PHONOLOGICAL PROCESSING OF DUAL LANGUAGE INPUT: THE RELATIONSHIP BETWEEN PHONOLOGICAL SYSTEMS FOR SPEECH-SIGN BILINGUALS

by

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Abstract

Hearing speech-sign bilinguals know languages in distinct sensory-motoric modalities. This allows simultaneous perception and production, entailing potential benefits for multimodal integration. Existing evidence shows dual-input processing benefits for semantically-based decisions. The present study investigates whether this holds for the non-overlapping phonological systems in these bilinguals. 13 fluent English-BSL bilinguals, 13 intermediate signers and 13 monolingual English controls made phonological decisions to audio/video stimuli. In Experiment 1, participants made BSL handshape decisions (sign-only vs. sign-with-speech). Intermediate and fluent signers were significantly more accurate with dual-input, but reaction times did not differ. In Experiment 2, participants monitored English phonemes (speech-only vs. speech-with-sign). Here both signing groups responded faster with dual-input, but only fluent signers performed significantly more accurately. Results suggest intermediate signers performed a speed-accuracy trade-off in both tasks. Overall, sign experience seemingly leads to phonological systems becoming linked, such that signers even profit from their weaker L2 when making English decisions.

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Table of Contents

List of Figures

List of Tables

Introduction

There is an abundance of redundant multimodal information in language, such as pointing, head movements and other forms of co-speech gesture. Is this built-in redundancy only required in the case of communication breakdown, or does such dual input improve language processing? In order to answer this question, we can turn to a further type of multimodal language production, one that draws on two natural languages simultaneously, and is found in hearing speech-sign bilinguals – users of both a signed and a spoken language. The distinct sensory-motor systems of a “bimodal” or “speech-sign” bilingual’s two languages allow them to comprehend and produce both words and signs simultaneously, known as “code blends” (Emmorey, Borinstein and Thompson, 2005; Emmorey, Borinstein, Thompson and Gollan, 2008; Bishop, 2010), as opposed to “code-switching” (switching between languages, only using one at a time). Investigating speech-sign bilinguals’ processing of dual language input will help further our understanding of why redundant signals exist in language, and what the upper limits of cognitive integration of multimodal information input are.

Hearing speech-sign bilinguals offer unique perspectives on the nature of bilingualism and the bilingual brain in general, due to their experience of language use in different modalities. Exploring the co-activation of speech-sign bilinguals’ two languages when presented with redundant linguistic information will provide insight into the degree to which the lexicons of each language are linked in terms of their storage and retrieval, and how this differs from the languages of speech-speech or sign-sign bilinguals. Beyond theoretical implications, the study of speech-sign input processing has practical implications for the teaching of signed languages, the use of speech-sign with babies and by special education teachers using multimodal input with autistic children, among others.

Dual Input and the Redundant Signals Effect

Much of the original work on multi-modal information processing centres on the Redundant Signals Effect (RSE). This is a theory based on the observation that participants respond more quickly when stimuli in multiple modalities are administered simultaneously. This was first noticed by Todd (1912) who presented participants with bimodal combinations of tone, light and electric shock stimuli and found a reduction in response times with bimodal stimuli compared to a unimodal stimulus alone. The coactivation model of the RSE states that information from multiple stimuli are combined and together co-activate a more intense signal than a unimodal stimulus would alone, leading to a faster response. Alternatively, multimodal stimuli may cause multiple activations in different sensory channels, with the signal that reaches the response level first being the one that triggers a reaction (Raab, 1962). I will follow the coactivation model, since it seems to account for the results of the only previous study of multimodal bilingual processing (Emmorey, Petrich and Gollan, 2012; discussed further later).

A variety of studies have replicated the RSE using cross-modal combinations of stimuli, predominantly with auditory-visual stimuli (Corballis, 1998; Diederich and Colonius, 1987; Giray and Ulrich, 1993; Hughes, Reuter-Lorenz, Nozawa and Fendrich, 1994; Miller, 1982; 1986; Miller and Ulrich 2003; Plat, Praamstra and Horstink, 2000), but also for unimodal stimulus combinations where two different tones or lights are compared to one stimulus alone (Marzi et al., 1996; Murray, Foxe, Higgins, Javitt and Schroeder, 2001). There are also studies featuring visual-tactile stimulus combinations (Amlôt, Walker, Driver and Spence, 2003; Diederich, Colonius, Bockhorst and Tabeling, 2003; Forster, Cavina-Pratesi, Aglioti and Berlucchi, 2002) where the RSE has also been replicated. Diederich and Colonius (2004) have also shown that responses to trimodal (visual, auditory and tactile) stimuli are faster than responses to bimodal stimuli combinations, which in turn are faster than reactions to a single unimodal stimulus.

Despite these replications, the RSE might not apply in all multimodal contexts. The RSE seems to hold when minimal semantic content is attached to bimodal stimuli, e.g. in Miller (1982), participants are told that both a light and a tone have the meaning ‘go’. However, this may not be the case for processing demanding input such as multimodal language, where semantic content is greater and many cognitive systems are involved (Thompson, Garcia and Malloy, 2007). It is thus plausible that language processing may cause the upper limit of the cognitive load to be exceeded; the additional information results in a processing slow-down and wipes out any potential RSE.

Multimodal Language Processing

There have been a number of studies attempting to investigate the RSE and multimodal processing of language. Hanson (1981) instructed participants to attend to one modality only when presenting them with semantic and lexical decision tasks, where words were presented in bimodal combinations: one visual and one auditory compared to unimodal stimuli. She found evidence of the RSE, suggesting there is a common processing system used for the attended-to and unattended-to stimuli. Thus, this study shows evidence of cross-modal activation even when participants are attempting to ignore one of the presented stimuli.

Language tasks requiring more complex cognitive processing, such as word recall, have also been investigated. Lewandowski and Kobus (1993) tested two separate samples on a lexical decision task and a word recall task. While results from both samples were consistent in showing no RSE for reaction time (RT, the time between presentation of a stimulus and subsequent response) or accuracy for the lexical decision task, this result should be treated with caution, since the onset of auditory and visual stimulus presentation differed by 50-300ms. However, in word recall, there was an RSE when the same category of word was presented simultaneously in auditory and visual channels, demonstrating that the RSE extends not just to complex linguistic stimuli but also to complex cognitive tasks. Therefore there may be scope for RSE benefits in even more cognitively difficult tasks, such as simultaneous multimodal processing of a signed and spoken language.

Given the potential memory benefits of multimodal stimulus presentation, a series of learning studies have investigated potential RSE benefits in the classroom. Kobus, Moses and Bloom (1994) examined how combinations of stimulus mode affected recall of items within 5 minutes of presentation. Recall was significantly better for groups receiving stimulus combinations with multiple modalities (printed word & picture & spoken word), suggesting redundant stimuli enhance recall. However, results the group with the combination picture + word was not significantly different to picture alone. One flaw was that participants' responses were only in writing – controlling response modes to explore other (e.g. speech, picture) might have been revealing about which modes are best for short-term storage.

A further learning study, Leahy, Chandler and Sweller (2003), explored whether audiovisual instruction would be beneficial or a hindrance compared to visual-only instruction. In their first experiment, they found that audiovisual presentations were more effective than equivalent visual-only presentations. However, this study did not investigate a baseline auditory-only condition, so it is unclear whether audiovisual instruction is also superior to auditory-only. Their second experiment featured a non-essential explanatory text presented aurally at the same time as written text within a diagram, which hindered learning. The authors argue this is because the aural text was an unnecessary distraction. They conclude that the efficacy of multimodal instruction depends on how auditory material is used.

The speech-sign bilingual brain and language production

The aforementioned language studies have focussed exclusively on processing in monolingual spoken language users. Since multimodal bilingual language processing involves the activation of two languages in different modalities, it is important to understand how signed and spoken languages are stored and accessed in the brain. While the neural systems supporting signed and spoken languages are very similar (MacSweeney, Capek, Campbell and Woll, 2008), the linguistic experience of being a speech-sign bilingual leads to its own unqiue neurocognitive changes. Emmorey and McCullough (2009) performed an fMRI study that revealed effects of both sign experience and deafness on brain organisation. Sign experience led to significantly different activation patterns within the superior temporal sulcus, which is involved in joint attention (necessary to comprehend eye-gaze in sign languages) and multisensory processing.

In terms of bimodal bilingual activation and language production, Pyers and Emmorey (2008) found that native English-American Sign Language (ASL) bilinguals produce more ASL-appropriate facial expressions during speech production than hearing non-signers. These were also synchronised with the relevant English clause onset, suggesting it is not always possible to fully inhibit the unselected language. Similarly, Emmorey, Borinstein, Thompson and Gollan (2008) suggest that dual lexical retrieval is less costly than language inhibition for native speech-sign bilinguals, based on a production study on English-ASL bilinguals who demonstrated a clear preference for code-blending over code-switching. Recent tentative evidence from “sign-speaking” Indian Sign Language-Hindi bilinguals suggests this ability may even extend beyond the level of the word, despite syntactic and semantic differences between the two languages (Zeshan, 2014). She suggests that it is possible for “sign-speakers” to fluently produce two sentences in two languages – thus simultaneous signals at the word level for the most part would not be semantically equivalent, due to differences between sign and spoken language syntax. More data needs to be gathered on these “sign-speaking” bilinguals to investigate this hypothesis fully, but the initial evidence implies that, in future, it may be worth exploring potential multimodal bilingual RSEs beyond the word level.

The preference for code-blending over code-switching in speech-sign bilinguals entails that these populations also have experience processing bilingual, multimodal input; two clear differences from the language use of speech-speech bilinguals. Only one study has compared sign-only, speech-only and dual language processing in speech-sign bilinguals (Emmorey, Petrich and Gollan, 2012). They found evidence for the benefit of bimodal language input for semantically-based decisions ('is it edible?'), where responses are speeded when words are presented in spoken English and ASL compared to English or ASL alone. The present study aims to extend this to see whether dual language input affects phonological processing in a similar way. In semantically-based decision tasks, simultaneously-presented linguistic stimuli in two modalities both point to a shared meaning. Crucially, however, there is no overlap of the phonological systems of spoken and sign languages, since they use different articulators. Investigating phonological processing across modality conditions will therefore develop our understanding of how speech-sign bilinguals store and access English words and British Sign Language (BSL) signs, namely the degree to which phonological processing overlaps or is separate.

Phonological Processing of Sign Languages

Previous studies exploring sign language phonology have been used for a variety of purposes, but none have explicitly considered phonological processing of a signed and spoken language in a speech-sign bilingual context. Processing of phonological similarity in sign recognition has been investigated for ASL by Hildebrandt and Corina (2002). Their study employed a forced-choice task, namely ‘‘choose the surrounding sign that is most similar to the centre sign”, with native and non-native deaf signers plus sign-naive participants. Participants rated non-sign stimuli for phonological similarity, using the parameters handshape, movement and location, which have been used as evidence of phonological coding in working memory (Wilson and Emmorey 1997; 1998; 2001; 2003). Hildebrant and Corina found that varying degrees of linguistic knowledge of the Deaf signers influenced their similarity judgements. Linguistic experience is likely to be a factor in speech-sign bilingual phonological processing too. Mayberry (1993) also investigated phonological identification of signs in Deaf late L1 and L2 learners of ASL. She proposed a “phonological bottleneck”, suggesting that particularly late L1 learners give more attention to the phonological identification and have less attention available to process lexical meaning. The present study includes a BSL-only phonological condition for native signers and late L2 signers. Thus we may gain information about whether or not phonological processing is also impoverished in hearing late L2 learners of BSL or whether fluency and language experience is more important.

Priming studies, such as Mathur, Best and Sahlin (2006) and Dye and Shih (2006), have investigated whether Deaf native and non-native signers use the aforementioned phonological parameters of sign language to access their mental lexicon. In the latter, participants performed a lexical decision task after viewing phonologically-related primes, and results showed native signers primarily used the parameters location and movement to access their mental lexicon, while non-native signers did not. This suggests that non-native signers' processing required greater effort and was less automated. In terms of decision tasks that specifically demand phonological processing, Thompson, Vinson and Vigliocco (2010) used a handshape task (curved or straight handshape?) to explore effects of iconicity, where the meaning of the sign stimulus was irrelevant. Using this handshape task, they were able to demonstrate the role of phonology in the processing of iconic signs in BSL in Deaf native and non-native signers. The current study adopts a similar method, asking participants to make a speeded decision: is the handshape curved or straight?

Motivation for Present Study

While it should be noted that almost all Deaf people are also 'sign-print' bimodal bilinguals, due to their acquisition of written language as either L1 or L2, there is little existing work on phonological processing in hearing speech-sign bimodal bilinguals, and what does exist has mostly focussed on native bimodal bilinguals (commonly known as CODAs: Children of Deaf Adults). A broader definition of bilingualism, encompassing non-native late learners too (Ortega, 2010), has the potential to be more informative about the complex bilingual processing involved in comprehending code-blends and 'sign-speaking'. In this study, phonological processing of BSL signs and English words in bimodal and unimodal language conditions is investigated via a phonological decision task in both languages.

Methodology

Design

The experimental design consists of a 3(language group: fluent signers, intermediate signers, non-signers)x2(modality condition: single, dual)x2(task type: handshape decision, phoneme monitoring) mixed design (Table 1). The between-groups variable was language group, and the within-group variables were task type and modality condition. The dependent variables were response accuracy and RT.

Table 1 – Experimental Design

Language Group	Handshape Decision		Phoneme Monitoring	
	Single Input	Dual Input	Single Input	Dual Input
Fluent Signers	Sign-Only	Sign-With-Speech	Speech-Only	Speech-With-Sign
Intermediate Signers	Sign-Only	Sign-With-Speech	Speech-Only	Speech-With-Sign
Non-Signers	Sign-Only	Sign-With-Speech	Speech-Only	Speech-With-Sign

Participants

Three population groups were investigated: two signing experimental groups and one non-signing control group (see Table 2). The signing groups were two different types of hearing English-BSL speech-sign bilinguals. The first group comprised fluent speech-sign bilinguals (*n*=13, mean age=33, range=22-51), including (*n*=5) native CODAs, plus (*n*=8) fluent non-native BSL users who began signing after age 12 (mean age=21, range=12-37) and had a mean 13 years' signing experience and a Level 6 certificate in BSL. These fluent non-native signers all use BSL on a daily basis, and all work at least part-time as BSL interpreters or Communication Support Workers. The second signing group (*n*=13, mean age=33, range=22-56) were English native speakers and late learners of BSL who began signing after the age of 16 (mean age of sign onset=24, range=17-31), and have reached an intermediate level of proficiency (minimum BSL Level 2; mean 8 years' signing experience). A third group of non-signing control participants (*n*=13, mean age=33, range=20-57) was also tested, comprising monolingual native English speakers with no previous exposure to any sign language or signed communication system.

Table 2 - Language Background Details

Language Group	NS	IS	FS
Gender	(4M; 7F; 2T)	(1M; 12F)	(2M; 11F)
Age	33	33	33
Years at uni?	3.6	3.3	2.7
Age at 1st Eng exposure?	0	0	0
Age at 1st BSL exposure?	n/a	21	9
Years of BSL exp	n/a	7	22
BSL Study yrs	n/a	5	5
Years of BSL exposure?	n/a	4	21
Hrs/ week using BSL?	n/a	19.2	25.4
%time/day using BSL	n/a	18.7	28.5
%time/day using Eng	100.0	80.8	71.2
%time/ month using BSL	n/a	21.4	33.5
%time/ month using Eng	100.0	78.2	64.6
Overall BSL Fluency (1-7)	n/a	4.4	6.0
Proficiency BSL prod (1-7)	n/a	4.5	5.7
Proficiency BSL recep (1-7)	n/a	4.2	5.8
Avg English Proficiency	7.0	6.9	6.9
Avg other Lg proficiency (1-7)	1.2	1.5	1.8

Signing participants were recruited from the local Deaf*/signing community in the West Midlands: via BSL teaching centres; Deaf community groups; the University of Wolverhampton Deaf Studies department and BSL practice groups on social media websites. Non-signing control participants were recruited from students and staff at the University of Birmingham. Participants were paid for taking part in the 25-minute experiment (signing groups: £7.50; control group: £4). Signing participants were paid more because, as a population with special skills, they are harder to recruit (although all participants were naïve about grouping and different payment levels).

Materials

Experimental tasks and conditions. An experiment with two phonological decision tasks was designed in *E-Prime 2.0*, made up of four blocks, each corresponding to a different language condition. Two of the blocks featured a phonological decision task in BSL, where participants decided whether the handshape of a sign was curved or straight, following criteria used in Thompson, Vinson and Vigliocco (2010). One of these blocks featured video stimuli of the BSL sign alone with no audio or

* Following convention, uppercase Deaf is used to refer to the signing Deaf community, who view themselves as a linguistic, not disabled, minority. Lowercase deaf is used when referring to deafness purely as an audiological hearing status.

mouthing (“sign only” condition); the other featured both video of the BSL sign and the spoken English translation equivalent produced simultaneously by the sign model with audio (“sign-with-speech” condition).

The other two blocks consisted of a phonological decision task in English, where participants decided whether a given phoneme (one of /b, d, p, t/) was present or absent in the English word, similar to phoneme monitoring tasks used by Foss and Swinney (1973) and Wurm and Samuel (1997), among others. One of these blocks featured audio stimuli of the English word alone with no video (“speech only” condition); the other featured both audio of the English word and video of the BSL sign produced simultaneously by the sign model with mouthing (“speech-with-sign” condition). The sign-with-speech and speech-with-sign conditions had to contain visible mouthing, instead of overlaying sign-only video with a separate audio track, to ensure simultaneous onset of the production of the BSL sign and English word.

Each of the four blocks contained 48 trials, with a break halfway. In the English task, the target phoneme changed after the break. Each block was preceded by 5 practice trials, and in the English task, there were 5 practice trials every time the target phoneme was changed. The order of blocks presentation was randomised.

Stimuli and lists. Four lists were created, each featuring 48 test items per condition, plus practice items (Appendix 1). The items were counterbalanced across the lists so that all appeared in each of the four conditions across the four experiment versions. The presentation order of the stimuli was randomised within each block. Participants from the three language groups were run on one of the four versions, balancing the versions as closely as possible (Table 3). All items had translation equivalents that were a single word or single sign. Where possible, items were selected for which BSL norms are available, such as the age of acquisition and familiarity norms from Vinson, Cormier, Denmark, Schembri & Vigliocco (2008) and the lexical frequency norms from Fenlon, Schembri, Rentelis, Vinson & Cormier (2014). 78 experimental items (39%) had norms from the BSL norms list and 164 (81%) had lexical frequency norms (Appendix 2). BSL items used scored >40/million frequency to ensure they were common enough to be known by intermediate signers. Items that would clearly vary in frequency across languages were avoided i.e. sound-related words (e.g. “guitar”) and deafness-related signs (e.g. HEARING-AID). However, since results from the BSL and English tasks will not be compared directly, the fact that norm matching was impossible is not deemed a critical flaw in the present study.

Table 3 – Distribution of participants across experiment versions

Version 1	Version 2	Version 3	Version 4
NS P5	NS P2	NS P3	NS P1
NS P7	NS P6	NS P8	NS P4
NS P10	NS P14	NS P11	NS P13
NS P15			
IS P16	IS P19	IS P17	IS P20
IS P18	IS P22	IS P23	IS P24
IS P21	IS P27	IS P25	IS P26
			IS P28
FS P29	FS P30	FS P31	FS P32
FS P33	FS P34	FS P35	FS P36
FS P37	FS P38	FS P41	FS P39
FS P40			

NS = Non Signers; IS = Intermediate Signers; FS = Fluent Signers; P = Participant.

English and BSL stimuli were created by a hearing sign model, a native English-BSL CODA working as an interpreter in Birmingham. The sign model was filmed producing all stimuli once in BSL and spoken English simultaneously, ensuring simultaneous onset of both languages, plus a second time in BSL alone with no lip pattern or voiceover (Figure 1). These were filmed with a camcorder in front of a blue screen and clipped into individual videos. Speech-only stimuli were created by extracting the audio from the speech-with-sign videos, ensuring comparable onset times across conditions.

Figure 1 – Example stimuli

Left – example of sign-with-speech/speech-with-sign stimulus (street/STREET). Right – example of sign-only stimulus (OPEN). For speech-only stimuli, participants saw a blank white screen

Experiment set-up

Video stimuli were displayed in the centre of a 47.5x29.5cm LG L226WTQ monitor with the dimensions 26.5x19cm. The keyboard was set up so that the handshape task used keys Q and P covered with stickers labelled [(] (curved) or [|] (straight); and the phoneme monitoring tasks used keys J and F covered with a green sticker (phoneme present) or red sticker (phoneme absent). The keys and stickers were switched for two of the four versions to ensure button press responses were balanced across participants.

Procedure

On arrival, participants read the study information sheet (Appendix 3) and signed a consent form (Appendix 4) to confirm their voluntary participation. Participants then filled out a language background questionnaire (Appendix 5) to find out more about their language learning history. The two signing groups also answered questions about their BSL use and self-rated their proficiency.

The experimenter then explained the study procedure orally. The signing groups watched a short instruction video in BSL explaining the handshape decision task. For the non-signing control group, the experimenter explained the task orally and demonstrated example handshapes. The experimenter explained the different keyboard buttons and instructed participants to respond to stimuli as quickly and accurately as possible. Participants asked any questions they had at this point.

Participants then put on the headphones and began the experiment in *E-Prime*, with further opportunities to ask questions after each practice block. At the end of the experiment, the experimenter asked participants whether they found the single- or dual-input conditions easier or more difficult for the two phonological tasks and de-briefed participants about the aims of the study.

Hypotheses

Since the two different tasks will be analysed separately, the BSL handshape decision task will, from here on, be referred as Experiment 1 and the English phoneme-monitoring task as Experiment 2.

Predictions across modality conditions. A main hypothesis and an alternative hypothesis have been developed. The main hypothesis predicts that, following Redundant Signals Effect theory, dual input should speed processing in both experiments. This means that responses should be faster and more accurate in the sign-with-speech condition than the sign-only condition, and faster and more accurate in the speech-with-sign condition compared to the speech-only condition.

The alternative hypothesis, however, predicts that a limited capacity for processing phonological input could lead to participants being overwhelmed and thus responding slower (and/or less accurately) to dual input (sign-with-speech and speech-with-sign) stimuli compared to the respective single-input stimuli (sign-only and speech-only).

There is also the possibility of asymmetric findings for the two experiments, independent of group differences. Activation of the task-irrelevant language may lead to benefits for dual modality input in the BSL experiment, but hindrance in the English experiment, or vice versa. This could be due to differences in lexical storage and access in the two languages.

Predictions across language groups. Since differences between the groups are predicted, post-hoc planned comparisons will be carried out across groups to understand whether the predicted differences are seen. Since it is also necessary to determine whether potential benefits of dual modality input in Experiment 2 can be attributed to the addition of BSL handshapes, not simply from speechreading, planned comparisons across group and modality condition will be carried out to compare the non-signing and signing groups.

In the single-input conditions (sign-only and speech-only), it is predicted that language experience and linguistic environment will be the influencing factors. In the dual input conditions (sign-with-speech and speech-with-sign), it is predicted that experience with dual language input will be the key factor. The predictions across language groups are summarised in Table 4.

Table 4 – Predictions across language groups in line with main hypothesis

Language Group	Exp 1: Handshape Decision		Exp 2: Phoneme Monitoring	
	Sign-Only	**Sign-With-Speech**	**Speech-Only**	**Speech-With-Sign**
Fluent Signers	Fastest and most accurate responses: most experience, proficiency and current BSL exposure	Fastest and most accurate responses: most experience and current exposure to sign-with-speech input	Slowest and most inaccurate responses: least current exposure to spoken English / least spoken English input in childhood	Fastest and most accurate responses: most experience and current exposure to speech-with-sign input
Intermediate Signers	Intermediate response accuracy and speed: some experience, proficiency and current BSL exposure	Intermediate response accuracy and speed: some experience and current exposure to sign-with-speech input	Intermediate response accuracy and speed: lifetime experience but slightly reduced current exposure to spoken English input	Intermediate response accuracy and speed: some experience and current exposure to speech-with-sign input
Non-Signers	Slowest and most inaccurate responses: no experience, proficiency or current BSL exposure	Slowest and most inaccurate responses: no experience or current exposure to sign-with-speech input	Fastest and most accurate responses: lifetime experience of only using English	Slowest and most inaccurate responses: no experience or current exposure to speech-with-sign input

Results

Procedure and exclusion criteria

For the phoneme monitoring task, only yes trials, i.e. ‘phoneme present’ trials were analysed, while for the handshape decision task both straight and curved responses were considered. Items with a correct response rate of <70% were excluded (phoneme task: 3 items, 1.5%; handshape task: 27 items, 14%). All incorrect responses were excluded (phoneme task: 74 trials, 8.3%; handshape task: 102 trials, 6.9%). One non-signer (participant ID 9) scored <70% accuracy in both modality conditions on the handshape task and was therefore excluded.

For both tasks, participants’ trials that were 2.5 standard deviations above or below their mean RT were considered outliers and excluded (phoneme task: 23 trials, 2.6%; handshape task: 30 trials, 2%). The average RTs of one fluent signer (participant 41) and one non-signer (participant 15) were >2500ms in both conditions. These participants were excluded, with their slowness attributed to not having followed the instructions to respond as quickly and accurately as possible.

Statistical analyses

The alpha level for significance was 0.05. All analyses were performed using *SPSS 22*. Normality and homogeneity of variance data is in Appendix 6**.** Experiment 1 and 2 are considered separately, looking at both RT and accuracy using 3x2 ANOVAs, planned comparison 1-way ANOVAs and paired samples t-tests.

Experiment 1 - Handshape Decision Task

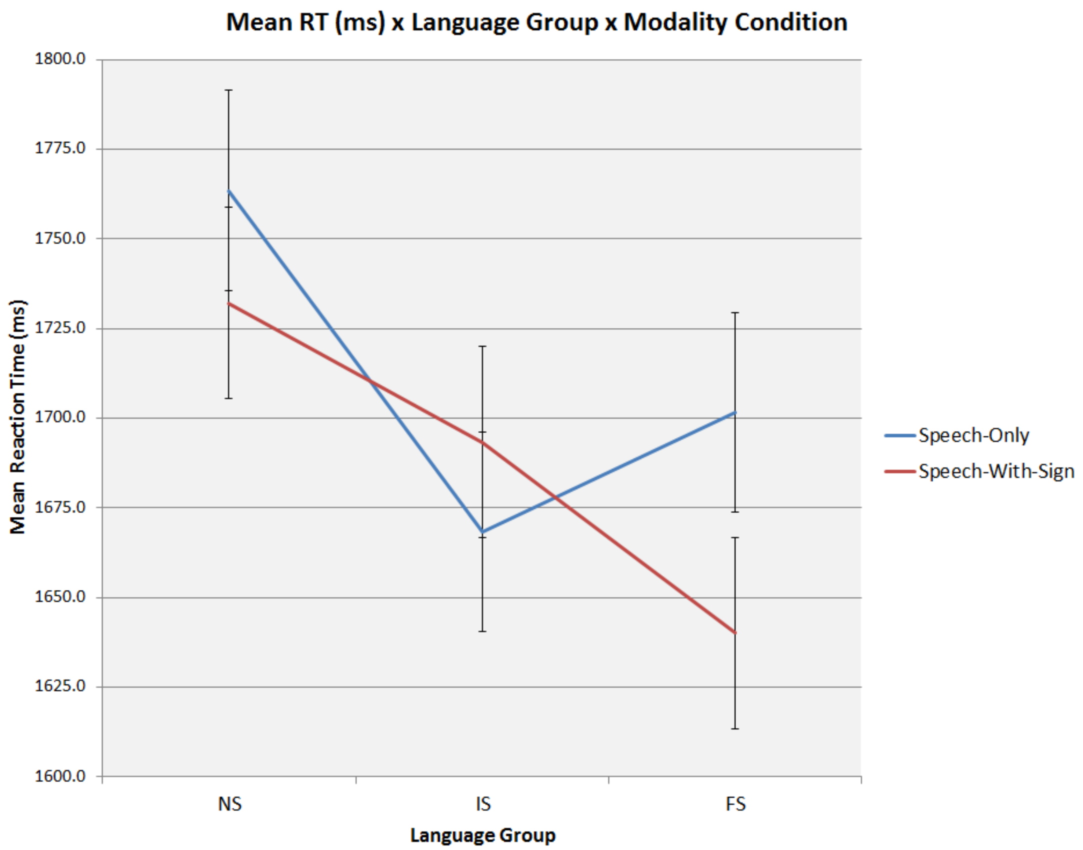
1. Reaction Time. Means and standard deviations are shown in Table 5/Figure 2.

Table 5 – Descriptive Statistics for Handshape Task Reaction Time (ms)

Group	Sign-only		Sign-with-Speech		N
	Mean	SD	Mean	SD	
NS	1754	428.1	1726	436.3	11
IS	1669	450.3	1693	439.0	13
FS	1697	358.2	1625	408.4	12

A 3(group: fluent, intermediate, non-signers)x2(modality: single input, dual input) mixed ANOVA showed the main effect of modality was not significant, $F(1,34)=0.801$, $p=0.377$, partial $\eta2=0.024$, nor was language group $F(2,34)=0.373$, $p=0.691$, partial $\eta2=0.022$. The interaction was also not significant, $F(2,34)=1.117$, $p=0.339$, partial $\eta2=0.063$.

Figure 2 – Experiment 1 – Handshape Task Reaction Time



Planned comparisons. A one-way between-groups ANOVA revealed no significant differences between groups in both the sign-only: $F(2,33)=0.506$, $p=0.608$, and sign-with-speech: $F(2,33)=0.391$, $p=0.679$, modalities.

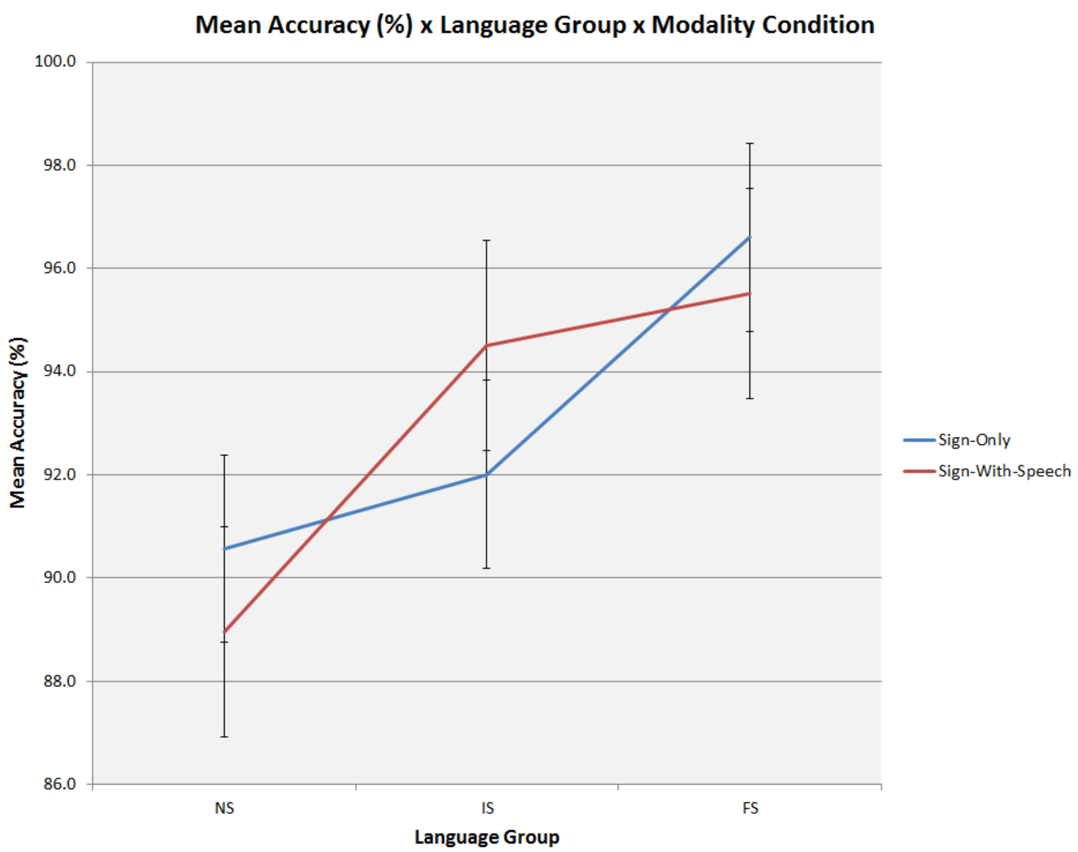
2. Accuracy. Means and standard deviations are shown in Table 6/Figure 3.

Table 6 – Descriptive Statistics for Accuracy

Group	Sign-only		Sign-with-Speech		N
	Mean	SD	Mean	SD	
NS	90.6%	5.9%	89.0%	5.0%	11
IS	92.0%	5.8%	94.5%	3.9%	13
FS	96.6%	4.0%	95.5%	6.2%	12

A 3(group: fluent, intermediate, non-signers)x2(modality: single input, dual input) mixed ANOVA showed the main effect of modality was not significant: $F(1,33)=0.006$,$p=0.937$, partial $\eta 2$ <0.001. The main effect of language group was significant: $F(2,33)=5.354$, $p=0.010$, partial $\eta 2=0.245$ such that fluent signers were more accurate overall, however this was qualified by a marginal interaction between modality and language group: $F(2,33)=2.731$, $p=0.08$, partial $\eta 2=0.142$, such that intermediate signers showed more benefit from dual input compared to fluent signers.

Figure 3 – Experiment 1 – Handshape Task Accuracy



Planned comparisons. A one-way between-groups ANOVA revealed a significant difference between groups in both the sign-only: $F(2,33)=4.148$, $p=0.025$ and sign-with-speech modalities: $F(2,33)=5.513$, $p=0.009$. A Tukey post-hoc test revealed that for the sign-only condition, the effect was being driven by fluent signers responding significantly more accurately than non-signers: 96.6%±6.0%, $p=0.027$. In the sign-with-speech modality, non-signers were significantly less accurate than both intermediate signers: 94.5%±5.5%, $p=0.031$ and fluent signers: 95.5%±6.5%, $p=0.011$.

Discussion

The handshape task showed no significant effects of modality or language group on RT, so no strong claims can be made about dual input being a benefit or hindrance to speed of language processing. The lack of a significant interaction could perhaps be due to the novel task with unusual criteria. Having learnt the straight/curved distinction just before beginning the experiment, the task required a high level of visual focus on the hands, meaning additional audio information in the spoken modality was not as helpful as it otherwise could have been. Beyond beginner's level, signers soon learn to mostly fixate on their interlocutor's eyes and not the hands (Poizner and Kegl, 1992), whereas this task demands a specific focus on the hands. This may feel therefore feel unnatural for the signing groups and may have led to a processing slow-down in both conditions. It may also have been worth controlling for sign location, since signers process handshapes and movements articulated on and near the face using foveal vision, and those away from the face using peripheral vision (Siple, 1978). This is important because Deaf signers have an advantage of auditory deprivation over both hearing signers and non-signers here, performing better in peripheral movement recognition (Bavelier et. al, 2000). The only previous study to use this task (Thompson, Vinson & Vigliocco, 2010) used almost exclusively Deaf participants, and considering the above, it could be argued that the straight/curved handshape decision task is not an ideal way to examine phonological processing in hearing signers. That study showed iconicity effects, such that more iconic signs were processed faster and more accurately than non-iconic signs. It would be interesting to investigate whether the same holds for the signs used for which there are iconicity norms, and if so, whether iconicity plays a greater role in the sign-only or sign-with-speech modality.

In terms of response accuracy, there was a significant main effect of language group such that fluent signers were more accurate overall. This can be accounted for by fluent signers' greater experience with sign-only input. It is likely that fluent signers benefit from more solid phonological representations that they can access faster than intermediate signers, giving them a significant advantage over non-signers and likely benefitting them in more borderline cases where the straight/curved distinction was more difficult. Non-signers cannot process handshapes phonologically since they cannot treat the brand new signs as lexical items, having to rely on visual processing alone, focussed exclusively on the sign model's hands. Thus we see there is a significant benefit of having a full phonological representation compared to none at all. However, there was also a marginal interaction between modality and language group, driven by a significant benefit for intermediate signers in the sign-with-speech modality compared to the sign-only modality. Given that intermediate signers cannot rely as fully on solid phonological representations as fluent signers can, it is sensible to suggest that they are using the extra information provided in English in the auditory modality to confirm their response. While this interaction is only marginal, given the slower RTs in the sign-with-speech modality, there is a possibility that intermediate signers are making a speed-accuracy trade-off, responding more slowly but more accurately in this condition. More evidence is given by individual participant comparisons across conditions (Appendix 7). This relationship may be revealed more clearly using a different task of phonological processing. It may also be of interest to develop a version of Experiment 1 with eye-tracking to confirm whether the nature of this task alters where a signer would normally look during sign comprehension.

Experiment 2 - Phoneme Monitoring Task

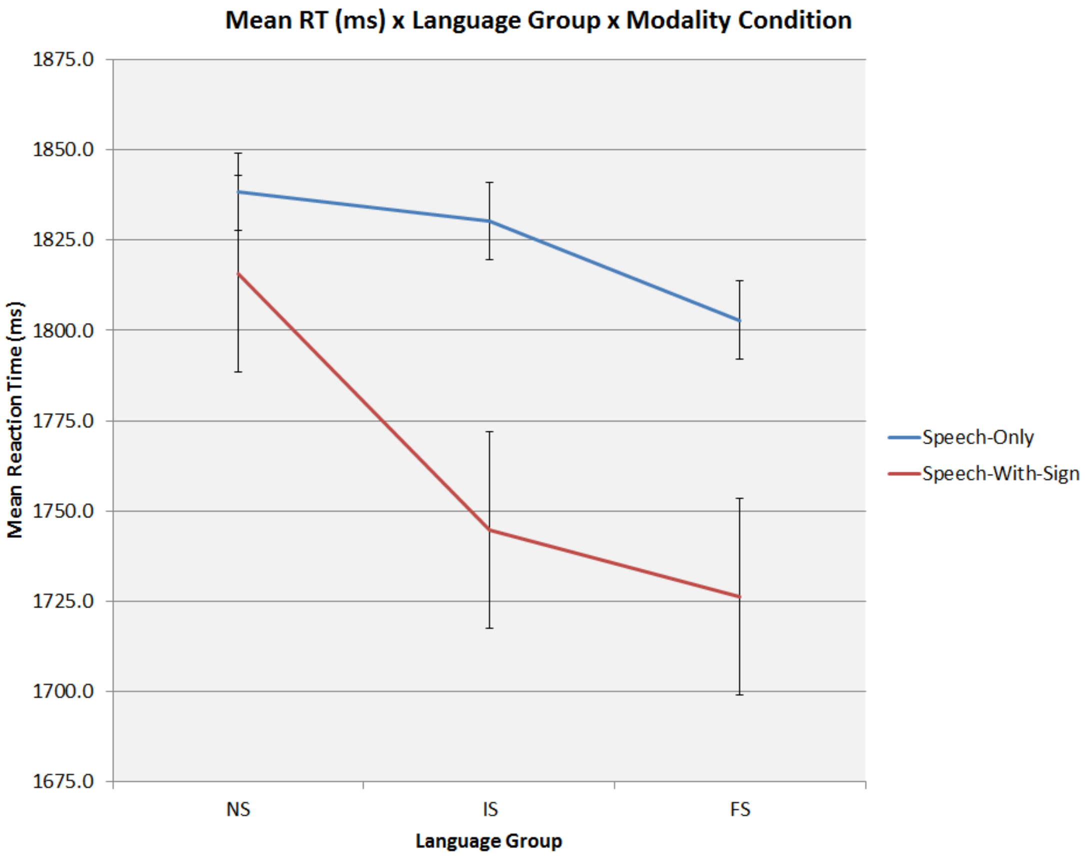
1. Reaction Time. Means and standard deviations are shown in Table 7/Figure 4.

Table 7 – Descriptive Statistics for Phoneme Task Reaction Time (ms)

Group	Speech-only		Speech-with-Sign		N
	Mean	SD	Mean	SD	
NS	1834	320.2	1805	371.4	11
IS	1831	310.7	1747	354.7	13
FS	1799	300.4	1730	320.7	12

A 3(group: fluent, intermediate, non-signers)x2(modality: single input, dual input) mixed ANOVA demonstrated that the main effect of modality was significant, $F(1, 34)=10.628$, $p=0.003$, partial $\eta 2=0.244$, such that all groups made English phoneme decisions faster in the speech-with-sign modality. The main effect of language group was not significant, $F(2,34)=0.774$, $p=0.469$, partial $\eta 2$ $=0.045$; nor was the interaction, $F(2,34)=0.742$, $p=0.484$, partial $\eta 2=0.043$.

Figure 4 – Experiment 2 – Phoneme Task Reaction Time



Planned comparisons. A one-way between-groups ANOVA revealed no significant differences between groups in the speech-only: $F(2,33)=0.324$, $p=0.726$, or speech-with-sign modality: $F(2,33)=1.053$, $p=0.360$.

To understand whether group differences were driving the main effect of modality, as the descriptive data suggest, a paired samples t-test was carried out. This revealed that while there was no significant difference between modality conditions for non-signers: $t(10)=0.930$, $p=0.374$, both intermediate signers: $t(12)=2.189$, $p=0.049$, and fluent signers: $t(11)=2.775$, $p=0.018$, responded significantly faster in the speech-with-sign condition.

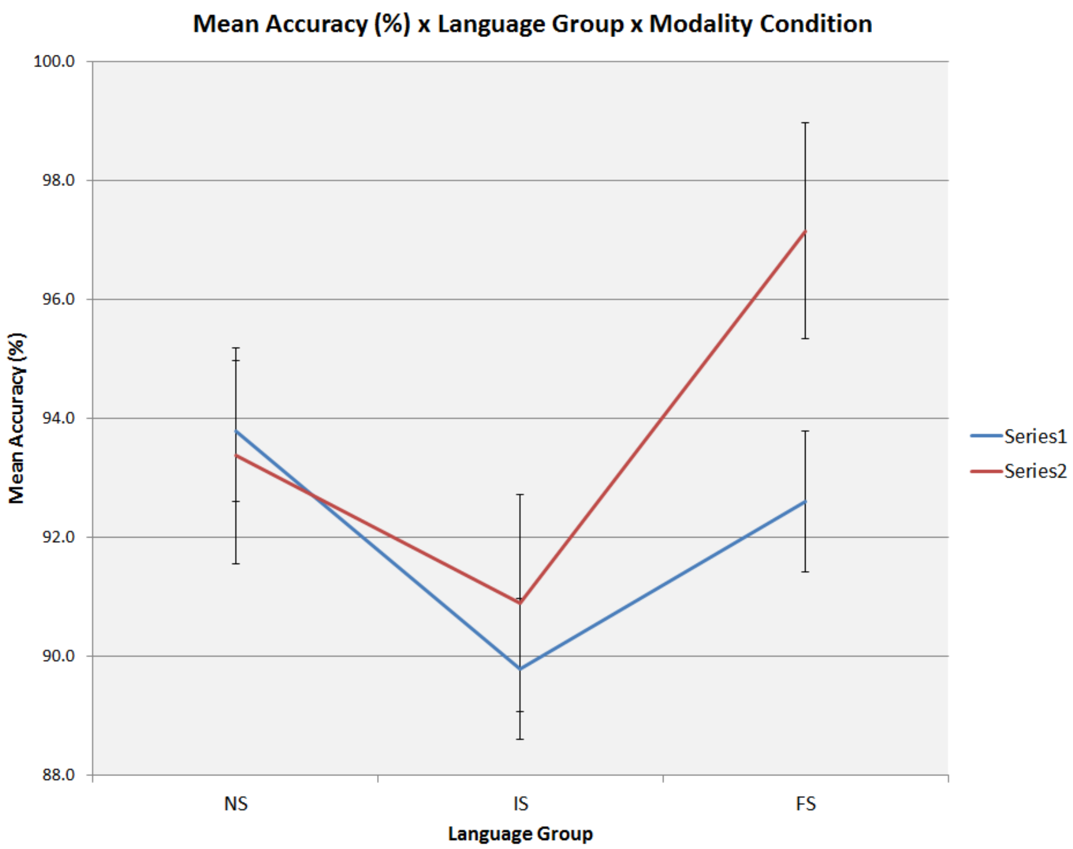
2. Accuracy. Means and standard deviations are shown in Table 8/Figure 5.

Table 8 – Descriptive Statistics for Phoneme Task Accuracy

Group	Speech-only		Speech-with-Sign		N
	Mean	SD	Mean	SD	
NS	93.8%	7.9%	93.4%	5.8%	11
IS	89.8%	8.8%	90.9%	6.6%	13
FS	92.6%	5.2%	97.1%	4.2%	12

A 3(group: fluent, intermediate, non-signers)x2(modality: single input, dual input) mixed ANOVA showed the main effect of modality was not significant: $F(1,33)=1.351, p=0.253$, partial $\eta 2 = 0.039$, while the main effect of language group approached significance: $F(2,33)=2.898$, $p=0.069$, partial $\eta 2=0.149$. The interaction was not significant: $F(2,33)=0.934$, $p=0.403$, partial $\eta 2=0.054$.

Figure 5 – Experiment 2 – Phoneme Task Accuracy



Planned comparisons. A one-way between-groups ANOVA revealed no significant difference between groups in the speech-only modality: $F(2,33)=0.918$, $p=0.409$, but a significant difference between groups in the speech-with-sign modality: $F(2,33)=3.877$, $p=0.031$. A Tukey post-hoc test revealed that this was being driven by fluent signers responding significantly more accurately than intermediate signers: 97.1% ± 6.2%, *p*=0.024.

Discussion

In the phoneme monitoring task, a main effect of modality was seen on RT such that responses were faster in the speech-with-sign modality than the speech-only modality. This initially appears surprising, suggesting that all groups, including the non-signers, see a benefit from BSL when making decisions about English. A potential explanation is that non-signers benefit from particularly iconic signs, potentially perceiving them like co-speech gesture (Kita and Özyürek, 2003). Alternatively, it could be the ability to lip-read from the video in the speech-with-sign modality that was providing this benefit for all groups. Planned comparisons revealed that the benefit was likely to be from the handshape information being processed lexically by the two signing groups, rather than lip-reading, since only the intermediate and fluent signers responded significantly faster in the speech-with-sign condition, unlike the non-signing group. While there was no significant interaction, this suggests that even non-fluent, non-native signers can and do use BSL to their advantage, even when making phonological decisions about the target language, spoken English. In terms of group effects, although differences in the speech-only modality were predicted such that the non-signers would perform best and intermediate signers would perform better than fluent signers, it seems that time spent using BSL and, for fluent CODAs, childhood exposure to BSL at the potential expense of English, was not an important factor. This is, however, unsurprising, given that all groups rated themselves equally proficient in English. While there were also no significant group differences in the speech-with-sign modality, this is likely because the two intermediate and fluent signers performed very similarly. Thus a case could be made for combining the two signing groups, but group size would be very unbalanced.

With regard to accuracy in Experiment 2, only group differences approached significance. Interestingly, intermediate signers were the least accurate in both modality conditions. Indeed, planned comparisons revealed that the marginal effect was being driven by differences in the speech-with-sign modality only, specifically fluent signers outperforming intermediate signers. This also suggests that intermediate signers may again be performing a speed-accuracy trade-off when processing dual modality input, albeit the reverse of Experiment 1, here responding more quickly but less accurately. Again the lack of a significant interaction means this interpretation needs to be treated with caution, , but further evidence is provided by comparing which conditions individual participants were more accurate and faster in (Appendix 8).

General Discussion

Taken together, both Experiments 1 and 2 seem to show some evidence of benefits of dual language input for the signing groups. Following the interpretation of intermediate signers following a speed-accuracy trade-off strategy in the dual modality conditions, arguably a more nuanced view than simply ‘benefit’ or ‘hindrance’ of bimodal bilingual input should be taken. While there is a significant benefit for accuracy only in Experiment 1 and a significant benefit for RT only in Experiment 2 for intermediate signers, it seems to be a case of one trading off against the other. By comparison, fluent signers demonstrate, as predicted, the fastest RTs and highest accuracy in dual-input conditions in both experiments. Planned comparisons showed that fluent signers sometimes significantly outperform intermediate signers when benefitting from dual-input conditions (Experiment 2 accuracy), but sometimes both signing groups perform similarly (Experiment 1 accuracy; Experiment 2 RT). This suggests degree of fluency is not necessarily a predictor of dual-input benefits and that in some cases, “intermediate” sign experience alone may be sufficient. However, it should be noted that both signing groups possessed many years of BSL experience (IS 8; FS 13), meaning for these relatively simple processing tasks, both are functionally fluent. Overall, these data suggest that sign experience is the most likely factor in whether bimodal bilingual input is beneficial compared to one language alone, implying that tightly-linked phonological systems develop as a result of signing experience. Particularly notable are the facilitation effects for both signing groups in Experiment 2, using their weaker language (BSL) to their benefit when making English language decisions.

In terms of future directions, first of all, further analyses could be carried out on the data presented here. Ideally, a linear mixed model analysis would be performed that considered further factors, in particular the iconicity norms and location information for the sign items used. However, only 39% of signs used in the present study had iconicity ratings. Now that semantic and phonological processing have been investigated, further studies could explicitly explore iconicity, by comparing the processing of highly iconic and non-iconic signs across modality conditions. Overall, dual-modal linguistic input continues to show evidence for processing benefits, suggesting there are many potential advantages to using sign language input with various hearing populations.

(5,998 words)

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APPENDIX

1. Full List of Items Used

Example below is from Version 1 of the experiment.

VERSION 1															
		SPEECH-WITH-SIGN			SPEECH-ONLY					SIGN-WITH-SPEECH			SIGN-ONLY		
		B trials:			D trials:					D trials:			B trials:		
prac-yes	1	binoculars	C	b	deer	S	d	prac-C	1	nudge	C	d	nudge	C	d
prac-yes	2	debate	S	dbt	distract	S	dtt	prac-C	2	lightbulb	C	tbb	lightbulb	C	tbb
prac-no	3	demolish	S	d	hope	S	p	prac-S	3	translate	S	tt	translate	S	tt
prac-no	4	page	S	p	vote	C	t	prac-S	4	factory	S	t	factory	S	t
prac-no	5	street	S	tt	trophy	S	tp	prac-S	5	open	S	p	open	S	p
exp-yes	1	nailbrush	S	b	advance	S	d	exp-C	1	bed	C	bd	scales	C	
exp-yes	2	bread	S	bd	hide	S	d	exp-C	2	daughter	C	dt	scarf	C	
exp-yes	3	beard	S	bd	dance	S	d	exp-C	3	cupboard	C	pbd	nut	C	t
exp-yes	4	bird	S	bd	devil	S	d	exp-C	4	award	C	d	key	C	
exp-yes	5	buy	C	b	demand	S	dd	exp-C	5	cards	C	d	eat	C	t
exp-yes	6	combine	C	b	provide	S	pd	exp-C	6	delay	C	d	mobilephon	C	bp
exp-yes	7	breathe	C	b	headphones	C	dp	exp-C	7	cousin	C		bridge	C	bd
exp-yes	8	bomb	C	bb	drop	C	dp	exp-C	8	laugh	C		bicycle	C	b
exp-yes	9	budget	C	bdt	birthday	C	btd	exp-C	9	machine	C		bank	C	b
exp-yes	10	bite	C	bt	discuss	C	d	exp-C	10	church	C		bell	C	b
exp-yes	11	break	C	b	dive	C	d	exp-C	11	government	C	t	umbrella	C	b
exp-yes	12	brick	C	b	draw	C	d	exp-C	12	chocolate	C	t	hamburger	C	b
exp-no	13	assess	S		acquire	S		exp-S	13	disk	S	d	kill	S	
exp-no	14	call	S		agree	S		exp-S	14	dog	S	d	knife	S	
exp-no	15	coffin	S		cancel	S		exp-S	15	duck	S	d	recognise	S	
exp-no	16	cow	S		cannon	S		exp-S	16	crocodile	S	d	relax	S	
exp-no	17	flag	S		summarise	S		exp-S	17	decorate	S	dt	shoe	S	
exp-no	18	floor	S		evening	S		exp-S	18	decide	S	dd	sing	S	
exp-no	19	egg	S		achieve	C		exp-S	19	give	S		swim	S	
exp-no	20	wall	S		argue	C		exp-S	20	glasses	S		ball	S	b
exp-no	21	kiss	C		cough	C		exp-S	21	know	S		bury	S	b
exp-no	22	curtains	C	t	kitchen	C	t	exp-S	22	lie	S		butcher	S	bt
exp-no	23	stir	C	t	create	C	t	exp-S	23	rifle	S		tube	S	tb
exp-no	24	tempt	C	tpt	protect	C	ptt	exp-S	24	river	S		rabbit	S	bbt
		T trials:			P trials:					P trials:			T trials:		
prac-yes	1	travel	C	t	aeroplane	S	p	exp-C	1	imagine	C		flower	C	
prac-yes	2	interrupt	S	tpt	support	S	ppt	exp-C	2	office	C		manage	C	
prac-no	3	explain	C	p	visit	S	t	exp-C	3	refuse	C		monkey	C	
prac-no	4	die	S	d	endure	C	d	exp-C	4	inject	C	t	garage	C	
prac-no	5	propose	C	pp	settle	S	tt	exp-C	5	tram	C	t	shine	C	
exp-yes	1	act	S	t	push	S	p	exp-C	6	coffee	C		dvd	C	dd
exp-yes	2	commute	S	t	spanner	S	p	exp-C	7	improve	C	p	boot	C	bt
exp-yes	3	tree	S	t	panic	S	p	exp-C	8	prison	C	p	bottle	C	btt
exp-yes	4	tease	S	t	pretend	S	ptd	exp-C	9	pull	C	p	teach	C	t
exp-yes	5	tell	S	t	operate	S	pt	exp-C	10	replace	C	p	cat	C	t
exp-yes	6	tent	S	tt	plate	S	pt	exp-C	11	sleep	C	p	tie	C	t
exp-yes	7	biscuit	C	bt	print	C	pt	exp-C	12	pool	C	p	town	C	t
exp-yes	8	stab	C	tb	paper	C	pp	exp-S	13	increase	S		house	S	
exp-yes	9	motorbike	C	tb	jumper	C	p	exp-S	14	kick	S		ignore	S	
exp-yes	10	badminton	C	bdt	prefer	S	p	exp-S	15	mouse	S		look	S	
exp-yes	11	water	C	t	sweep	C	p	exp-S	16	rain	S		merge	S	
exp-yes	12	write	C	t	cup	C	p	exp-S	17	scissors	S		roof	S	
exp-no	13	alarm	S		announce	S		exp-S	18	sell	S		school	S	
exp-no	14	animal	S		arrive	S		exp-S	19	slap	S	p	criticise	S	t
exp-no	15	cheese	S		clock	S		exp-S	20	pray	S	p	try	S	t
exp-no	16	cherry	S		close	S		exp-S	21	hospital	S	pt	fight	S	t
exp-no	17	exchange	S		fail	S		exp-S	22	point	S	pt	heart	S	t
exp-no	18	face	S		finish	S		exp-S	23	poster	S	pt	introduce	S	td
exp-no	19	ask	C		chair	C		exp-S	24	applaud	S	ppd	doctor	S	dt

2. Norms Data

		BSL Norms				English Norms
English word	BSL sign	Age of Acq.	Iconicity	Familiarity	Freq /million	Freq /million
achieve	ACHIEVE	x	x	x	40.49	49.23
acquire	ACQUIRE	x	x	x	40.49	12.31
act	ACT	x	x	x	80.97	148.46
advance	ADVANCE	x	x	x	40.49	20.00
aeroplane	AEROPLANE	4.61	6.40	6.10	526.32	8.46
agree	AGREE	10.28	3.05	6.55	971.66	298.46
alarm	ALARM-BELL	x	x	x	80.97	5.38
animal	ANIMAL	x	x	x	80.97	28.46
announce	ANNOUNCE	13.72	3.78	5.70	x	1.54
applaud	APPLAUD	x	x	x	80.97	0.77
argue	ARGUE	9.28	3.40	6.10	40.49	33.08
arrive	ARRIVE	7.28	3.20	6.40	2307.69	28.46
ask	ASK	6.94	3.15	6.75	1255.06	323.08
assess	ASSESS	x	x	x	121.46	20.77
award	AWARD	x	x	x	161.94	26.92
badminton	BADMINTON	x	x	x	40.49	2.31
ball	BALL	x	x	x	161.94	36.92
bank	BANK	10.28	3.05	5.75	242.91	67.69
beard	BEARD	x	x	x	121.46	9.23
bed	BED	6.83	3.80	6.30	x	76.92
bell	BELL	x	x	x	40.49	53.08
bicycle	BICYCLE	x	x	x	121.46	8.46
bird	BIRD	x	x	x	40.49	19.23
birthday	BIRTHDAY	x	x	x	80.97	10.77
biscuit	BISCUIT	5.74	2.55	5.95	x	9.23
bite	BITE	x	x	x	121.46	2.31
bomb	BOMB	11.28	4.85	5.25	40.49	22.31
boot	BOOT	8.61	5.05	5.80	x	3.08
bottle	BOTTLE	6.68	5.40	6.00	80.97	10.00
bread	BREAD	5.83	4.00	6.45	40.49	25.38
break	BREAK	x	x	x	40.49	105.38
breathe	BREATHE	7.83	5.50	5.60	121.46	11.54
brick	BRICK	x	x	x	40.49	13.08
bridge	BRIDGE	x	x	x	40.49	71.54
budget	BUDGET	x	x	x	80.97	62.31
bury	BURY	x	x	x	40.49	6.15
butcher	BUTCHER	x	x	x	80.97	0.77
buy	BUY	8.39	2.50	6.20	931.17	172.31
call	CALL	x	x	x	40.49	350.77
cancel	CANCEL	x	x	x	40.49	7.69
cannon	CANNON	x	x	x	80.97	1.54
canoe	CANOE	10.88	5.78	4.50	x	0.00
cards	CARDS	7.83	5.90	5.60	x	20.00
cat	CAT	x	x	x	80.97	8.46
chair	CHAIR	6.94	3.85	5.95	161.94	12.31
cheese	CHEESE	8.06	2.50	5.95	x	5.38
cherish	CHERISH	x	x	x	121.46	0.00
cherry	CHERRY	10.28	3.00	5.05	x	1.54
chocolate	CHOCOLATE	7.26	1.85	5.95	x	5.38
church	CHURCH	8.17	4.25	5.70	364.37	102.31
clock	CLOCK	6.79	6.20	4.85	40.49	15.38
close	CLOSE	x	x	x	121.46	93.85
coffee	COFFEE	x	x	x	80.97	83.08
coffin	COFFIN	x	x	x	80.97	2.31
combine	COMBINE	x	x	x	80.97	6.92
commute	COMMUTE	x	x	x	121.46	1.54
cough	COUGH	5.33	5.55	5.55	x	22.31
cousin	COUSIN	x	x	x	40.49	6.92
cow	COW	x	x	x	364.37	9.23
create	CREATE	13.61	2.55	5.95	80.97	50.77
criticise	CRITICISE	x	x	x	40.49	0.00
crocodile	CROCODILE	5.61	6.20	5.15	x	0.00
cup	CUP	x	x	x	80.97	32.31
cupboard	CUPBOARD	x	x	x	161.94	1.54
curtains	CURTAINS	6.17	5.80	5.90	x	6.15
dance	DANCE	x	x	x	283.40	46.15
daughter	DAUGHTER	x	x	x	769.23	44.62
decide	DECIDE	12.17	2.75	6.10	121.46	97.69
decorate	DECORATE	x	x	x	40.49	2.31
delay	DELAY	x	x	x	80.97	5.38
demand	DEMAND	14.17	3.05	5.25	x	51.54
devil	DEVIL	x	x	x	80.97	7.69
die	DIE	8.61	2.80	6.05	728.74	62.31
discuss	DISCUSS	x	x	x	1052.63	70.00
disk	DISK	x	x	x	80.97	0.77
dive	DIVE	9.83	6.10	4.65	40.49	0.00
doctor	DOCTOR	x	x	x	40.49	82.31
dog	DOG	4.61	3.55	6.10	769.23	40.00
draw	DRAW	x	x	x	161.94	106.15
drop	DROP	8.50	5.55	5.55	607.29	77.69
duck	DUCK	4.50	6.00	5.30	x	6.92
dvd	DVD	16.61	3.00	5.45	121.46	0.00
eat	EAT	3.17	6.80	6.85	1093.12	63.08
egg	EGG	6.91	3.37	4.55	x	23.85
endure	ENDURE	x	x	x	161.94	0.77
evening	EVENING	x	x	x	161.94	135.38
exchange	EXCHANGE	x	x		80.97	50.00
explain	EXPLAIN	x	x	x	1052.63	86.92
face	FACE	x	x	x	404.86	114.62
fail	FAIL	x	x	x	121.46	20.77
feel	FEEL	x	x	x	2105.26	493.08
fight	FIGHT	7.94	3.05	5.95	80.97	40.00
finish	FINISH	x	x	x	2267.21	56.15
flag	FLAG	x	x	x	80.97	12.31
floor	FLOOR	x	x	x	x	46.92
flower	FLOWER	5.74	3.50	5.35	x	20.77
garage	GARAGE	x	x	x	x	16.15
ghost	GHOST	x	x	x	80.97	1.54
give	GIVE	x	x	x	2024.29	636.15
glasses	GLASSES	x	x	x	121.46	10.77
government	GOVERNMENT	x	x	x	161.94	635.38
hamburger	HAMBURGER	x	x	x	80.97	0.00

		BSL Norms				English Norms
English word	BSL sign	Age of Acq.	Iconicity	Familiarity	Freq /million	Freq /million
headphones	HEADPHONES	x	x	x	80.97	0.00
heart	HEART	x	x	x	80.97	58.46
hide	HIDE	x	x	x	121.46	2.31
hospital	HOSPITAL	7.83	2.60	5.40	121.46	63.85
house	HOUSE	5.94	4.50	5.75	2105.26	401.54
hurt	HURT	x	x	x	121.46	19.23
icecream	ICECREAM	3.61	5.95	5.90	202.43	0.00
ignore	IGNORE	10.28	3.20	6.25	x	13.08
imagine	IMAGINE	x	x	x	161.94	124.62
improve	IMPROVE	x	x	x	121.46	53.85
increase	INCREASE	x	x	x	40.49	80.00
inject	INJECT	x	x	x	x	0.77
interrupt	INTERRUPT	x	x	x	40.49	5.38
introduce	INTRODUCE	13.83	2.60	5.50	x	20.00
jacket	JACKET	5.56	6.40	5.75	x	6.15
jumper	JUMPER	5.61	5.50	5.95	x	0.00
key	KEY	5.94	6.05	6.30	40.49	29.23
kick	KICK	x	x	x	769.23	13.85
kill	KILL	x	x	x	121.46	25.38
kiss	KISS	x	x	x	40.49	10.00
kitchen	KITCHEN	7.61	2.00	5.90	40.49	34.62
knife	KNIFE	7.83	5.23	5.85	x	7.69
know	KNOW	x	x	x	4574.90	4054.62
laugh	LAUGH	7.17	5.05	6.30	890.69	119.23
lie	LIE	7.39	1.95	6.30	80.97	23.08
look	LOOK	4.72	4.90	6.60	6356.28	928.46
machine	MACHINE	x	x	x	80.97	96.15
manage	MANAGE	x	x	x	161.94	46.15
merge	MERGE	x	x	x	80.97	3.85
mobilephone	MOBILE-PHONE	x	x	x	161.94	0.00
monkey	MONKEY	4.72	5.90	5.45	x	4.62
motorbike	MOTORBIKE	x	x	x	323.89	0.00
mouse	MOUSE	6.72	2.25	5.15	40.49	3.08
nailbrush	NAILBRUSH	x	x	x	161.94	0.00
nut	NUT	9.39	3.35	5.50	40.49	6.92
office	OFFICE	x	x	x	80.97	163.08
operate	OPERATE	x	x	x	161.94	40.00
panic	PANIC	x	x	x	121.46	6.15
paper	PAPER	6.39	1.55	5.90	x	163.85
plate	PLATE	x	x	x	80.97	10.77
point	POINT	x	x	x	80.97	846.92
pool	POOL	9.39	6.32	5.25	x	12.31
poster	POSTER	x	x	x	80.97	6.15
pray	PRAY	x	x	x	121.46	10.77
prefer	PREFER	x	x	x	161.94	46.92
pretend	PRETEND	x	x	x	x	12.31
print	PRINT	x	x	x	80.97	28.46
prison	PRISON	x	x	x	202.43	91.54
propose	PROPOSE	15.17	2.25	5.55	x	10.00
protect	PROTECT	13.62	2.53	5.15	40.49	26.15
provide	PROVIDE	x	x	x	121.46	97.69
pull	PULL	5.61	6.35	5.60	404.86	38.46
push	PUSH	5.28	6.35	6.25	566.80	29.23
rabbit	RABBIT	4.50	5.98	5.50	x	3.08
rain	RAIN	x	x	x	121.46	24.62
recognise	RECOGNISE	x	x	x	202.43	0.00
refuse	REFUSE	8.72	1.70	5.75	161.94	6.92
relax	RELAX	11.94	3.33	6.05	283.40	9.23
replace	REPLACE	x	x	x	161.94	15.38
rifle	RIFLE	x	x	x	80.97	1.54
river	RIVER	x	x	x	80.97	22.31
roof	ROOF	x	x	x	161.94	15.38
scales	SCALES	x	x	x	40.49	2.31
scarf	SCARF	9.17	4.95	4.40	40.49	3.85
school	SCHOOL	9.06	1.60	4.90	1943.32	660.77
scissors	SCISSORS	x	x	x	x	2.31
sell	SELL	x	x	x	202.43	74.62
settle	SETTLE	x	x	x	121.46	28.46
shine	SHINE	x	x	x	x	3.85
shoe	SHOE	x	x	x	121.46	4.62
sing	SING	8.83	3.70	5.55	40.49	20.00
slap	SLAP	7.38	6.20	5.00	121.46	1.54
sleep	SLEEP	6.22	5.55	6.15	323.89	44.62
sock	SOCK	x	x	x	40.49	1.54
spanner	SPANNER	x	x	x	x	0.00
stab	STAB	x	x	x	80.97	0.77
stir	STIR	x	x	x	40.49	3.85
summarise	SUMMARISE	14.83	3.30	5.15	x	0.00
support	SUPPORT	x	x	x	121.46	120.77
sweep	SWEEP	x	x	x	80.97	2.31
swim	SWIM	x	x	x	728.74	17.69
teach	TEACH	10.61	3.10	6.15	1578.95	110.00
tease	TEASE	x	x	x	202.43	0.77
tell	TELL	6.21	3.68	6.35	x	380.00
tempt	TEMPT	x	x	x	202.43	1.54
tent	TENT	x	x	x	121.46	0.00
tie	TIE	7.28	6.40	5.48	x	15.38
tomato	TOMATO	8.56	2.90	4.35	x	0.77
town	TOWN	x	x	x	364.37	134.62
tram	TRAM	x	x	x	121.46	1.54
travel	TRAVEL	x	x	x	161.94	76.15
tree	TREE	6.28	6.25	5.70	323.89	8.46
try	TRY	x	x	x	1052.63	393.85
tube	UNDERGROUND-T	x	x	x	x	6.92
umbrella	UMBRELLA	x	x	x	202.43	8.46
violin	VIOLIN	9.94	5.70	4.75	x	8.46
visit	VISIT	x	x	x	242.91	40.77
wall	WALL	x	x	x	121.46	54.62
wash	WASH	x	x	x	80.97	13.85
water	WATER	7.28	2.00	6.45	283.40	170.00
write	WRITE	5.28	6.45	6.25	850.20	283.85

3. Study Information

UNIVERSITY OF BIRMINGHAM
DEPARTMENT OF PSYCHOLOGY

UNIVERSITY OF BIRMINGHAM

Participant Information Sheet
Confidential

Study name: Response time experiment

Thank you very much for your interest in our research. Before you decide whether you would like to participate or not, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

In this study we are interested in how fast you and accurately you make decisions about BSL signs and English words. In two of the four sections, you will be asked to make a handshape decision (straight or curved handshape?) by pushing a keyboard key. In the other two sections, you will be asked to make a decision about a sound (is sound 'X' present?) by pushing a keyboard key.

Because we are interested in response times, you should try and respond as fast as you can- but try to be accurate at the same time. You will be given a series of practice trials, and will have the opportunity to ask any further questions before the actual experiment begins. The experiment will last around 30 minutes in total; you will have the opportunity to take breaks at regular intervals.

The software that generates the displays onscreen will be recording the time it takes you to make your responses. Your responses will be coded with an identifying number and not directly associated to your identity. Recorded data will be confidentially secured in our laboratory and accessed only by our research staff; data resulting from these experiments will be composite data from multiple participants. Illustrative material involving any individual will only be used with that individual's full consent. Our research is compliant with the Data Protection Act 1998.

There are no risks associated with your participation in this study. You do not have to take part in this study if you do not want to. If you decide to take part, you may withdraw at any time without having to give a reason and without penalty.

All proposals for research using human subjects are reviewed by an ethics committee before they can proceed. This proposal was approved by the UoB Research Ethics Committee.

As you will gain no other benefit from your participation in this study, you will receive a payment at the rate of £15 per hour. Following your participation in the study, we will provide you with further information regarding the specifics of the study, and you may contact Dr Robin Thompson r.thompson@birmingham.ac.uk if you desire more information.
If you agree to participate in this study, please complete the participant consent form and video consent form.

Dr Robin Thompson
Department of Psychology
University of Birmingham
Birmingham, B15 2TT
r.thompson@bham.ac.uk

4. Consent Form

UNIVERSITY OF BIRMINGHAM
DEPARTMENT OF PSYCHOLOGY

UNIVERSITY OF BIRMINGHAM

Informed Consent Form for Participants in Research Studies

This form is to be completed independently by the participant after reading the Information Sheet and having listened to (or seen in BSL) an explanation about the research.

Title of project: Multimodal, multilingual language processing

Specific study: Response Time Study

This study has been approved by the UoB Research Ethics Committee
Head of Project: Dr Robin Thompson: r.thompson@bham.ac.uk

Participant's Statement

I ………………………………………………………………… agree that

- I have read the information sheet and the project has been explained to me orally / in BSL
- I have had the opportunity to ask questions and discuss the study; and
- I have received satisfactory answers to all my questions or have been advised of an individual to contact for answers to pertinent questions about the research and my rights as a participant and whom to contact in the event of a research-related injury.
- I am being paid for my assistance in this research and that some of my personal details will be passed to UoB Finance for administration purposes.
- I understand that I am free to withdraw from the study without penalty if I so wish
- I consent to the processing of my personal information for the purposes of this study only and that it will not be used for any other purpose.
- I understand that such information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998.

Signed: ______________________ Date: ______________________

Investigator's Statement

I, Richard Atkinson, confirm that I have carefully explained the purpose of the study to the participant and outlined any reasonably foreseeable risks or benefits (where applicable).

Signed: ______________________ Date: ______________________

5. Language Background Questionnaire*

UNIVERSITY OF BIRMINGHAM

BACKGROUND QUESTIONNAIRE

Today's Date:
Name:
Gender:
Date of birth:
Where did you grow up?
Current place of residence:
Email address:

What is your first/native language(s)? ....

Do you consider yourself bilingual or multilingual? Yes No

If yes, please give details:

Have you ever learnt any sign language or sign-based communication system (BSL, SSE, Makaton etc.)? Yes No

If yes, please give details:

Do you have any deaf relatives?
If yes, please list:

What is your occupation? ....

Do you go to university? Yes No If yes, for how long? ....
What is your highest qualification? ....

Are you left-handed, right-handed or ambidextrous? ....

Are you dyslexic or do you have any other language-related learning difficulties? (please detail)
....

Do you have any hearing problems? ....

Please list all of the languages you know or have studied, from the most proficient to the least proficient, and indicate the age at which you were first exposed to each (including your native language).

	Language	Age at 1st Exposure	Formal Study (#yrs)	Informal Exposure (#yrs)	Method of exposure
1					
2					
3					
4					
5					
6					

If you listed any languages other than English, approximate the percentage of time during an average day that you use:

Language	% of time during day	% of time during month
English		
Other: …………………………		
Other: …………………………		
Total	100%	100%

If you listed any languages other than English, please rate your proficiency in each language using the following scale:

1	2	3	4	5	6	7
almost none	very poor	fair	functional	good	very good	like a native

	Language	Speaking	Reading	Writing	Understanding
1					
2					
3					
4					
5					
6					

*Participants in the non-signing group received a modified version of this questionnaire.

6. Normality and Homogeneity of Variance

Experiment 1 - Handshape Task

Reaction Time. Data were parametric according to the Shapiro-Wilk Test: Sign-only, NS: $D(11)=0.946$, $p=0.593$; IS: $D(13)=0.959$, $p=0.737$; FS: $D(12)=0.910$, $p=0.212$; Sign-with-Speech, NS: $D(11)=0.887$, $p=0.129$; IS: $D(13)=0.955$, $p=0.670$; FS: $D(12)=0.177$, $p=0.241$. Equal variances between the groups were confirmed for both modalities by Levene's Test for Equality of Variances: sign-only: $F(1, 33)=1.256$, $p=0.298$; sign-with-speech: $F(1, 33)=0.060$, $p=0.942$.

Accuracy. Most data were parametric according to the Shapiro-Wilk Test: Sign-only, NS: $D(11)=0.905$, $p=0.211$; IS: $D(13)=0.945$, $p=0.526$; FS: $D(12)=0.807$, $p=0.011$; Sign-with-Speech, NS: $D(11)=0.952$, $p=0.669$; IS: $D(13)=0.874$, $p=0.060$; FS: $D(12)=0.728$, $p=0.002$; except for the fluent signers group - this is likely because their high accuracy levels caused a ceiling effect. Equal variances between the groups were confirmed for both modalities by Levene's Test for Equality of Variances: sign-only: $F(2, 33)=1.580$, $p=0.221$; sign-with-speech: $F(2, 33)=1.106$, $p=0.343$.

Experiment 2 – Phoneme Task

Reaction Time. Almost all data were parametric according to the Shapiro-Wilk Test: Speech-only, NS: $D(11)=0.930$, $p=0.412$; IS: $D(13)=0.943$, $p=0.501$; FS: $D(12)=0.859$, $p=0.048$; Speech-with-Sign, NS: $D(11)=0.921$, $p=0.329$; IS: $D(13)=0.901$, $p=0.137$; FS: $D(12)=0.940$, $p=0.501$. Equal variances between the groups were confirmed for both modalities by Levene's Test for Equality of Variances: speech-only: $F(1, 33)=2.528$, $p=0.095$; speech-with-sign: $F(1,33)=0.312$, $p=0.734$.

Accuracy. Half of the data were parametric according to the Shapiro-Wilk Test: Speech-only, NS: $D(11)=0.787$, $p=0.006$; IS: $D(13)=0.916$, $p=0.224$; FS: $D(12)=0.859$, $p=0.047$; Speech-with-Sign, NS: $D(11)=0.907$, $p=0.225$; IS: $D(13)=0.948$, $p=0.565$; FS: $D(12)=0.735$, $p=0.002$. However, some non-normality is likely to be attributable to ceiling effects due to high accuracy levels. Equal variances between the groups were confirmed for both modalities by Levene's Test for Equality of Variances: speech-only: $F(2, 33)=2.314$, $p=0.115$; speech-with-sign: $F(2,33)=1.586$, $p=0.220$.

7. Individual Participant Averages – Handshape Decision Task

		Sign-Only		Sign-With-Speech		More acc.	Faster
Group	Participant	Accuracy %	Mean RT (ms)	Accuracy %	Mean RT (ms)	condition?	condition?
NS	2	88.6	1587.3	92.9	1558.9	SWS	SWS
NS	3	92.1	2038.8	83.7	1806.4	SO	SWS
NS	4	85.0	1628.8	92.1	1565.3	SWS	SWS
NS	5	95.3	1604.5	97.7	1566.0	SWS	SWS
NS	6	93.2	1729.0	90.5	1818.1	SO	SO
NS	7	90.5	1903.3	93.2	1723.7	SWS	SWS
NS	8	97.4	2209.7	87.5	2217.3	SO	SO
NS	10	81.4	1818.7	81.8	1588.0	SWS	SWS
NS	11	94.7	1794.7	85.4	2140.5	SO	SO
NS	13	81.1	1634.7	83.3	1666.6	SWS	SO
NS	14	96.9	1448.6	90.5	1402.0	SO	SWS
						(5SO; 6SWS)	(4SO; 7SWS)
IS	16	88.1	1655.2	93.2	1491.6	SWS	SWS
IS	17	89.5	1441.3	95.2	1549.3	SWS	SO
IS	18	97.6	1455.8	97.7	1560.5	SWS	SO
IS	19	95.5	1239.4	97.6	1190.8	SWS	SWS
IS	20	100.0	2029.6	100.0	2167.6	-	SO
IS	21	88.1	2235.3	95.5	2082.4	SWS	SWS
IS	22	100.0	1845.7	92.9	1763.3	SO	SWS
IS	23	86.8	1790.6	95.1	1798.9	SWS	SO
IS	24	82.5	1759.6	84.2	1755.3	SWS	SWS
IS	25	97.4	1773.9	97.6	1869.7	SWS	SO
IS	26	92.5	1414.9	94.7	1560.1	SWS	SO
IS	27	93.2	1633.8	92.9	1622.9	SO	SWS
IS	28	85.0	1412.6	92.1	1599.8	SWS	SO
						(2SO; 10SWS)	(7SO; 6SWS)
FS	29	95.2	1520.6	100.0	1290.9	SWS	SWS
FS	30	100.0	1450.1	97.6	1303.0	SO	SWS
FS	31	89.5	1768.5	80.5	1917.2	SO	SO
FS	32	100.0	1851.1	100.0	1773.2	-	SWS
FS	33	95.2	1539.8	100.0	1367.0	SWS	SWS
FS	34	88.6	1575.9	85.7	1486.1	SO	SWS
FS	35	100.0	1781.8	97.6	1971.2	SO	SO
FS	36	97.6	1801.8	94.7	1864.4	SO	SO
FS	37	97.6	1809.9	97.7	1798.8	SWS	SWS
FS	38	95.5	1576.7	97.6	1649.0	SWS	SO
FS	39	100.0	1951.9	94.7	1771.1	SO	SWS
FS	40	100.0	1791.3	100.0	1488.6	-	SWS
						(6SO; 4SWS)	(4SO; 8SWS)

8. Individual Participant Averages – Phoneme Monitoring Task

		Speech-Only		Speech-With-Sign		More acc.	Faster
Group	Participant	Accuracy %	Mean RT (ms)	Accuracy %	Mean RT (ms)	condition?	condition?
NS	2	95.7	1799.7	95.8	1675.6	SWS	SWS
NS	3	100.0	1819.5	83.3	1862.4	SO	SO
NS	4	96.0	1799.4	95.7	1989.5	SO	SO
NS	5	87.0	1950.8	100.0	1775.9	SWS	SWS
NS	6	100.0	1790.0	91.3	1712.7	SO	SWS
NS	7	91.7	2024.6	87.0	1996.3	SO	SWS
NS	8	100.0	1904.5	100.0	1955.0	-	SO
NS	10	73.9	1884.4	87.0	1994.7	SWS	SO
NS	11	100.0	1745.5	100.0	1610.1	-	SWS
NS	13	91.7	1788.5	91.3	1791.5	SO	SO
NS	14	95.7	1715.0	95.7	1607.5	-	SWS
						(5SO; 3SWS)	(5SO; 6SWS)
IS	16	84.0	1662.0	92.0	1639.4	SWS	SWS
IS	17	87.0	1862.3	83.3	1550.4	SO	SWS
IS	18	79.2	1812.2	83.3	1813.8	SWS	SO
IS	19	82.6	1857.7	91.3	1765.1	SWS	SWS
IS	20	100.0	1883.1	100.0	2114.6	-	SO
IS	21	87.5	2038.7	100.0	1852.1	SWS	SWS
IS	22	95.7	1754.9	91.3	1737.2	SO	SWS
IS	23	72.7	1842.9	95.8	1543.1	SWS	SWS
IS	24	100.0	1839.8	87.0	1808.5	SO	SWS
IS	25	100.0	1887.8	79.2	1729.6	SO	SWS
IS	26	95.8	1715.2	87.0	1683.6	SO	SWS
IS	27	87.0	1762.4	95.7	1703.6	SWS	SWS
IS	28	95.8	1874.2	95.7	1739.4	SO	SWS
						(4SO; 6SWS)	(2SO; 11SWS)
FS	29	82.6	1779.0	91.3	1677.5	SWS	SWS
FS	30	95.7	1662.1	95.7	1594.1	-	SWS
FS	31	91.3	1767.2	100.0	1618.7	SWS	SWS
FS	32	91.7	1891.0	100.0	1804.1	SWS	SWS
FS	33	95.7	1759.9	100.0	1803.3	SWS	SO
FS	34	95.7	1655.5	100.0	1529.3	SWS	SWS
FS	35	100.0	1731.2	100.0	1817.1	-	SO
FS	36	96.0	1657.6	100.0	1737.9	SWS	SO
FS	37	83.3	1990.9	95.7	1797.2	SWS	SWS
FS	38	95.7	1695.0	87.5	1545.8	SO	SWS
FS	39	92.0	2034.3	95.7	1928.0	SWS	SWS
FS	40	91.7	2010.7	100.0	1861.0	SWS	SWS
						(1SO; 9SWS)	(3SO; 9SWS)