, but also on previous scholarship showing the varying structures characterizing the different parts of the ASL lexicon. Expanded knowledge of any variation that exists in reduction patterns within the ASL lexicon can deepen our understanding of the mechanisms shaping language production. This can provide insight into, for example, whether reduction is driven by language producer internal constraints, as posited by language production accounts like that of Bell et al. (2009) or by pressures on the language producer to balance reducing articulatory effort while maintaining an intelligible signal, as would be argued by other accounts (Jurafsky et al., 2001; Aylett and Turk, 2004). For instance, the structural and articulatory constraints of different linguistic systems, like that of fingerspelling and of core signs, exhibit different possibilities in reducing articulatory effort and so pressure towards reducing might influence variation in each of these systems in ways that are unique to each. Following from this, variation in each of these systems might have distinct a impact on the interlocutor's reception of the signal and so by determining what this looks like, we can begin to understand whether the way that interlocutor's perceive and process these forms also influences how signers reduce.

Not only will knowledge of variation in reduction between these systems help inform our understanding of which models better explain the mechanisms behind language production, but it also might provide new perspectives on how modality itself influences linguistic variation. Although fingerspelling and signs exhibit significant structural differences, aspects of their articulation are similar due to their shared presence in the manual-visual modality. Similarity in reduction patterns between these two systems, contrasting with patterns seen in speech, might then point to modality related pressures that shape language production. This investigation relies on questions not only of differences between different parts of ASL, each of which has distinct properties, but also questions about how modality-related properties of sign languages influence their production.

4.2.1 The ASL lexicon and forces shaping reduction

Any understanding of reduction patterns in ASL, and how these might vary, relies on conceptualizations of the composition and structure of the lexicon of ASL that assume that it is comprised of different parts, each of which has properties that set it apart from the others. The perspective taken here is that proposed in Brentari and Padden (2001), and adapted in later accounts (Fenlon et al., 2017; Cormier et al., 2012) wherein the lexicon is divided into two overlapping components: the native lexicon component and the non-native lexicon component[1]. The area of overlap between the native and non-native components of the lexicon comprises the core lexicon, which encompasses core signs in ASL (see Figure 4.1 for a visual representation). The non-overlapping component of the non-native lexicon encompasses fingerspelled words. The remaining component of the lexicon, comprising the

1. This discussion is taken with the caveat that the lexicon and its internal components are not necessarily stable. For example, forms both move between different components, or are not easily put into one category in the lexicon based on one set of criteria (See discussion in Lepic (2019), Cormier et al. (2012), and Brentari and Padden (2001).) For this reason, the present analysis will not be considering forms clearly undergoing the process of lexicalization, which share properties of multiple parts of the lexicon, and leaves this to future research.

native, non-core component, comprises classifier constructions.

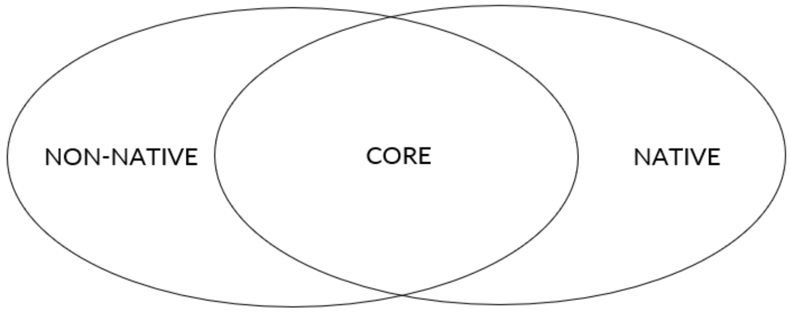

Figure 4.1: Representation of the ASL lexicon, as adapted from Brentari and Padden (2001)

Each of these parts of the lexicon differs in the constraints that determine how they are articulated, resulting in forms with distinct structures within each category (Brentari and Padden, 2001; Eccarius, 2008). As an example, classifier constructions, which are excluded[2] from the present analysis, are distinct from core signs in the increased allowances they make for the modification of the parameters and are not limited by the prosodic constraints that shape core signs (Aronoff et al., 2003). The core lexicon and fingerspelling, the focus of the present investigation, while sharing some similarities in form and articulation, exhibit considerable differences in both their structural and articulatory properties. This, in turn, results in distinct allowances for reduction within each system.

Core signs, comprising forms that are highly standardized, are limited in their possibilities for articulation along each of the parameters[3] and show constraints on the degree of sequentiality allowed within each sign. Within a core sign, any change in hand configuration is restricted to the same set of selected fingers[4]. In addition, although core signs can be articulated with a wide range of different movements and locations, they are limited in the

2. Because classifier forms are less likely to be repeated in discourse and are more variable in their form they are not included in the present analysis.

3. Further description of the articulation of core signs can be found in Chapter 3.

4. Some compounds and multi-morphemic constructions do not adhere to this restriction, but are highly infrequent in the lexicon.

number of distinct sequential movements they can contain to no more than two movements (Brentari, 1998). Core signs are also characterized by a set of handshapes that overlap with those of fingerspelling but are not shared completely, with the exception of initialized signs.

The sequential versus simultaneous nature of core signs has been emphasized to different degrees in models of their structure. Core signs involve some amount of sequential organization that is integral to their articulation, since a sign's movements must start and end at different times. This has been highlighted in models such as Liddell and Johnson (1989)'s Movement-Hold model. However, although signs can comprise up to two distinct movements, the sign parameters are largely structured to occur simultaneously (Brentari, 1993). Models of the structure of signs following the Movement-Hold Model incorporated both the sequential and the simultaneous organization of signs into their representations (Sandler, 1989; Brentari, 1998; Van der Kooij, 2002; Van der Hulst, 1993). This pressure towards the simultaneity seen in the structure of signs has been attributed to, for example, the slowness of the manual articulators in comparison to those of speech. Its effect on the linguistic system has been argued to be evidenced by a preference for morphological modifications in ASL to be expressed simultaneously rather than sequentially, as seen in many spoken languages that more heavily employ concatenative morphology (Fernald and Napoli, 2000). Together with phonological constraints on sequentiality, this limits the amount of reduction that can occur within any sequential structures of signs but doesn't eliminate it.

In contrast, fingerspelled words consist of the sequential articulation of fingerspelled letters in the neutral signing space, letters which correspond to characters from the English alphabet. Fingerspelled letters consist of a distinct set of handshapes, as well as a limited set of palm orientations and movements, that are typically rapidly articulated in sequence (Keane and Brentari, 2016). In addition to relying more heavily on sequentiality than core signs, the rapid articulation of handshapes in sequence distinguishes fingerspelling from signs from an articulatory standpoint. As fingerspelling involves more complex handshapes that are otherwise less frequent in the other components of the ASL lexicon, this necessitates increased dexterity which contributes to increased difficulty of articulation. This difficulty is seen, in part, by how fingerspelling presents a challenge for adult L2 learners as they learn this system (Geer, 2016), in comparison to other systems within ASL, like core signs (Wilcox, 1992; Quinto-Pozos, 2011). For this reason, pressures to lessen articulatory effort might result in increased reduction in forms within this part of the lexicon.

As a result of their diverging articulatory and structural properties, fingerspelling and core signs differ in their rates of articulation. Reported rates of both signing and fingerspelling vary considerably although on average, across accounts, signs are shorter in duration than fingerspelled words. While few studies have directly compared the two categories, studies have been conducted analyzing sign and fingerspelling rate separately. For example, Wilbur (2009a) reports normal signing to occur at a rate of 1.95 signs per second, on average, while Baker and Padden (1978), in looking at the average signing rate for pairs of signers, found rapid signing rates to be at 3.12 and 3.00 signs per second, with slower rates reported around 2.5 signs per second. In contrast, rates for fingerspelling are reported to be between 3.33 (Wilcox, 1992) to 8.00 (Quinto-Pozos, 2010) individual letters a second. Although the rate of fingerspelled words per second has received less attention, under the assumption that fingerspelled words have at least three letters, then fingerspelled words are articulated from at least 1.3 to 2.6 fingerspelled words per second. Given that this is for the shortest of fingerspelled words, and fingerspelled words can vary considerably in their length in letters, on average fingerspelled words are likely to be longer than signs, although this requires further study.

Each of these differences has the possibility of shaping distinct patterns of reduction. Different relationships to sequentiality and the articulatory difficulty involved in producing forms in each of these systems might exert different pressures on the articulatory system, both to reduce effort and maintain a comprehensible signal. While not all aspects of their articulation can be compared as, for example, core signs comprise parameters like movement and location that can undergo reduction in ways that aren't feasible for fingerspelling, their durations can be compared.

Previous accounts analyzing the effect of repetition of fingerspelled words, along with result's from Chapter 2's analysis, have shown fingerspelling reducing in duration across multiple repeated mentions, also undergoing segment deletion and coarticulation (Wager, 2012; Brentari, 1998; Lepic, 2019; Thumann, 2012). Core signs, in contrast, have been shown in previous scholarship to reduce in duration (Grosjean, 1979; Hoetjes et al., 2014), but the degree of this reduction, nor the relationship between duration and mention number, has not been compared across categories in the lexicon. Although fingerspelling and core signs have both been shown to reduce in the context of repetition, and Chapter 3 of this work provides more insight into the trajectory of duration reduction for core signs across mentions, a direct comparison examining the same variable and using the same experimental methodology can help answer whether the two systems differ along their comparable dimensions of reduction.

Because fingerspelling is organized through the rapid, sequential articulation of handshape segments, while core signs are largely structured around the simultaneous organization of the parameters[5], involving larger movements of the articulators, different predictions can be made regarding results of a comparison of trends in reduction between the two categories. Due to these differences, and the increased potential for the deletion of full segmental material for fingerspelled words, this leads to the prediction that fingerspelled words will, on average, reduce in duration more steeply than core signs between repeated mentions, reducing to a greater degree across multiple mentions.

5. Signs with repeated movements are characterized by a degree of sequential organization, but because these only comprise a subset of core signs and typically have fewer sequential segments than fingerspelled words, the organization of the parameters in the core lexicon can be considered to largely simultaneous.

4.2.2 Modality and reduction

Although the initial prediction entertained in the present analysis posits a difference between duration reduction patterns in fingerspelling and core signs, a contrasting, null hypothesis could be entertained in which there is no significant difference between duration reduction patterns in fingerspelling and in core signs. If this is the case, the *shared* properties of fingerspelling and core signs, perhaps stemming from commonalities associated with language production in the visual-manual modality, could be shaping the similar patterns. Studies on repetition reduction in spoken languages like English (Bell et al., 2009) and Thai (Vajrabhaya and Kapatsinski, 2011) have shown the effect of repetition to be a binary one, in which there is a significant decrease in duration only between first and subsequent mentions of words. Contrasting with this, Chapter 2 demonstrated a trend in which fingerspelled words continued to reduce after second mentions, showing a differing pattern from that in speech. Chapter 3, testing reduction patterns in core signs, also showed reduction continuing after second mentions. Together, these suggest a wider difference between reduction patterns across modalities. However, as each of these analyses looked at the fingerspelling and core sign systems separately, comparing these systems within the same analysis will reveal the extent of any commonalities in duration reduction.

Differences in modality and how these might shape reduction could be attributed both to the physical processes involved in articulation, as well as differences in the perceptual systems. As perhaps the most visible example, there are bigger muscles and articulators that articulate signs than articulate speech. As such, the arms and hands are subject to different articulatory pressures from those that constrain reduction in speech. As one example, even the impact of gravity might be considered to be stronger for articulators with more mass. Napoli et al. (2014, p. 449) found that sign languages “may exhibit tendencies toward effort reduction based on mass being moved" when testing how effort reduction might be realized via the joints used in articulation, which influences the size of articulators used.

Another factor contributing to potential differences in reduction patterns between speech and sign, and similarities between fingerspelling and core signs, might simply be the larger amount of time it takes to articulate words and signs in ASL. In comparing rates of articulation, signs and fingerspelled words have been shown to be longer, on average, than spoken words. For example, Bellugi and Fischer (1972), analyzed signing and speaking rate in stories told in ASL and in spoken English by CODA participants. They found that, in the signed story, there were an average of 2.37 signs per second (collapsing signs and fingerspelling), while there were 4.7 words per second for the same stories in spoken English.

Expanding to encompass additional types of communication in the visual modality, work on repetition reduction in gesture provides an addition comparison point within the manual-visual modality. More specifically, gesture might share articulatory pressures with signing due to their shared articulation with the manual articulators[6]. When looking at repetition reduction in gestures used in referring expressions, Hoetjes et al. (2015) found that the duration of referring expressions decreased significantly not only between first and second mentions, but also between second and third mentions. When looking at the repetitions of individual gestures themselves, there was also a difference in duration between initial and repeated mentions, although this difference was not statistically significant. However, subsequent studies on repetition reduction effects in gesture, using a more targeted, controlled experimental paradigm, found a significant effect of repetition on duration, where repeated gestures were significantly shorter than their first articulations (Holler et al., 2022). Together this indicates that communication across modalities, even extending to the gestural components of language, is shaped by a pressure to reduce. Trends of reduction in both sign languages and gesture show that pressure from articulatory effort or towards the routinization of articulation is pervasive in the manual-visual modality and that modality-related pressures may be shaping reduction. However, as it has not been specifically tested for man-

6. Fingerspelling does distinguish itself through the additional articulatory difficulty in relation to gestures, as might signing although to a lesser extent

ual gestures whether reduction continues past second mentions, there is not yet conclusive evidence of whether there is a greater articulatory pressure towards reduction within this modality.

4.3 Methodology

This analysis employs a corpus approach in which previously annotated corpora are combined to compare trends in reduction between fingerspelling and core signs. The dataset used to compare trends in duration reduction between these parts of the lexicon comprises a corpus of videos in ASL, drawn from publicly available online video sources, first annotated for fingerspelled words and then for core signs. It was used in the previous analyses of fingerspelling (Chapter 2) and core sign (Chapter 3) reduction. Although the previous analysis of core signs included annotations of narratives from the Canary Row corpus, the present analysis excluded these data. This was to ensure that the signers were the same in the samples for the core sign and fingerspelling parts of the dataset, as well as to analyze datasets that share the same recording conditions.

4.3.1 Annotation

The annotations included in this analyses are those that encompass properties shared between core signs and fingerspelled words. These include information about the temporal properties of each, encompassing duration, phrasal position, and time between repeated mentions. A detailed description of dataset annotation can be found in Chapters 2 and 3, for the fingerspelling and core sign datasets. But, as a brief summary, each sign and fingerspelled word in the dataset was annotated for its duration, its mention number, and its phrasal position, including phrasal position to control for any phrase final lengthening effects. Duration, for core signs and for fingerspelling, was determined as falling between when a form settled fully into its first handshape and when it relaxed out of the final handshape, encompassing any movement or fingerspelled letters between the two of these. Phrasal position was determined by the adjacency of a form to a phrasal boundary, as indicated by a significant pause or the beginning of a new phrase. The combined dataset also includes information about the temporal distance between repeated forms, as measured through the difference between their start times. The original datasets for fingerspelling and core signs include annotations indicating the number of segments and the number of segment deletions, encompassing fingerspelled letters and internal movement repetitions. However, due to the different properties of the segments themselves, handshapes in one case and movements in the other, they will not be considered as exactly comparable here and will be excluded from the present, comparison analysis.

The data used in the present analysis encompasses core signs and fingerspelled words, repeated between 1 and 6 times. The fingerspelling portion of the dataset encompasses 116 fingerspelled words, that, along with all of their repetitions, make-up a total 609 individual tokens of fingerspelled words. The core sign portion of the dataset encompasses 223 core signs which, including each individual mention, includes 1016 individual sign tokens. The difference in the number of tokens per category can be attributed to the smaller amount of fingerspelling found in naturalistic data, increasing the difficulty of finding repeated versions of the forms when compared to repeated core signs.

4.3.2 Signers

The corpus includes fingerspelled words and core signs from 30 signers total. 26 of the signers were right hand dominant (ie. signed primarily with their right hand), while 4 of the signers were left hand dominant

4.4 Analyses & Results

The analyses in this chapter compare variation in duration between the fingerspelling and core sign parts of the lexicon. The goal of this analysis is to determine whether there are significant differences in the trajectories of duration reduction between these two categories. The first part of this analysis tests patterns in reduction for mentions 1 through 6 of the fingerspelled words and core signs within the dataset. The second part of this analysis tests patterns in reduction for mentions 2 through 6 for each of these categories, where it additionally controls for the distance between repeated mentions. If, for example, fingerspelled words were farther apart in general than repeated core signs, taking into account between-mention distance will help factor out any influence this might make on any of the duration patterns between the two categories.

4.4.1 Comparison analysis 1: Mention number

The first part of this analysis examines the trajectory of duration reduction between core signs and fingerspelled words across repeated mentions 1-6. It tests how mention number impacts the duration of forms between each mention and subsequent repetitions, while testing whether category in the lexicon has a significant impact on how the duration values of these forms vary across repeated mentions. The analysis also incorporates the influence of phrasal position, to account for phrase final lengthening effects. The average values for the duration data can be seen summarized in Figure 4.1. The duration values of the fingerspelled word and core sign tokens were positively skewed (skewness=1.764, kurtosis=6.649) and, as a result, the remaining analysis was conducted on log-transformed duration values.

Table 4.1: Mean duration values (in milliseconds) for fingerspelled words and core signs at each mention number. The descriptive statistics show means along with standard deviations in parentheses. The averages are separated into each of the factors analyzed, including category in the lexicon and phrasal position.

Mention #		1 [n=335]	2 [n=335]	3 [n=328]	4 [n=261]	5 [n=206]	6 [n=157]
Total		648.979	499.276	462.161	442.739	442.106	426.643
		(403.271)	(326.316)	(277.097)	(281.203)	(269.732)	(235.807)
Category	Fingerspelling	934.339	735.608	650.304	613.555	599.618	540.434
		(442.131)	(379.337)	(313.657)	(329.432)	(311.138)	(258.286)
	Sign	500.488	376.851	360.582	338.351	322.290	319.876
		(285.706)	(208.673)	(189.637)	(180.923)	(147.044)	(148.475)
Position	Final	847.155	669.318	603.076	568.223	577.0196	496.177
		(439.595)	(358.851)	(303.668)	(317.417)	(293.596)	(226.750)
	Non-final	515.875	416.87	396.736	391.189	397.716	398.705
		(314.027)	(274.424)	(237.568)	(247.977)	(246.682)	(234.561)

As in previous analyses of fingerspelling and core signs, trends in duration reduction were analyzed using linear mixed effects regression models, employing *lmer()* in the *lme4* R package (Bates et al., 2015). The analysis tested the influence of mention number, phrasal position, and category in the lexicon, as well as the interaction between mention number and category. It uses a five level Helmert Coding contrast, where the mean of values at each mention are compared to the combined means of subsequent mentions. The analysis was conducted by adding model factors to a base model which included mention number as the only fixed effect, testing mention number's impact of duration, with signer and the identity of each core sign or fingerspelled token. The base model is as follows:

$$\text{DURATION} \sim \text{MENTION NUMBER} + (1 \mid \text{SIGNER}) + (1|\text{TOKEN ID})$$

Fixed effects were then added to the base model (Model 1a) to see if their addition improved model performance, beginning with phrasal position (Model 1b), and then with category in the lexicon being added as an interaction term with mention number (Model 1c). Phrasal position and type (category in the lexicon) were treatment coded. Signer and each token's ID (the sign or fingerspelled word) were included as random effects for every model. The *lme4* formula for the base model is as follows:

Table 4.2: Model structures, presented as the *lme4* formula, used to compare the effect of mention number, data source, and phrasal position on the duration of signs.

Model 1a:	DURATION ~ MENTION NUMBER + (1 | SIGNER) + (1|TOKEN ID)
Model 1b:	DURATION ~ MENTION NUMBER + PHRASAL POSITION + (1 | SIGNER) + (1|TOKEN ID)
Model 1c:	DURATION ~ MENTION NUMBER * CATEGORY + PHRASAL POSITION + (1 | SIGNER) + (1|TOKEN ID)

.

The estimates for each of the predictors included as fixed effects in the analyses for each of the models be seen in Table 4.3[7]. Table 4.3[8] also shows the results of the model comparison,

7. Regression tables were created using the R package Stargazer (Hlavac, 2015)

8. An expanded table can found in the appendix in Table A.5, showing the model comparison including a

in which the performance of each subsequent model is compared with an ANOVA. Model 1c, which incorporated category in the lexicon as a fixed effect, best accounted for variance in the data and will be used to discuss the results of significant factors included in the model.

The results from Model 1c show a significant effect of mention number, phrasal position, and category in the lexicon, with no significant interaction between mention number and category. Focusing on the effect of mention number, results show a significant difference between first and subsequent mentions (*Estimate*=0.155, SE=0.015, T(1625)=10.243, $p<0.001$), as well as between second and subsequent mentions (*Estimate*=0.067, SE=0.016, T(1625)=4.278, $p<0.001$). The effect of third and subsequent mentions was not significant. There was a significant positive effect of phrasal position (*Estimate*=0.151, SE=0.009, T(1625)=16.882, $p<0.001$), showing that phrase final tokens were significantly longer than non-final tokens. There was also a significant negative effect of category in the lexicon (*Estimate*=-0.243, SE=0.017, T(1625)=-14.108, $p<0.001$), in which core signs were significantly shorter in duration. The interaction between mention number and category was not significant at any level of mention number.

The trajectory of duration reduction across mentions can be seen in Figure 4.2 which shows the mean duration of tokens at each mention number for fingerspelled words and core signs. The plot shows the continued reduction in duration across mentions for both categories in the lexicon, as well as the shorter duration of core signs.

4.4.2 Comparison analysis 2: Distance between mentions

In the second part of this analysis, the temporal distance between repeated fingerspelled words and core sign tokens is incorporated into the analysis. This analysis only uses a subset of the data, encompassing mentions 2 through 6, as first mentions have no preceding

model with category as a fixed effect, but not as an interaction. Addition of the interaction between mention number and category did not improve model fit between models with and without the interaction term, but is being included in the present analysis to test the research question.

Table 4.3: Linear regression model comparison analyzing changes in duration across mentions for signs and fingerspelling, conducted using data from mentions 1 through 6. Results of an ANOVA comparing model performance are included at the bottom of the table.

	Dependent variable:		
	Duration (log transformed)		
	Model 1a	Model 1b	Model 1c
Constant	2.652***	2.601***	2.723***
	(0.097)	(0.088)	(0.018)
Mention>1	0.161***	0.145***	0.155***
	(0.010)	(0.009)	(0.015)
Mention>2	0.053***	0.047***	0.067***
	(0.010)	(0.009)	(0.016)
Mention>3	0.030***	0.024**	0.024
	(0.011)	(0.010)	(0.016)
Mention>4	0.016	0.011	0.003
	(0.013)	(0.012)	(0.019)
Mention>5	0.011	0.017	0.023
	(0.017)	(0.015)	(0.023)
Category: Sign			−0.243***
			(0.017)
Phrasal Position: Final		0.151***	0.151***
		(0.009)	(0.009)
Mention>1*Category			−0.016
			(0.019)
Mention>2*Category			−0.031
			(0.020)
Mention>3*Category			−0.002
			(0.021)
Mention>4*Category			0.011
			(0.024)
Mention>5*Category			−0.012
			(0.031)
Observations	1,625	1,625	1,625
Log Likelihood	455.322	586.782	593.724
Akaike Inf. Crit.	−890.643	−1,151.564	−1,155.448
Bayesian Inf. Crit.	−836.711	−1,092.238	−1,069.156
Chi-squared		262.921	13.885
p-value		p<0.001***	p=0.016**
Note:			*p<0.1; **p<0.05; ***p<0.01

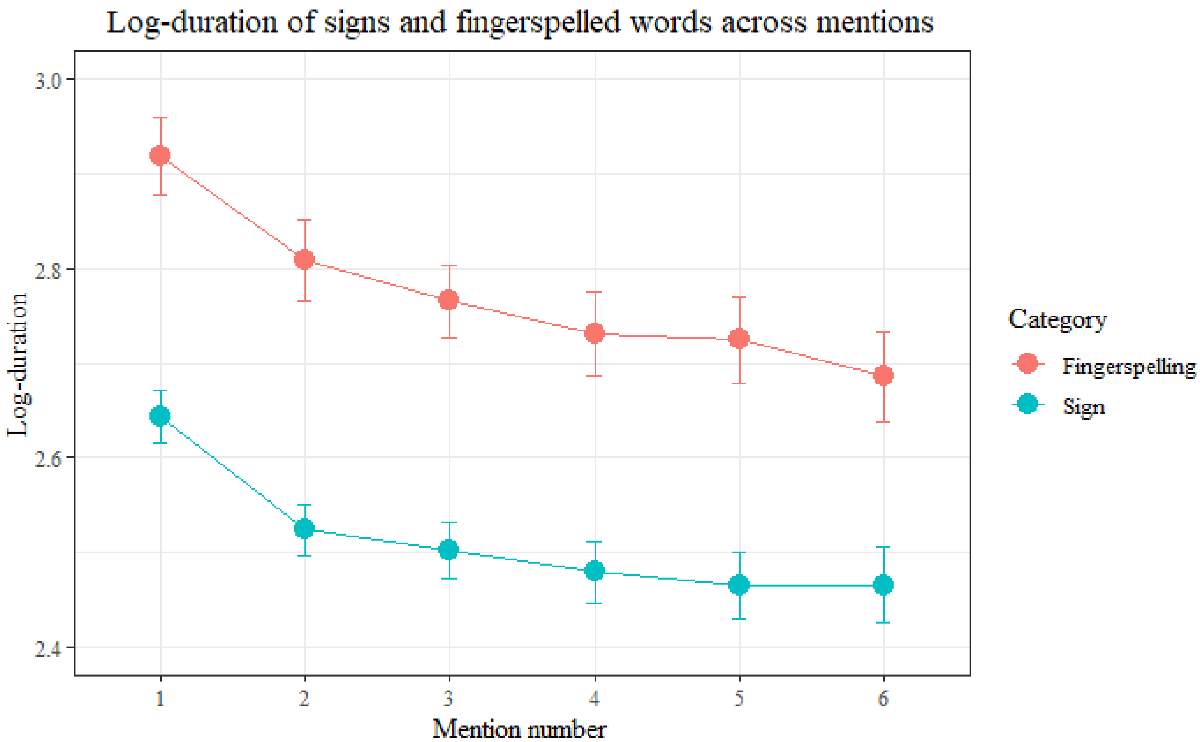

Figure 4.2: Mean duration of fingerspelled words and core signs across mentions (mentions 1-6)

mention with which to compare their beginning time. As with the duration values, the distance between repeated mentions were positively skewed (skewness = 4.094, kurtosis = 23.817). Because of this, distance values were log transformed for analysis to normalize their distribution.

The relationship between duration and distance between mentions is shown in Figure 4.3. The trends in the scatter plot showed that for both categories in the lexicon increased distance corresponded to increased token duration. A regression was run testing the effect of between mention distance on duration, as well as any interaction with category in the lexicon. The regression model was structured as follows: DURATION ∼ DISTANCE*CATEGORY. Results showed showed a positive correlation between duration and between-mention distance (Estimate=0.076, SE=0.016, T(1289)=4.929, p<0.001), but no significant interaction between the distance between mentions and category in the lexicon.

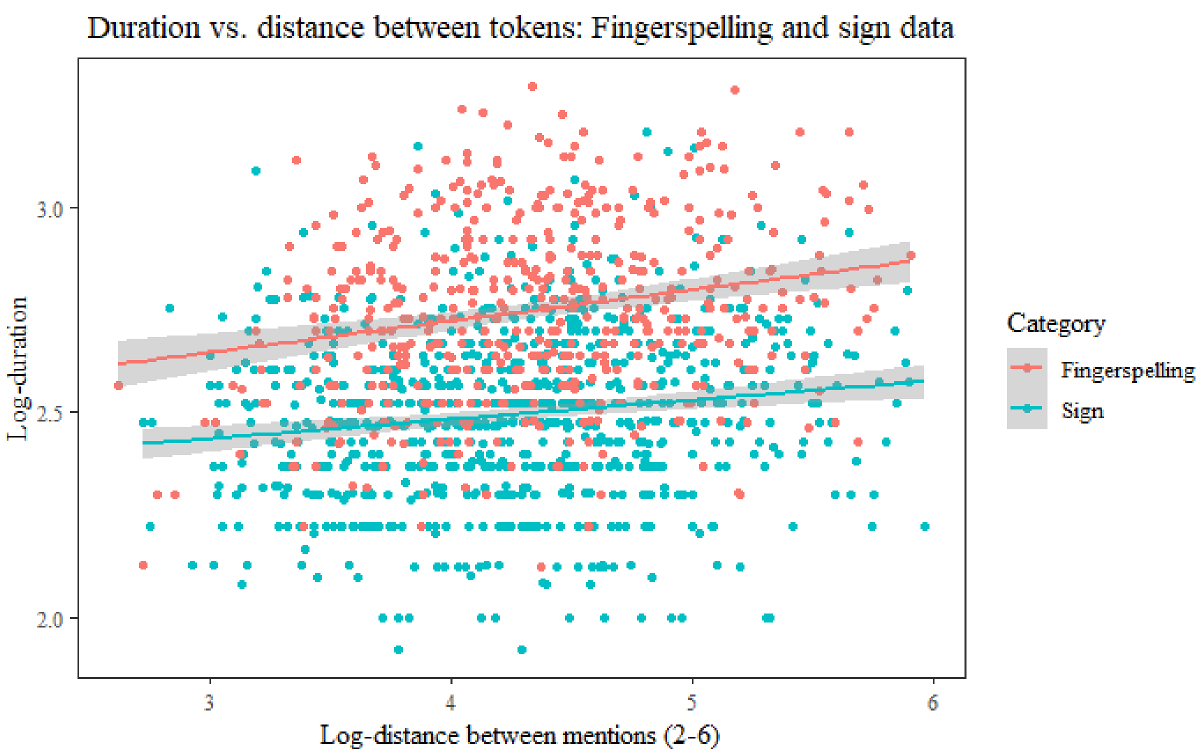

Figure 4.3: Scatter plot comparing token duration and distance from preceding mention, by category in the lexicon (mentions 2-6)

Information about the distance between repeated mentions was incorporated into the wider comparison regression analysis, to account for any influence of between-mention-distance on variation in the duration of fingerspelled and sign tokens. Phrasal position and category in the lexicon were treatment coded. Because the present analysis only targets mentions 2-6, mention number was coded via four level Helmert Contrast coding.

The base model for the regression analysis included mention number as a fixed effect, with random effects included for signer and token ID (Model 2a). Within the model, phrasal position was then added as a fixed effect (Model 2b), category in the lexicon was added as an interaction effect with mention number (Model 2c), and then distance between mentions was added as a fixed effect (Model 2d). The structure of these models can be seen in Table 4.4.

Table 4.4: Model structures, presented as the *lme4* formula, used to compare the effect of mention number, data source, phrasal position, and distance between mentions on the duration of repeated mentions 2 through 6.

Model 2a:	DURATION ~ MENTION NUMBER + (1|SIGNER) + (1|TOKEN ID)
Model 2b:	DURATION ~ MENTION NUMBER + PHRASAL POSITION + (1|SIGNER) + (1|TOKEN ID)
Model 2c:	DURATION ~ MENTION NUMBER * CATEGORY + PHRASAL POSITION + (1|SIGNER) + (1|TOKEN ID)
Model 2d:	DURATION ~ MENTION NUMBER * CATEGORY + PHRASAL POSITION + DISTANCE+ (1|SIGNER) + (1|TOKEN ID)

Results of the model comparison can be seen in Table 4.5. Model performances, as factors were added between models, were compared using an ANOVA. The results show that addition of distance between mentions significantly improved model fit. The best performing model, Model 2d, will be used for subsequent discussion of the results.

Model 2d, including fixed effects for mention number, phrasal position, category, and distance between mentions, showed a significant effect for each of the fixed effects included in the model, but showed no significant interaction between category and mention number. The regression analysis again showed a significant effect of mention number, with a significant differ-

Table 4.5: Linear regression model comparison analyzing changes in duration across mentions for core signs and fingerspelling, conducted using data from mentions 2 through 6. Results of an ANOVA comparing model performance are included at the bottom.

	Dependent variable:			
	transformed_duration			
	(1)	(2)	(3)	(4)
Constant	2.594***	2.546***	2.703***	2.448***
	(0.017)	(0.017)	(0.018)	(0.036)
Mention>2	0.050***	0.045***	0.068***	0.065***
	(0.011)	(0.010)	(0.016)	(0.015)
Mention>3	0.028**	0.022**	0.025	0.030*
	(0.011)	(0.011)	(0.017)	(0.016)
Mention>4	0.012	0.008	0.005	0.008
	(0.013)	(0.012)	(0.019)	(0.018)
Mention>5	0.008	0.016	0.024	0.018
	(0.017)	(0.016)	(0.023)	(0.022)
Category: Sign			−0.248***	−0.245***
			(0.018)	(0.018)
Phrasal Position: Final		0.159***	0.149***	0.148***
		(0.011)	(0.010)	(0.010)
Distance				0.059***
				(0.007)
Mention>2*Category			−0.029	−0.015
			(0.020)	(0.020)
Mention>3*Category			0.001	−0.001
			(0.021)	(0.021)
Mention>4*Category			0.008	0.012
			(0.025)	(0.024)
Mention>5*Category			−0.014	−0.008
			(0.032)	(0.031)
Observations	1,289	1,289	1,289	1,289
Log Likelihood	253.669	354.953	434.913	466.441
Akaike Inf. Crit.	−491.339	−691.907	−841.825	−902.882
Bayesian Inf. Crit.	−450.046	−645.452	−769.563	−825.458
Chi-squared		202.568	159.919	63.157
p-value		p<0.001***	p<0.001***	p<0.001***
Note:			*p<0.1; **p<0.05; ***p<0.01	

ence between second and subsequent mentions (*Estimate*=0.065, SE=0.015, T(1289)=4.172, $p<0.001$), with a marginally significant difference between third and subsequent mentions (*Estimate*=0.030, SE=0.016, T(1289)=1.823, p=0.068). There was a significant positive effect of phrasal position on duration (*Estimate*=0.148, SE=0.010, T(1289)=14.537, $p<0.001$), as well as a negative effect of category in the lexicon (*Estimate*=-0.245, SE=0.018, T(1289)=-13.946, $p<0.001$). There was also a significant positive relationship between duration and distance between mentions (*Estimate*=0.059, SE=0.007, T(1289)=8.051, $p<0.001$), showing that duration tended to increase as distance between mentions increased.

4.5 Discussion

In comparing fingerspelling and core signs, results from both parts of this analysis show similar patterns in reduction across these two categories of the lexicon. Both analyses showed significant reduction for both categories across multiple mentions, as well as phrase final lengthening and increased reduction for more temporally close forms. It also confirmed that fingerspelled words are considerably longer than core signs on average. However, within the analysis there was not a significant interaction between mention number and category in the lexicon, suggesting considerable similarity in the trajectory of duration reduction across mentions for both categories in the lexicon.

This finding, where a significant difference between the patterns of reduction for core signs and fingerspelling was not found, goes against the initial study predictions. Although fingerspelling and core signs have considerable structural differences, both in their articulation and relationship to simultaneity, these differences did not exert pressure on language production in ways that resulted in significantly diverging patterns in duration reduction across multiple repeated mentions. A few possibilities can be entertained to explain the similar patterns in reduction, stemming from both similarities shared by the fingerspelling and core sign systems, as well as from the differences between the two systems. These potential explanations can fit within both producer and interlocutor oriented theories of language production.

As one possibility, similarities in reduction patterns may be due to shared properties of the manual-visual modality and increased allowances for reduction as a result of these properties. From a language production standpoint, the articulators used for both fingerspelling and signs are bigger than those used for speech, which might contribute not only to the longer length of signs and fingerspelling, but the increased pressure to reduce effort due to the larger amount of mass being moved. Signs and fingerspelled words are also longer, on average, than spoken words (Bellugi and Fischer, 1972), and so they may simply have more temporal material available that can potentially undergo reduction. From a different angle, that of language perception, they may have more room to reduce without a loss in comprehension as, even with considerable reduction, they leave more time to process the signal. Any one or a combination of these factors could contribute to the similarities in reduction patterns seen here.

It is also possible that it is the articulatory differences themselves between fingerspelling and signing that are contributing to similarities in patterns of duration reduction. Articulatory difficulty can stem from many sources, and so pressure towards ease of production might be exerted from different features of each of these systems. Articulation of signs requires the use of more proximal joints, moving articulators with larger mass than fingerspelling which only involves the more distal finger joints. Some have argued that more effort is required to move the articulators that utilize more proximal joints (Napoli et al., 2014; Sanders and Napoli, 2016a), and so if pressure from the muscular effort required to articulate signs is greater for signs than fingerspelled words, then this could be contributing to the pattern in which signs reduce considerably over multiple mentions. Relatedly, the effort involved in reducing torso movement as a result of certain types of path movements has been shown to shape the distribution of certain types of signs in the lexicons of sign languages (Sanders and

Napoli, 2016b), indicating that additional pressure to reduce articulatory effort can influence the articulation of signs in ways that are distinct from fingerspelling.

In contrast, fingerspelling, while involving the use of more distal joints than those used in signs, has a separate set of properties that could result in substantial reduction. The pressure to reduce on the fingerspelling system may be due to the articulatory effort involved in rapidly articulating complex handshapes in sequence. Fingerspelling thus presents additional demands on the articulatory system in terms of the coordination of the articulators. This is also paired with the potential for the loss of fingerspelled letters. Articulatory pressures acting on the differing properties of the sign and fingerspelling systems could then be shaping similar patterns in duration reduction, although they stem from different sources.

Although the interaction between mention number and category was not significant for core signs, non-significance is not necessarily indicative of true similarity between two, as certain study-related limitations might contribute to the lack of statistical significance. Due to the logistical constraints of finding, for example, a large number of repeated fingerspelled words, which themselves are already less frequent within signed discourse in ASL, the sample size used in the present study, while larger than many studies on ASL repetition reduction conducted in the past, was relatively small. As such, the lack of a significant difference could be attributed to the size of the samples included in the current analysis. In a similar vein, considerable statistical power is necessary to discern any interactions between factors whose otherwise have relatively small effect sizes. Corpus methodology had the advantage of providing a sample that is representative of a wide swath of the signing community and is relatively unconstrained by biases introduced by recording in an experimental, lab environment. However, this does result in considerably more variability within the sample of data collected. For this reason, in the future these research questions could benefit from additional, expanded study to determine the robustness of trends seen here, relying on many types of data, including more controlled data collected in a lab setting. Although these study constraints introduce the need for further study, the present results show that, when looking at patterns of duration reduction between fingerspelling and core signs, any difference, if present, is likely quite small.

4.6 Conclusion

The present chapter used a corpus of repeated fingerspelled words and core signs to compare patterns in duration reduction between these two categories in ASL. Against initial hypotheses, considerable differences in the trajectory of duration reduction across multiple mentions between the two categories in the lexicon were not found. The next chapter will address whether this similarity is also shared in the perception of fingerspelled words and core signs. This will contribute to our understanding of whether, in reducing forms within discourse, an interlocutor's understanding of the signal is taken into account in mediating reduction.

Although they shared similar duration reduction trajectories, previous chapters demonstrated that repetition reduction is realized differently in some ways between the two categories analyzed here. For example, reduction in core signs occurred along other parameters like location and internal movement repetitions, while in fingerspelling reduction was seen in the deletion of fingerspelled letters. These differing reduction strategies could result in a disconnect between the degree to which interlocutors are sensitive to these differences in the signal, which in turn might point to differing impacts on comprehension. Through a discrimination study, the next chapter will test whether signers are equally sensitive to reduction in fingerspelling and core signs in perception.

CHAPTER 5

PERCEPTUAL SENSITIVITY TO REDUCTION IN FINGERSPELLING AND CORE SIGNS

5.1 Introduction

In positing the mechanisms that determine how language is produced, linguistic theories have relied not only on evidence from language production but also on evidence from language perception. The linguistic models explaining the factors that shape phonetic and phonological reduction patterns in language rely on findings showing that more predictable forms are reduced in their articulation, but some, in explaining these patterns, also posit a connection to the perception and intelligibility of these forms. More specifically, a subset of linguistic theories (Fowler and Housum, 1987; Aylett and Turk, 2004; Jurafsky et al., 2001) argue that language producers use knowledge about contextual information available in the linguistic signal to maintain a comprehensible signal for their interlocutors, while allowing for reduction that allows language to be produced more efficiently. While these interlocutor-oriented theories suggest reduction processes are mediated to ensure intelligibility, there is mixed evidence, discussed at greater length in Chapter 1, that this is the case.

However, in research on both spoken and signed languages, more attention has been given to the production side of reduction processes, testing how contexts of increased predictability in both spoken and signed languages correspond to patterns in reduction. While this is the case, not only do some theories of language production posit that a reduced form's intelligibility plays a role in shaping reduction processes, but at least in the case of sign languages, some evidence suggests variation in the perception of reduced forms across linguistic systems. This prompts questions about how these differences might provide further insight into the connection between perception and production in shaping reduction processes. While the bulk of this dissertation has focused on the varying patterns of reduction in the production of the ASL fingerspelling and core sign systems, to better understand how these might distinctly impact perception, the present chapter focuses on the corresponding influence of reduction on perception.

The findings from Chapters 2-4, detailing reduction processes in the production of fingerspelling and core signs, were used to inform the creation of a study examining perceptual sensitivity to differences between reduced and unreduced core signs and fingerspelled words. In addition to further connecting the perception and production of reduction processes in ASL, the choice to examine these differences is motivated by the following observations:

- There is not a significant difference in the trajectories of duration reduction between fingerspelled words and signs (Chapter 4).
- Empirical attention has been given to considerable perceived repetition reduction for fingerspelled words, in a way that exceeds that given to core signs.
- Previous scholarship suggests that signers may not be sensitive to repetition-reduction related differences between reduced and unreduced core signs (as seen in Hoetjes et al. (2014)).

The present study then tests how sensitive ASL signers are to reduction effects for fingerspelled words and core signs, looking at both differences between fingerspelled words and signs, as well as the effect of the degree of reduction in each of these categories. This is tested through a discrimination task, of an AXB design, that was conducted online with signers of ASL.

To help discern whether signers limit the degree to which they reduce forms as they sign to ensure the comprehension of their interlocutor, an ideal experimental task would test how repetition reduction impacted the intelligibility of reduced verses unreduced forms. However, due to methodological challenges (discussed in §5.2.3), constructing a task specifically testing the intelligibility of reduced fingerspelled words and core signs presented numerous challenges, and so this question will instead be approached through the angle of ease of discrimination between reduced and unreduced forms in these two categories. Although this does not directly address whether similar degrees of reduction result in a similar impact on intelligibility, ease of discrimination between reduced and unreduced forms, as tested here, serves as a preliminary glimpse into differences in how signers perceive reduction between the fingerspelling and core sign systems.

5.2 Background

This study is built on findings showing similar patterns in duration reduction for fingerspelling and core signs across multiple repetitions, but it is also informed by scholarship on spoken and signed languages about how reduction impacts the perception of reduced forms. Considerably less work has addressed the perception of reduced forms in ASL specifically, for either fingerspelling or core signs, and so predictions will be supported by previous work not only on the perception of reduced forms in sign languages and spoken languages, but also on wider work about the information that signers use when processing the manual-visual signal. Although the present study does not test the intelligibility of reduced forms directly, it provides a first step towards determining how reduction impacts the processing of signs and fingerspelled words. The rational for using this approach is motivated by evidence from spoken language research showing a connection between people's ability to distinguish between reduced and unreduced forms and the intelligibility of reduced items.

5.2.1 The intelligibility and discriminability of reduced forms

Reduced forms are pervasive in discourse across modalities, especially within contexts of higher predictability, and reduction has been shown to impact multiple domains of language perception. When presented without additional context, reduced spoken words have been found to be more difficult to recognize and understand than their unreduced variants (Fisher and Tokura, 1995; Fowler and Housum, 1987; Hunnicutt, 1985; Samuel and Troicki, 1998; Ernestus et al., 2002; Ernestus and Baayen, 2007; Janse et al., 2007; Tucker and Warner, 2007), showing the importance of contextual information in understanding a linguistic signal that has fewer cues available to help with word recognition. However, in describing the impact of reduction on perception, the presence of reduction itself is not sufficient, as people's ability to understand these forms is tied not only to whether they are reduced, but also how much they are reduced (Janse et al., 2007). Although the intelligibility of reduced forms has not been directly tested for sign languages, work on spoken languages has shown reduction to impact the intelligibility of words, as well as shown a connection between the intelligibility of reduced forms and people's ability to distinguish reduced from unreduced forms. This connection is key in justifying any conclusions drawn from a discrimination study about parallel impacts on intelligibility.

The connection between the discriminability of reduced forms and their intelligibility has not been probed extensively, but the discrimination and subsequent word identification related to gradient phonetic differences resulting from reduction was examined in Janse et al. (2007). Their investigation targeted both the discrimination and lexical activation of partially reduced and fully deleted realizations of /t/ in Dutch. Using an oddity task to test discrimination ability, participants in their study were tasked with distinguishing words with partially and fully reduced variants of /t/ from words with unreduced variants. Their results showed that participants could successfully discriminate between unreduced and reduced forms with a higher success rate for the fully reduced than the partially reduced forms. Testing the lexical activation of these forms, they then found that activation is the slowest for the most reduced forms and that the smaller number of cues available in partially reduced forms also slows activation, but not to the same degree as for the fully reduced variants.

This finding suggests that even gradient forms of reduction that are recognized in discrimination can impact the recognition of words. It also showed that both discrimination and the intelligibility of forms was impacted by greater degrees of reduction, such those involving the full deletion of a segment. Findings like these have been used to argue that often, mild reduction processes that are barely discernible can have some influence on the process of lexical recognition (Ernestus, 2014). While these conclusions are drawn from research on spoken languages, they not only show the influence of reduction on the ability to distinguish reduced from unreduced forms, but they also tie the discriminability of reduced forms to their recognition. For this reason, the assumption is made here that that the degree of ability to successfully discriminate between reduced and unreduced forms for forms in sign languages corresponds to a decrease in comprehension of the reduced forms.

Although neither the intelligibility of reduced forms nor the ability to differentiate between reduced and unreduced forms have been examined for ASL, a related question has been analyzed for another sign language, focusing on the perceived perception of repeated core signs in comparison to their first mentions. In a study conducted on the Sign Language of the Netherlands (NGT), Hoetjes et al. (2014) looked at the influence of repetition reduction on the perceived precision of signing, using precision as a metric through which to test how signers recognized differences between reduced and unreduced forms. Hoetjes et al. (2014)'s study first compared productions of repeated signs in NGT with their first mentions, finding that the repeated signs were significantly shorter in their duration than the first mentions. The authors then compared the perceived precision of the repeated and first mentions of the signs within their study. Signers and non-signers were presented with first mentions and third mentions of a sign, and asked to pick which were more precise. For the NGT signer participants of the study, there was no difference in the perceived precision of first and third mentions for the signing participants. However, for participants who were not signers, the repeated signs were judged to be less precise. This presents some evidence that repetition reduction results in a difference in discriminability, as non-signers could distinguish between reduced and non-reduced forms. However, since the study tested perceived precision, rather than the discrimination or intelligibility of reduced signs directly, its unclear how generalizable these conclusions might be.

5.2.2 The perception and intelligibility of signs and fingerspelling

Although there has not been extensive research into the perception of reduced forms in ASL, related research pertaining to the ways that signs and fingerspelled words are processed suggests a few ways that reduction processes might impact the perception of reduced forms in ASL. This research indicates other factors related to repetition reduction that might contribute to the processing and general intelligibility of signs and fingerspelled words, including both predictability and signers' ability to identify forms in more visually difficult contexts. While the impact of increased predictability on the perception and processing of forms in ASL has not been examined through the lens of repeated discourse mentions, related research can supplement our understanding of how repetition reduction might impact perception, informing our predictions.

The frequency of signs in ASL, which is closely tied to their predictability, influences their perception. Specifically, lexical access is facilitated by lexical frequency (Caselli et al., 2021) and signs that are more frequent are recognized more quickly. This shows that predictability-related information is used by signers in perception, with higher levels of predictability in the signal facilitating processing.

Although not reduction itself, people's ability to perform sign identification in the visual peripheries can also provide insight into what kind of information is used by signers when it is more difficult to extract information from the visual signal, as is also the case for reduced forms. In ASL, sign identification ability decreases as signs are articulated at increasingly peripheral distances (Emmorey et al., 2009; Swisher et al., 1989), showing more broadly that identification ability is negatively impacted in more visually difficult contexts. At these peripheral locations, lexical information has been shown to assist in handshape identification (Schotter et al., 2020), indicating that top-down linguistic information is used by signers in processing when the signal is more difficult to interpret. We can thus assume that, in the case of repetition, where there is more contextual information to support the smaller amount of information available in the reduced signal, this additional, top-down information is likely used by signers in processing.

While top-down information can be helpful to processing in contexts where the linguistic signal is less clear, introducing additional difficulty within the signal has been shown to have an unequal impact on intelligibility in different parts of the ASL lexicon. The impact of signing presentation rate on comprehension in ASL has demonstrated this for fingerspelling and core signs. Higher rates of presentation in signing and fingerspelling have been shown to correspond to a decrease in intelligibility, but to an unequal degree across the two categories. In Reed et al. (1990), the effect of fingerspelling rate on comprehension was tested by presenting signers with videos of fingerspelled words sped up to multiple times their original rate. This study found that when signers were presented with fingerspelled words sped up to twice their original rate, comprehension was unaffected, but when the rate of presentation increased to three times the original speed, comprehension dropped to roughly 50%. A similar study, examining the effect of presentation rate on the comprehension of core signs, was performed in Fischer et al. (1999). Within this study, the authors found that when rate of presentation of individual signs was increased to three times the original speed, accuracy in comprehension dropped to 78%, a rate higher than that found for fingerspelled words in the preceding study.

Together, these results suggest that, at increased speeds, core signs remain more intelligible than fingerspelled words. However, as reduction phenomenon in language typically not only involve a faster rate of presentation, but also other articulatory realizations of reduction including shortening, coarticulation, and deletion of segments or features, it is unclear how generalizable these findings are to reduction processes as they naturally occur in language. This, coupled with Hoetjes et al. (2014)'s finding that signers show little sensitivity to differences in precision between reduced and unreduced signs in NGT, suggests that reduction may impact fingerspelling perception, and perhaps even intelligibility, to a greater degree than signs.

Adding additional support to this prediction, fingerspelling in particular has been noted to be difficult to perceive and understand. For example, for second language learners of ASL, teachers and students report particular difficulty in learning to understand fingerspelling when compared to learning other components of ASL (McKee and McKee, 1992). People who primarily use ASL, as well as second language learners of ASL, also show variable performance in fingerspelling comprehension and report increased difficulty with this task in comparison to the comprehension of other systems in ASL (Geer, 2016, 2019). Similarly, in comparison to ASL signs, reduction in ASL fingerspelling has been noted to be particularly salient, as evidenced by the considerable attention repetition reduction processes have received in previous research (Wager, 2012; Lepic, 2019; Brentari, 1998; Channer, 2012; Thumann, 2012) when compared to repetition reduction processes for core signs in ASL (Grosjean, 1979).

The properties of the visual perception system might also influence these differences in the perception of fingerspelling and core signs. In particular, sign perception is impacted by the size of the articulators and their corresponding movements, which differs between the fingerspelling and core sign systems. For example, for movements articulated with more distal joints, there is more information within the movement itself that can be used to identify signs (Poizner et al., 1981). However, larger movements, articulated with more proximal joints, are more visually salient (Poizner et al., 1981; Brentari, 1998; Napoli et al., 2014) and, as such, can be more easily identified. This difference between more distal and more proximal movements could result in a distinct impact on the perception of fingerspelling and core signs, as fingerspelling employs more distal joints at a considerably higher rate, using the wrist and finger joints for the majority of the contrastive articulatory movements that comprise these forms. Fingerspelling, using these more distal joints, is then conveying a larger amount of information in a short amount of time, perhaps increasing processing difficulty. In contrast, for core signs, while distal joints are employed in articulation, the joints used in articulating core signs are, on the whole, more proximal. This could facilitate comprehension due to the increased visible salience of the movements produced.

Together, previous scholarship on signed and spoken languages suggests not only that reduction might influence the perception of the core sign and fingerspelling systems in unequal ways, but it also suggests that it is possible to approach this through the lens of discriminability. Although the connection between discrimination and the recognition of reduced forms has only been examined for speech, findings from that research suggest that the more easily discriminable reduced forms are, the larger the impact on comprehension. It has also shown the intelligibility of forms in sign languages to be influenced by similar factors to those in speech, such as top-down information, which is used in the identification of signed forms. Previous work also suggests that reduction has an unequal impact on the processing of fingerspelling and core signs, as not only do properties of the visual signal suggest that the use of smaller joints might make forms more difficult to understand, but work reporting instances when signing is more difficult to discern, including increasing the rate of presentation, shows this impacting fingerspelling to a greater degree.

Based on these findings, in conducting the present study I predicted that fingerspelling reduction would have a greater impact on discrimination ability than reduction in core signs. Additionally, following findings from speech research showing that full reduction of segments is easier to distinguish and more difficult to understand, I hypothesized that increased reduction in ASL, through full segmental deletion, would make reduced forms easier to discriminate for both fingerspelling and for core signs.

5.2.3 *Methodological challenges in study design*

While the most direct way to discern the impact of reduction on comprehension in ASL is to design an experiment that tests the intelligibility of reduced forms, designing a comprehension study that can be run remotely[1] for both ASL fingerspelling and core signs using stimuli from naturalistic data presented considerable challenges. There were various motivations for using naturalistic stimuli. First, reduction processes impact signs and fingerspelled words in a variety of ways, including length, but also encompassing the size and speed of articulation and coarticulatory processes. While much work on language perception uses artificially manipulated stimuli, artificially manipulating visual stimuli to include each of these dimensions presents considerable challenges when representing sign languages. For example, adding or removing frames can be done to increase or decrease the length of signs, but can result in artificial looking stimuli that could bias the results in ways that are not related to reduction itself, but instead the stimuli manipulation. Naturalistic stimuli, in contrast, capture the reduction processes and do not result in any manipulation-related bias.

There is additionally precedent from both the speech (Fowler and Housum, 1987; Ernestus et al., 2002) and sign research (Hoetjes et al., 2014) to use naturalistic stimuli in studying the perception of reduction processes. However, reduction and its impact on the comprehension of signed forms has not yet been tested, as Hoetjes et al. (2014) tested whether repeated mentions of core signs in NGT were deemed to be more precise than first mentions, instead of testing comprehension directly. While their study provided a first step in testing the impact of repetition reduction on the perception of signs, it's unclear what perceived precision indicates about the processing of signs and a finer grained measure might provide further insights into the ways that reduction impacts sign perception.

1. The timing of the data collection portion of this dissertation coincided with the height of the COVID-19 pandemic and so an online study was designed to prioritize the health and safety of the study participants, as well as to allow for participation by participants across the United States, widening the study's participant pool.

Unlike studies that employ naturalistic stimuli in many comprehension tasks, like those for speech, written English cannot be used to test comprehension for both fingerspelling and for core signs in a comparable task. This approach was used previously to study the comprehension of fingerspelling, for example by Reed et al. (1990) and Geer (2016) who showed participants fingerspelled words and had participants write down or type the word they saw spelled. While this approach was initially considered, using a similar method of evaluating comprehension for core signs by having participants type the names of signs would require signers to use their knowledge of English in the task and would turn the experiment into a translation task for core signs. This adds an additional dimension of difficulty and makes the task no longer comparable to a similarly designed task for fingerspelling.

Using a separate approach to test comprehension for core signs, Fischer et al. (1999) had respondents sign back phrases or signs that were shown to them at various speeds of presentation and calculated comprehension through the accuracy of their reproductions. This approach was considered, as it would allow for the implementation of a similar task for fingerspelling and signs. However, one drawback to this approach is, as signs are repeated back, it is difficult to ensure that signers are responding with the sign or fingerspelled word they observed or instead exactly copying whatever form they observed. Additionally, this approach comes with the danger of ceiling effects, wherein participants are able to correctly identify all of the signs they see.

To allow for online implementation of the study, collection of a gradient response measure, and avoidance of the methodological pitfalls noted above, the present study approaches this issue from an angle by instead testing signers' ability to distinguish reduced from unreduced forms. This experiment is conducted under the assumption, supported by the findings from (Janse et al., 2007), that increased ability to discriminate between reduced and unreduced forms corresponds to a greater impact on comprehension.The connection seen in their experiment is drawn upon here, with the assumption that a greater ability to discriminate between reduced and unreduced forms will have a corresponding negative impact on comprehension. Increased discrimination ability points to greater perceived difference between forms, with the reduced form deviating more in perception with increased discriminability. Comprehension is then likely most successful for forms that are perceived as closer to first mention forms, as language perceivers are attuned to more information in the linguistic signal that indicates their identity.

The study was then designed to test signers' ability to successfully judge reduced forms to be more similar to one another than an unreduced form, as well as compare speed of discrimination judgements between reduced and unreduced forms. Within discrimination tasks for audio stimuli, reaction time has been shown to correlate with the ability to distinguish between acoustic differences. Faster reaction times have been shown to correspond to, for example, successful discrimination of contrasts characterized by larger acoustic differences (Pisoni and Tash, 1974), as well as a increased accuracy of contrast discrimination for second language learners (Nelson, 2020).

The rationale for this design was also supported by findings from Chapters 2 and 3 of the present work, wherein, although both signs and fingerspelled words reduced between the first and second as well as second and following mentions, the degree of reduction was considerably smaller between mentions two and the subsequent mentions. This larger difference between first and second mentions renders subsequent forms more similar to one another. We can then test whether signers are sensitive to this difference between the reduced and unreduced forms, as well as compare whether this differs between fingerspelling and core signs.

The present study presents a first step in testing how the perception of signs and fingerspelling are impacted by repetition reduction, providing a comparable metric across these two categories in the lexicon. It asks whether, when presented with reduced and unreduced forms, signers can pick out the unreduced forms from reduced forms and whether this is easier for fingerspelling than it is for core signs. If signers can successfully identify reduced from unreduced forms at an above-chance rate, this might provide distinct evidence from that presented in Hoetjes et al. (2014) wherein there was no significant difference in signers' perceived precision of repeated versus first mentions of core signs. It also presents a methodological contribution in testing the feasibility of using naturalistic stimuli in an online sign language perception task to obtain finer-grained measures of how signers perceive core signs and fingerspelled words.

5.3 Methodology

The discrimination study was conducted online with an AXB-type task, using naturalistic data from the previously annotated corpora to test whether signers can distinguish between reduced and unreduced core signs and fingerspelled words. Study participants completed the experiment on their own laptop and desktop computers through their internet browsers. After viewing instructions for the task presented in ASL and in written English, they proceeded with the experimental task[2]. In each trial, participants were presented with a video of two reduced forms and an unreduced form, and tasked with picking which forms were the most similar. After a short practice trial to familiarize them with the experimental procedure, participants moved on to the main experiment.

5.3.1 Experimental conditions

Participants' ability to distinguish between reduced and unreduced forms was tested for two conditions, referred to here as 'reduced' and 'highly reduced'. A description of the criteria used to select these is as follows:

- The 'reduced condition' stimuli exhibited reduction in duration, but no type of seg-

2. This study was approved under the University of Chicago IRB (Title: "Perception Reduction ASL," Number: IRB22-0193)

mental reduction[3].

- The 'highly reduced' condition stimuli exhibited reduction in duration, as well as reduction in segmental material. For fingerspelling, this was letter segments, while for core signs this was repeated movements.

The reduced condition was chosen to test whether people are sensitive to reduction in duration, as well as whether there is a difference between fingerspelling and core signs in how easily this difference is discerned. The highly reduced condition was chosen to test whether discrimination ability was additionally impacted by the full deletion of segmental material, whether this comprised fingerspelled letters or repeated movements. These categorical types of reduction are common, especially at later discourse mentions, and so a fuller understanding of the impact of reduction on perception necessitates their inclusion.

The measures of participants' responses within the study included both a similarity judgement, measuring whether the reduced forms were identified as the most similar to one another, as well as reaction time. The similarity judgement measurement was used to determine if participants can discern the difference between reduced and unreduced forms, as determined by whether they judge two reduced forms to be more similar to one another than to an unreduced form. Reaction times, reflecting the time participants took to make their selection, were used to determine the level of difficulty that subjects experienced in making their decision. Previous work using reaction times as a measurement accompanying discrimination tasks has argued that these indicate task difficulty (Kilpatrick et al., 2021; Best and Hallé, 2010), as well as indicate participants' confidence in their response (Hallé et al., 2004). Higher reaction times were hypothesized to indicate increased difficulty and less confidence in making a decision distinguishing between the stimuli within the present study.

3. These stimuli did not exhibit deletion of letters or internal movement segments

In making predictions for study results, the experimental design and previous findings suggesting differences between fingerspelling and signs in perception led to the prediction that participants would identify reduced fingerspelled words as similar to one another at higher rates than they do for signs, with faster reaction times when responding to fingerspelled stimuli. When looking at differences between conditions, I predicted higher rates of participants selecting highly reduced forms to be similar to one another when compared with the reduced condition stimuli, with slower reaction times for the reduced condition stimuli.

5.3.2 Participants

Participants in the study were signers of ASL who used ASL as their primary form of communication in their daily lives. 28 signers of ASL participated in the study. A greater number of participants were female (15) than male (13). Participants were recruited for the perception study via email by reaching out to previous study participants from the University of Chicago's Sign Language Linguistics Lab, word of mouth, and social media advertising. Participants were monetarily compensated for their participation in the study with an online gift card.

5.3.3 Procedure

The study was conducted online through the Penn Controller for Ibex (PCIbex) platform (Zehr and Schwarz, 2018). This platform gives participants access to the study through a link, allowing them to complete the experiment remotely from their own computers. The PCIbex platform was designed to maintain independence from internet connection quality, and so it provides accurate control of experimental timing and measurements of timing within experiments themselves, including for measures like reaction time (Schwarz and Zehr, 2021). The PCIbex platform has been used previously in measuring reaction time, successfully finding differences between small effect sizes in reaction times (Wilder et al., 2019; Creemers and Embick, 2022).

The present study employed an AXB within-subject design wherein participants were shown a sequence of three videos and asked to pick which were the most similar to one another. Participants were shown a sequence of 3 videos: A video of a reduced form or unreduced form (A) and then a reduced form (X) and another reduced or unreduced (B) version of the same word or sign. They were asked to determine whether the first or last form was the most similar to the second form they saw, and made their selection via a button press. Discrimination tasks using an AXB design have been used previously for sign languages to test categorical differences between particular contrasts (Emmorey and Herzig, 2003; Baker et al., 2005; Best et al., 2010). The AXB order was chosen due to the lower demands on short-term memory associated with the AXB type task, in contrast to XAB and ABX (Best et al., 2001), and has been used with success to test phonological differences in perception for signers of ASL (Best et al., 2010), albeit not with naturalistic stimuli.

There were multiple trials per condition, and stimuli were presented in two blocks. There were six different trials for each of the four conditions (reduced fingerspelling, reduced core signs, highly reduced fingerspelling, and highly reduced core signs). The stimuli and condition summary can be seen in Table 5.1. The number of trials was kept to six to 1) reduce the cognitive load and prevent participants losing attention in a considerably difficult task 2) align with the constraints imposed by finding appropriate stimuli from the highly variable corpus data. Stimuli were presented twice in two separate blocks, with the reduced and unreduced (AB) options counterbalanced between blocks so each occurred in both first and last position. This decision was to help mitigate any memory-related recency effects on decisions and reaction times as a result of stimuli order[4]. Stimuli order for fingerspelled words and core signs, for both the reduced and highly reduced conditions, was randomized

4. This decision follows previous studies that employ AXB tasks in auditory discrimination that employed similar counterbalancing measures to avoid biases as a result of stimuli sequence in the decision and reaction time measures, like those of Kilpatrick et al. (2021) and Best and Hallé (2010).

Table 5.1: Summary of the properties of the perception study stimuli conditions

	Unreduced	**Reduced**	**Highly reduced**
Core signs	First mention	Duration only	Duration + movement deletion
Fingerspelling	First mention	Duration only	Duration + letter deletion

for each participant to reduce any possible effect of trial order.

For each trial, participants pressed the space bar to play the videos on the screen and viewed all stimuli in sequence. Videos were shown in sequence on the same page and participants were only allowed to view the videos once. Participants indicated their selection using a key press. They were instructed not to make their selection until the end of the stimuli items, to ensure that they were making judgements based on the full forms of the stimuli presented. Reaction time was measured[5] from the end of the last stimuli item until the participant made their selection via a button press. This decision follows Hallé et al. (2004)'s finding showing considerable variation between participants in an AXB discrimination task in whether they waited for the end of the final stimulus item before making their response. Because the B stimuli in the present study are different lengths, allowance for variation in participant's decision to wait for the final stimuli before responding would result in additional response time variation as a result of stimuli length. To avoid this, following Best and Hallé (2010), participants were instructed to respond following the end of the third stimuli video, and reaction time was recorded from that point to the moment of their response.

5. Previous work has varied in its choice of participant instruction and reaction time measurements in AXB discrimination tasks. In some studies, reaction time is measured from the onset of the B stimuli (for example, Hallé et al. (2004); Kilpatrick et al. (2021)), while others measure reaction time starting at the end of the B stimuli (for example, Best and Hallé (2010); Tantibundhit et al. (2012)). However, work comparing AX and AXB discrimination tasks suggest that participants process all three AXB stimuli in discrimination tasks, rather than treating them as AX comparisons (Gerrits, 2001).

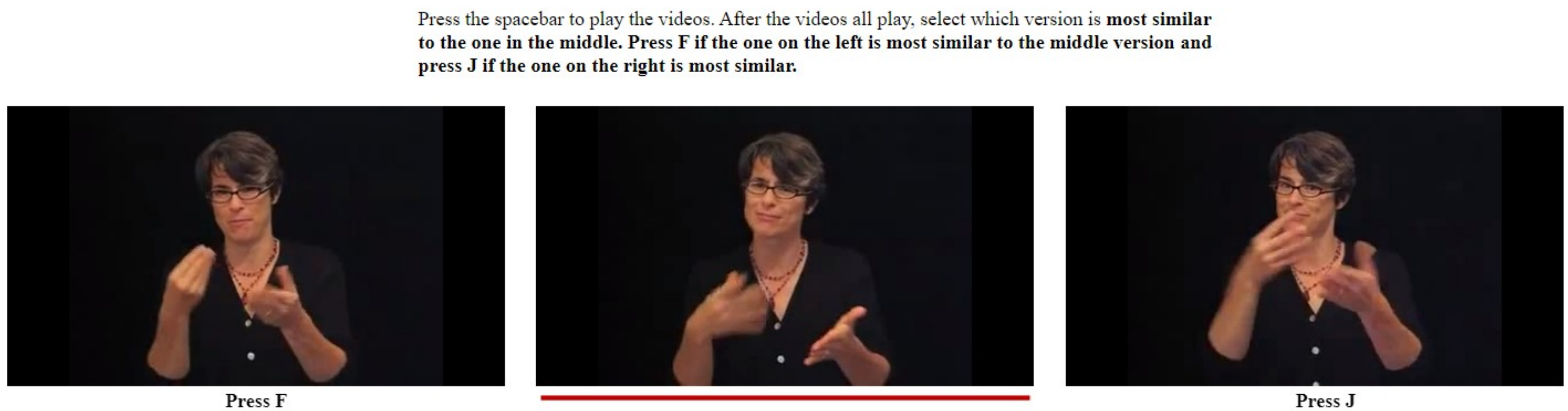

Figure 5.1: Image of experimental set-up for one trial. Videos would play from left to right. Original video in this image is from https://youtu.be/gpcKN2oXp9Y

5.3.4 Stimuli

The study stimuli were selected from the previously annotated corpora used for the production analyses, drawn from publicly available online videos of repeated core signs and fingerspelled words. Because of the wide range of variation in the dataset, stimuli were chosen that exhibited a specific reduction profile. The stimuli for both the reduced and highly reduced conditions were chosen from the set of repeated tokens from the corpora, encompassing second through sixth mentions. All forms categorized as unreduced were selected from first mentions. Due to the considerable variation in the dataset, the choice of repeated, reduced stimuli was controlled so they were as similar as possible to one another within each experimental trial. This was to ensure that there was not a large difference in duration between the reduced stimuli for each trial. For the reduced condition, the reduced tokens were selected as experimental stimuli if they were only reduced in duration and if difference the between them in length was $\sim$10% or less of the duration of the unreduced first mention. For the highly reduced condition, the reduced tokens were selected if they were reduced in duration and if they showed the same additional type of reduction (i.e. same deleted letters and number of deleted movements). Like with the reduced condition, the highly reduced stimuli were selected to be as similar as possible, such that the difference the between them in length was no more than 10% of the duration of the unreduced first mention.

Across stimuli categories, stimuli in the reduced and highly reduced conditions were reduced in duration with respect to their first mentions. As in the production experiment, due to their longer general duration, the fingerspelled words were more reduced in duration than the core signs. This difference can be seen in Figure 5.2. A linear regression revealed that this difference between fingerspelled words and signs was significant, showing that duration of the difference between the stimuli for the reduction conditions and their first mentions for core signs was significantly shorter than it was for fingerspelling (Estimate=-148.66, SE=73.42, $T(48)=-2.025$, $p=0.049$). Specifically, for the highly reduced stimuli, the difference between reduced and unreduced stimuli was then chosen to vary, rather than by duration, by the presence of deletions (letters for fingerspelled words and movements for core signs). The reduced fingerspelled words in the highly reduced condition each had one deleted letter, while the core signs had, on average, 1.5 movement deletions. A list of individual stimuli and their properties can found in Tables A.6 and A.7 in the appendix.

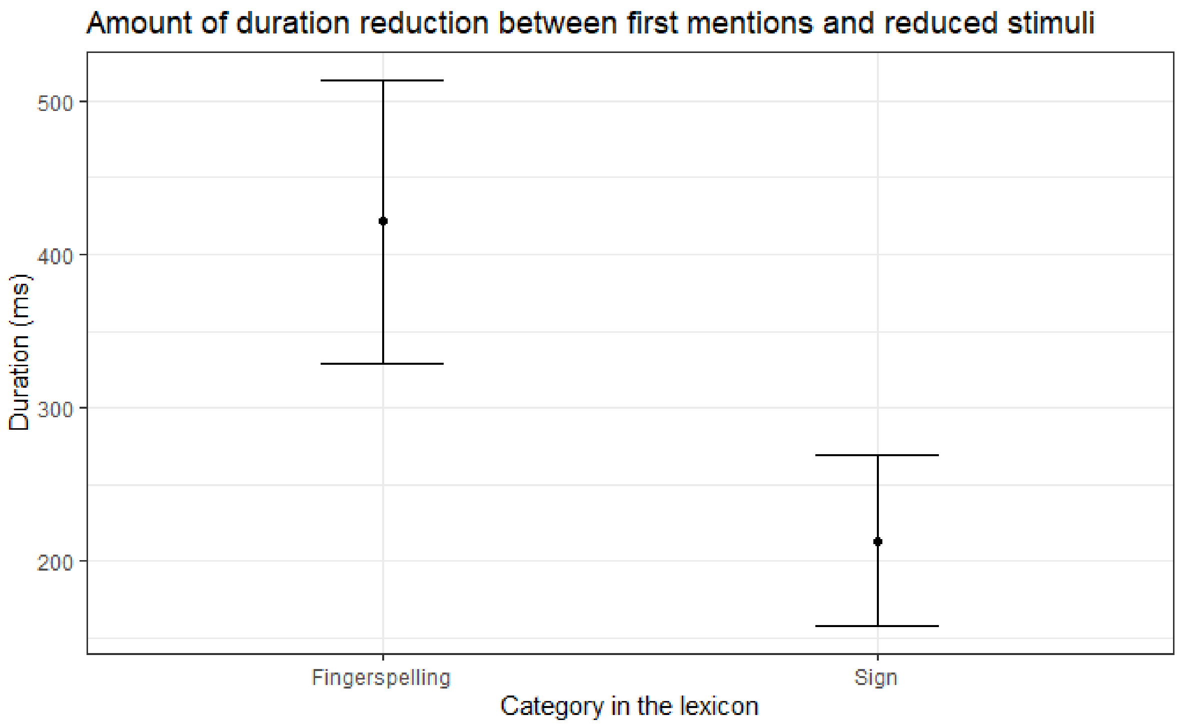

Figure 5.2: Degree of reduction for experimental stimuli for both conditions in each category of the lexicon. Bars indicate confidence intervals.

Stimuli profile for each condition:

- *Reduced condition:* On average, the stimuli from repeated mentions for core signs were 67% of the duration of their first mentions and 65%[6] of the duration of their first mentions for fingerspelling. The duration of reduced tokens ranged between 50-80% of first mentions.

6. This difference was deemed to be small enough not to impact the results in a substantial way.

- *Highly reduced condition:* On average, the stimuli from repeated mentions for core signs were 55% of the duration of their first mentions and 56% of the duration of their first mentions for fingerspelling. The duration of repeated tokens ranged between 40-80% of first mentions. Stimuli in this condition also shared the same type of segmental deletion (ie. letters or repeated movements).

The video stimuli for the experiment were processed using the program Davinci Resolve 17 on a Windows computer. All files were formatted as mp4 videos for consistency and to align with the platform requirements of the Penn Controller for Ibex platform. Video durations were clipped so that the video began a frame before the beginning handshape of each sign or word was established and ended a frame after the final handshape relaxed. Transition movements from preceding signs or words were excluded to, as much as possible, avoid any differences that would result from differing surrounding environments of each of the stimuli items.

5.4 Analyses & Results

To analyze signers' ability to distinguish between reduced and unreduced forms, the number of reduced forms identified as similar to one another and participants' reaction times[7] were analyzed separately. This was to determine if signers can distinguish between reduced and unreduced forms for fingerspelled words and core signs, as well as judge ease and confidence of participants' decisions between the experimental conditions. Mixed effects models were used to analyze trends in both participant selection and reaction time.

7. In analyzing the data, responses with reaction times of longer than 5 seconds were removed, as this indicates that participants may have become distracted during their response and analysis should target responses that are as automatic as possible.

5.4.1 Similarity judgements of reduced forms

The first analysis targets patterns in participants' ability to judge reduced forms to be more similar to one another than to an unreduced form. Analysis of the significance and magnitude of these trends was conducted using logistic mixed effects regression models, using *glmer()* in the *lme4* R package (Bates et al., 2015). Within the analysis, both of the predictor variables, category in the lexicon and condition, were treatment coded. The base model included category in the lexicon as a fixed effect and then added factors to determine whether their addition improved model performance. Models were compared using an ANOVA. Selection choices were coded as 1 (participant selected the reduced form as most similar to reduced comparison form) and 0 (participant selected the unreduced form as most similar to the reduced comparison form). The analysis was conducted with participant and study block as random effects[8]. The base formula is as follows:

$$\textsc{Selection} \sim \textsc{Lexicon Category} + (1|\ \textsc{participant}) + (1|\ \textsc{block}\ )$$

In the analysis, condition was first added as a fixed effect (Model 1b) to see if the fit of the model improved and then it was tested as an interaction effect with category in the lexicon (Model 1c). The summaries of the models can be seen in Table 5.2.

Table 5.2: Model structures, presented as the *glme4* formula, used to compare the effect of category in the lexicon and experimental condition on similarity judgements.

Model 1a:	SELECTION ~ LEXICON CATEGORY + (1|PARTICIPANT) + (1|BLOCK)
Model 1b:	SELECTION ~ LEXICON CATEGORY + CONDITION + (1|PARTICIPANT) + (1|BLOCK)
Model 1c:	SELECTION ~ LEXICON CATEGORY * CONDITION + (1|PARTICIPANT) + (1|BLOCK)

The model comparison can be seen in Table 5.3. When compared via an ANOVA, model

8. In the model selection process, models with more complex structures, including by-subject random slopes for lexical category and condition, were tested but did not converge and so these are not reported here.

performance improved through the addition of each of the fixed effects, with both the addition of condition and an interaction term between category and condition improving model performance. The model with the best performance, Model 1c, will be used to report results of the analysis. Within the model comparison, there was a significant effect of condition, as well as an interaction between condition and lexicon category.

Table 5.3: Logistic regression model comparison analyzing stimuli selection choices. Results of an ANOVA comparing model performance are included at the bottom of the table.

	Dependent variable:		
	Selection		
	Model 1a	Model 1b	Model 1c
Constant	0.569^{***}	0.415^{***}	0.248^{**}
	(0.084)	(0.099)	(0.112)
Category: Sign	-0.327^{***}	-0.336^{***}	-0.004
	(0.115)	(0.115)	(0.159)
Condition: Highly Reduced		0.326^{***}	0.701^{***}
		(0.115)	(0.170)
Category*Condition			-0.705^{***}
			(0.233)
Observations	1,273	1,273	1,273
Log Likelihood	-853.406	-849.398	-844.771
Akaike Inf. Crit.	1,714.812	1,708.797	1,701.542
Bayesian Inf. Crit.	1,735.409	1,734.542	1,732.437
Chi-squared		8.015	9.254
p-value		p=0.005**	p=0.003***
Note:			*p<0.1; **p<0.05; ***p<0.01

The results of Model 1c did not show a significant effect for the category in the lexicon in participants' similarity judgements. It showed a significant effect of condition, wherein participants were significantly better at judging the highly reduced forms to be more similar to one another (*Estimate*=0.701, SE=0.170, Z(1273)=4.112, p<0.001). As seen in the significant interaction between condition and category, it also showed that the effect of condition was smaller for signs than it was for fingerspelled words (*Estimate*=-0.705, SE=0.248, Z(1273)=-3.033, p=0.002).

These results can be seen represented graphically in Figures 5.3 through 5.5. Figure 5.3 shows the result for category in the lexicon, where the rates at which reduced signs words are identified as similar to one another were lower than for fingerspelling, but not to a significant degree (64% reduced forms selected for fingerspelling and 56% for core signs).

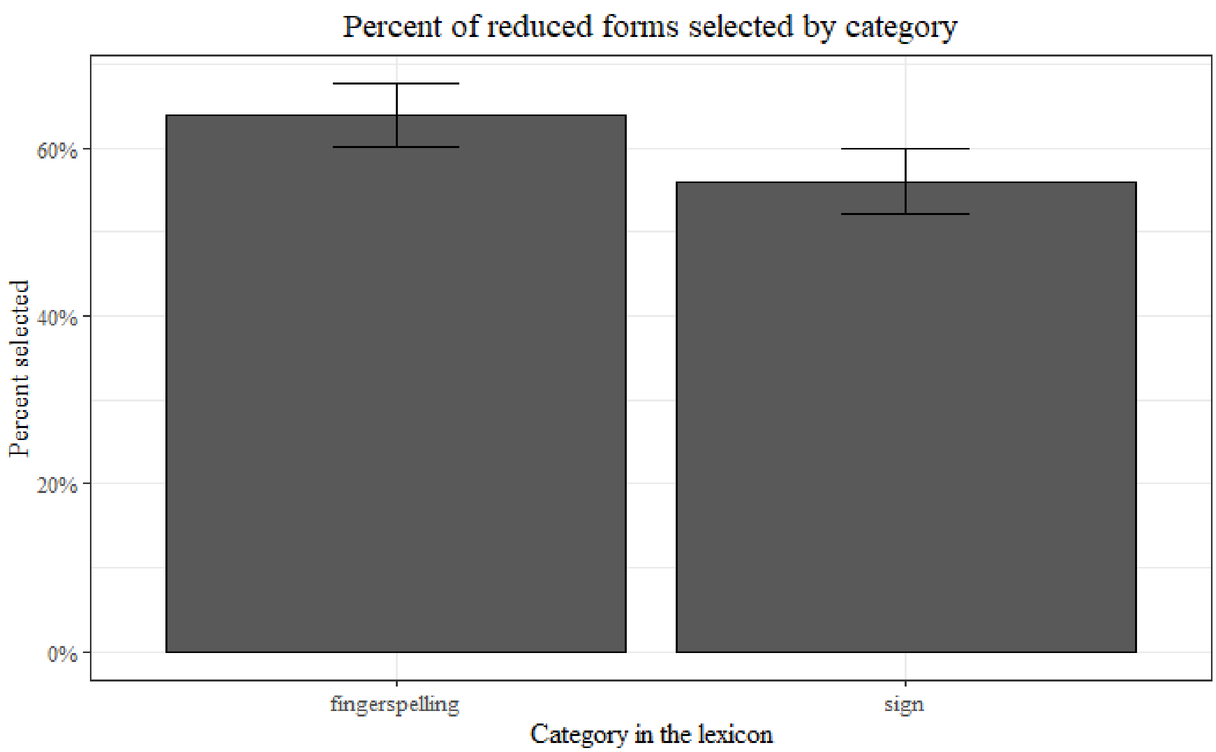

Figure 5.3: Percent of reduced forms identified as similar to the other reduced stimuli item (as opposed to the unreduced item), separated by category in the lexicon. Bars indicate confidence intervals.

The analysis showed that reduced forms in the highly reduced condition were selected as similar to one another at a significantly higher rate than those in the reduced condition. This can be seen in Figure 5.4. Participants also performed above chance for both conditions, suggesting that signers are able to distinguish between reduced and unreduced forms generally, albeit perhaps at a higher rate when categorical deletion processes are involved.

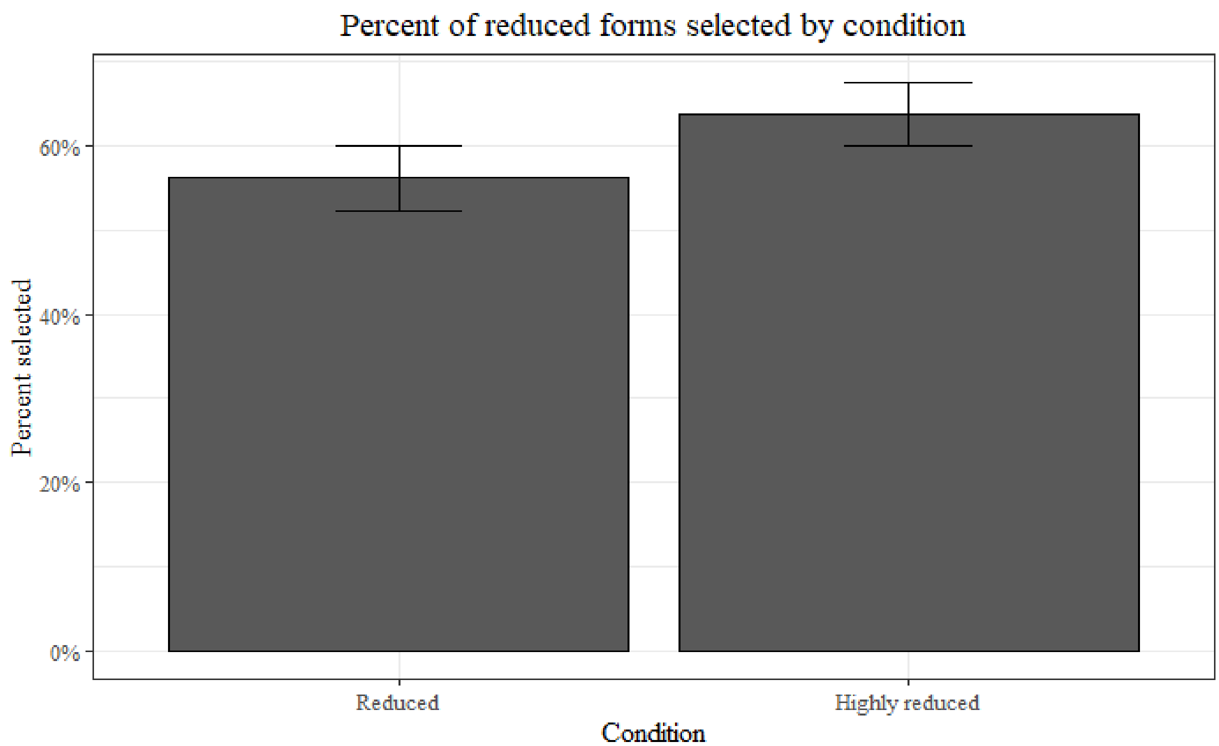

Figure 5.4: Percent of reduced forms identified as similar to the other reduced stimuli item (as opposed to the unreduced item), by reduction condition ('Reduced' or 'Highly reduced'). Bars indicate confidence intervals.

However, just looking at each of these dimensions alone does not provide a complete picture of results explaining the rates at which the reduced stimuli were successfully selected as similar to one another across both categories in the lexicon and reduction conditions. Figure 5.5 exemplifies the significant interaction effect, showing that the difference between conditions was greater for fingerspelled words than it was for core signs. Fingerspelled words showed considerable difference between reduction conditions, with highly reduced forms being selected at a much higher rate than reduced form. However, there was negligible difference in the percent of reduced forms selected as similar between the reduction conditions for core signs.

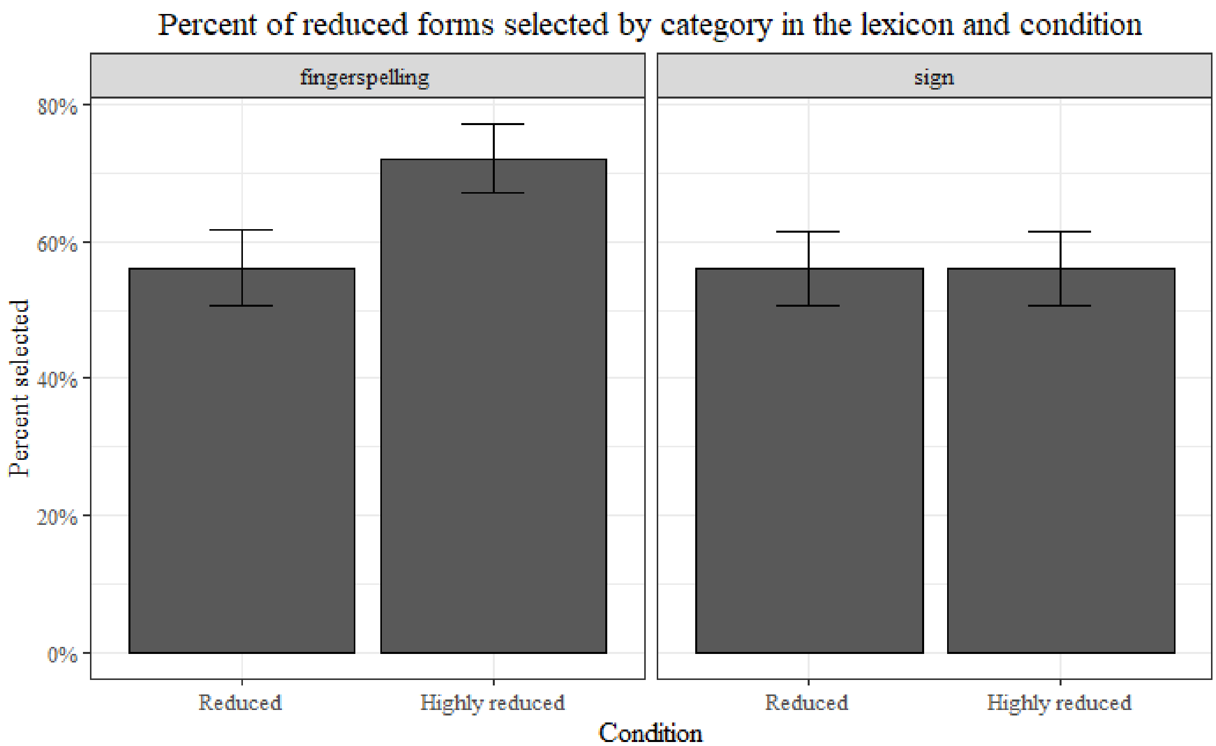

Figure 5.5: Percent of reduced forms identified as similar to the other reduced stimuli item (as opposed to the unreduced item), by category in the lexicon and condition ('Reduced' or 'Highly reduced'). Bars indicate confidence intervals.

Table 5.4: Summary of raw reaction times by category in the lexicon and reduction condition

Category	Condition	Mean (ms)	SD
Fingerspelling		1251.464	848.1545
Signs		1486.657	969.2162
	Reduced	1428.898	935.778
	Highly reduced	1311.911	898.3141
Fingerspelling	Reduced	1233.009	855.8485
	Highly reduced	1271.329	840.7642
Signs	Reduced	1626.617	972.0574
	Highly reduced	1349.266	947.9583

5.4.2 Reaction time

The second analysis examined how differences in the category within the lexicon and reduction condition impact reaction times. Reaction times were positively skewed (skewness=1.184, kurtosis=4.410) and so they were log-transformed for analysis. A summary of the average reaction times, before log transformation, can be seen in Table 5.4.

The reaction time data were analyzed using linear mixed effects models, using the *lme4* package in R (Bates et al., 2015). The analysis tested the impact of both the category in the lexicon and reduction condition variables by adding each of these as fixed effects to determine whether their addition better explained trends in the data. Model performance was compared via an ANOVA. The base model was as follows:

$\textsc{Reaction Time} \sim \textsc{Lexicon Category} + (1|\textsc{participant}) + (1|\textsc{block})$

Each factor was then added to see if its addition improved model fit. The base model for this comparison, using the reaction time data, included individual participant and experimental block as random effects, and category in the lexicon as a fixed effect (Model 2a). Experimental condition was added as a fixed effect (Model 2b) and then added as an interaction term (Model 2c) to see if their inclusion continued to improve the model performance. The models used in the comparison can be seen in Table 5.5.

The performance of each model as factors were added was compared using an ANOVA. The analysis of the model comparison can be found in Table 5.6. The ANOVA results showed

Table 5.5: Model structures, presented as the *lme4* formula, used to compare the effect of category in the lexicon, condition, and their interaction, on reaction time.

Model 2a:	REACTION TIME ~ LEXICON CATEGORY + (1 | PARTICIPANT) +(1 | BLOCK)
Model 2b:	REACTION TIME ~ LEXICON CATEGORY + CONDITION + (1 | PARTICIPANT) + (1 | BLOCK)
Model 2c:	REACTION TIME ~ LEXICON CATEGORY * CONDITION + (1 | PARTICIPANT) + (1 | BLOCK)

.

that that addition of the interaction term between category in the lexicon and reduction condition improved model performance.

Table 5.6: Linear regression model comparison analyzing selection reaction time. Results of an ANOVA comparing model performance are included at the bottom of the table.

	Dependent variable:		
	Log transformed reaction time		
	Model 2a	Model 2b	Model 2c
Constant	2.990***	3.014***	2.978***
	(0.058)	(0.061)	(0.063)
Category: Sign	0.080*	0.081*	0.151***
	(0.044)	(0.042)	(0.056)
Condition: Highly reduced		−0.048	0.023
		(0.042)	(0.056)
Category*Condition			−0.142*
			(0.080)
Observations	1,273	1,273	1,273
Log Likelihood	−339.078	−338.466	−336.981
Akaike Inf. Crit.	690.156	690.932	689.962
Bayesian Inf. Crit.	721.051	726.976	731.155
Chi-squared		1.22	2.97
p-value		p=0.269	p=0.084*
Note:	*p<0.1; **p<0.05; ***p<0.01		

The best fitting model, Model 2c, will be used to report the results. Within this model, there was a significant effect of category in the lexicon and a significant interaction between category and condition. For category in the lexicon, response times in making a selection between core sign stimuli were significantly longer than for fingerspelling ($Estimate$=0.151, SE=0.056, T(1273)=6.142, p<0.001). The effect of experimental condition alone was not significant in the model, but there was a marginally significant interaction between category in the lexicon and condition ($Estimate$=0.142, SE=0.080, T(1273)=-3.782, p=0.088), with reduced signs exhibiting longer reaction times than highly reduced signs and both conditions for fingerspelling.

The difference in reaction time for signs and fingerspelling can be seen in Figure 5.6, showing higher reaction times for signs than fingerspelled words.

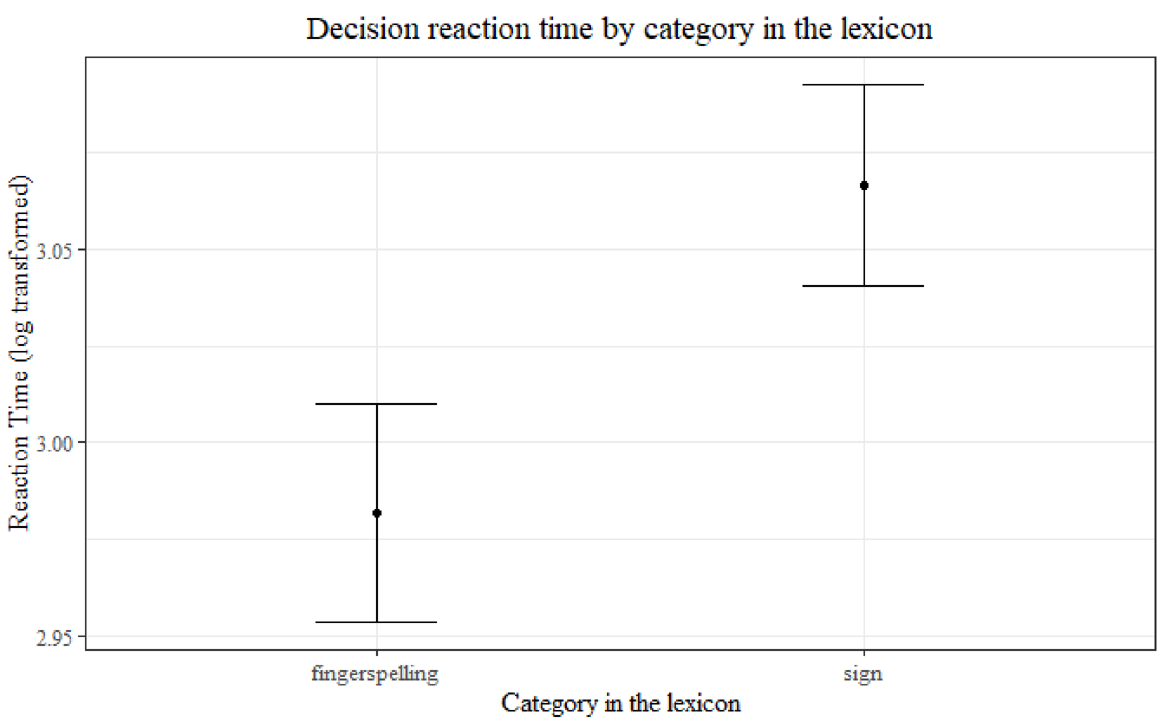

Figure 5.6: Mean reaction time by category in the lexicon. Bars indicate confidence intervals.

The lack of a significant difference in condition can be seen in Figure 5.7, where reaction time was not considerably higher for the reduced than the highly reduced condition.

Exemplifying the reaction time results by both category and reduction condition, Figure

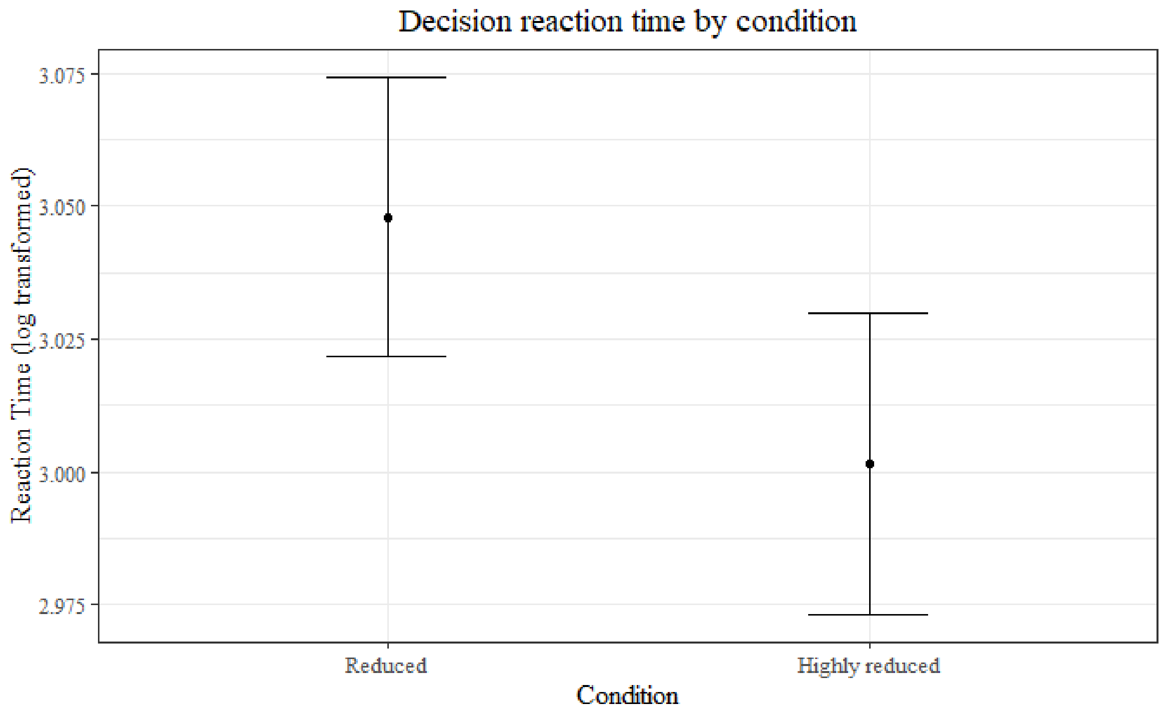

Figure 5.7: Mean reaction time by experimental condition. Bars indicate confidence intervals.

5.8 shows a more complicated set of trends. Reaction times for signs in the reduced condition were the highest, while there was little difference between reaction times between the highly reduced signs and both of the conditions for fingerspelled words.

5.5 Discussion

The study reported here tested signers' ability to discriminate between reduced and unreduced forms, measuring this through their judgements of whether reduced forms are more similar to one another than to an unreduced form, as well as the response time taken to make this decision. Experiment results showed differences in participants' responses for fingerspelled words and core signs, an effect that not only was modulated by the amount of reduction exhibited by the reduced stimuli but that also showed distinct sets of patterns between the experimental measurements taken.

The analysis of participants' similarity judgements showed that while reduced forms were

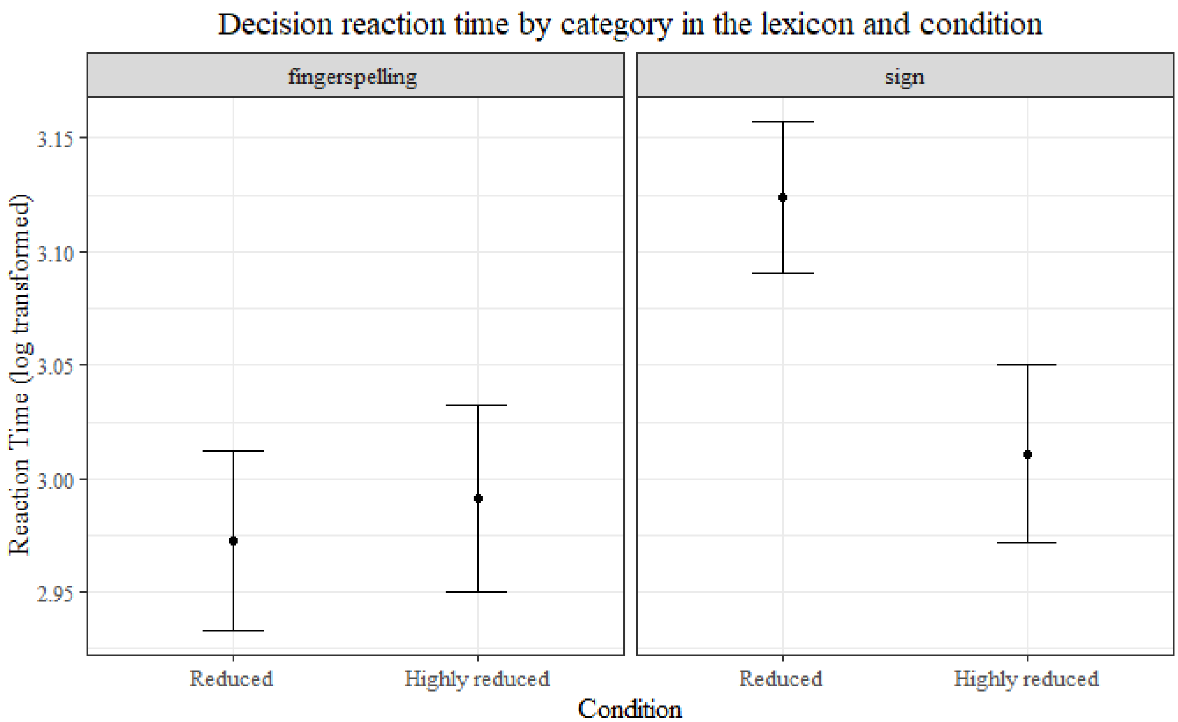

Figure 5.8: Mean reaction time by experimental condition and category in the lexicon. Bars indicate confidence intervals.

not judged to be more similar to one another at a significantly higher rate for fingerspelled words than for core signs as a whole, there were significant differences in similarity judgements between conditions, as well as an interaction between conditions and category in the lexicon. Highly reduced forms were identified as similar to one another at rates significantly higher than reduced forms. This was driven by a difference between categories, wherein highly reduced fingerspelled words were identified at a higher rate than reduced fingerspelled words as well as both conditions for signs. This shows a higher rate of discriminability between reduced and unreduced forms for highly reduced fingerspelled words. This result for fingerspelling aligns with Janse et al. (2007)'s finding that discrimination was easiest for forms that involved full segmental deletions in Dutch, in contrast to more gradient forms of reduction, and suggests that ASL signers are most able to notice differences between unreduced and highly reduced fingerspelled forms.

One explanation for this difference in judgements between highly reduced fingerspelled forms and all other conditions, including the reduced fingerspelling and all core sign forms, may stem from the larger number of cues available to identify reduction processes in fingerspelling, arising from the many handshapes and transitional movements between handshapes that comprise each word. This may also be due to the higher information content of the movements involved in articulating fingerspelled words, in contrast to core signs (Poizner et al., 1981). As fingerspelled words reduce in duration, each of the individual handshape segments within the word can reduce, as well as the transitions between them. This then is further reinforced in the highly reduced context, in ways that are distinct from those in signs. A smaller number of the salient individual components that make up core signs, such as individual movements, can undergo reduction and, for this reason, reduction processes may be less clear, even when they include full segmental deletions.

Contrasting with the similarity judgement results, the decision reaction times within the experiment showed a different set of significant results across categories in the lexicon and reduction conditions. For reaction time, there was a significant effect within the experiment for category within the lexicon, with participants responding to fingerspelled words at a faster rate. This finding could indicate that the discrimination task was easier for fingerspelled words than it was for core signs, or that participants were more confident in making their judgements, although this did not necessarily correspond to success in discrimination. Results also showed a significant interaction between category and condition, with a difference in reaction times between conditions only clearly evident for the core signs.

Although Chapter 4's findings showed that the trajectories of reduction are similar between the fingerspelling and core sign categories within the lexicon, it also showed that fingerspelled words are considerably longer on average than core signs. The reaction time results in the present analysis could be attributed to the longer length of these forms, as the increased duration gives people more time to process the stimuli as they are presented, providing them with additional time to make their decision within the task. This difference might then suggest that the task was more difficult for the core sign stimuli than it was for fingerspelling. Fingerspelled words, even when reduced, are longer on average than signs and so participants had more time while the stimuli were presented to process them.

However, in appealing to explanations for the present results, neither the length of the stimuli nor their linguistic features may be sufficient as an explanation, as movement perception is complex and does not always simply align with the temporal properties of stimuli. Human perception of the duration of movement does not correlate exactly with the duration of the movement itself and is influenced by a number of other qualities of the perceived movement, including their velocity and the complexity of the movement (Gavazzi et al., 2013). These are crucially related to how fingerspelled word and sign duration might be perceived. Regarding the speed of movements in perception, faster movements are perceived as longer when compared to slower movements of the same duration (Kaneko and Murakami, 2009; Tomassini et al., 2011). In addition, movements that are more complex, involving an additional number of components, are also perceived as longer than simpler movements of the same duration (Brown, 1995; Schiffman and Bobko, 1974). Although much of the research on movement perception has relied on findings from experiments using non-linguistic stimuli, it might provide additional explanation for the present finding that the highly reduced fingerspelling stimuli were most often successfully distinguished from the unreduced stimuli. Given the increased speed and complexity of the finer-grained movements associated with fingerspelling, signers' perception of changes in deleted letters, which decrease the complexity of the movement considerably, might be more distinct than those in the other categories. The other categories of stimuli encompassed either only a decrease in duration for fingerspelled words, or a decrease in the duration or repeated movement segments for signs, which involve fewer changes than those seen in the highly reduced fingerspelling stimuli. While this is a preliminary explanation, a more comprehensive understanding of movement perception as it relates to movement features associated with reduction, and how this differs from auditory perception, might provide further clarity to explanations for the present results.

The differences between experimental conditions, for both category in the lexicon and reduction condition, were not as clear-cut as predicted in initial experiment hypotheses, and provide mixed support for findings from previous empirical work related to signers' ability to distinguish between reduced and unreduced forms. The results in both similarity judgments and reaction time do not align with the findings of Hoetjes et al. (2014), where, for their signing participants, there was no significant difference in the perceived precision of signing between repeated mentions and first-mentions of signs in their dataset. However, the differing measurements and experimental methodologies could contribute to explaining the misalignment between these findings.

In tying the experimental results to the broader theoretical questions underpinning this work, conclusions made here connecting discrimination ability and comprehension follow from Janse et al. (2007)'s finding that there is a relationship between discriminability and the recognition of reduced forms, with more successfully discriminated forms corresponding to a greater negative impact on word recognition. The results of the present study showed reduction within highly reduced fingerspelled forms to particularly impact discrimination ability, with the highly reduced fingerspelled words showing the highest rates of discriminability. The results provide suggestive, albeit not conclusive, evidence that greater degrees of reduction in fingerspelling might have a greater impact on the understanding of fingerspelled words than for core signs. This aligns with Reed et al. (1990) and Fischer et al. (1999)'s work showing fingerspelling to be more difficult to comprehend at faster rates than core signs. This also aligns with scholarship suggesting that fingerspelling comprehension is particularly difficult for learners of ASL (Geer, 2016, 2019; McKee and McKee, 1992). However, because this study did not directly test comprehension, relying on a correlation reported from research on speech, more research is required to determine both how discrimination ability relates to intelligibility, as well as the direct impact of reduction on the intelligibility of signed forms. For this reason, conclusions here are drawn hesitantly and it remains an open question whether reduction impacts comprehension to a greater degree for fingerspelling than for signs.

Although both the similarity judgement and reaction time results were more complex than predicted in initial hypotheses, they both demonstrated differences in the perception of fingerspelling and core signs in discriminability between reduced and unreduced forms. These findings hint at, although not definitively, a disconnect between the production and perception of reduction in fingerspelling and signs in ASL. More specifically, they show a larger impact of reduction on the perception of fingerspelling than for signs, wherein reduction in the highly reduced versions of these forms is more salient. Highly reduced fingerspelled forms, those with deleted letters, were shown in the production study to be more likely at later mention numbers. If the production results reflected signers mediating reduction in fingerspelling and signs in similar ways for the sake of their interlocutor, limiting the amount they reduce to retain intelligibility, given the similarity in trajectories of duration reduction between the two categories, we would expect to see similarly equal patterns in perception. Should future study show the difference in discrimination seen here between signs and highly reduced fingerspelled words to correspond to an unequal impact of reduction on comprehension, this would provide evidence in favor of language production models in which the impetus for reduction relies largely on producer-internal constraints on articulation, as argued in accounts like that of Bell et al. (2009), as it would suggest that signers may not be taking their interlocutors into account as they continue to reduce.

While these findings have implications for our understanding of the perception of reduction processes in sign languages, the results should be considered in tandem with reflections on the experiment's methodology. The task itself was not an easy one, and some participants commented that the experimental task of differentiating between very similar stimuli was difficult. In addition, using naturalistic stimuli from a largely uncontrolled corpus taken from online sources added variation to the stimuli that may have influenced the results in unforeseen ways. Given the limited number of stimuli available within the dataset with the target length or segment deletion profile, additional variation between the stimuli was not strictly controlled for. Post-hoc examination of the experimental items showed potential confounds within some of the experimental stimuli. These included additional non-manual cues that were shared across some, but not all of the stimuli items, as well as coarticulatory effects from surrounding signs. However, the present interpretation of the experimental results relies on the assumption that participants were making their similarity judgements based on cues associated with reduction processes.

Future versions of the task might overcome this methodological challenge by prompting participants specifically to make their similarity judgement based on a specific feature, like speed or length of articulation, to better ensure that participants are using a criteria related to reduction to discriminate between stimuli. Future experiments might also elicit repeated fingerspelled words and core signs in a more controlled setting to then use as experimental stimuli. This would reduce the likelihood of additional non-linguistic or non-reduction factors related to the varied data collected from the internet corpus. The present study also did not include the signer within each video as a factor within the model, and this may have impacted the similarity judgements made by study participants. Future work should control for signer as another factor influencing the perception of reduced forms. However, this analysis provided a first step in the direction of answering how signers of ASL perceive reduction in both fingerspelling and signs by including stimuli that included natural, holistic representations of reduction processes.

5.6 Conclusion

The present study aimed to present a preliminary comparison of the perception of reduction processes across the lexicon of ASL, focusing on fingerspelling and core signs. It was motivated by results from findings within language production showing similar trajectories of duration reduction between fingerspelling and signs, and builds on this with a corresponding study to see if these similarities persisted in testing signers' ability to discriminate between reduced and unreduced forms. The results from the analysis suggest a disconnect between how signers of ASL perceive repeated, reduced forms in comparison to unreduced forms, with highly reduced fingerspelled forms showing a magnified effect in perception when compared to signs. It also showed differences in reaction times between categories in the lexicon, which might indicate further differences in how signers process these forms. This study also provides a novel methodological contribution by using naturalistic stimuli to test the perception of reduction processes in ASL. Future work can build on the present findings and methodology by directly testing the impact of reduction on comprehension, as well as determining what linguistic features are most crucial in maintaining comprehension.

CHAPTER 6

CONCLUSIONS

Through the analyses in each of its chapters, this dissertation answers how forms in ASL reduce as they are repeated. This investigation into reduction in ASL focuses not only on how various types of reduction are produced both in fingerspelling and core signs, but also supplements this with an experiment on how reduction of these forms impacts perception. In doing so, it examines the mechanisms behind reduction from several angles, looking at how modality-dependent articulatory constraints unique to each of the systems examined might shape reduction processes, as well as how cross-linguistic and cross-modal pressures influence the patterned variation seen in reduction processes.

This investigation was set within wider bodies of research on both spoken and sign languages that show reduction occurring in contexts of increased predictability. Using repetition as an environment that conditions reduction, it adds cross-modal support for theories proposed to explain the mechanisms behind language production. It also relies on research on reduction more broadly in sign languages, outside of repetition reduction, that show reduction occurring along many of the properties of signed forms. These include their duration, as well as letter deletions for fingerspelling and variation in location and repeated movements for core signs. Together, the results of these studies add greater detail to our understanding of how these reduction processes are realized for signed forms when they are repeated. They also expand on previous work by testing the realization of addition types of reduction, as in the case of the repeated movements articulated within some signs. The findings from this investigation then supplement our understanding of reduction processes and the forces shaping linguistic form not only in sign languages, but language more generally.

6.1 Summary of predictions and findings

Initial predictions for each investigation were built off of previous work showing reduction in different categories of the lexicon as well as suggesting ways that reduction might impact the perception of forms in ASL. These are also tied to broader predictions that underlie this dissertation about the relationship between modality and reduction, as well as the link between the production and perception of reduced forms. However, not all of the initial predictions were borne out. The main misalignment between study findings and predictions, discussed further below, occurred in the comparison between reduction patterns in the production of core signs and fingerspelled words. In addition to this misalignment between initial predictions and study results, not all of the results were as clear-cut as initially predicted, as in the case of the experiment on the perception of reduced forms. A summary of initial project predictions, and whether the results did or did not align with these, can be found in Table 6.1. The summaries of the predictions for each chapter are then expanded in the following paragraphs with an elaboration of project findings from each study.

Analysis	**Prediction**	**Result**
Fingerspelling production	*Duration:* Fingerspelling reduction will continue past second mentions	Aligned
	Duration: Increased between-mention distance will correspond to decreased reduction	Aligned
	Deleted letters: The deletion of letters will increase in the context of repetition.	Aligned
	Deleted letters: Fingerspelled words with fewer letters will exhibit fewer deletions.	Aligned
Core sign production	*Duration:* Duration reduction will occur in the context of repetition	Aligned
	Duration: Increased between-mention distance will correspond to decreased reduction	Aligned
	Repeated movements: Repeated movements will decrease in number in the context of repetition	Aligned
	Location: A sign's location will centralize on the body when repeated	Aligned
Fingerspelling-sign comparison	*Duration:* Fingerspelling will reduce in duration more steeply than core signs between repeated mentions, reducing to a greater degree across multiple mentions	Misaligned
Fingerspelling-sign perception	*Similarity judgement:* Reduced, fingerspelled words will be distinguished from unreduced fingerspelled words at a higher rate than reduced signs and highly reduced forms will be identified at a higher rate than reduced forms	Partial
	Reaction time: Reaction times will be faster for fingerspelled words than for core signs, and the highly reduced condition will be fastest for both categories	Partial
Full investigation	*Modality:* Reduction in ASL will be shaped by the affordances of the manual-visual modality as constrained by the fingerspelling and core sign systems, resulting in patterns distinct from those in speech	Aligned
	Perception-production: A disconnect between trends in reduction patters for fingerspelling and core signs in production and perception will point to a disconnect between the mechanisms driving reduction in production and perception	

Table 6.1: Summary of main dissertation predictions and findings for each study

The first analysis targeted repetition reduction in ASL fingerspelling, with the hypothesis that fingerspelling would not only exhibit reduction across multiple mentions, following findings from smaller studies on fingerspelling, but that this duration reduction would be influenced by other factors, including the time that has passed between mentions. Along the variable of letter deletion, it was also hypothesized that the number of fingerspelled letter deletions in a word would increase as mentions continued. These questions were tested using an annotated corpus of fingerspelled words that were drawn from publicly available, online videos that encompassed a range of signers and signing styles. The analysis confirmed that repetition reduction continues across multiple mentions, contrasting with previous findings for spoken languages, and showed that fingerspelled words do not reduce to the same degree between each mention, reducing most between earlier mentions. Results also demonstrated that not only does the number of times a word has been repeated contribute to how much it reduces, but this is also influenced by the time since it has previously been mentioned, with fingerspelled words reducing less when mentions are farther apart. The analysis of letter deletions showed that, as mentions increased, letter deletions also increased, with the likelihood of deletions being present in a word leveling off around the third mention of a fingerspelled word. The number of deletions in a word was further influenced by the length of a word, with words with a greater number of letters exhibiting a higher number of deletions.

The second analysis focused on trends in repetition reduction for core signs in ASL, specifically analyzing trends in duration reduction, deleted movements, and changes in locations articulated on the body. The analysis used data from both a corpus of online videos and a set of narratives elicited in a lab setting. Evidence from previous work showing repetition reduction occurring for core signs in two different sign languages led to the hypothesis that this effect would be robust when tested using corpus and narrative data, and, as with fingerspelling, additional time between mentions would lead to less reduction in duration. Previous findings from both spoken language research and research on fingerspelling showing segmental reduction in the context of repetition supported the additional hypothesis that a sequential feature of some signs, repeated movements, would delete in the context of repetition. Lastly, I predicted that signs articulated on the body would centralize in their location from more peripheral locations in the context of repetition, a prediction informed by scholarship showing signs at other locations, like on the head and face, reducing via centralization in contexts like that of increased signing rate. Results supported initial predictions and showed core signs reducing in duration across multiple mentions, with increased between-mention distance resulting in less reduction. Repeated movements were also increasingly deleted in the context of repeated mentions, with movement deletion interacting with mention number, such that the presence of deleted movements resulted in increased reduction in duration across mentions. Body-located signs were also found to vary predictably in the analysis, centralizing in the context of repetition. However, a case-study of one sign, MONKEY, showed that the phenomenon of repetition reduction does not adequately capture the factors shaping variation from the citation location of signs, as first mentions can often be reduced in some way.

The third analysis compared trends in duration reduction between fingerspelling and core signs, using data from the same annotated online video corpus used for previous analyses. Previous scholarship on reduction in fingerspelled words and core signs, as well as increased attention given to the considerable degree of reduction in fingerspelled words led to the prediction that fingerspelling would show an increased amount of duration reduction across mentions when compared to signs. However, the analyses showed that, when controlling for phrasal position and between-mention distance, there was not a significant difference between the trajectories of duration reduction across mentions between fingerspelled words and signs, with both categories following a similar trajectory in duration reduction as mentions increased. The analysis also confirmed a similar effect of between-mention distance for both categories.

The final analysis encompassed an experiment comparing the perception of duration reduction in fingerspelling and in signs, which also tested whether additional, segmental types of reduction facilitated this process. Due to methodological challenges associated with designing a comprehension experiment using naturalistic stimuli that could be run online, the experiment instead tested signers' ability to distinguish between reduced and unreduced forms. Previous research on the perception of fingerspelling and core signs, showing an increased negative impact of more difficult visual conditions on fingerspelling, motivated the hypothesis that reduction would have an unequal impact on signers' ability to judge reduced forms as more alike to one another than to unreduced forms, with both higher rates of discrimination and faster reaction times for fingerspelled words. Using stimuli drawn from tokens from the previous corpus analysis, the experiment, of an AXB-type design, provided mixed support for the initial hypotheses. Results showed that highly reduced fingerspelled forms, those with deleted letters, are the most frequently successfully identified as similar to one another when compared to not only the category of reduced fingerspelled words, but also to reduced and highly reduced core signs. Reaction time measures from the experiment showed signers responding fastest to both reduced and highly reduced fingerspelled words, with slowest reaction times for reduced signs.

6.2 Implications

The results of this analysis have implications not only for our understanding of sign languages but also for language production more broadly. The analyses of the different types of reduction seen in the fingerspelling and core sign systems in the lexicon demonstrated how the affordances of distinct linguistic and articulatory systems shape reduction in unique ways. At the same time, this investigation provided new contextualization for reduction patterns in ASL within wider, cross-modal theories of language production.

The characteristics of each linguistic system examined here, fingerspelling and core signs, influenced the articulation of distinct reduction patterns in the more predictable context of repetition. These findings add detail and confirm work on reduction in sign languages, both within and outside of the context of repetition. This was evident through the letter deletions that occurred increasingly over discourse mentions in repeated fingerspelled words, a product of the rapid-sequential articulation of complex handshapes, and the deletion of repeated movements for core signs, a feature of this subset of signs within the ASL lexicon. In addition, signs showed trends towards centralization in location variation for body-articulated signs, demonstrating another dimension of the articulation of signs along which they can reduce. These different types of reduction exemplify ways that the affordances of each of these systems allowed for unique patterns in reduction.

In showing numerous ways that reduction continued across multiple mentions, these results also demonstrate that the *given* versus *new* distinction previously used to argue for the contribution of mention number in shaping reduction patterns needs to be modified. Specifically, this representation needs to be more saturated, adjusted to express that the reduction of a form is better determined by its degree of *givenness* rather than by whether it is simply given in the discourse. The givenness of a form is influenced not only how many times it has been mentioned, but also the time since its previous mention (supported by the findings of Rodriguez-Cuadrado et al. (2018)). This suggests an enriched conceptualization of the givenness of a form within the common ground available to a language producer within a discourse context, suggesting a representation that is more gradient than the previous, binary treatments of the given versus new distinction.

Although both the fingerspelling and core sign systems in ASL showed repetition reduction occurring across multiple mentions, contrasting with trends reported in previous work on spoken languages (Bell et al., 2009; Vajrabhaya and Kapatsinski, 2011), the reasons behind the similar patterns between the two systems in ASL are less clear and point to a need to further probe reduction in these systems. For example, articulatory pressures acting on the differing properties of the fingerspelling and sign systems could be driving these patterns. The articulatory complexity, coordination demands, and potential for letter deletion of fingerspelling contrasts with the larger mass and potential for reduction along many of the parameters of signs. It is possible that each of these features interact with pressures towards articulatory ease to result in almost parallel patterns of duration reduction. While this is one possible explanation, the shared properties of the fingerspelling and sign systems as a result of their shared modality could also be driving the similar patterns seen in duration reduction. The larger manual articulators used for both could result in increased articulatory pressure to reduce, due to the increased effort involved in moving articulators of larger mass than those used in speech. In addition, the increased duration of fingerspelled words and core sign forms, when compared to speech, could allow for this increased degree of reduction without the same degree of negative impact on the comprehension of these forms. This potential explanation appeals to theories of language production wherein reduction is shaped by the language producer's knowledge of their interlocutor's comprehension of each of these systems.

However, the results from the perception study indicated that this explanation may not quite be a complete one, especially when appealing to explanations relying on the comprehension of fingerspelled and signed forms. Although they do not discount comprehension playing a role in shaping reduction, the differing impact of reduction for fingerspelling and core signs on signers' ability to distinguish reduced from unreduced forms suggests that perception processes for fingerspelling may differ from those for core signs. More specifically, they suggest that reduction might be more salient when it comes to the perception of highly reduced forms within the fingerspelling system. Although present study did not test comprehension directly, should future work confirm the assumed connection between discriminability of reduced forms and comprehension, it would support conclusions suggesting an unequal impact of reduction on fingerspelling when compared to core signs.

In this way, in addition to demonstrating ways that distinct articulatory systems shape reduction, the combined findings from the production and perception studies could have possible implications for our understanding of theories of language production that have been proposed to explain processes of reduction. This disconnect between the production and perception of reduced forms, paired with the similar trajectory of the duration reduction patterns seen occurring between fingerspelling and core signs, prompt questions of whether reduction patterns are shaped by signers mediating for the understanding of their interlocutors. A contrasting, producer oriented explanation for these patterns might then appeal to the articulatory pressure exerted on fingerspelling due to its articulatory properties. This articulatory pressure is a constraint internal to signers, shaping these patterns of reduction which involve considerable divergence from first mentions, despite their increased impact on perception. This explanation suggests that an internal mechanism, namely, articulatory pressure, may be the primary force shaping the reduction patterns seen here. This finding could then provide better support for models of language production that argue that producer-internal constraints shape patterns of repetition reduction cross-linguistically, like that of Bell et al. (2009), rather than those that also appeal to accommodations to an interlocutor.

Focusing on this investigation's methodological approach, the present study primarily relied on data from naturalistic online sources, both in the language production and perception investigations, and showed the feasibility of using this approach in studying repetition reduction for sign languages. The rationale for using naturalistic online data relied on arguments like those of Hou et al. (2020) and Hou et al. (2022) that cite the more heterogeneous set of subjects present in online datasets, and by extension, more varied representation of language use that is more widely representative of ASL communities. They also argue that these data are more naturalistic, free of observer's bias, and are more spontaneous and representative of ASL used in interactions outside of the lab. The present study made a methodological contribution in showing the continued value of using naturalistic data in studies of ASL production and perception of reduction processes, although there is also benefit to using both corpus based and more constrained, lab based approaches.

Through its descriptive, theoretical, and methodological contributions, the present work deepens our understanding of reduction in ASL, as well as how to study it. Building on previous work on reduction in sign languages, it adds detail to our understanding of how reduction proceeds along various dimensions across multiple repeated discourse mentions. These results provided further insight into theories intended to explain reduction patterns cross-linguistically by situating explanations of this phenomenon within arguments that emphasize the cross-modal impact of pressures to minimize articulatory effort in language production. In addition, while the perception study was preliminary, it also made a methodological contribution in showing one new way reduction processes can be examined in sign language perception using naturalistic stimuli. Despite the contributions of the present work, there are numerous ways it can be expanded to improve our understanding of reduction in sign languages and how it contributes to wider theoretical questions.

6.3 Limitations & future work

The limitations of the present work point to new ways that the study of reduction processes in sign languages can be approached to more thoroughly address how these processes are realized and what mechanisms drive them. While repetition reduction is one type of predictability-based reduction, repetition is among many different kinds of predictability that shape how forms reduce. Other measures of predictability, such as conditional probability or frequency, might have a distinct impact on reduction in ASL. Research on speech has shown that not all types of predictability result in the same types of reduction (Clopper and Turnbull, 2018), and so it is important to test multiple types of predictability to gain a fuller picture not only of what reduction looks like, but also what different types of reduction occur in sign languages. However, calculating these types of predictability often requires the use of large, annotated corpora, which are more infrequently available and more difficult to construct for sign languages.

The present analysis focused on two parts of the ASL lexicon, but was not completely representative of reduction processes across the entire lexicon itself. Future work should examine how reduction occurs in classifier forms, which have a distinct set of constraints on their form and have the possibility for more variation along the movement parameter. Testing how reduction occurs for classifiers would provide additional insight into how the allowances of different articulatory systems interact with communicative pressures in the context of reduction. The present analysis also excluded forms that were not easily categorized into one part of the lexicon. For example, lexicalized fingerspelled forms were excluded from the corpora used here, both due to their higher frequency and their unique articulatory properties. Although these were excluded from this analysis, future work on how repetition reduction impacts the production of ASL should include these forms to determine whether they share reduction strategies with either or both parts of the lexicon that they are transitioning between. This would also provide a clearer understanding of how processes of diachronic language change in ASL and synchronic reduction processes influence one another.

The present studies also only controlled for a limited set of factors within the production analyses of repetition reduction, looking at how phrasal position and distance between mentions impacted the duration of reduced forms. Future work, with access to larger corpora, should control for additional factors that might correlate with or impact duration in other ways. For example, signing rate might vary across the course of a discourse and impact sign duration. In addition, controlling for sign frequency in an analysis of repetition reduction could prove beneficial. This is especially important, as higher frequency spoken words (Bell et al., 2009) and fingerspelled words (Lepic, 2019) have been shown not to undergo duration reduction in contexts of higher predictability, such as repetition.

Additional areas for expansion of the present work encompass methodological aspects of the experiment on the perception of reduced fingerspelled words and signs. The perception study, comparing fingerspelling and signs, did not directly test the effect of reduction on intelligibility. Although for the present study the choice to use naturalistic stimuli limited the type of study, future work can adjust the stimuli type and experimental design in order to approach this from a different angle. To more directly answer the research question, future studies should test how reduction impacts the understanding of reduced forms by testing their intelligibility in comparison to unreduced forms. To avoid the methodological challenges discussed in Chapter 5, this will require either the artificial manipulation or controlled lab creation of stimuli, which would nicely complement the present, less controlled experimental stimuli. Additionally, it would be beneficial for a future study to incorporate lexicalized or semi-lexicalized fingerspelled forms within experimental stimuli, to determine whether forms with features of both signs and fingerspelling pattern more like one category or the other when reduced.

On a broader, methodological note, the datasets used in the present study were highly variable, due in part to their naturalistic nature, and so it was difficult to control for every factor that was influencing this variation. Using data elicited in a laboratory setting for a similar study would make it easier to control for phonetic and linguistic environment, a drawback of the present studies, as well as other factors that contributed to variability within the data. Further insight and additional support to the claims made here should draw from both corpus-based approaches as well as elicited data collected in a lab setting.

Future work on reduction processes in ASL should address these limitations with larger datasets while expanding the present type of analyses to other sign languages and modalities. Expanding analyses of repetition reduction will help determine how robust the effects noted here are cross-linguistically and cross-modally. Potential avenues for this include testing repetition reduction processes within fingerspelling in languages like British Sign Language, which has a fingerspelling system articulated with two hands but exhibits similarities in articulatory complexity and structure to fingerspelling in ASL. Systems in other sign languages with distinct constraints can reveal further ways that linguistic systems shape reduction, better situating and supporting current theories of language production within patterns of variation seen in the world's languages.

APPENDIX A

SUPPLEMENTARY TABLES AND FIGURES

Table A.1: Summary of frequency of fingerspelled tokens of different lengths (count and percentage of the dataset)

Length in Letters	**Count**	**Percent**
3	72	11.70%
4	143	23.20%
5	125	20.30%
6	130	21.10%
7	36	5.80%
8	66	10.70%
9	3	0.50%
10	19	3.10%
11	10	1.60%
13	12	1.90%

Table A.2: Table with description of ELAN tiers and their content for the core sign annotations.

Tier	**Content**
Sign Gloss	The gloss for the core sign
Mention number	How many times the sign has been articulated
Internal repetitions - number	Number of internal movement repetitions (if applicable)
Internal repetitions - type	Type of repeated movement: Path (straight, curved, circular), Local (aperture change, radio-ulnar, wiggle, tap)
Contact - number	Number of points of contact (0, 1, or 2)
Body location	See Figure A.1 for setting distinctions coded
Phrasal position	Final vs. non-final

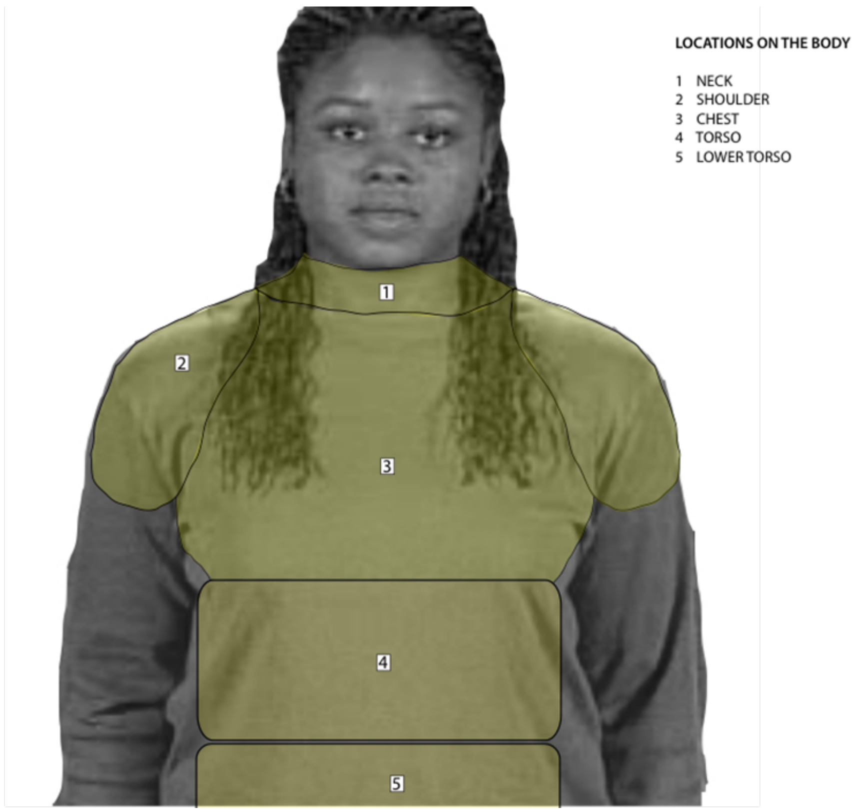

Figure A.1: Image of location regions annotated. Image is adapted from Valli (2006), used with permission from Gallaudet University Press.

Table A.3: Summary of the distribution of the number of movement repetitions for each sign in the dataset for signs with repeated movements.

Mention Number	**Number of movements**	**Count**	**Percent of each mention**
1	1	42	12.50%
	2	217	64.58%
	3+	77	22.92%
2	1	105	31.44%
	2	180	53.89%
	3+	49	14.67%
3	1	86	37.72%
	2	120	52.63%
	3+	22	9.65%
4	1	63	40.65%
	2	82	52.90%
	3+	10	6.45%
5	1	44	43.14%
	2	51	50.00%
	3+	7	6.86%
6	1	28	40.58%
	2	36	52.17%
	3+	5	7.25%

Table A.4: Table showing the counts of body located signs (mentions 2-6) by first location and direction of location change.

First mention location	Shift direction	Count	Frequency
chest	down	2	1.90%
	no change	103	98.10%
lower-torso	no change	7	58.33%
	up	5	41.67%
neck	down	3	25.00%
	no change	9	75.00%
shoulder	down	4	33.33%
	no change	8	66.67%
torso	no change	12	40.00%
	up	18	60.00%

Table A.5: Linear regression model comparison analyzing changes in duration across mentions for signs and fingerspelling, including category in the lexicon and mention as fixed effects, and adding an interaction term between the two. Results of an ANOVA comparing model performance are included at the bottom of the table.

	Dependent variable:			
	Log duration			
	(1)	(2)	(3)	(4)
Mention>1	0.161***	0.145***	0.145***	0.155***
	(0.010)	(0.009)	(0.009)	(0.015)
Mention>2	0.053***	0.047***	0.047***	0.067***
	(0.010)	(0.009)	(0.009)	(0.016)
Mention>3	0.030***	0.024**	0.024**	0.024
	(0.011)	(0.010)	(0.010)	(0.016)
Mention>4	0.016	0.011	0.011	0.003
	(0.013)	(0.012)	(0.012)	(0.019)
Mention>5	0.011	0.017	0.017	0.023
	(0.017)	(0.015)	(0.015)	(0.023)
Phrasal Position		0.151***	0.151***	0.151***
		(0.009)	(0.009)	(0.009)
Mention>1:Category				−0.016
				(0.019)
Mention>2:Category				−0.031
				(0.020)
Mention>3:Category				−0.002
				(0.021)
Mention>4:Category				0.011
				(0.024)
Mention>5:Category				−0.012
				(0.031)
Category			−0.245***	−0.243***
			(0.017)	(0.017)
Constant	2.652***	2.601***	2.724***	2.723***
	(0.097)	(0.088)	(0.018)	(0.018)
Observations	1,625	1,625	1,625	1,625
Log Likelihood	455.322	586.782	591.938	593.724
Akaike Inf. Crit.	−890.643	−1,151.564	−1,159.875	−1,155.448
Bayesian Inf. Crit.	−836.711	−1,092.238	−1,095.156	−1,069.156
Chi-squared		262.920	10.311	3.573
p-value		p<0.001	p=0.001	p=0.467
Note:				*p<0.1; **p<0.05; ***p<0.01

Table A.6: Table showing the properties of fingerspelling stimuli.

Word	**Duration**	**Proportion of 1st Mention**	**Condition**	**letters deleted**
age	920	NA	Reduced	NA
	680	0.73913	Reduced	NA
	640	0.695652	Reduced	NA
arts	603	NA	Reduced	NA
	402	0.666667	Reduced	NA
	442	0.733002	Reduced	NA
bipolar	2102	NA	Reduced	NA
	1335	0.635109	Reduced	NA
	1335	0.635109	Reduced	NA
crustaceans	2002	NA	Reduced	NA
	1435	0.716783	Reduced	NA
	1201	0.6218	Reduced	NA
detox	767	NA	Reduced	NA
	433	0.564537	Reduced	NA
	467	0.608866	Reduced	NA
expo	917	NA	Reduced	NA
	542	0.591058	Reduced	NA
	584	0.636859	Reduced	NA
assets	1126	NA	Highly reduced	
	626	0.55595	Highly reduced	s
	709	0.629663	Highly reduced	s
carb	334	NA	Highly reduced	
	233	0.69760479	Highly reduced	r
	266	0.796407186	Highly reduced	r
diet	601	NA	Highly reduced	
	233	0.387687	Highly reduced	e
	300	0.499168	Highly reduced	e
factors	1246	NA	Highly reduced	
	534	0.402087	Highly reduced	t
	634	0.508828	Highly reduced	t
kosher	1334	NA	Highly reduced	
	761	0.570465	Highly reduced	e
	584	0.437781	Highly reduced	e
march	934	NA	Highly reduced	
	601	0.643469	Highly reduced	r
	633	0.67773	Highly reduced	r

Table A.7: Table showing the properties of sign stimuli.

Sign	Duration	Proportion of 1st Mention	Condition	# of movements
accept	333	NA	Reduced	NA
	250	0.750751	Reduced	NA
	250	0.750751	Reduced	NA
angry	567		Reduced	NA
	300	0.529101	Reduced	NA
	300	0.529101	Reduced	NA
australia	634	NA	Reduced	NA
	367	0.578864	Reduced	NA
	367	0.578864	Reduced	NA
body	467	NA	Reduced	NA
	301	0.64454	Reduced	NA
	334	0.715203	Reduced	NA
deaf	267	NA	Reduced	NA
	200	0.749064	Reduced	NA
	200	0.749064	Reduced	NA
measure	367	NA	Reduced	NA
	267	0.72752	Reduced	NA
	267	0.72752	Reduced	NA
basketball	634	NA	Highly reduced	3
	401	0.632492	Highly reduced	2
	367	0.578864	Highly reduced	2
blue	292	NA	Highly reduced	2
	209	0.715753	Highly reduced	1
	208	0.715753	Highly reduced	1
retirement	440	NA	Highly reduced	2
	240	0.545455	Highly reduced	1
	240	0.545455	Highly reduced	1
remove	1201	NA	Highly reduced	6
	634	0.527893	Highly reduced	2
	667	0.555371	Highly reduced	2
time	434	NA	Highly reduced	2
	201	0.463134	Highly reduced	1
	167	0.384793	Highly reduced	1
custom	584	NA	Highly reduced	3
	292	0.5	Highly reduced	2
	292	0.5	Highly reduced	2

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