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The Effects of Language Experience and Ease of Articulation on Categorical Perception in Taiwan Sign Language

語言經驗及手形難易度對台灣手語類別知覺之影響

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Abstract

The goal of this thesis is to see the influence language experience and ease of articulation have on the categorical perception (CP) of handshapes in Taiwan Sign Language (TSL). Two experiments were conducted in this study with three tasks in total. Experiment 1, following Emmorey et al. (2003) and Baker et al. (2005), predicted that only TSL signers would display CP effects while Mandarin nonsigners would not. Four handshape contrasts were tested through an identification task and a discrimination task. It was predicted that there would be similar identification for both groups but the signer group would have a better performance across category than within category in the discrimination task. Results showed that (1) both groups performed similarly in the identification task, (2) not only TSL group but also non-signer group got better performance on across category than within category, (3) TSL group showed bigger difference between across and within categories than non-signer group. Experiment 2, with the intention to see how ease of articulation influences sign perception, had three handshape contrasts tested with a combination of easy-easy, hard-hard, and easy-hard through an identification task. The prediction was that TSL signers should have higher tolerance to the hard handshape that moves the boundary location toward the easy side in the easy-hard contrast. Results showed that there was a significant difference between the easy-hard pair and the same ease pairs; however, we did not find evidence to prove that ease of articulation is the main influence on sign perception. For the overall results, we suggested that CP may have different influence on different handshapes and that there may be other factors such as frequency and topological effects which may have greater influence on sign perception.

Key word: categorical perception, handshape, ease of articulation, identification, discrimination, Taiwan Sign Language (TSL)

摘　要

本論文的目的旨在探討手語語言經驗及手型難易度對於台灣手語（Taiwan Sign Language）類別知覺（categorical perception）的影響。整個研究分為兩個部分，共三個小實驗來進行。實驗 1A、1B 參照了 Emmorey et al. (2003)以及 Baker et al. (2005)所使用的實驗方法，我們預測只有實驗組會表現出類別知覺現象而對照組不會。我們透過辨認實驗以及 AX 判斷實驗測試了四組手形。我們預測在辨認實驗中，實驗組及對照組將有類似的表現。但實驗組在 AX 區辨實驗中，跨類別的判斷表現將優於類別內的判斷表現。我們發現：(1)兩組在辨認實驗中有類似的表現、(2)在 AX 判斷實驗中，不只是實驗組表現出預測模式，對照組同樣在跨類別的判斷上優於類別內的判斷、(3)實驗組在跨類別及類別內的判斷表現上較對照組有更大的差距。實驗 2 則意欲探討手形（發音）難度對於手語知覺之影響。我們使用辨別實驗測試了三組不同難易度的手形（簡單－簡單、困難－困難、簡單－困難）。我們預期在簡單－困難的手形組中，實驗組對於較困難的手形會有更高的容忍度，以至於類別的邊界會往簡單的手形移動。研究結果顯示受試者在處理困難－簡單及另外兩組同樣難度的手形判斷上有顯著差異，然而，我們並不能證明手形難易度為影響手語類別知覺的主因。綜觀兩部分的研究，我們認為類別知覺在不同的音韻特性、甚至是不同的手形中擁有的影響力不同。其他像是使用頻率及拓樸效應（topological effects）等之因素在手語知覺的影響上可能位於更高的位階。

關鍵字：類別知覺、手形難易度、手形、辨認實驗、AX 區辨實驗、台灣手語

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Chapter 1

Introduction

1.1 The concept of categorical perception

According to Harnad (2003), things can be described in two ways in linguistics: (1) all-or-none, as with cats: it is a cat or it is not a cat, which we could call "categorical". (2) a matter of degree, as with what adjectives do: Patty is prettier than Peggy; An apple is smaller than a pineapple. In the second concept, we could call it "gradient". These two concepts are everywhere in our daily lives. So how does the human brain process this? Are they born with the skill to process this innately or are we trained to do it? There is no doubt that animals (not only humans) have the concept of categories born innately. From the example of Harnad, it is natural for a frog to detect "flies"; it only needs to be put in the environment where it normally should be, then it can recognize and capture them. Humans, in the same way, are born to have similar category-detectors. It is normal for us to distinguish human faces from others, similar to our concepts of basic color categories. However, it has been claimed in the Whorf Hypothesis (Whorf, 1956), also called the linguistic relativity hypothesis, that colors are influenced by our culture and language. However, no matter whether it is innate or acquired, categories are important because they help us to see and act in a proper order in this world.

Perception, from the definition by Wiktionary (2021), is what people detected through senses like eyes, ears and nose within consciousness. It is the sense of humans (and animals) that allows one to perceive the outer world. Categorical perception (CP) is one kind of perception. Unlike general perception, which is conscious, categorical perception is when one perceives a set of gradient-changing stimuli, his or her brain automatically perceives and processes them into categories.

Language, being so special, is one of the most important elements which builds the world in our brain. Research has shown that "phonemically contrastive forms" in languages are perceived categorically rather than continually (Liberman et al., 1957, MacKain et al., 1981, Emmorey et al., 2003). By gradiently varying the voice onset time, it is found that when people listen to a set of sounds changing from /ba/ to /pa/ in equal steps, instead of hearing gradiently varying sounds, they perceive only *ba*'s or *pa*'s (Liberman et al., 1967). Participants divide sounds they hear into two categories. Liberman suggested that this kind of perception was unique to speech, that it made speech special, and, in what came to be called "the motor theory of speech perception", he suggested that the secret of categorical perception can be solved with the anatomy of speech production. However, further research proves the universality of categorical perception. Although speeches are perceived by ears and signs are perceived by eyes, it is found that for Deaf people, whose main languages are not spoken but signed, also shown to perceive handshapes categorically (Emmorey et al, 2003).

Even though research has shown that humans are born with the concept of perception, language experience seems also to play an important role. For example, Japanese speakers who have no English experience have difficulties distinguishing /r/ and /l/ (Miyawaki et al, 1975). And the reason could be because that /r/ and /l/ are not phonemic contrasts in Japanese and the 'rrr' type of sound in Japanese, the 'ra, ri, ru, re, ro (ら, り, る, れ, ろ)', is articulated somewhere between /r/ and /l/. The language experience of their first language (L1) holds them from telling the difference between certain sounds. Research done on American Sign Language (ASL) also suggests that there are significant differences between participants with and without language experience of ASL. Just as vocal cords and mouth are the organ to articulation in speech, hands (or manual) are the organ of articulation of signs that have their

biological limits. During the process of perceiving languages, one person is watching the other person and building a mental model of articulation of the other person in his head. The perceiver knows how difficult the handshape that the signer is signing is, and that influences how he perceive what the signer is doing. This concept of motor theory has led us to the discussion of ease of articulation which will be an important part of this thesis.

Ease of articulation is the central issue for Ann (2006). Focusing on Taiwan Sign Language (TSL), Ann examines the relationship between the frequency of occurrence of handshape and the ease of articulation of handshapes. In the second study of this thesis, ease of articulation is examined to see if it affects the location of the boundary between different stimuli pairs in different combinations of ease of articulations.

1.2 Motivation

There will be two experiments reported in this thesis. Typically, an experimental thesis would call it experiment A and experiment B. But since the first experiment contained two tasks and second study contained one task, we would call it Experiment 1A, 1B and Experiment 2 to make it clear.

Experiment 1 tested if Taiwan Sign Language (TSL) users exhibit categorical perception. An identification task and a discrimination task were done in Experiment 1 with both native TSL signers and hearing non-signers. CP research is not a new issue in linguistics and that there were research done on different aspects of spoken languages (Liberman et al., 1957, Liberman et al., 1967, Damper & Harnad, 2000, Eimas, 1975, Gilkerson, 2005, Kuhl & Miller, 1975, Lasky et al., 1975, Miyawaki et al., 1975, MacKain et al., 1981, Steven et al., 1985, Massaro, 1987). Liberman claimed that people tend to treat sounds and speech different and that CP is only displayed by speakers of their languages. With the development of language studies,

the universalities of languages are no longer limited to sign languages. Although sign languages are in a different modality, they consist of complete structure as do spoken languages. Related CP research have been done in sign languages (Campbell et al., 1999, Emmorey et al., 2003, Baker et al., 2005, Morford et al., 2008, McCullough & Emmorey, 2009 and Best et al., 2010). And yet, this research has not yet been done in Taiwan Sign Language (TSL), which makes this thesis the first study to test CP in TSL.

Experiment 2 was motivated by the result of Experiment 1. The process of identifications and discriminations in CP studies is a process of perceiving. But as in what Liberman claimed in motor theory, how people produce speeches affect how they perceive speeches. Within a different modality, we wonder if signers are also influenced in sign languages. Motor theory is about action, and handshapes are the direct outcomes of actions. An identification task was conducted to see how boundary locations of handshape contrast pairs were influenced in different combinations of ease of articulations. If ease of articulation is the main influence to sign perception, it is assumed to see a boundary shift on the different ease contrast pair.

1.3 Outline of the thesis

In chapter two of this thesis, we introduce a broad review of categorical perception, how it is defined and studied in the past, what theories were used to support it and which factors would influence it. We will look through the debate about whether such perception is innate or learned. Related research about categorical perception from spoken languages, face discriminations, animal languages to sign languages are also discussed. Since all typical CP experiments conduct identification and discrimination experiments, we will also talk about how these two experiments are crucial for looking for CP effects. Also, since this research is done using Taiwan

Sign Language based on related studies, it is necessary to introduce how categorical perception experiments are conducted in sign languages. An ASL CP experiment will be introduced here as an example of CP research. Then, we will introduce some basic sign phonology, including ease of articulation. Being one of the central issues of this study, we will introduce how ease of articulation of handshapes is scored according to Ann (2006). The rest if the thesis is organized as follows.

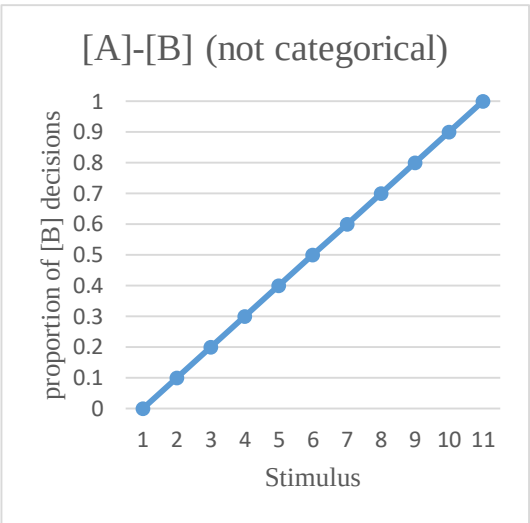
Chapter 3 reports two studies including two tasks in Experiment 1 and one task in Experiment 2. Chapter 4, with the review of both studies, a general discussion will be given. We will also compare both studies for further analysis. The final chapter of this thesis gives the conclusion for the findings of this thesis, and subsequently, we discuss several questions for future research, such as other possible factors which might also affect the result. Finally, successes and failures of the experiment and how it can be improved will be discussed.

Chapter 2

Literature review

2.1 Development of categorical perception research

Categorical perception (CP) is a psychophysical phenomenon where certain stimuli are perceived categorically rather than continuously even when in a continuous variation in form (Liberman et al, 1967). For example, by varying voice onset time (VOT), Liberman and his team generated a set of sound stimuli changing slightly from /ba/ to /pa/. In the experiment, participants were asked to discriminate whether the sound they heard is /ba/ or /pa/. Instead of hearing the difference along the continuum, the participants responded that they heard only ba's and pa's. This suggested a predisposition of people to perceive acoustic sounds categorically (Liberman et al, 1967). As illustrated in Figure 1, if participants perceive every gradient changed sound, the graph would be like the left one where the proportion increases steadily. But categorical decisions display like the right graph. For stimuli one to four, most people respond [A]; then some of them choose [A] and some of them choose [B] in the middle stimuli; after that, most people identify the stimulus they see as [B]. Instead of a straight line, decisions that are made categorically show a curve dline.



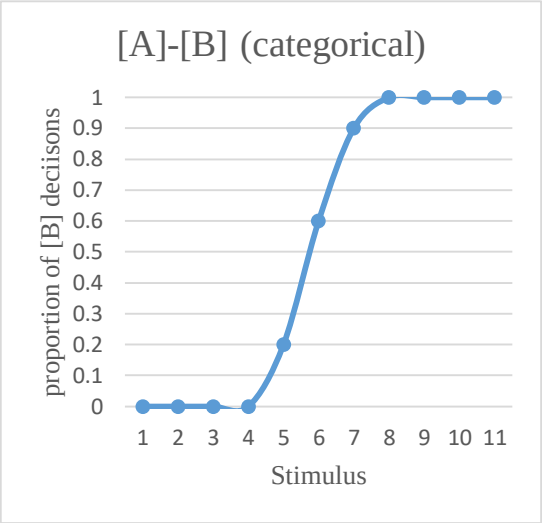


Figure 1. Categorical and not categorical identifications

Another experiment was done using the phonemes /ba/, /da/ and /ga/, which are stop-consonants that differ in their place of articulation. When a set of equally spaced stimulus pairs from the continuum is presented to be discriminated, the participants performed better when the pairs went across phoneme boundaries (Liberman et al, 1957). This has become important to the motor theory of speech perception. Liberman claimed that unlike a general perception, categorical perception has its special function in the phonemic level in language processing (Liberman et al, 1967). Liberman claimed that phonemes are perceived as an acoustic signal which carries information in continuous phonemic segments. Sounds are not only a cipher or alphabet, but a special "code" on the phonemic structure of language. People could therefore detect them more efficiently than normal sounds due to its contained phonemic information (Liberman et al, 1967, Liberman & Mattingly, 1985).

There are three factors important in CP experiments (Emmorey et al., 2003). The first one is the perceptual predisposition. Phonemes, being codes that carry secret information, prompt perceivers to expect to hear certain sounds. "Hearing" here is an ambiguous term: (1) mentally perceiving; (2) receiving physical signals into the sense organs. Even though the actual sounds they hear (what ears receive) were not the

"right" sounds, the perceivers think they are (mentally perceiving). This helps perceivers' process faster. This perspective has been supported by Rosenblum et al. (1997), who tested McGurk effect in infants (a similar effect has been found on adults, too). McGurk effect is an interaction between hearing and vision in speech perception (McGurk & MacDonald, 1976). In the research, they tested a combination of visual and audio /ba/-/va/-/da/ on infants. The result showed that infants had no difficulty in making correct responses when the sound and visual matched (e.g. audio /ba/ plus visual /ba/). The same was true when they paired audio /da/ plus visual /va/. But when it came to paired audio /ba/ plus visual /va/, the correct response rate dropped down to 1.6%. This indicates infants (and adults, according to the research) are influenced by visual information and thus have the predisposition to hear certain sounds (even if they physically did not). So far, what we could tell from above is that CP is innate. These certain sounds and images go together for physical reasons, but infants don't have enough experience with physics to have learned this, so this predisposition must be innate.

The second factor is language experience. Although people (or animals) have the tendency to perceive certain sounds, it can be improved upon or changed through practice. Gilkerson (2005) tested CP of natural and unnatural categories. Natvie English speaking participants were divided into two groups. One group was tested with a stimuli pair based on the Jordanian Arabic uvular/pharyngeal contrast. The other group was tested with an unnatural stimuli pair which does not contrast in their own language (English) and not in any language known in the world. There were two stages of experiments. The same experiment was conducted two times. Before each stage started, participants were trained to perceive the stimuli. The length of practice doubled in the second stage of the experiment. Results showed that although the performance of both groups improved in the second experiment (this showed that

experience influenced perception), the group which was set to perceive the natural category became significantly more sensitive to across-category pairs than participants in the unnatural group. This indicates three things. First, if participants were using the kind of general perception, there should not be difference between the two groups. Second, with more practice (more language experience), people are able to sense the difference between categories better. Third, this also provides support for the innate predisposition since English speakers could learn real but non-English contrasts better than unnatural non-English contrasts.

The third factor is development and maturation. Three research are illustrated here. Eimas (1975) had infants, aged 2 and 3 months, do the discrimination of the phonetic contrast /r/ and /l/ through recording the nipple sucking rate of the infants. Result showed that infants in such an early period discriminated /r/ and /l/ into two categories. Also, they had performed better when the stimuli located in different phonetic categories than when they were acoustic variations of the same category. MacKain et al. (1981) tested the /r/ and /l/ contrast on Japanese speakers with no English experience, Japanese bilinguals with intensive English training and English speakers. Result showed that (1) Japanese speakers with no English experience showed a near-chance performance which means that they were not making consistent responses. As they learned Japanese, it destroyed their innate ability to perceive the contrast, as implied by the Eimas study, (2) Japanese bilinguals with English training perceived /r/ and /l/ categorically, (3) the overall performance of the Japanese bilinguals was lower than the English speakers. However, it was not mentioned in Eimas (1975) whether the subjects are English-acquiring infants or Japanese-acquiring infants. The influence of the growing environment therefore could not be valued. Lasky et al. (1975) found that 4-6.5 months old infants performed similarly to infants from English speaking families but differently to the Spanish speaking adults

in discriminating bilabial stop consonants. Although their results suggested that experience has little influence, the reports of the inability of Spanish adults to make similar discriminations indicated that human have the kind of innate perception that could be later influenced by the language experience. With the three studies above, we have come up with three points, (1) there is the kind of perception which is somehow an innate mechanism that enables infants to discrimination between categories, (2) through the development and maturation of people's language ability, people were shaped and constrained with the categorical perception of their own language, (3) the ability of discrimination could be enhanced through practice and training, but there may still be differences between native speakers and near-native speakers. The third point should be particularly kept in mind since TSL signers in Taiwan are mostly near native signers rather than native signers. Research has shown that 90% of deaf kids were born to hearing parents (Mitchell & Karchmer, 2004). These kids were not exposed to sign languages until they entered deaf school. The lateness of their sign language acquisition makes them near-natives by definition. Even though there are some deaf kids who were born to deaf parents, since many of these parents were not native signers as well, it is to be discussed whether they have acquired TSL as native signers.

These three factors, perceptual predisposition, language experience, and development/maturation, are said to be important in CP experiments (Emmorey et al., 2003). Each factor has its influence on CP and has interactions with each other. This study aims to see how perceptual predisposition and language experience affect CP in Taiwan Sign Language (TSL). As research mentioned in the research above (and those we did not mention), most research about CP conducted two experiments (or tasks) which are the identification (or categorization in some research) task and the discrimination task. In the next section, we will talk about the importance of the two

tasks and how they are used to test CP through two research testing CP using these two tasks on American Sign Language (ASL).

However, some research claimed that CP can not be limited only to language processing, Beale & Keil (1995) tested CP on faces and found that the accuracy of participants discriminating face-pairs across the category is higher than within category. Kuhl & Miller (1975) found that chinchillas could distinguish the same perceptual variation for VOT as do human. Similar perception could be found for facial expressions (Calder et al., 1996, De Gelder et al., 1997) and colors (Pilling et al., 2003). So far, it is unclear if CP is language specific, but we know that there are different levels of perception. One is the kind of perception at a general level as for the perception of faces; the other one is the kind of perception (CP we want to focus in the thesis) at a more specialized level which could only be found in language like the /ba/ and /pa/ experiment. Also, CP was not found in all contrasts, e.g. vowel distinctions (Fry et al., 1962).

2.2 Identification experiments and discrimination experiments

To see if the participants exhibit language-specific CP, there are two crucial experiments we need, (1) to see whether the stimuli is identified categorically, (2) to see whether discrimination is better across category boundary than within category boundary. By conducting the identification experiment, point one is easily proven. But this result could not be used alone to prove since identification is a higher level cognition. CP should work unconsciously (Damper & Harnad, 2000; Massaro, 1987). The theory is that participants should have better performance across boundary than within boundary since they have subconsciously perceived stimuli within same category as same phonemes. In other words, participants should be more sensitive to stimuli pair across category than within category. To find out how sensitive

participants are to the difference, a discrimination task is a suitable tool. In a discrimination task, or so called an ABX (or AX) discrimination task, participants are asked to answer if the second stimulus given is the same (A or B) or different (X) as the model stimulus. The prediction is that it would be more difficult for the target group (the group with the language experience of the target language) to discriminate when the first and the second stimulus they are given are within category. Examples will be illustrated later.

2.2.1 Revised Signal Detection Theory (SDT)

To compare and see how sensitive participants are to the stimuli, Signal Detection Theory (SDT) is usually applied to the result of the discrimination experiment (Green & Swets, 1966). SDT is a commonly used method in psychology that uses means to measure how well the participants detect the signal. As showed in Table 1, participants are asked to decide if they see (or hear) the target. It will be a hit if the target is presented and the participants answer “yes”, but a miss if the participants answer “no”. The signal which is not the target is called a distractor which keeps participants from answering “yes” for everything. It will be a correct rejection if participants answer “no” to a distractor while a false alarm (FA) if they answer “yes”. Based on the Hits and FAs (i.e. accuracy for “yes” responses), we could estimate the sensitivity numerically, sensitivity index d’ or d’ scorer can be calculated from it. In this thesis, however, a revised SDT will be applied with only the hits would be calculated (the revised method will be discussed in chapter 3).

Table 1. Signal Detection Theory (SDT) model

		response	
		Respond “No”	Respond “Yes”
signal	Target	Miss	Hit
	Distractor	Correct Rejection	False Alarm

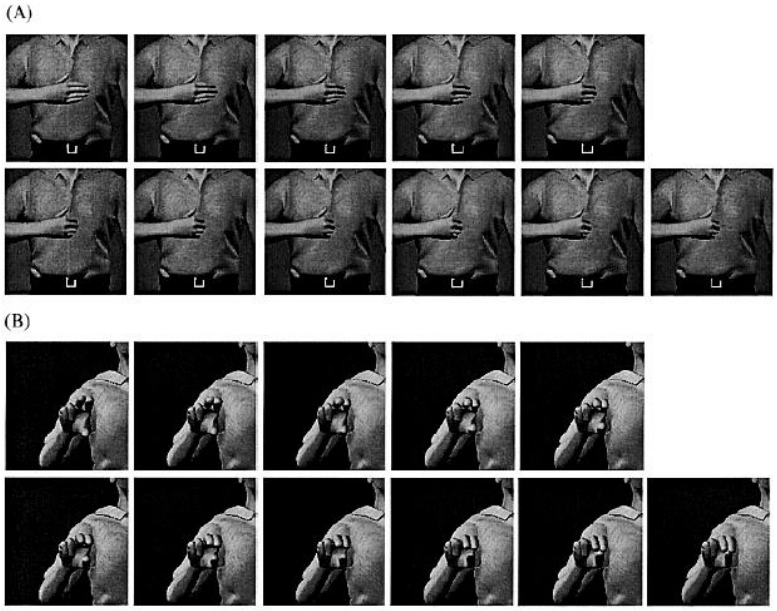
2.3 Categorical Perception research in sign languages

Many related research has been done on sign languages, such as Campbell et al. (1999), Emmorey et al. (2003), Baker et al. (2005), Morford et al. (2008), McCullough & Emmorey (2009), and Best et al. (2010). Emmorey et al. (2003) found that both signers and nonsigners separated the handshapes into two categories perceptually, but only signers exhibited linguistic CP. Baker et al. (2005) found similar patterns where only signers exhibited linguistic CP. Morford et al. (2008) stated that language experience influences how signers process handshapes. They found that native signers performed better than non-native signers. The hearing L2 signers also showed similar patterns of CP but did not reach significance. They concluded that the influence was due to the early language experience. McCollough & Emmorey (2009) looked for CP by conducting experiments on affective facial expressions and linguistic facial expressions in ASL through Deaf native signers and hearing nonsigners. They found that hearing nonsigners performed better across category boundaries than within categories for both experiments; however, Deaf native signers only showed CP effects for linguistic facial expressions. They also found that viewing linguistic facial expressions first would slow down the response time for affective time for affective facial expressions and thus claimed that CP for affective facial expressions can be influenced by language experience. Best et al.

(2010) tested ASL handshapes (U-V: finger-spreading) on four groups (deaf early signers, deaf late signer, hearing late signers, and hearing nonsigners). The result did not support classic CP research since no group showed a high peak in discrimination across category boundary. The above research showed that CP in sign perception may work differently on different parameters and thus may be more like vowels in speech perception, but more research is needed.

We are going to walk through Emmorey et al. (2003) as an example of CP research in ASL since it not only did the experiments on handshapes (hand configuration, HC) but also on place of articulation (POA), which did not show CP for the result in the research for POA. As in Figure 2, four stimuli pairs were chosen in the research, two handshape pairs with one phonemic handshape pair and one allophonic handshape pair, and two place of articulation (also a phonemic one and allophonic one). When handshapes are said to be allophonic, it means the difference is predictable. As shown in Figure 2 (1B), the open and close handshapes are predictable in SAY-NO-TO in ASL. Figure 3 illustrates an example of allophonic handshape pairs in TSL), the extended fingers of handshapes like [1] become bent in certain environments (i.e. pointing fingertips downward, Tsay & Myers, 2009).

One crucial point about CP is that people tend to perceive the stimuli categorically rather than continuously even when the variation is the latter. So it is important to produce continuum from one endpoint to the other endpoint with slight change and equal difference. For each continuum, 11 images were produced. An ASL group with native ASL signers and a control group with non-signers were involved in the research. Both groups completed the identification experiment and the discrimination experiment.



(1) Illustration of stimulus continua varying in (A) phonemic handshape (from the sign PLEASE to the sign SORRY) and (B) allophonic handshape (from 'open-N' to 'close N' in the sign SAY-NO-TO). (Emmorey et al., 2003, Figure 1, p.27)

(2) Illustration of stimulus varying in (A) phonemic place of articulation (from the sign ONION to the sign APPLE) and (B) allophonic place of articulation (from the chin to the back jaw in the sign DEAF). (Emmorey et al., 2003, Figure 2, p.28)

Figure 2. Continuum presented in Emmorey et al. (2003)

ONE (index finger extended)

DEEP (index finger bent to point downward)

Figure 3. Allophonic handshape pairs in TSL

Figure 4 are the results of the four contrasts. The left image presents the result of handshape pairs and the right image presents the result of place of articulation. For each group, the upper graph shows the result of the identification experiment, and the lower graph shows the result of the discrimination experiment. The upper graph shows the mean percentage participants made choosing the right endpoint of the contrast. Take the phonemic hand configuration (HC, handshape) of Deaf signers as an example, for continuum 1-3, the percentage of participants choosing 'A' (the answer is whether the image is handshape A or handshape B) is lower than 10%. This indicates that most of the participants identified the image they see as 'A'. For continuum 6-11, the percentage is more than 90%. This shows that almost all the answers the participant made were 'B'. This has showed clearly that the two handshapes belong to two categories. For continuum 4-6, the answers participants made varied (some answered 'A' and some answered 'B'), which resulted in the percentage laid in the middle. The boundary is defined where the percentage changes

from 33% to 66% (when the decision percentage is 50% means half of the decisions were ‘A’ and half of them were ‘B’).

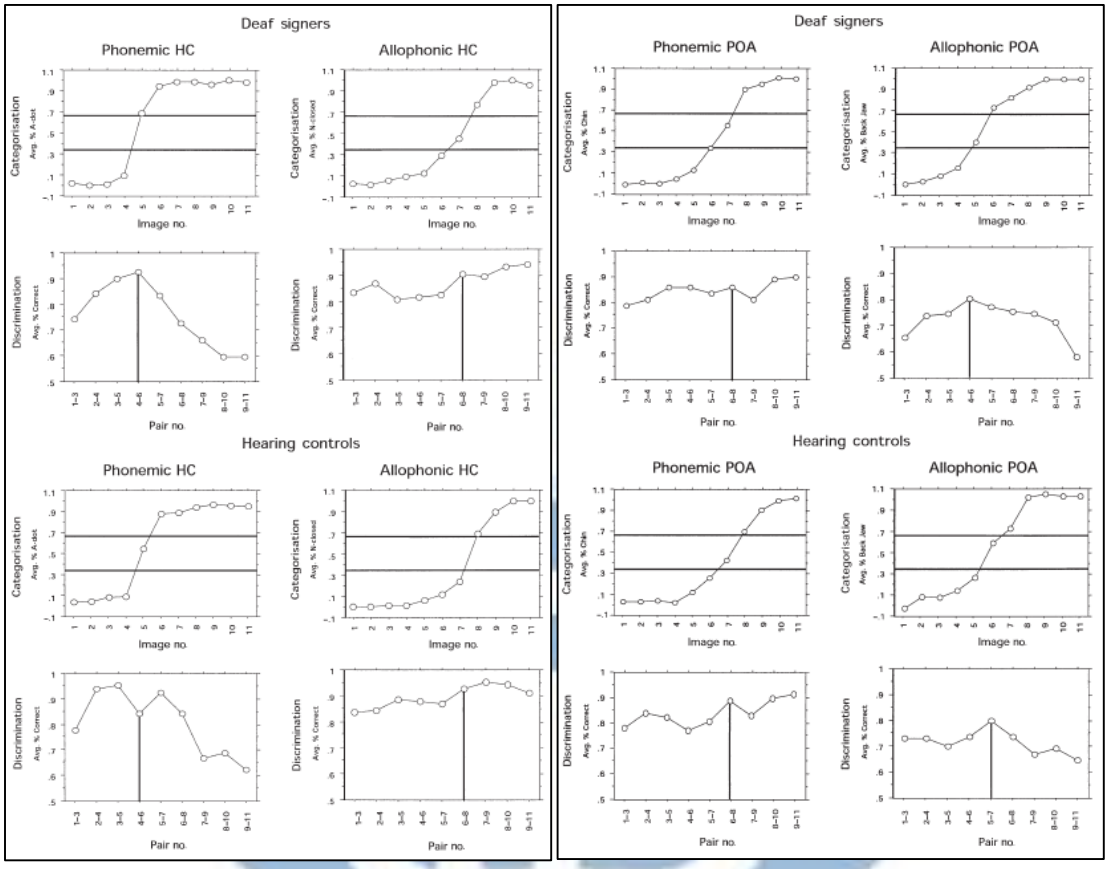


Figure 4. Result of Emmorey et al. (2003)

Data of the four stimuli contrasts of the two groups. Left block: handshape, right block: place of articulation, (Emmorey et al., 2003, Figure 3 and Figure 4, p.30-31)

Again, the result of identification alone cannot be used to prove CP since identification is a conscious choice. The lower graph is the correct response rate of participants in the discrimination experiment. We can see that the Deaf signers group got a high correct rate when across boundary (continuum 4-6) while performed poorly when discriminating within category pairs.

The result showed that for all four contrasts, both groups made identifications categorically. This indicates that in this process of identification, it was more a general

perception rather than a linguistically categorical perception since identifications are conscious decisions and CP is an innate mechanism that works unconsciously. But as it moved to the discrimination experiment, according to the authors, only the deaf signers showed the predicted result. It was, as predicted, that the signers, being constrained by their language, are good at making discriminations across boundary but poor at making discriminations within category for the phonemic contrast. The result showed that place of articulation showed no significance between two groups and within their discriminations. Both groups exhibited similar discriminations across and within categories. This suggests CP may not have such strong influence among all phonetic factors. However, as in Figure 4, the result of both groups for the allophonic POA also showed a high peak of accuracy crossing the boundary. This does not make sense since there should not be CP for allophones. But this could also indicate that CP may work differently in a way expected from the nature of sign modality.

Baker et al. (2005) also found similar results that only Deaf people displayed CP but not the nonsigners. Their d' score for the Deaf group and English hearing group (see Figure 5) showed that the English group performed similarly for the discrimination within and across categories. In contrast, the ASL group showed an obvious difference between discriminations within and across categories. The Deaf group got a high d' score across category (even higher than the English group) but a poor score within category. The results are consistent with classical CP research.

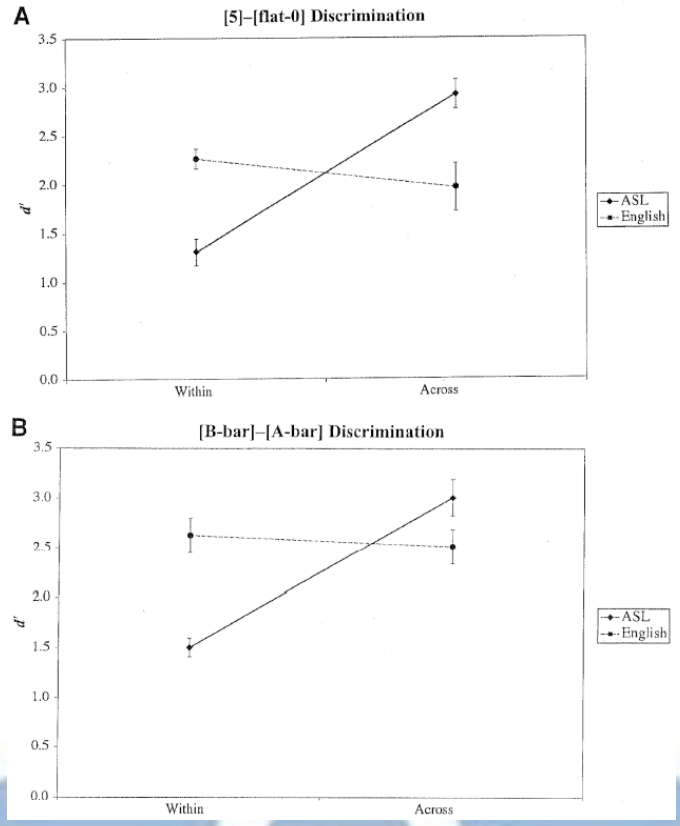


Figure 5.

d' score results of the ASL group and English group in discrimination experiment (The figure is taken from Baker et. al (2005), p,21-22, figure 4A-4B.)

2.4 Sign phonology

Sign languages are visual languages that combine manual, facial and body movements (Stokoe, 1960). They are commonly known as the preferred languages of the Deaf community. Like oral languages, there are many sign languages around the world. Although there might be some similarities, signers from different sign languages might not understand each other when communicating with their own sign languages (Sandler & Lillo-Martin, 2006).

(A) Sign HAIR

ASL

TSL

(B) Sign HOME

ASL

TSL

Figure 6. Lexicon comparison in ASL and TSL

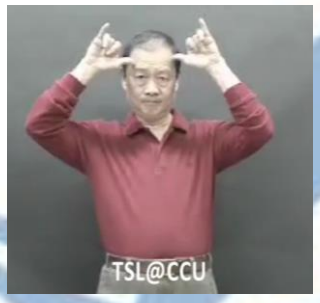
(A) Sign HAIR in ASL and TSL (B) Sign HOME in ASL and TSL.

Note: All ASL examples come from ASL Dictionary (https://www.handspeak.com/word/search/), all TSL examples come from TSL Online Dictionary (Tsay et al, 2017).

Example A in Figure 6 shows the signs for HAIR in ASL and TSL; in both signs, signers pinch their hair with their fingers. However, in example B, the sign HOME in ASL bend and touch all fingers together, first touch the cheek near the mouth, then move backward and touch back part of the cheek; and in TSL, the sign HOME is to extend and close all five fingers together, make both hands touch on the fingertips and imitate the triangle roof of a house.

Like spoken languages, sign languages have a complete language structure and can be analyzed at the phonological, morphological, grammatical and lexical levels. In language, phonology consists of a list of meaningless but linguistically significant elements (Sandler &Lillo-Martin, 2006). A phoneme is an indivisible unit of sound in a given language, and likewise, although sign language phonology is not about sound but space, it works in a similar way. The smallest units in sign languages are defined by four parameters: hand configuration (also called handshape), location, movement and orientation. Figure 7 shows minimal pairs that differ in handshape, location, movement and orientation. COW and DEER share location (temple), movement (touch and stay on the temple) and orientation, but differ in handshape. BE and PLEASE share the same handshape (four fingers extended and touched, with thumb closed), movement (touch the location) and orientation (face the side), but differ in location. BE is signed at the chin and PLEASE is signed at the forehead. GO and SIR share the same handshape (with thumb extended but other fingers closed), location (in front of body) and orientation, but differ in movement. GO moves the hand outward and SIR shakes the hand left and right slightly. FLOWER and THROW share the same handshape (first all fingers closed, then open but bent a little bit), same location (in front of body) and same movement (move straight), but differ in orientation (FLOWER faces up and THROW faces outward). While some of the signs in Figure 7 may look iconic (like COW and DEER), it could support the point that these elements

function like meaningless phonological elements in sign languages. A fifth parameter was added recently which is the facial expression. It was found earlier in Campbell et al. (1999) that facial expressions were crucial in certain signing conditions, for example, to express “surprise” or “puzzlement”. Although facial expression may not only be demonstrated in signs but may also be distinctions that are perceived universally, later research (Mohr, 2014, Tomaszewski & Farris, 2010) has supported it to be one of the standard elements.



COW DEER

a. differing in handshape

BE PLEASE

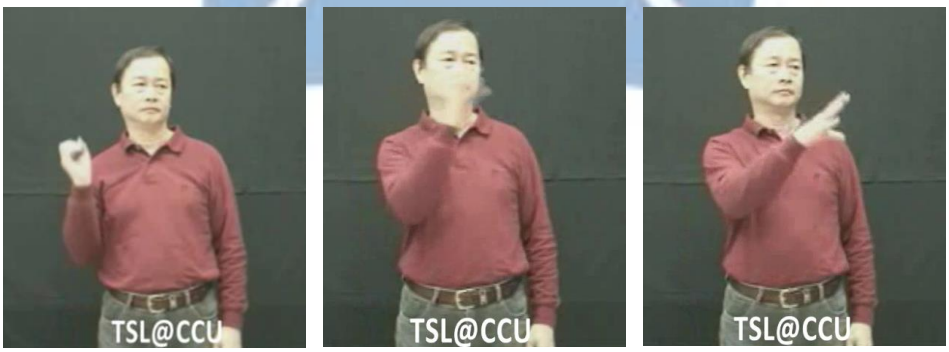
b. differing in location

GO

SIR

c. differing in movement

FLOWER



THROW

d. differing in orientation

Figure 7. Minimal pairs in TSL

Note: All TSL examples come from TSL Online Dictionary (Tsay et al, 2017).

Among all five elements, this thesis focuses on CP for handshapes in TSL. To remove the influence of movement, all continuums are static rather than dynamic. Location and orientation also remain the same. One thing crucial to handshape is the ease of articulation, which is how hard or easy a handshape can be manually signed. In the next section, we take a deeper look at how ease of articulation affects handshapes.

2.4.1 Ease of articulation

The relationship between manual-visual modalities in sign languages is similar to the relationship between vocal-auditory modalities in spoken languages. In sounds, not all sounds are easy to articulate. For example, /r/ is more difficult to pronounce than /i/. Hands (or say manual articulation), also have their limit. With the combinations of muscles and joints, hands can form handshape. Handshape is the configuration of how hands articulate a sign. And obviously, some handshapes are easy to articulate, for example, as in Figure 8, in TSL, ONE and TWO are easier than EIGHT and AIR PLANE.

Ann (2006) has analyzed the anatomy and physiology of different handshapes and applies five criteria to calculate the ease scores of each handshape; muscle opposition in configurations of handshapes (MOC), support for extension (SE), support for flexion (SF), tendency to oppose the thumb (TOT), and tendency to spread (TS). According to Taiwan Sign Language Online Dictionary, there are now 63 handshapes in TSL. Following Ann (2006), all handshapes can be given an ease of articulation score, which is the focus of study B in this thesis.

ONE

TWO

EIGHT

AIR PLANE

Figure 8**.** Easy and hard signs in TSL

Note: All TSL examples come from TSL Online Dictionary (Tsay et al, 2017).

Our expectation is that when it comes to a handshape pair consisting of a hard handshape and an easy handshape, an innate perceptual bias happens and the tolerance of handshape is enhanced. For example, in spoken languages, not everyone could articulate all sounds 100% correct. But because of the motor theory of speech perception that perceivers are expecting for certain sounds, they are able to perceive similar articulation correctly. Like /zhi/ in Mandarin (IPA /tʂ/, as for KNOW(知道 /zhīdào/) is a hard sound like the “j-“ but one needs to curl his or hers tongue and move it back. But in real life, even though one only curl his tongue a little bit, often there is no problem for the perceiver to get what the speaker is trying to say. In other words, the category range of this hard sound is enlarged. We wonder if this also works similarly in sign perception. Since the identification task is a binary choice task, when participants do the identification, they have a higher tolerance towards the hard handshape and thus enlarges the category range and moves the boundary toward the

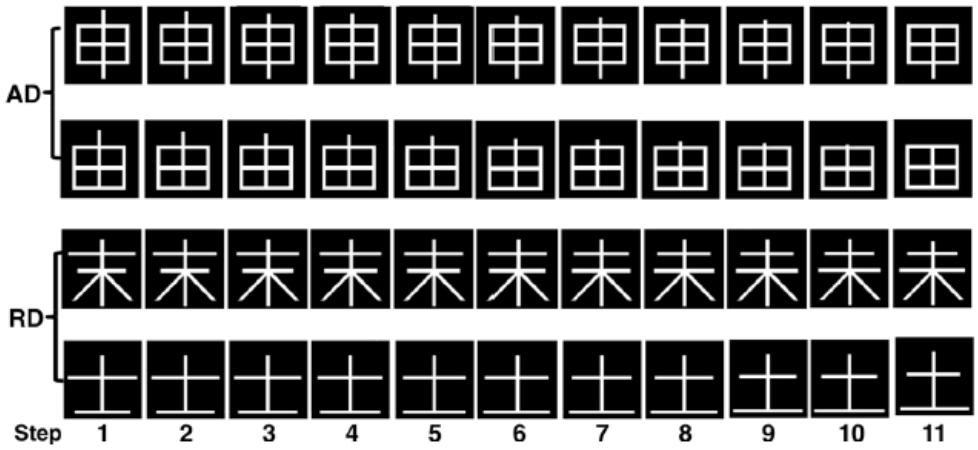
easy handshape. Which is, signers do not need to sign 100% correct to be understand by the perceivers.

2.4.2 Topological Effects and Contact Detectors

Another two factors that we would like to talk about is the topological effect and the contact detectors. Yang & Wang (2018) found that Hong Kong Chinese (HKC) traditional character readers' presented differences in perceiving character stimuli with certain features in comparison to Mainland China Chinese (MLC) simplified character readers. As shown in Figure 9, two types of Chinese characters, Absolute-Difference (AD) and Relative-Difference (RD) were tested.

These two types of characters share the same configuration but differ in their topological properties (relating to spatial relations that stay the same regardless of precise measurements: e.g. topologically, a square is just a "pointy" circle, but changing only line shape and length cannot turn a circle into a cross shape). AD type characters can be identified if the line touches or protrudes past the edge. RD type characters are distinguished by the length of the two lines of themselves. Results showed similar patterns for both MLC and HKC and fitted the prediction that participants do perceive these two kinds of characters differently. The result of RD type characters patterns is more like the expectations of typical CP research. Participants performed better across category than within category, which displays a high peak in the middle. AD type characters showed a low discrimination score until the right edge of continuum. This indicated that "touching" is a really distinct feature that may have a bigger influence, where participants could discriminate easily if the line protrudes past the edge. Link it with handshapes, some handshapes have these kinds of distinct features such as the touching of two fingers. We could therefore expect to see different patterns in the results for related handshapes.

(1) Continuum pair



(2) Results

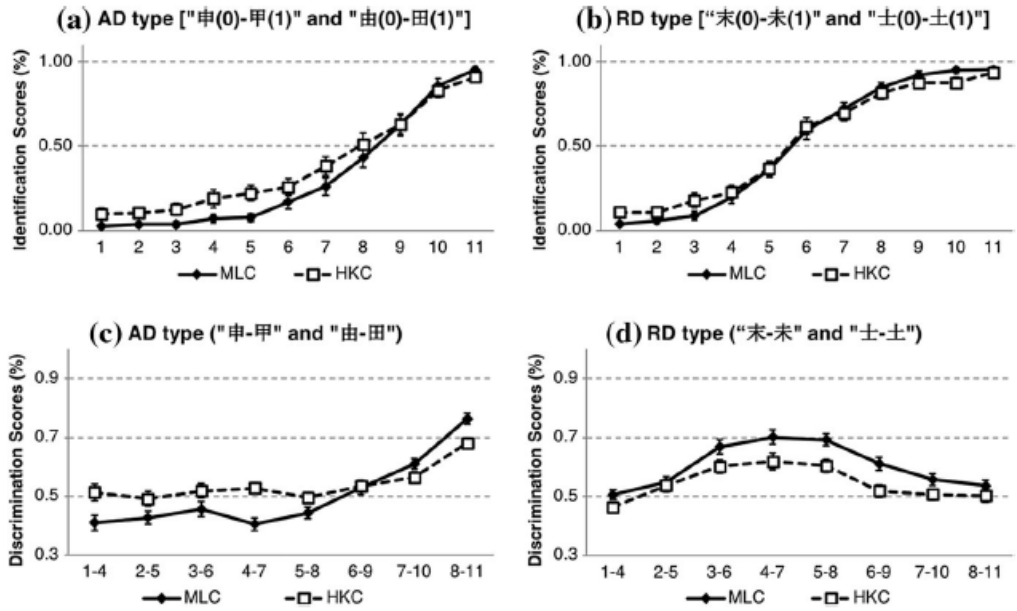


Figure 9. Two types of line characters and their continuum: Absolute-Differentiation (AD) and Relative-Differentiation (RD) and Results

Note: Figure taken from Yang & Wang (2018), figure 2, p.9, figure 6, p.14

Landau and Jackendoff (1993) claimed that prepositions in human language encode a small number of categorical spatial relations because human cognition naturally perceives space in terms of these categories, instead of recording only the precise locations. In relates with our motor system, people take visual, auditory and haptic as input information which guide their behaviors (see Figure 10). One of their core categories is "contact" - e.g. "on" is +contact while "above" is -contact, even though otherwise both are +high. This concept is important later on when we analyze our data since the relationship between contact and not contact is similar to straight and not straight of handshapes.

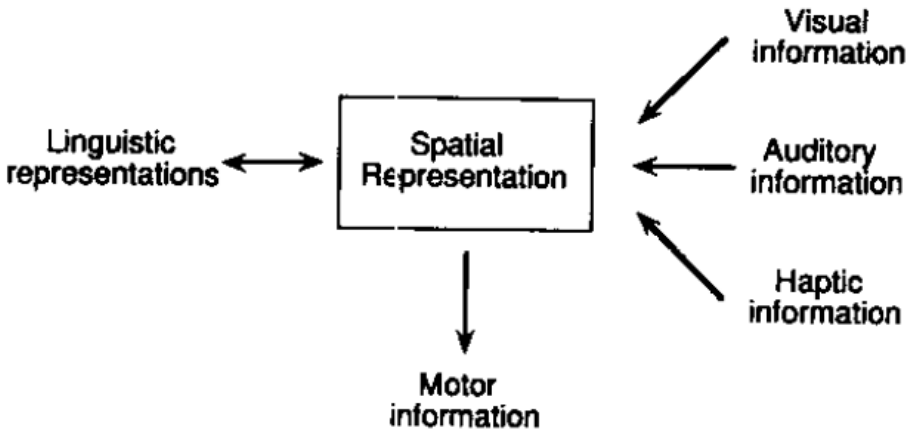


Figure 10. Schematic diagrams for spatial representations

Note: Figure taken from Landau & Jackendoff (1993), figure 1, p.218

2.4.3 Cultural background of Deaf in Taiwan

To investigate the language cognition of a certain community, its cultural background cannot be neglected. The capital “Deaf” indicates an identity of belonging to the group. Although the concept of “Deaf gain” instead of “hearing loss” has become more and more popular in recent years (Bauman & Murray, 2009). Many Taiwanese hearing people are still unaware of their deaf friends having TSL as their own languages (Huteson, 2003). According to Liu et al. (2014), Many Taiwanese people do not consider Taiwanese Deaf people to have their own unique culture like American people. Instead, most people think them to be physically handicapped rather than culturally and linguistically different. The Hearing education system rarely teach about the Deaf community and its language use. Therefore, hearing parents are usually depressed when they found they bore a hearing impaired kid. Some of these kids are sent to deaf school in early childhood, but still many of them enter hearing school first, and are then transferred to deaf school after they were found unable to catch up with their peers. Most of these kids do not know TSL until school ages (劉, 2019), so their usage of signs were limited to some home gestures with their hearing parents (Marschark et al., 2006), which indicates the lack of language exposure since they cannot hear, but almost everything around them in their early childhood is audio-dominated, such as kid channels on TV or people who visit their parents. Their language development may therefore be limited. But what about hearing kids of deaf parents (CODA)? Research showed that there are no significant difference on language development between CODAs and hearing kids (Hofmann & Chilla, 2015). This finding is easily accepted. Although CODAs cannot receive audio and spoken language input from their parents, their living environment provides these things. Deaf people in Taiwan are still considered to be a minority and could therefore influence how they express their opinions even in phonology experiments.

2.5 Research questions

In this thesis, both experiments were done using TSL. We wonder how TSL language experience and ease of articulation influence CP in TSL. The first experiment includes an identification task and a discrimination task. In the second experiment, we focus more on how ease of articulation may influence sign perception. There are two advantages choosing TSL as our target language. This thesis is to be the first CP study in TSL so the result can be used to compare with similar studies in other sign languages (Campbell et al., 1999, Emmorey et al., 2003, Baker et al., 2005, Morford et al., 2008, McCullough & Emmorey., 2009, and Best et al., 2010).

Accordingly, we address two research questions: (1) Do TSL users also exhibit categorical perception while non-signers don't? (2) Does the ease of articulation influence the location of the boundary in pairs of different difficulties?

Chapter 3

Experiments

Two studies with three tasks in total will be reported in this chapter.

The first part reports two tasks that were conducted to see if CP was displayed by TSL signers (see section 3.1). Based on the previous categorical perception experiments done in sign languages (Campbell et al., 1999, Emmorey et al., 2003, Baker et al., 2005, Morford et al., 2008, McCullough & Emmorey, 2009, and Best et al., 2010), the signer group is predicted to display CP and the Hearing non-signer group is not. In other words, we predict that the signer group should be good at making discrimination when the stimuli pairs go across the category but having poor performance when the stimuli pairs locate within the category.

In the second part, only one task is reported (section 3.2). It aims to see if ease of articulation affects the boundary location. Our prediction is that people should have higher flexibility (or better level of tolerance) when it comes to difficult handshapes; therefore, we predict that the boundary should move away from the difficult edge of the stimuli pair (larger range to recognize the handshape). In other words, when it comes to a hard handshape, since it is hard to articulate, people would have higher flexibility in perceiving the handshape. Signers do not need to sign the handshape 100% correct to let the perceiver understand what they are signing.

3.1 Experiment 1: Categorical Perception in TSL

This experiment aims to see if TSL signers in Taiwan display CP effects in TSL, and if it is significantly different from the hearing non-signers. The experiments were designed based on previous categorical perception experiments and the target group is TSL signers. However, as discussed in Ch2, most TSL signers in Taiwan are near-native signers instead of native signers due to certain cultural factors. It is common for hearing parents who have deaf kids to have such stereotype that it is an obstacle and not normal to be deaf and that one should learn speaking rather than signing even though he is hearing-impaired. The delay of learning age and the lack of signing environment have therefore valued the importance of language experience and fluency. In this section, two tasks are described including an identification task and a discrimination task.

3.1.1 Participants

There are two groups of participants: (1) signer group: 6 deaf adults including four males and two females aging from 21 to 50. Four of them were born deaf and two of them wear hearing aids. According to their own description, four of them acquired TSL after they entered the deaf school at the age of seven and two acquired TSL around 4-5 years old. All of them use TSL often and have reported to have TSL as their preferred language. Mandarin is considered to be their L2. Only one of them is able to speak Mandarin orally, but all of them are able to read lips. Two of them are now college students, two of them have graduated from high school and two of them have bachelor degree. Every participant is paid after the experiments. (2) non-signer group: 8 hearing adults including three males and five females. All of them have reported to have Mandarin Chinese as their native language and have no previous exposure to TSL before. All of the hearing participants are college students and are

paid after the experiments.

3.1.2 Methods

Stimuli and Procedure

Four handshape pairs were used: [1] – [X], [Open F] – [F], [5] – [Open B] and [B] – [Open B] (See Figure 11). As shown in Figure 12, [1] – [X], [Open F] – [F] and [5] – [Open B] are phonemic contrasts that differs in handshapes. [B] – [Open B] is not a minimal pair. As demonstrated in Tsay and Myers (2009), [B] and [Open B] are treated as allophones in TSL, and yet, Hong Kong Sign Language (HKSL) signers treat this pair as lexically distinctive (Myers, 2017). [1] is the handshape with index finger stretched and all other fingers closed. [X] is similar to [1] but with index finger bent. [F] has the middle, ring and pinky stretched and opened while index and thumb make a circle. [Open F] is similar to [F] but thumb and index make a 'C' shape instead of a circle. [5] has all five fingers stretched and opened. [Open B] has all five fingers stretched and index, middle, ring and pink closed. [B] looks similar to [Open B] but thumb closed. Since only phonemic distinctions are supposed to produce CP effects, the given sounds or handshapes should appear in the set of minimal pairs in the target language (TSL).

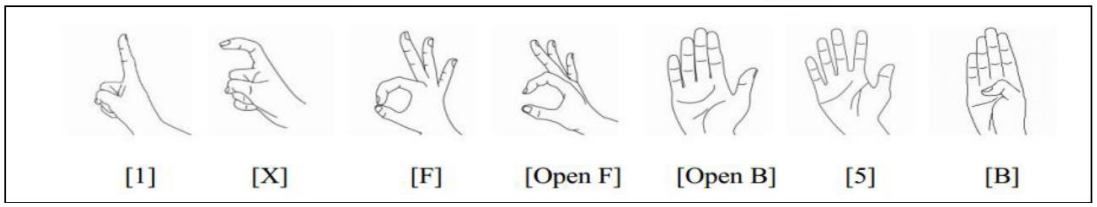


Figure 11. Pictures of handshape used in Experiment 1

(A) handshape pair [1]-[X]

[1] [X]

(B) handshape pair [Open F]-[F]

[Open F] [F]

(C) handshape pair [5]-[open B]

[5] [Open B]

(D) handshape pair [B]-[open B]

[B] [Open B]

Figure 12. Phonemic contrast of the four pairs

Note: All figures are from TSL Online Dictionary (Tsay et al., 2017)

In order to create stimuli for the experiment, the two handshapes in the stimulus pair have become the endpoint of a 9-step continuum. However, for pair [F] – [Open F], only 7-step continuum were made since the distance for the difference of the two handshape was too short. It is only 3 centimeters long for the distance between thumb and index finger of the demonstrator. The equal difference would be as little as 0.33 cm if we divide it into nine continuum points. All continuum points were made in equal difference from one to another (See Table 2).

Table 2

Experiment 1: Continuum of the four contrast pairs

(1) Handshape [1] – [X]
#1 #2 #3 #4
#5 #6 #7 #8
#9

(2) Handshape [F] – [Open F]

#1

#2

#3

#4

#5

#6

#7

(3) Handshape [5] – [Open B]

#1

#2

#3

#4

#5

#6

#7

#8

#9

(4) Handshape [B] – [Open B]

#1

#2

#3

#4

#5

#6

#7

#8

#9

The handshapes were articulated by the demonstrator sitting against a white wall and were digitally shot by a smart phone. The torso, arm, and hand of the signer were visible; only the lower part of the face was visible so that we can excluded the effect of the facial expression which could also be influencing the participants as a phonetic factor. The demonstrator was turned 45 degrees for [1] – [X] and [open F] – [F] so that the change of the handshape could be seen more clearly. Similar to CP in ASL (Emmorey et al., 2003, Baker et al., 2005, and Best et al., 2010) and the /ba/ and /pa/ used for speech perception research, all the handshapes were from existing TSL handshapes, but all of the stimuli were meaningless phonetic units without movement and facial expression.

The stimuli were presented on a computer using Microsoft PowerPoint. All participants did the identification task first, and then the discrimination task. The

details of the tasks are described as follows.

3.1.3 Experiment 1A: Identification task

The continua were organized randomly and each continuum point was identified three times by each participant to ensure that the participants were making consistent decisions. In the beginning of the identification task for a continuum point, each participant was shown the two endpoint handshapes and confirmed that each of them knew the two handshapes clearly. After that, participants were presented a single handshape at a time which was selected randomly from the nine (or seven) stimuli. The participants were asked to decide which one of the endpoints the handshapes on the scene more closely resembled. The participants made checks on the questionnaire sheets they got from the researchers. Each of the stimuli is shown one second and participant is not allowed to watch it for the second time so that the control variable remains the same. If the participants are allowed to watch the stimulus more than one time at the same trial, they may be hinted by previous memory.

Results for identification task

In the identification task, every stimulus was identified three times per participant to make sure the decision was consistent; therefore, the score each stimulus got for every participant was the average (the average of decision 0s and 1s) of the three identification (see Appendix A). For all four continua tested in the identification task, both signer group and non-signer group identified the stimuli as different categories and showed a sharp boundary (see Figure 13 to Figure 16). We also ran a logistic regression (Xu et al., 2006) to get slopes for each group on all contrasts and the results showed the sharp boundary with all slopes >1 (see Table 3). Thus, both groups had the potential to identify the handshapes categorically. However,

since identification could occur through a perceptual sorting process it is of conscious decision, we cannot use the result of identification experiment alone to argue for CP effects. Therefore, the result of the discrimination experiment below would give more information in suggesting that there are CP effects.

Table 3. Logistic regression for identification results

contrast	group	b0	b1 (slope)
[1] – [X]	Signer	-7.1224	1.6232
	Non-signer	-12.0239	2.3851
[F] – [Open F]	Signer	-6.2234	2.9555
	Non-signer	-8.1218	2.3778
[5] – [Open B]	Signer	-10.3601	1.5012
	Non-signer	-9.9983	1.4883
[B] – [Open B]	Signer	-12.7947	1.6632
	Non-signer	-15.1301	2.1105

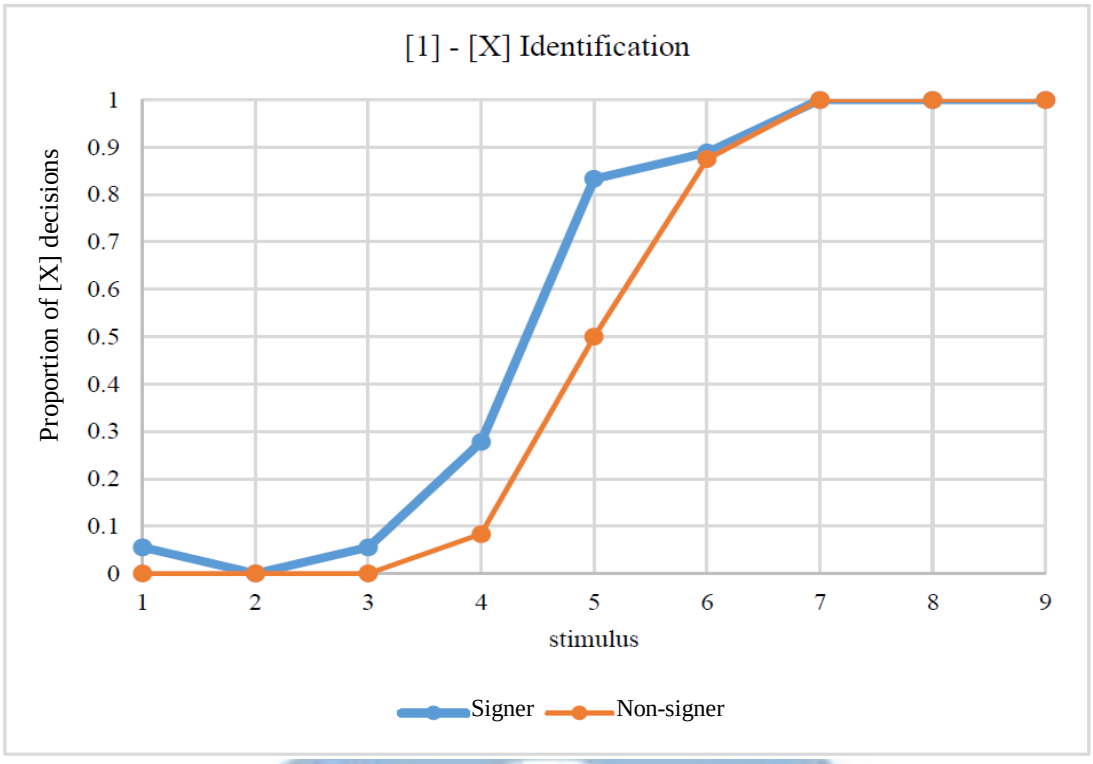


Figure 13. Experiment 1A: [1] – [X] Identification

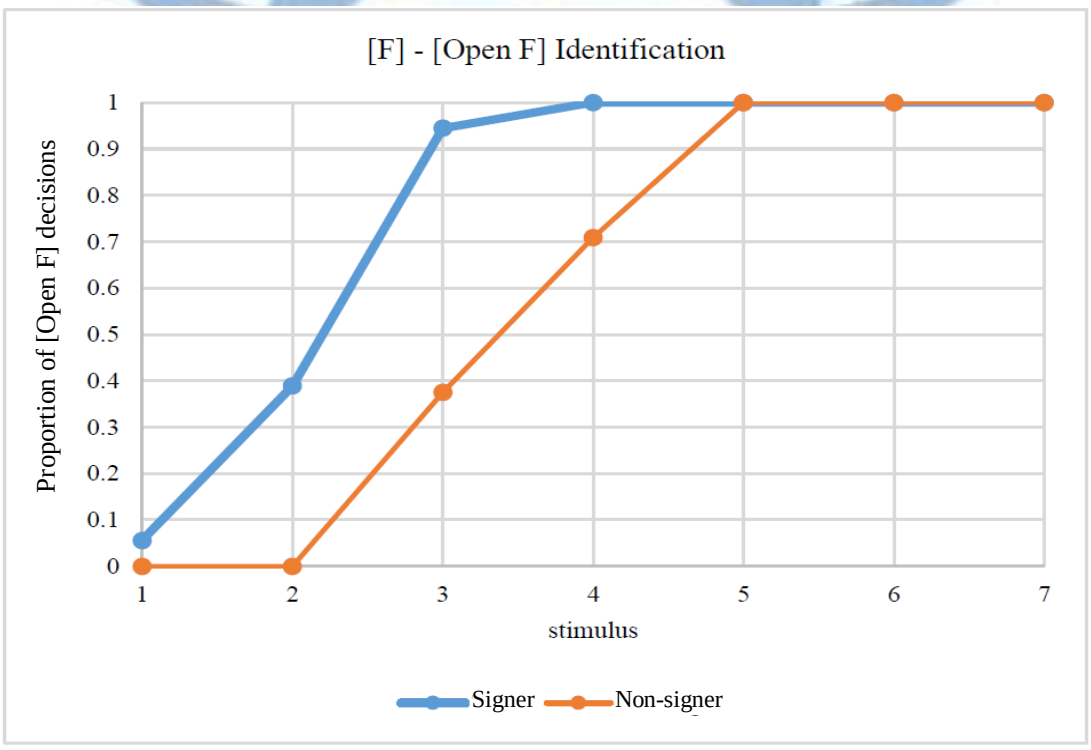


Figure 14. Experiment 1A: [F] – [Open F] Identification

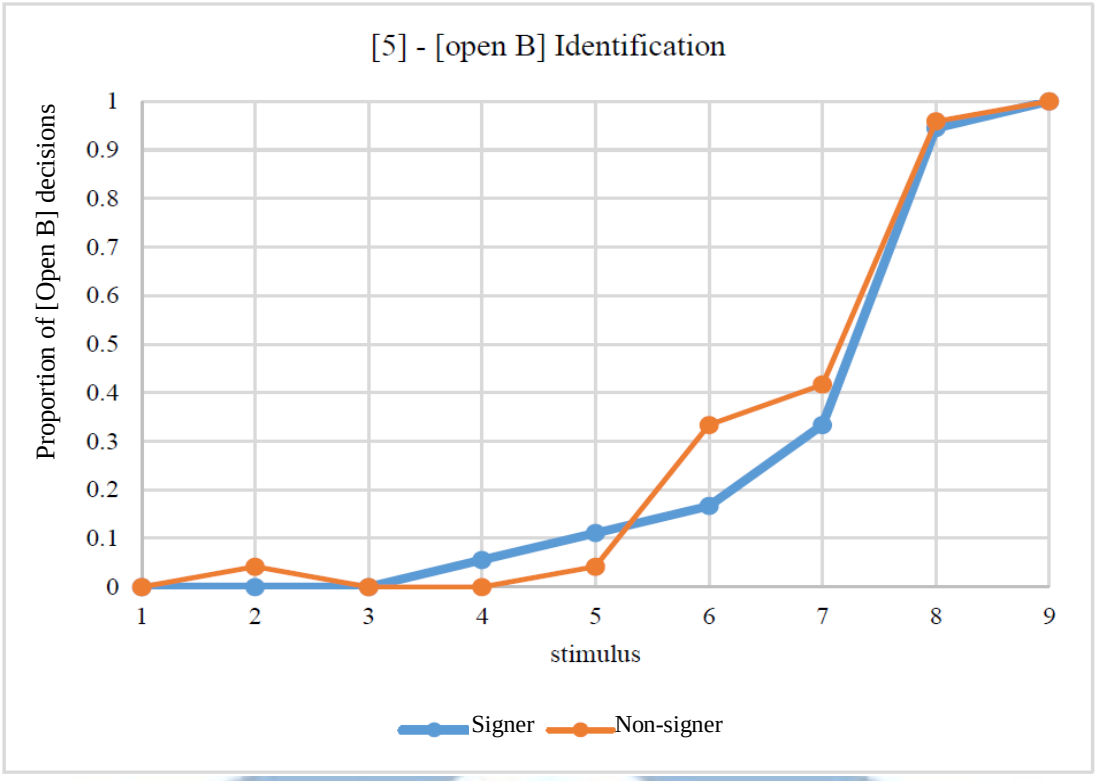


Figure 15. Experiment 1A: [5] – [Open B] Identification

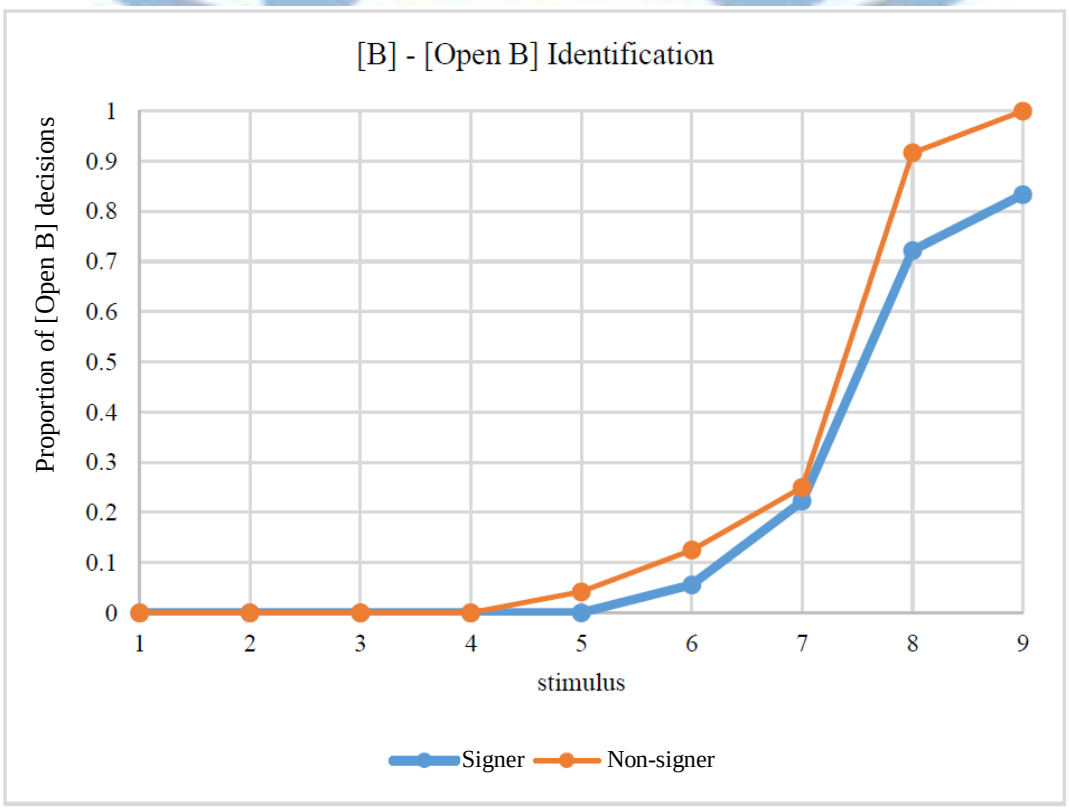


Figure 16. Experiment 1A: [B] – [Open B] Identification

We conducted a linear regression for Figure 13 and Figure 14 since the performance of the two groups looks different. The result for the regression showed a significant difference ($p < 0.05$) between the signer group and the non-signer group (See Table 4). The result showed that there were significant differences between how signers group and non-signer group treated [1] – [X] and [F] – [Open F] separately. The continuum were in gradient change. So, if the continuum were perceived continuously as well, we would get a straight line instead of a curve line. The proportion of participants choosing [X] should climb gradually in equal speeds. And yet, the percentage changed suddenly around stimulus 4-6 with a steep slope. This indicated that both groups tend to make the identification categorically. Yet, with a steeper slope, the signer group show more potential in identifying continuum categorically.

Table 4. Experiment 1A: Linear Regression for Figure 13 and Figure 14

(intercept)	**Coefficients**			
	(Intercept)	***Group***	***Stimulus***	***Group× Stimulus***
[1] – [X]	-0.262924	0.057677	0.158912	-0.004282**
[F] – [OpenF]	-0.01885	0.20139	0.17386	-0.02703*

Discussion for identification task

In the identification task, we found results similar to previous research in that both signer and non-signer group identified handshapes categorically. In Figure 13 to Figure 16, most of them showed a sharp boundary; however, the boundary of Figure 15 and Figure 16 was located at the right edge, namely at the edge of [Open B], a handshape in which all five fingers are extended, facing front and touching each other. This indicates that most participants (even in the non-signer group) consider a handshape to be [Open B] only when the fingers are touching or virtually touching.

We suggest that since touching is a topologically distinct feature (Yang & Wang, 2018), participants may be doing the identification not by its phonological feature, but its topological feature. In other words, the participants are doing identification based on whether it is “touched” or “untouched” instead of its phonological features.

Another interesting thing is the identification of [F] and [Open F] (see Figure 14). The boundary of non-signer group was located closer to the middle, and their slope was not that sharp as for the signer group. This may have something to do with the language experience of signer group since that most of the lexical items using [F] are about money. The finger circle symbolize the shape of coin. When the circle is open, it looks different to the signer. But non-signers, without the knowledge, were not affected. The statistics (see Table 3 and Table 4) has shown that the non-signer group has better potential in making identification categorically.

3.1.4 Experiment 1B: Discrimination task

The AX discrimination task followed Baker et al. (2005). Each stimulus item was presented 1 second, followed by an interstimulus interval [ISI] of 2.5 seconds, and then a second stimulus item of 1 second was presented. What participants needed to do is to decide whether the second stimulus item is the same stimulus as the first stimulus. [A] is the model (first stimulus) and X is what needed to be compared with (second stimulus). The stimuli used here were the same stimuli used in the identification task. The boundary was determined by the percentage of the identification when the percentage of the identification crosses 50% (when half of the identification is either 0 or 1). After the boundary was set, four stimuli pairs were chosen to be in the discrimination task, one or two stimuli pairs go across the boundary and two stay within the boundary. For example, the boundary of [Open B] – [5] was located at 6.5, the pairs 2/4 and 7/9 were within-category judgments, and 5/7

and 6/8 were set for the across-category judgments. See Table 5 for the boundary setting for the four pairs of the handshapes. The participants were asked to make checks on the questionnaire sheet to record the answer of their discriminations.

Table 5. Boundary setting

Continuum	Settings		
	Boundary Range	Stimulus Pairs: Non-identical	Stimulus Pairs: Identical
[1] –[X]	signer Group: 4.5-6.5 non-signer Group: 4.5-6.5	1/3, 4/6, 5/7, 6/8, 1/2, 2/3, 3/4, 4/5, 5/6, 6/7, 7/8, 8/9	1/1, 2/2, 3/3, 4/4, 5/5, 6/6, 7/7, 8/8, 9/9
[F] –[Open F]	signer Group: 1.5-2.5 non-signer Group: 2.5-4.5	1/3, 3/5, 4/6, 5/7, 1/2, 2/3, 3/4, 4/5, 5/6, 6/7	1/1, 2/2, 3/3, 4/4, 5/5, 6/6, 7/7
[5] –[Open B]	signer Group: 6.5-7.5 non-signer Group: 5.5-7.5	1/3, 2/4, 5/7, 6/8, 1/2, 2/3, 3/4, 4/5, 5/6, 6/7, 7/8, 8/9	1/1, 2/2, 3/3, 4/4, 5/5, 6/6, 7/7, 8/8, 9/9
[B] –[Open B]	signer Group: 6.5-7.5 non-siger Group: 5.5-7.5	1/3, 2/4, 5/7, 6/8, 1/2, 2/3, 3/4, 4/5, 5/6, 6/7, 7/8, 8/9	1/1, 2/2, 3/3, 4/4, 5/5, 6/6, 7/7, 8/8, 9/9

As discussed in chapter 2, the purpose of the discrimination ask is to see if the participants are more sensitive to the difference in the stimuli across the category than within the category. A revised Signal detection theory (SDT) is applied here since SDT can be used whenever there are two things need to be discriminated. As shown in Table 6, in the discrimination task, a “different” response is expected. When the stimuli go across the boundary (signal: different), the correct answer is expected to be “different”. So if the participants respond “different”, it is a hit. But if the response “same” is made, it is a miss. On the other hand, when the stimuli go within the boundary (signal: same”), responding “same” is a correct rejection while “different” is a false alarm. However, different from traditional SDT, since the answer could never be “different” for the within category trial, there is no way to get a “false alarm” (Emmorey et al., 2003). Therefore, we would just call it “correct response score”

instead of d' score. To get this correct response score, we need to value the hit rate minus the false alarm rate so that the response bias[1] can be removed. Therefore, only hits are calculated (see Appendix B).

Table 6**.** The revised SDT applied in Experiment 1B

		signal	
		Different (across boundary)	Same (within boundary)
response	different	**hit**	false alarm
	same	miss	correct rejection

Results for discrimination task

For the result of the discrimination task, in order to assess the participants' detection of differences between the stimuli, a revised Signal Detection Theory (SDT) was applied (Green & Swets, 1966; Emmorey et al., 2003) to see how sensitive the participants are to the difference of the stimuli. The important research question in the discrimination task is whether participants perform differently for pairs between categories versus those within category. If a CP effect exists, the discrimination (that the participants respond "different") should be higher when discriminating pairs from across category boundary. We predict that the signer group should have better performance when discriminating across category pairs than within category pairs. The correct response score was calculated for each participant, one for within category pairs and one for across category pairs (Macmillan &Creelman, 1991) (see appendix B). This is a direct way to look at whether CP effects were observed or not.

[1] A response bias is that some participants tend to answer "yes" (or "different" in this case) even when they are not sure what is the correct response.

If participants have CP for the handshape contrasts, the average of the across-category pairs should be higher than the average of the within-category. As discussed earlier, d' score is used to see how sensitive the participants are to the difference of the stimuli. We calculated all the hits (since there is no false alarm to be deducted following Emmorey et al., 2003) and got the correct response score for all participants (see Appendix B). However, as showed in Figure 17, Figure 18 and Figure 20, both signer group and non-signer group got a higher correct response score for cross category than for within category.

We conducted a mixed ANOVA on correct response scores (see Table 7), with handshape contrast ([1] – [X], [F] – [Open F], [5] – [Open B] and [B] – [Open B]), category (within or across) and groups (signer group and non-signer group). This analysis revealed that there were significance differences between groups since that the correct response score of signer group is always lower than the non-signer group ($p < .01$).

From the result of discrimination task, we can see that both groups had better performance in across-category than in within-category, except for pair [5] – [Open B] (See Table 4, Table 7 and Figure 17 to Figure 20). The result of the mixed ANOVA showed that the responses to across-category pairs were significantly different from responses to within-category pairs ($p < .005$). Three handshape pairs showed consistent graph that showed the higher score of across-category than within-category (See Figure 17, Figure 18, and Figure 20). But note that the slope for the signer group of the correct response score within and across category are bigger than the non-signer group.

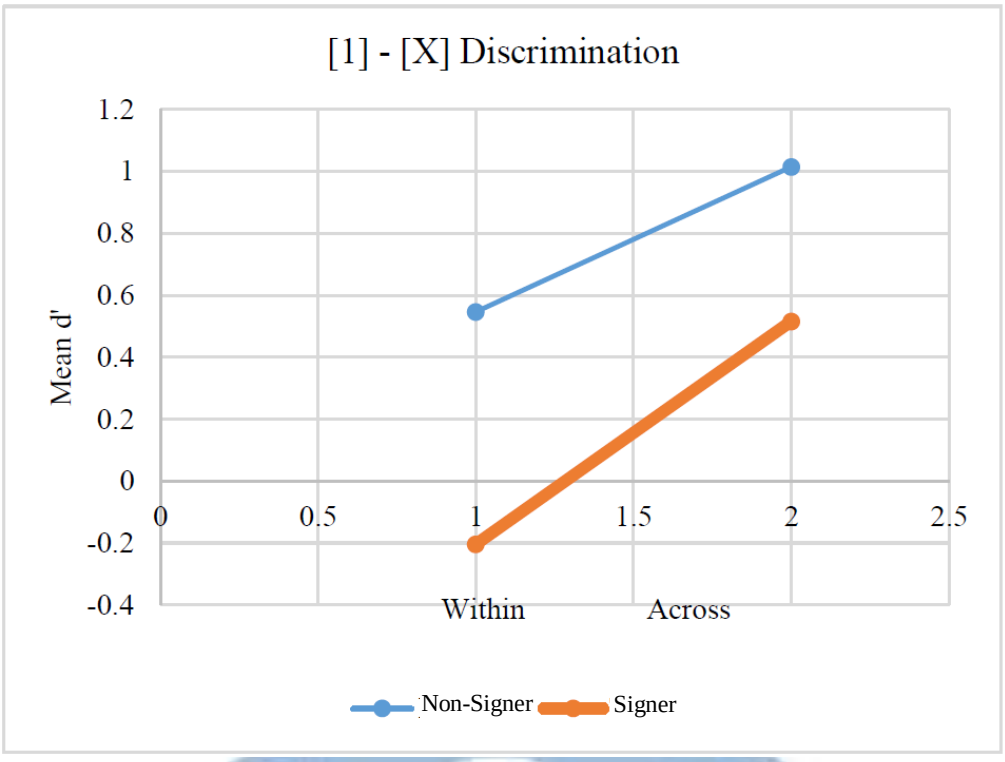


Figure 17. Experiment 1B: [1] – [X] Discrimination

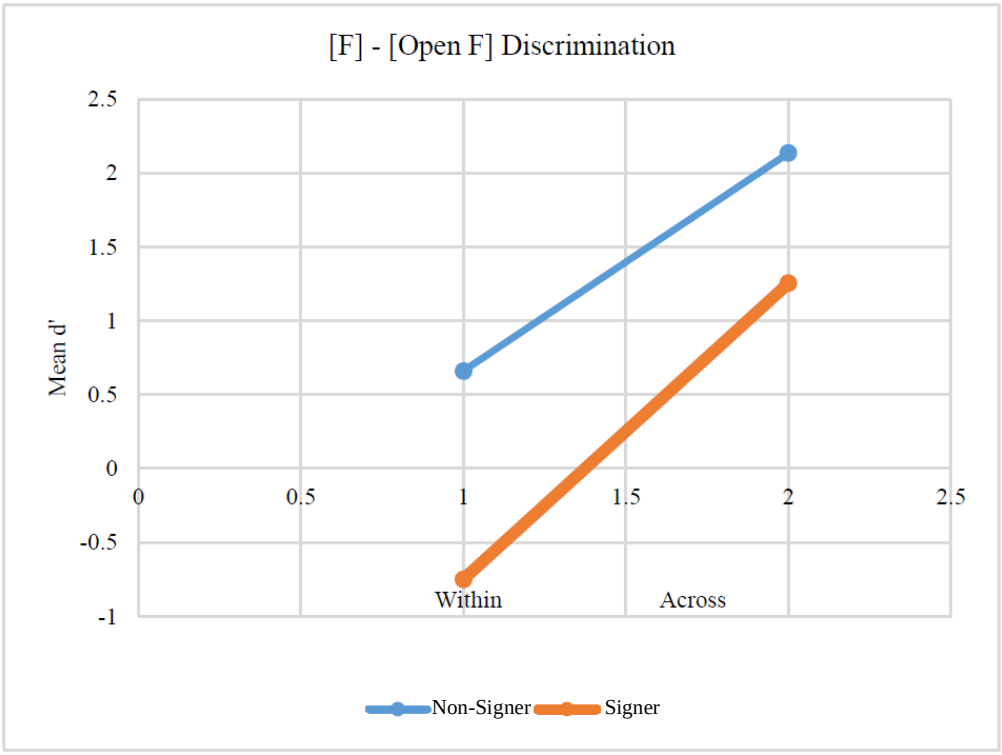


Figure 18. Experiment 1B: [F] – [Open F] Discrimination

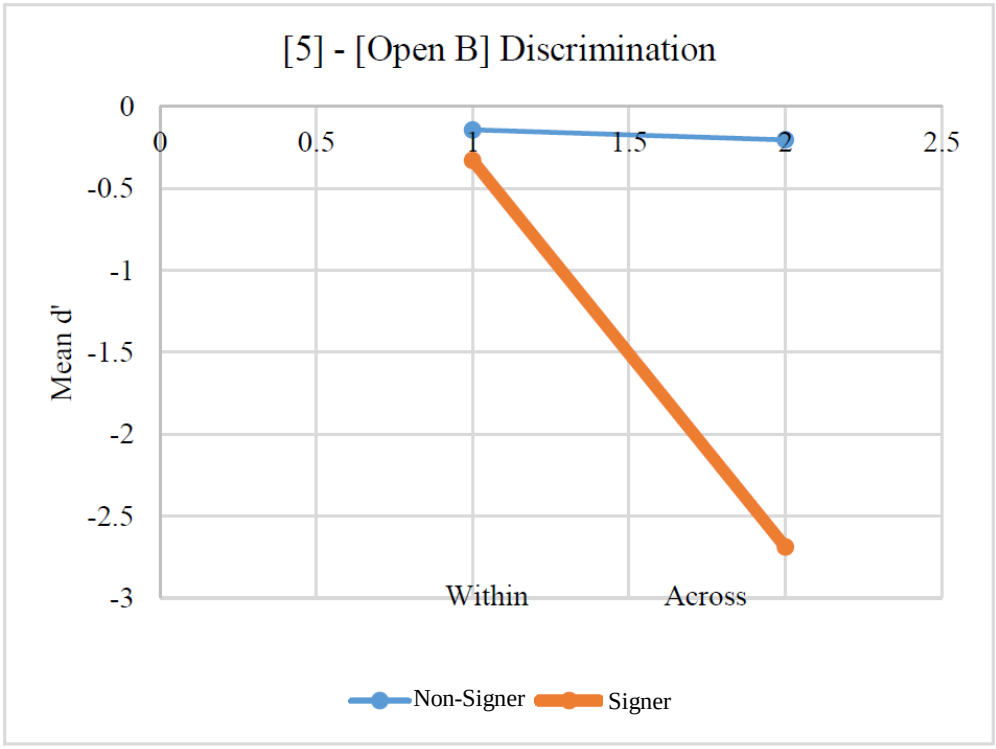


Figure 19. Experiment 1B: [5] – [Open B] Discrimination

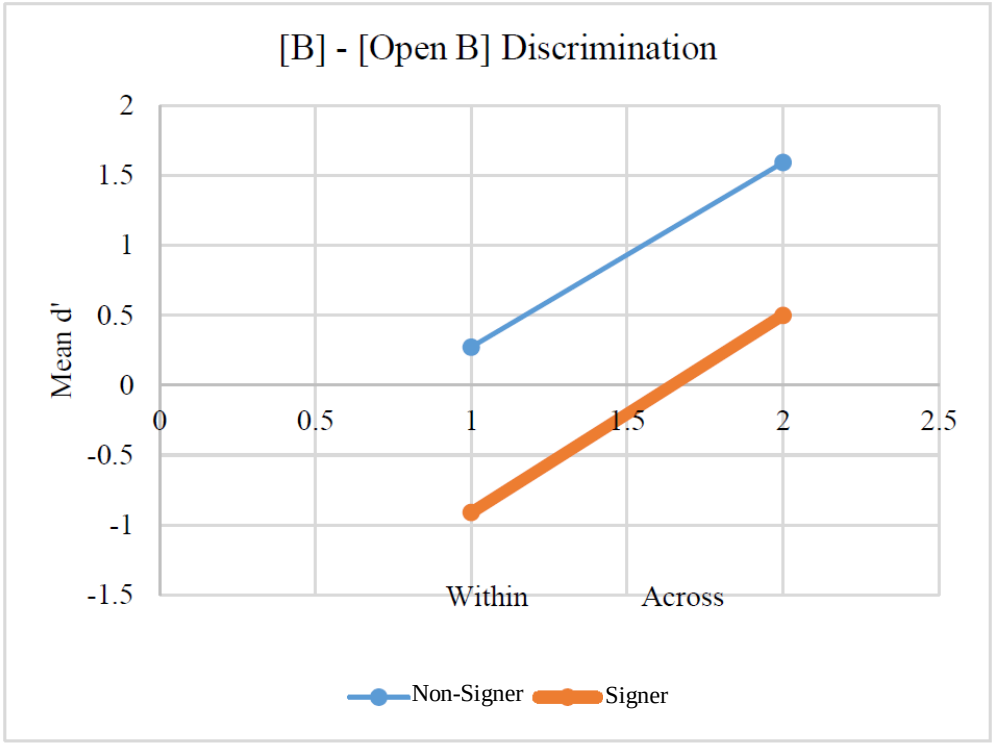


Figure 20. Experiment 1B: [B] – [Open B] Discrimination

Table 7. Experiment 1B: mixed ANOVA for Category Effects

	Statistics				
	Df	***Sum Sq***	***Mean Sq***	***F value***	***Pr (>F)***
Category	1	11.226	11.226	12.93	0.00489**
Group x Category	1	0.009	0.009	0.001	0.92115
Residuals	10	8.684	0.868		

Discussion for discrimination task

The results showed that although both groups seem to perform CP, the differences the signer group have within and across category are even bigger. Surprisingly, Figure 19 showed that non-signer group got similar correct response score for across and within-category but signer group did worse in across-category discrimination than in within-category. It is unclear what could have cause this. Perhaps we should go back and reexamine the chosen contrast and the stimulus. Also, since we calculated only the hits for the correct response score, we could not get rid of the possibilities that there might be response bias among our participants.

The overall results indicate that participants of both signer and non-signer group are more sensitive to the difference across category than within category. This was not consistent with previous research, but the data may not be big enough to reveal the difference between the signer group and the non-signer group.

3.1.5 Discussions of Experiment 1

Study A was designed based on previous experiments on categorical perception (CP) in sign languages (Emmorey et al., 2003, Baker et al., 2005, and Best et al., 2010). In these studies, both ASL and the English group showed the potential of CP in the identification task. And yet, results from discrimination tasks indicated that only

the ASL group exhibited CP effects, but not the non-signer group (English group). Using the same research design but different handshapes, participants and languages (TSL & Mandarin Chinese are used instead of ASL & English), the similarities and differences were as follows.

The result of identification task was basically consistent with previous research. It seems to be quite normal for human kind to make categorical decisions. On the other hand, participants were given binomial choices; which is, the responses they made were either A or B. This has forced the participants to put stimulus into two categories. This has also made the existence of discrimination important. In the discrimination experiment, the prediction was that non-signer group should get similar correct response score for across and within category discriminations and the signer group would have better correct response score for across category than within category. However, we have got different results. Unlike the result of Baker et al. (2005) and Emmorey et al. (2003), both the signer group and the non-signer group showed CP effects (See Figure 17, Figure 18 and Figure 20). The correct response score is higher for across category than the score of within category. Both groups showed a consistent graph which the mean correct response score of the across category is higher than the mean correct response score within category. This not only indicates that both groups exhibit CP effects but also suggest that the participants may not be using similar strategies in the experiment. We here provide two possibilities that the participants may either all using their general perception (like what people do in the color and facial expression experiments) or they may all be using their sign perceptions. A T-test was conducted and there were no significant differences between slopes ($p > 0.05$). This may be due to the insufficient sample size we have for the study.

For the different graph shown in Figure 19, the non-signer group has similar correct response score in within and across-category; signer group got a worse response score in across-category than the correct response score for the within-category contrast. We suggest, that in this circumstance, signers are constrained and influenced by their language experience. In the usage of TSL, except for signing numbers, there are no big difference between [5] and [Open B] in actual use. In other words, this may not be a phonemic contrast. What is more, since [Open B] is a really distinct and hard handshape, it consumes more strength to make all the fingers touch each other. Therefore, signers tend to use [5] instead of [Open B]. For example, the standard sign of BEFORE and AFTER uses [Open B] as the 'standard' handshape, and yet, most signers use [5] when they are signing. Their tolerance for [5] and [Open B], which is not standardly signed, are higher than for other handshapes. In other words, they tend to take it as the same handshape in certain conditions. Therefore, they got even lower correct response score in across-category than in within-category. Yet the sample was small and we cannot be sure if this result is convincing. Also, the non-signer group got an average higher correct response score than the signer group. We suggest the possible reasons may be due to the social status of signer groups. Some research reported a bias that kids tend to make a lot of "yes" responses because experimenters remind them of their teachers. Deaf people may be not willing to make strong responses like "yes" and "no" in an experiment run by hearing people. There are possibilities that there are response bias on the

To get a statistically effective result, this research needs more participants. The sample size may not be big enough to provide reliable data. We found that not only the signer group showed categorical perception, but also the non-signer group. In particular, for both groups, discrimination accuracy across categories was higher than within categories (except for pair [5] – [Open B]). It is not obvious that if the prior

language experience played its role in the experiment due to the small sample size. But it is possible that both groups were using their inner sign perception in the experiment. However, the bigger difference between across category and within category of the signer group may indicate the influence of language experience, but further research is needed. Another question to be answered is the interesting boundary location of pair [5] – [Open B] and [B]-[Open B], which was not located in the middle but swayed to either side of the edge. What could be the factor influencing it? We have already discussed that the weird [5] – [Open B] result may be that they are not real phonemic contrast. Another possible reason for the [5] – [Open B] and [B] – [Open B] results could be that participants are influenced by the topological constraints in visual perception as do HKC and MLC readers (Yang & Wang, 2018). We have already known that perception could be influenced by many different factors (e.g. language experience, inner mechanism, maturation, and topological effects, etc). The aim of study B is to see if the different ease of articulation of the handshapes would influence the sign perception by moving the boundary location.

3.2 Experiment 2: Ease of articulation influences

This study aims to see if ease of articulation influences the category boundary location. Since the change from one endpoint to the other endpoint is gradient, boundary location should be located in the middle of the stimuli.

Three continua for handshapes (with an extra pair for practice) were chosen for this study, comparing different combinations of ease of articulations. All chosen handshape pairs are phonemically contrastive. Since we ran the experiment through Worldlikeness (Chen & Myers, 2021), once the experiment starts, no pause is allowed. To make sure that the participants fully understand the procedure, pair [4]-[5] is used for practice before the real experiment starts. The other three contrast pairs

[1]-[X], [V]-[Curved V], and [5]-[5-Curved-Pinky] are used for the real experiment. All continua are static rather than dynamic.

3.2.1 Participants

There were 33 Deaf TSL signers and 30 hearing non-signers involved in the experiment. None of them participated in study A. For the signer group, 15 male participants and 28 female participants were involved with the age of participants ranged from 24 years old to 56 years old (median: 44, with an outlier of 85 years old). One of them did not get education higher than junior high school, 13 of them have graduated from senior high school, 18 of them have a bachelor degree and one has a master degree. According to participants' own descriptions, five of them started signing before going to school since they were born to deaf parents; 18 of them started to learn TSL and signed Chinese in deaf school (in elementary school); 5 of them started to learn TSL in high school years; and the rest of the participants (5 of them) learned TSL around 18-20 years old. As for the usage frequency, most of the participants (25 of them) reported to use TSL often/everyday and all of them reported to know Mandarin as well.

There were 12 female participants and 18 male participants in the non-signer group (control group), all 30 hearing participants reported to have acquired at least 2 languages (Mandarin with Southern Min, Hakka, or English), but have no knowledge of any sign language. They aged from 21 years old to 64 years old. Only eight of them did not get a bachelor or a master degree.

3.2.2 Methods

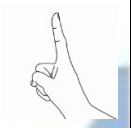
Materials

Seven handshapes were used in the experiment (see Table 8). The crucial part of this experiment is the ease of articulation of the handshape. We quantified ease of articulation using the measures developed by Ann (2006) for TSL handshapes. Ann constructed a model of handshape ease of articulation based on the physiological facts. She divided handshapes into three groups: easy to articulate, difficult to articulate, and physically impossible to articulate. Each handshape is therefore given an "ease score". Five criteria were defined based on hand physiology: muscle opposition in configurations of handshapes (MOC), support for extension (SE), support for flexion (SF), tendency to oppose the thumb (TOT), and tendency to spread (TS). These criteria refer mostly to muscle function. The joint structures in the hand contribute less prominently. A handshape would be analyzed by these five criteria. For example, the level of difficulty of a curved configuration would be given a score "3", which is considered to be most difficult; the level of difficulty of a closed configuration, which is considered to be the easiest, would be given a score "0". Then add in the second criterion (SE), then the third criterion (SF), until all five criteria were taken into consideration. Taken from Ann (2006), p.102-103, an algorithm came with considerations of all those considerations:

$$(SE+SF) \times MOC_{\text{of least flexed fingers in a rest-closed handshape and most flexed fingers in a rest-open handshape}} + TS/TOT$$

With the algorithm, the ease of articulation of the used handshapes taken from the book is as shown in Table 8.

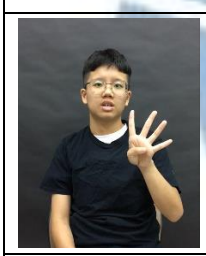
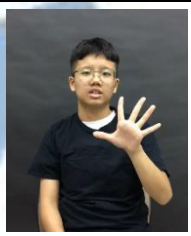
Table 8. Handshape pair used in the experiment and its ease of articulation[2]

TSL handshape name in ASL handshape form	Handshape name in TSL	Picture of handshape	Ease score	Ease of articulation	Stimulus pair
[1]	[1]		0	Easy	[1] - [X] easy - easy
[X]	[10]		0	easy	[1] - [X] easy - easy
[V]	[2]		1	hard	[V] - [Curved V] hard - hard
[Curved V]	[20]		3	hard	[V] - [Curved V] hard - hard
[4]	[4]		0	easy	[4] - [5] easy - easy
[5]	[5]		0	easy	[4] - [5] easy - easy --- [5] - [5-Curved Pinky] easy - hard
[5-Curved Pinky]	[8]		3	hard	[5] - [5-Curved Pinky] easy - hard

[2] Pictures of handshapes were downloaded from Taiwan Sign Language Online Dictionary (Tsay et al., 2017) and the ease of articulation is scored according to methods in Ann (2006).

Ann (2006) states that there are significant correlations between ease of articulation and token frequencies. The more difficult the handshape is, the less frequent the handshape is. Therefore, to lower the effect of the frequency of the handshape, the handshapes chosen for the study are all related to numbers in TSL, which is then in the same category (the category: number). The pairing of its meaning linking with numbers are, [1]: one, [X]: ten, [4]: four, [5]: five, [V]: two, [Curved V]: twenty, and [5-Curved-Pinky]: eight. The real endpoint stimuli are as follows (see Table 9).

Table 9. List of the stimuli pair used for Experiment 2

Endpoint stimuli	Target handshape	Stimuli pair	Target handshape	Endpoint stimuli
		[4] - [5] easy - easy		
		[1] - [X] easy - easy		
		[V] - [Curved V] hard - hard		
		[5] - [5-Curved Pinky] easy - hard		

The stimuli were created in several steps. First, a demonstrator was asked to sign the continuum pair, changing from one endpoint to the other endpoint handshape. An iphone 6s plus is used to record the signing video. The video is then transformed into images with screen print and modified in Paint. 13 images were made out of the video with transformation in equal spacing according to the still images for each continuum pair (See Table 10).

Table 10.

Continuum of the Three Contrast Pairs and Contrast Pair for Practice for Experiment 2

(1) Handshape [5] – [4] (Practice)

#1 #2 #3 #4 #5

#6 #7 #8 #9 #10

#11 #12 #13

(2) Handshape [X] – [1]

#1

#2

#3

#4

#5

#6

#7

#8

#9

#10

#11

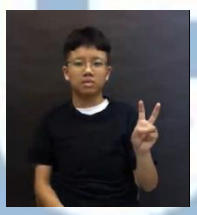
#12

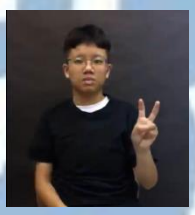
#13

(3) Handshape [V] – [Curved V]

#1

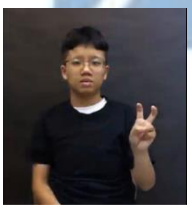
#2

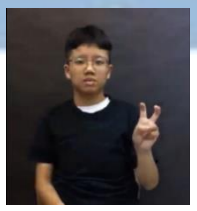

#3

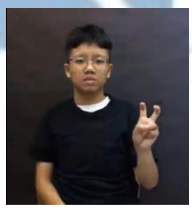

#4

#5

#6


#7


#8


#9

#10

#11

#12

#13

(4) Handshape [5-Curved-Pinky] – [5]

#1

#2

#3

#4

#5

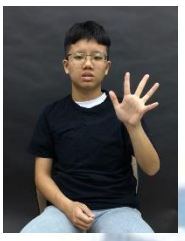
#6

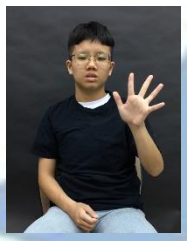
#7

#8

#9

#10


#11


#12

#13

Procedure

The identification task is chosen in this study following one of the experiment designs in categorical perception in ASL (Emmorey et al., 2003). It is used to decide where the boundary locates between the two handshapes. The entire experiment was done through Worldlikeness, which is a web-based tool for typological psycholinguistics (Chen & Myers, 2021).

In the beginning of the experiment, participants were shown an experiment description (see (1) in Appendix C) to let them know the purpose of the experiment. Then, since all the experiments are done on Worldlikeness, participants are asked to decide whether he or she would like their result to remain anonymous in this database (all users/users that are registered and identified/experimenter of this experiment) (see (2) in Appendix C). After that, related information was collected before the

experiment started (see (3) in Appendix C), such as age, gender, highest education, first language, second language, handedness, frequency using TSL and age when one starts learning TSL (since the non-signer group never learn TSL, this question was not required for the non-signer group. This information was collected before the experiment). The experiment started after the instruction is given (see (4) in Appendix C).

The experiment was divided into three parts (three stimuli pairs) with an extra practice before the real experiment started. Participants could take some rest between each part of the experiment so that their reaction would not be influenced due to exhaustion or impatience. After the experiment instructions were given, participants were shown two endpoint handshapes (two endpoint handshapes for that part of the experiment) by the researcher before the start of each task. On each trial, participants were presented with a single image randomly selected from the 13 image continuum. They were asked to decide which endpoint handshape was the image they saw most resembled. For example, participants pressed 'S' key if the image most resembled the [4] handshape and the 'L' key if it most resembled the [5] handshape (see (5) in Appendix C). Since these handshapes are all related to numbers in TSL, the smaller number was always represented by the key on the left side of the keyboard ('S' key). Stimuli lasted until participants pressed the key and each image were presented 3 times in total to make sure their identifications are consistent, resulting in 39 randomly ordered trials for each continuum.

3.2.3 Results

For all three continua in the identification task, both signer and non-signer groups identified them categorically and showed a sharp boundary (see Figure 21, Figure 22 and Figure 23). A logistic regression was also conducted for the slope (see

Table 11). To get the boundary of each continuum, the average response is needed (see Appendix D). Every stimuli is identified 3 times by each participant, with 33 Deaf native signers and 30 Hearing non-signers, resulting in 99 identifications and 90 identifications, respectively Figure 21, Figure 22 and Figure 23 showed the average identifications for the two groups.

Table 11. Experiment 2: logistic regression for slope

Contrast	Group	b0	b1 (slope)
[1] – [X]	Signer	-0.6842	3.7990
	Non-signer	-1.16896	7.02539
[V] – [Curved V]	Signer	-6.68243	1.29128
	Non-signer	-6.99252	1.13976
[5] – [5-curved-pinky]	Signer	-8.04847	1.00885
	Non-signer	-11.920	1.429

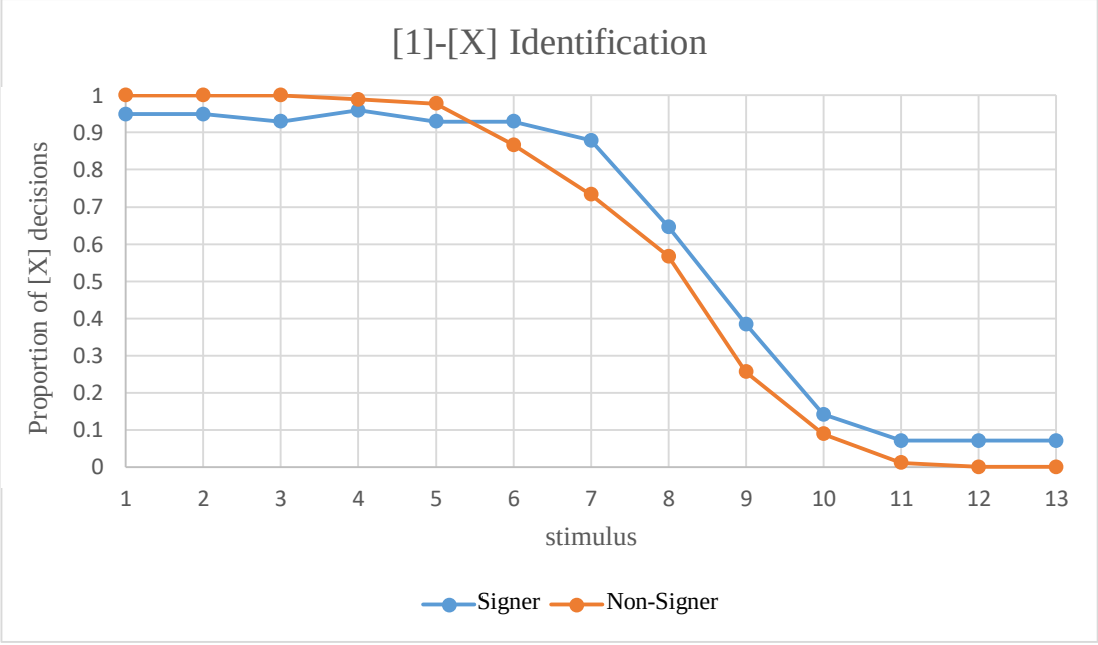


Figure 21. Experiment 2: [1] – [X] Identification

easy - easy
(no boundary prediction)

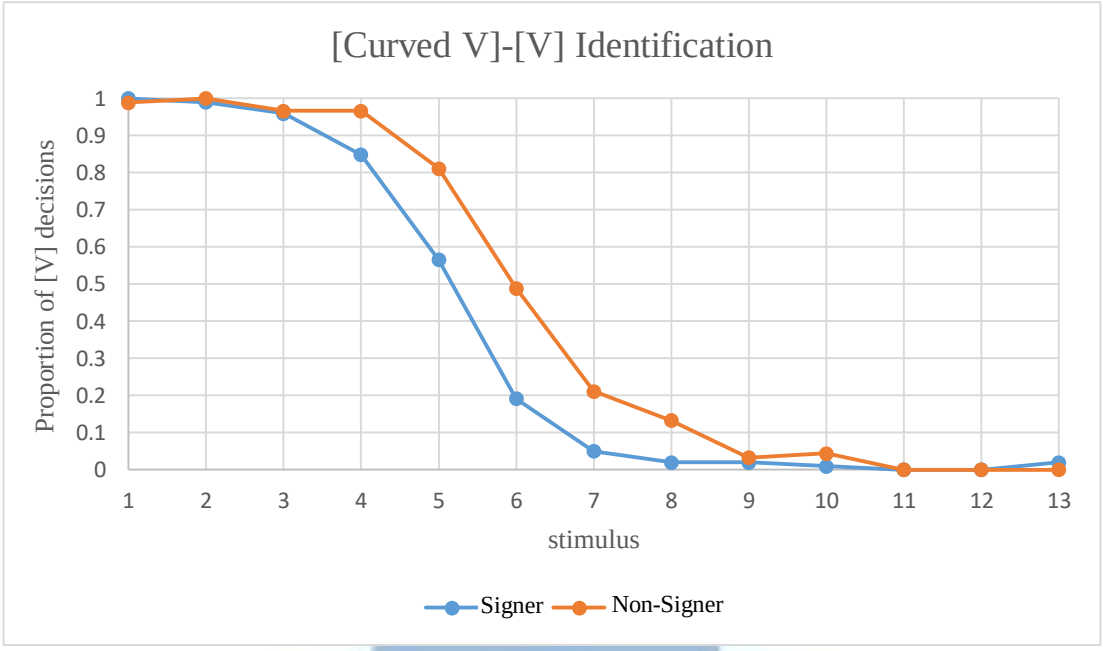


Figure 22. Experiment 2: [Curved V] – [V] Identification

hard - hard
(no boundary prediction)

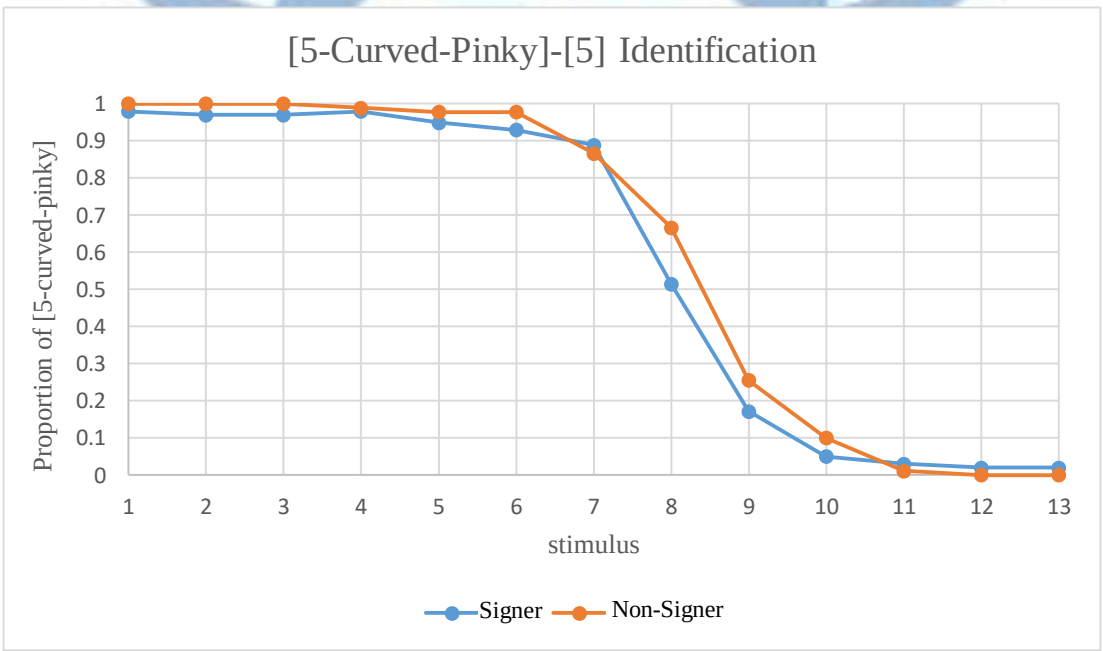


Figure 23. Experiment 2: [5-Curved-Pinky] – [5] Identification

hard - easy
(boundary predicted to
shift to the right side)

According to our original prediction, the boundary should move when the ease of articulation of one side of the handshape is more difficult than the other side. Therefore, Figure 21 and Figure 22, with which the combination of ease of articulation are “easy – easy” and “hard – hard”, are predicted to have no boundary shifting (if ease of articulation is the only possible cause of boundary shifting). Figure 23, whose combination is “hard – easy”, is predicted to have its boundary sway toward the easy side of the continuum. Perceivers may have better tolerance of the hard handshape which expands its category size and pushes the boundary toward the easy side. However, the result did not fit our prediction.

We ran a linear mixed model on the data in order to look for the interactions between the two groups and three contrasts. We compared two groups (the signer group and the non-signer group) and three stimuli pairs ([1] – [X], [V] – [V-curved], and [5] – [5-curved-pinky]). This model took the non-signer group and pair [5] – [5-curved-pinky] as the baseline and made comparison between signer group and non-signer group, pair [1] – [X] and non-signer group, pair [Curved V] – [V] and non-signer group. Also it looks for the interaction between non-signer group, signer group and pair [1] – [X]; and the interaction between non-signer group, signer group and pair [Curved V]. As shown in Table 12, (1) there were no significant difference between the two groups for the main effect ($p > 0.05$); it can also be seen in Figure 21, Figure 22 and Figure 23 that these graphs between the two groups look similar. In other words, in this identification task, both groups may not be using their linguistic ability when doing the identification since the non-signer group does not have TSL experience; or they may be both using their innate knowledge about sign phonology (even if that the hearing group may not know they are using it). This result did not conflict with previous studies (Baker et al., 2005; Emmorey et al., 2003) in that there were no significant differences between the signer group and the non-signer group in

identification experiment, nor did our result in study A. (2) The base contrast pair is [5] – [5-curved-pinky], which is the only easy-hard contrast that we expected to have significant difference in compare with the same-ease contrasts. The result showed there were significant differences between [5] – [5-curved-pinky] and the same-ease contrasts. As shown in Figure 24, the signer group tends to put the [1]-[X] boundary "later" than the non-signer group and the [V]-[Curved V] boundary "earlier", but the two groups treat the [5]-[5-curved-pinky] boundary the same. And yet, if our prediction were true, the blue dot for [1] – [X] and [V] – [Curved V] should locate around 7 (midrange) while the blue dot for [5] – [5-curved-pinky] shifts upward toward the easy handshape (in this case, handshape [5]). (3) There were significant interactions in between groups and contrasts. One main point we want from this experiment was to see if the participants differ in the location of their boundaries and the last two rows of Table 12 showed so ($p < .05$).

Table 12. Linear mixed model of data of Experiment 2

	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	7.35472	0.07779	182	94.551	< .0001
Signer Group	-0.05674	0.07779	182	-0.730	.46663
[1] – [X]	0.87915	0.11026	182	7.974	< .0001
[Curved V] – [V]	-1.71230	0.10988	182	-15.583	< .0001
Signer Group: [1] – [X]	0.32287	0.11026	182	2.928	.00384
Signer Group x [Curved V] – [V]	-0.26750	0.10988	182	-2.434	.01588

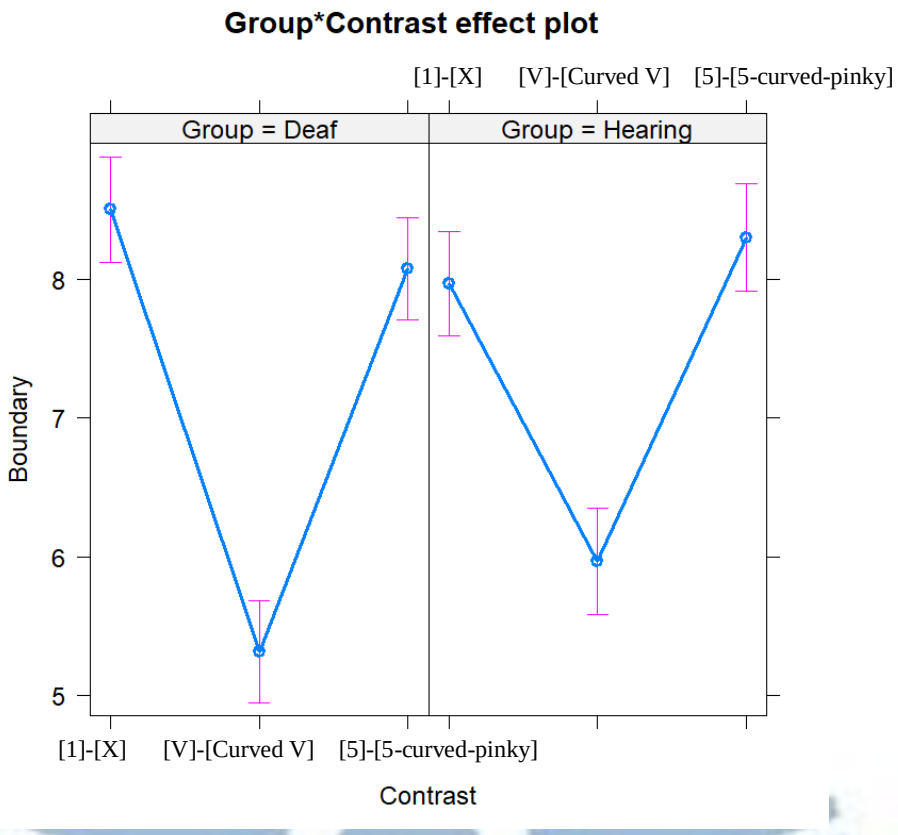


Figure 24. Plot of Boundary Location between Groups and Stimuli Pairs

We then put together the result of the boundary location and the difficulty setting (as in Table 13). None of the boundary locations of the three stimuli pairs were located in the middle, which should be stimuli number 7 (the middle of 13 stimuli). What we got from the data is that participants treated the easy-hard contrast differently from same-ease pairs. However, if our prediction were true, the boundary of pair [1] – [X] (easy – easy) and [V] – [Curved V] (hard – hard) should stay in midrange while the boundary of [5] – [5-curved-pinky] moved toward [5] side. In other words, although both groups treated the contrasts in a different pattern, we did not find evidence in this study to prove that the ease of articulation influence the location of the boundary.

Table 13. Comparison of three stimuli pairs

Stimuli pair	[1] – [X]	[5] – [5-curved-pinky]	[V] – [Curved V]
Ease of articulation	easy-easy	easy-hard	hard-hard
Boundary location	Signer : 8.6 Non-signer: 8.2	Signer 8.1 Non-signer: 8.4	Signer: 5.2 Non-signer: 5.9

3.2.4 Discussions of Experiment 2

There are two things we want to find from our data: (1) When doing the identification, is there significant difference between the signer group and the non-signer group? (2) Do the participants treat the third stimuli contrast, which is [5-Curved-Pinky] – [5] (hard-easy), differently in comparison with the other two contrasts ([1] – [X] (easy-easy) and [V] – [Curved V] (hard-hard))? The main purpose of Experiment 2 was to find out whether ease of articulation influences CP judgments (sign perception). In other words, do people have higher tolerance for the "hard" handshapes than the "easy" handshapes? Our expectation is that when it comes to a hard handshape, since it is hard to articulate, people would have higher flexibility in perceiving the handshape. Signers do not need to sign the handshape 100% correctly to let the perceiver understand what they are signing. However, other factors would also affecthow people recognize the word, the sentence, and the meaning. What's more, in order to reduce the influence of other factors, the six chosen handshapes ([1], [X], [V], [curved-V], [5-curved-pinky] and [5]) are related to numbers that are signed in front of the body.

As shown in the results, first of all, though it cannot be seen from the first sight, there was significant difference between the signer group and the non-signer group on their identifications. There were steep slopes for both groups which shows that both groups were doing the identification categorically (though this process of sorting may

be the general perception since the decisions are made consciously). Second, the graph of the two groups which compares the boundary location of the identification experiment looks surprisingly similar (see Figure 24), but the precise points still differ systematically across the two groups (as demonstrated by the significant interactions in Table 12). Statistics told that the two groups showed different patterns. The boundary of the signer group swayed a little more from the center (stimulus 7), the results are basically different from our prediction (that only the hard-easy contrast would have influences on the boundary). For the similarity of the two groups, we suggest that although the non-signer group do not have the language knowledge of TSL, signs and the use of hands are common in daily life, non-signers may be using their inner perception and could also feel how difficult it is to do certain gestures, resulting in the similar identifications. This indicates that non-signers may have their sign perception even though they were not aware of it. To sum up, we predicted that ease of articulation influences the boundary location. We searched for evidence in support but did not find any. All we know now is that articulation may not have strong effects on sign perception, at least it is not the main effect, but more research is needed. We have tested only one hard-easy pair in this thesis. But other factors may also be influencing the boundary, for example, topological effects (Yang & Wang, 2018) or the spatial detectors (Landau & Jackendoff, 1993). There may be different findings if we could test more hard-easy pairs. Also, it could be purely a visual effect where articulatory does not have influence at all.

Chapter 4

Discussion

4.1 General discussion

In this thesis, two experiments were reported. First, an identification task and a discrimination task were conducted in Experiment 1. Then, an identification task was conducted in Experiment 2. With same target language (TSL) and same target group (TSL signers), we now make a comparison between the two experiments.

To take a quick look at the two experiments, what can be seen is that handshape pair [1] – [X] appeared in the identification task in both studies. However, the results were different. To make a comparison, we stacked two results together (see Figure 25). Since there were only nine stimuli in Experiment 1 but thirteen stimuli in Experiment 2, to compare the data, two data sets were stacked together using Excel. It can be seen clearly that the boundary location was different. Boundary of Experiment 1A stayed more in the midrange while the boundary of Experiment 2 moved to the right side (the side toward [X]). The result of the non-signer group from both studies are more consistent to each other in compare to the signer group. The signer group in Experiment 1A tended to put the boundary location earlier than the non-signer group; however, the signer group in Experiment 2 tended to put the boundary later. And yet, we could not run statistics on these two data since two sets of stimulus were not the same. We suggest that since non-signers do not have the TSL knowledge, this kind of identification is more a test to decide which end of handshape does the stimuli they see most resembled to, resulting for more consistent results. Signers, with more possible variations, are more unpredictable.

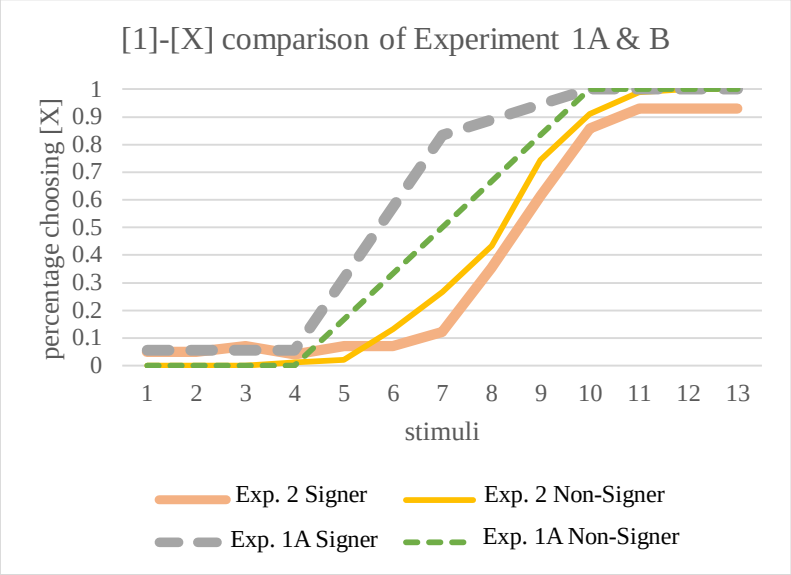


Figure 25. [1] – [X] comparison of Experiment 1A and 2

According to all our results, we have two suggestions that our participants may either using their general perception or their sign perception. And yet, from the result (see Figure 25), we could observe that the slope of the signer group are generally steeper than the non-signer group. This may indicate that signers somehow did the identification in a more categorical way. In addition, the correct response scores of both signer and non-siger group showed consistent results. They all got higher accuracy across categories than within categories. This, however, did not fit our prediction. If our predictions were true, the non-signer group would get a similar accuracy in both across categories and within categories while the signer group would get a higher correct response score in across categories than within categories (see Figure 5). But again, further research will be needed since there were not many participants in Experiment 1A. It may be more convincing if more participants could be involved to get a statistically significant result.

Then, when it comes to the discussion of the influence ease of articulation has on the boundary location, there was no significant difference between the signer group and the non-signer group. Both experiments had consistent identification results. In

addition, although there were significant differences between the identification between the three stimuli pairs (see Table 12), we could not find apparent evidence on how ease of articulation may influence the boundary location. The stimuli contrast which was predicted to have a boundary move did not sway a lot from the center while the two stimuli contrasts which were expected to stay in the midrange did not do so, either. There may be more findings if more hard-easy contrasts could be tested. So far, what we could see from our study is that the ease of articulation may not be the main influence.

There are multiple factors we know that have its impact on CP so far, namely perceptual predisposition, language experience, and development/maturation (Emmorey et al., 2003). We have predicted that language experience and ease of articulation should be influencing sign perception but failed. We have come up with some explanations: in accordance with Liberman, phonemes may be codes which carry information that helps people to perceive efficiently. Signs are not only meaningful to Deaf signers but also to non-signers. In a face to face speech conversation, it is natural for non-signers to make gestures or movements with hands and bodies which help one to communicate. These gestures and movements may be meaningful to non-signers; for example, the handshape [V] signed in front of body may mean TWO in TSL, but it could also be the ‘peace’ sign which is used commonly by non-signers and the [Curved V] could be the “air quotes” sign. Non-signers, therefore, may develop some kinds of sign perception in another way. To narrow down and see how each factor may be influencing the perception, we now know the ease of articulation may not be the main factor. We suggest that frequencies and that handshapes which are not so commonly used in hearing world should be tested so that we could deduct the influence signs could have to the control group even more.

To have some further analysis, we searched for the frequencies of used

handshapes from Ann (2006) and showed it in Table 14.

Table 14. Comparisons for ease of articulation and frequencies from Ann (2006)

	Handshape	Ease of articulation	Token Frequency based on conversation data	Type Frequency based on conversation data
	[1]	easy	618	64
	[X]	easy	14	5
	[V]	hard	79	17
	[Curved V]	hard	25	6
	[5]	easy	144	29
	[5-curved-pinky]	hard	1	1

An easy handshape does not necessarily have a high frequency, as with [X]. But as seen in Table 14, our contrast pairs were all a combination of high and low frequencies (even though they are all in the category of “numbers”), which may be the noise of our study. As we searched for more related research, there are more possible factors that may cause boundary shifts, e.g. more common words may tend to be perceived more readily than less common words (Connie et al., 1993); words with

more lexical neighbors (e.g. containing handshapes that appear in more dictionary itens) also tend to be perceived more readily than those with few neighbors (Newman et al., 1997). Visual effects like topological effects (Yang & Wang, 2018) or the spatial detectors (Landau & Jackendoff, 1993) may also have the interactions with sign perception.

In addition to the analysis in Table 14, we also tried to look for more correlations of the preferred handshapes. As shown in Figure 24, participants tend to choose more [X], [Curved V], and [5-Curved-Pinky]. These three handshapes all share similar features such as bent or curve. We suggest that it is reasonable for participants preferred these handshapes. This echoes the ideas what Landau & Jackendoff (1993) presented that human are born with some kinds of contact detector since the difference between straight and curved is similar to that between on and not on. A form can only be straight in one way, but can be curved in many ways. So participants would tend to say “straight” only if it is very straight, but say “curved” the rest of the time.

We made some conclusions with all these comparisons we have made. It was predicted that ease of articulation may influence sign perception based on motor theory but failed. Although there were significant differences between the different ease contrast and same ease contrast, participants seem to be influenced more by its visual feature. But ease of articulation may still has its influence on sign perception since there are significant differences between the different ease contrast and same ease contrast. This indicates that the influence of sign perception works wider than we think that not only do signers, but also non-signers use it. We suggested earlier that participants may either be using their general perception or their sign perception, but we suggest that participants may be using their sign perceptions after these reviews. The development of sign perception could be traced back long ago that some research

told that human use sign languages (or body movements) to communicate even earlier than spoken languages.

Chapter 5

Conclusion

5.1 Summary and discussion of findings

There are several conclusions suggested by our results. First, for two identification tasks in both experiments, there were significant differences between the signer group and the non-signer group. Both groups did the identification categorically. Second, in the discrimination experiment, both signer group and the non-signer group exhibited categorical perception by getting a higher correct response score across categories than within categories. From the two points above, we suggest two possibilities; (1) all participants were doing these identifications and discriminations not with their language experience but their general perception, (2) all participants use their innate sign perception. Third, with a different combination of ease of articulation, although there were significant differences between the different ease contrast and same ease contrasts, we did not find obvious evidence that ease of articulation enhances or deduct people's tolerance of handshapes which then move the boundary location. With the comparison of its visual feature, it is more likely that these visual features, such as bent and curve, have bigger influence.

Results we got for Experiment 1 were inconsistent with previous CP research. But the small sample size of our participants may be influencing the overall results we got and causing difficulties to get a statistically significant analysis. But sign perception should be working on non-signers since this is an innate mechanism which everyone has it. The result showed in Figure 4 that allophones for POA also showed a high peak also indicated that there might be more to be revealed. However, revisions may also be required for our experimental methods. For example, it may be more accurate if the stimuli can be made by computer programs so that the transformation

from one endpoint to the other endpoint could be precisely controlled. Also, whether the sign perception of native signers and near native signers works in the same way is worth discussion.

For the overall results, so far as we know, ease of articulation may not be the main influence to sign perception. And yet, CP may have different influence on different handshapes or phonology distinct as well that more handshapes should be tested. As for the performance of the non-signer group, we suggest that they may also be using their sign perception and have developed it with signs (or gestures) that are commonly used.

5.2 Implications for further research

Although there were significant differences between different ease contrast pairs and same ease contrast pair, our intention to see if ease of articulation influences sign perception did not succeed. Yet the handshapes we chose may be too common (or frequent) in the hearing world. We suggest that these handshapes are not only codes to signers but may even be meaningful to non-signers in some ways. There may be more findings if we could test more hard-easy handshapes that do not appear in the hearing world, or that allow us to test if frequencies have more influence on sign perceptions. The use of the model of the ease of articulation scoring might also need more details that there might still be different levels of difficulties in difficult handshapes.

Visual perception should be taken into consideration, such as topological effects (Yang & Wang, 2018) and the contact detectors (Landau & Jackendoff, 1993). What we could see from our review is that our participants seem to prefer handshapes with those distinct features. But further research is needed.

It is not easy to test how innate language mechanisms work on Deaf people through spoken languages due to the biological limits. But this thesis provides a new

way that this innate mechanism should own by all people. Sign perception, which is also innate, should also work on non-signers.

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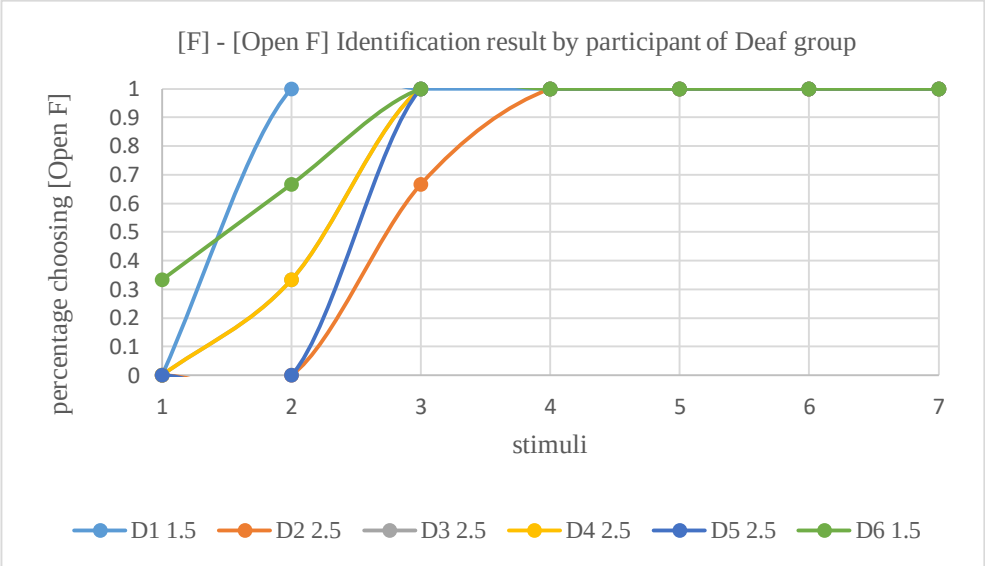
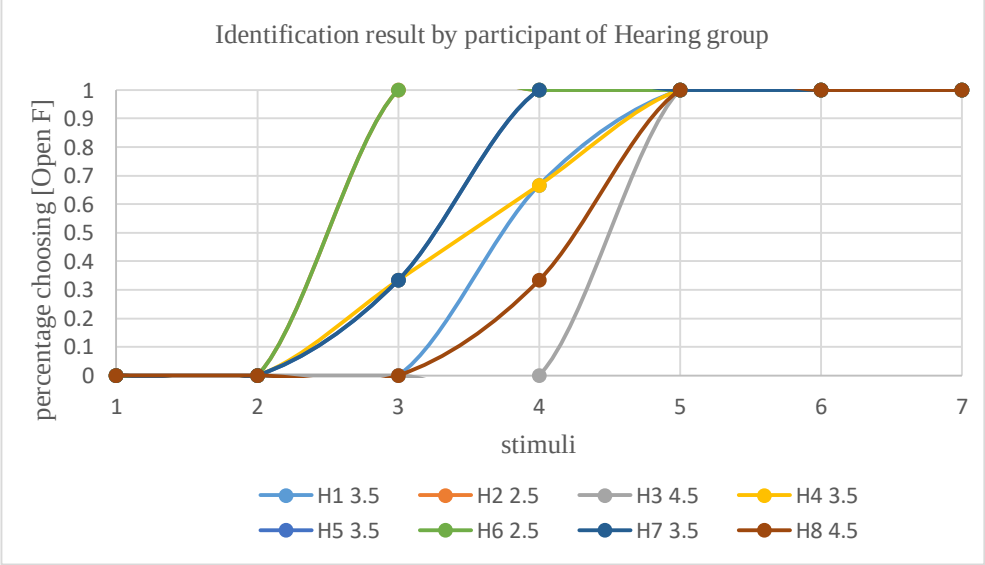
Appendices

Appendix A. Experiment 1A: results of identification task for each participant

A. Handshape [F] – [Open F]

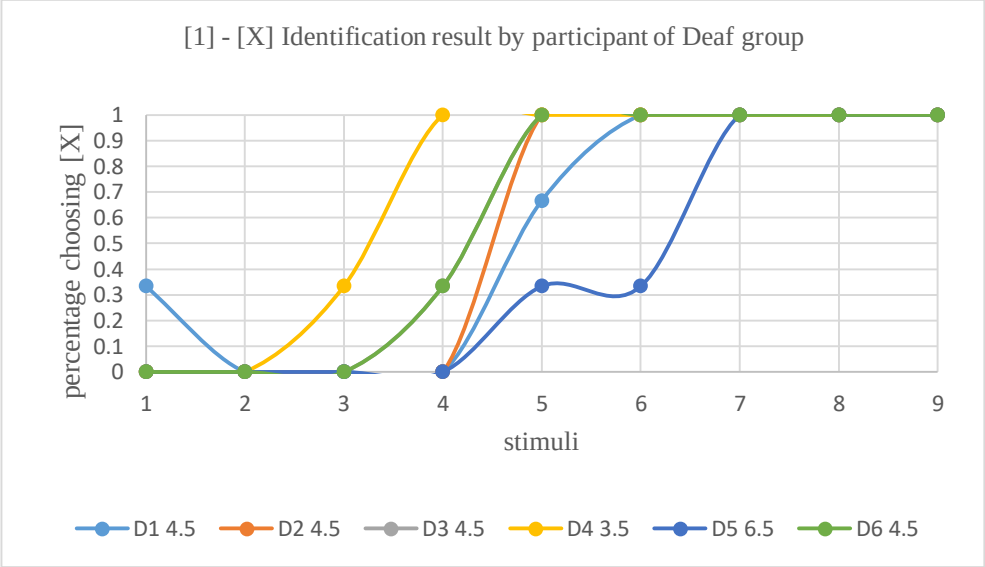
stimuli	D1	D2	D3	D4	D5	D6	H1	H2	H3	H4	H5	H6	H7	H8
1	0	0	0	0	0	0.3	0	0	0	0	0	0	0	0
2	1	0	0.3	0.3	0	0.7	0	0	0	0	0	0	0	0
3	1	0.7	1	1	1	1	0	1	0	0.3	0.3	1	0.3	0
4	1	1	1	1	1	1	0.7	1	0	0.7	1	1	1	0.3
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1

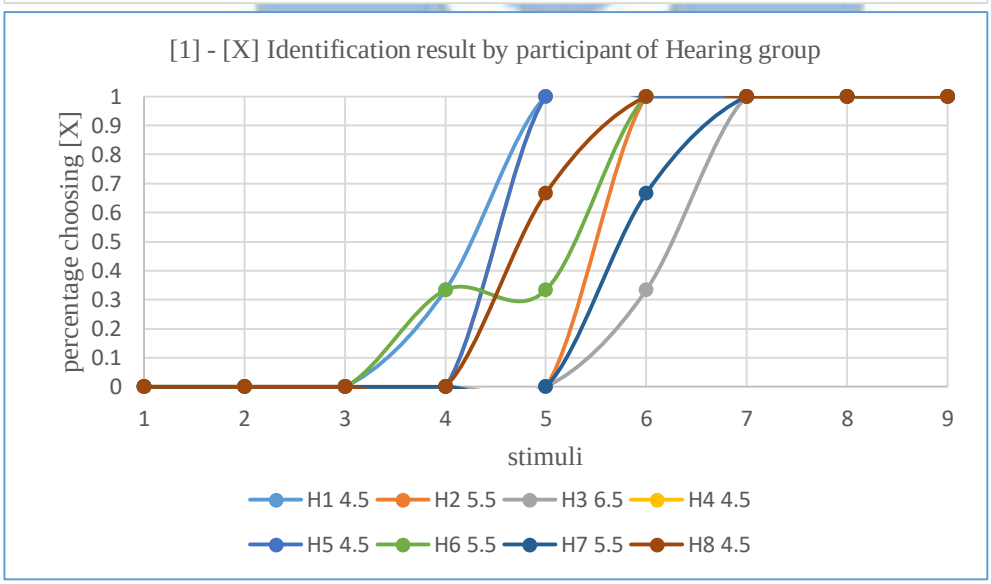




B. Handshape [1] – [X]

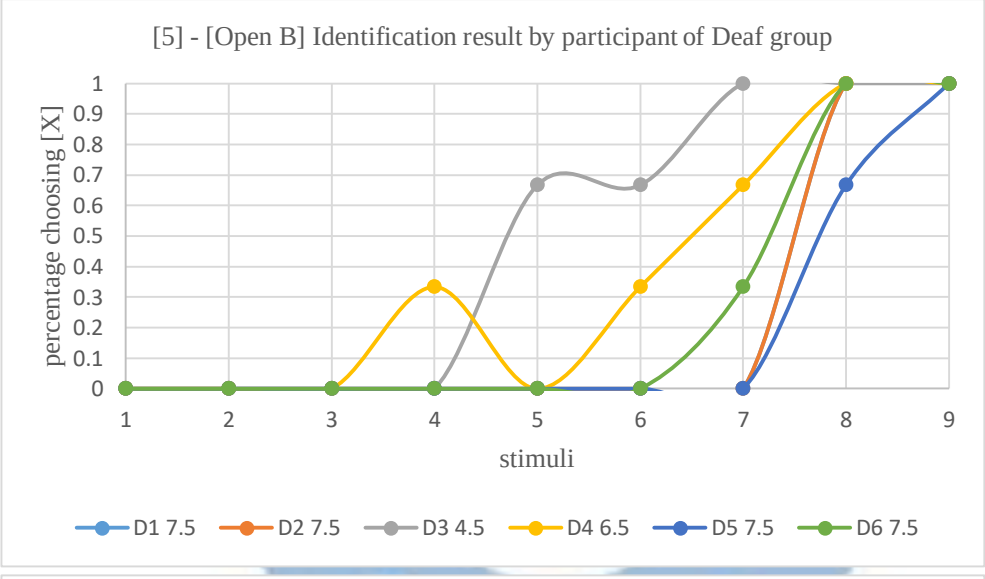
stimuli	D1	D2	D3	D4	D5	D6	H1	H2	H3	H4	H5	H6	H7	H8
1	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0
4	0	0	0.3	1	0	0.3	0.3	0	0	0	0	0.3	0	0
5	0.7	1	1	1	0.3	1	1	0	0	1	1	0.3	0	0.7
6	1	1	1	1	0.3	1	1	1	0.3	1	1	1	0.7	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1

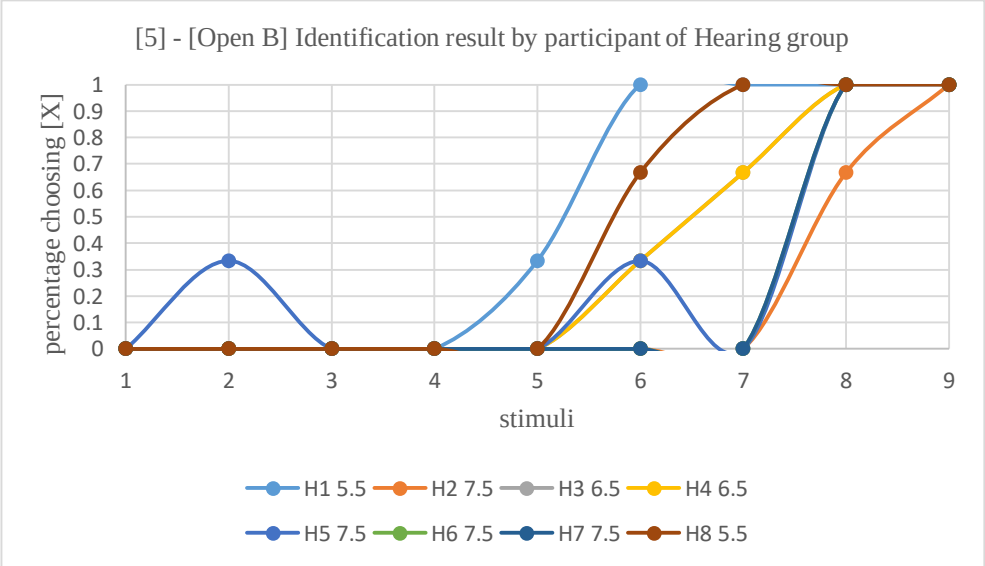




C. Handshape [B] – [Open B]

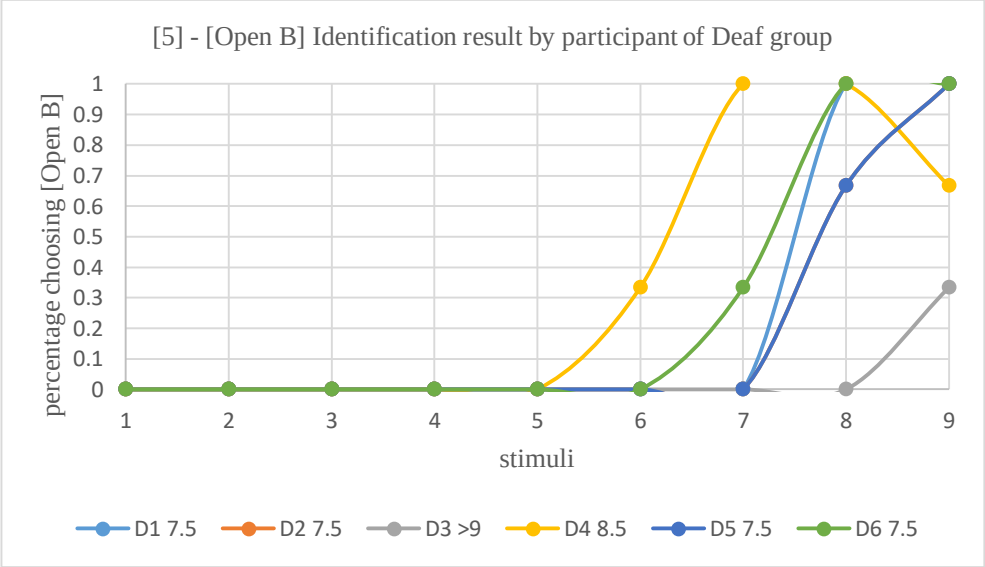
stimuli	D1	D2	D3	D4	D5	D6	H1	H2	H3	H4	H5	H6	H7	H8
	7.5	7.5	4.5	6.5	7.5	7.5	5.5	7.5	6.5	6.5	7.5	7.5	7.5	5.5
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0.3	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0
5	0	0	0.7	0	0	0	0.3	0	0	0	0	0	0	0
6	0	0	0.7	0.3	0	0	1	0	0.3	0.3	0.3	0	0	0.7
7	0	0	1	0.7	0	0.3	1	0	0.7	0.7	0	0	0	1
8	1	1	1	1	0.7	1	1	0.7	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1

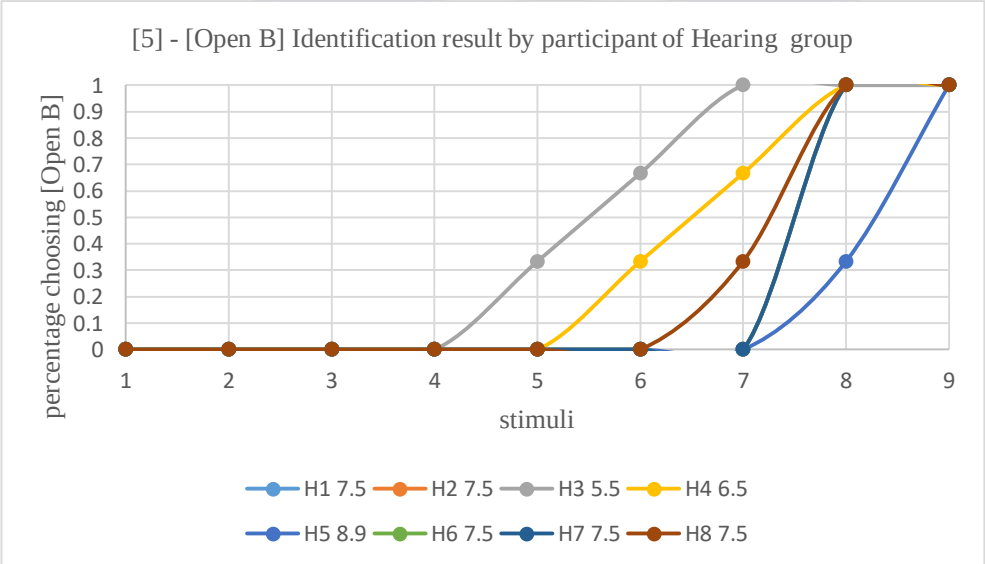




D. Handshape [5] – [Open B]

stimuli	D1	D2	D3	D4	D5	D6	H1	H2	H3	H4	H5	H6	H7	H8
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0.3	0	0	0	0	0
6	0	0	0	0.3	0	0	0	0	0.7	0.3	0	0	0	0
7	0	0	0	1	0	0.3	0	0	1	0.7	0	0	0	0.3
8	1	0.7	0	1	0.7	1	1	1	1	1	0.3	1	1	1
9	1	1	0.3	0.7	1	1	1	1	1	1	1	1	1	1

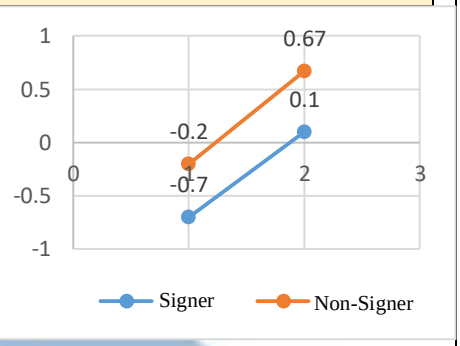




Appendix B. Experiment 1B: correct response score derived from discrimination task

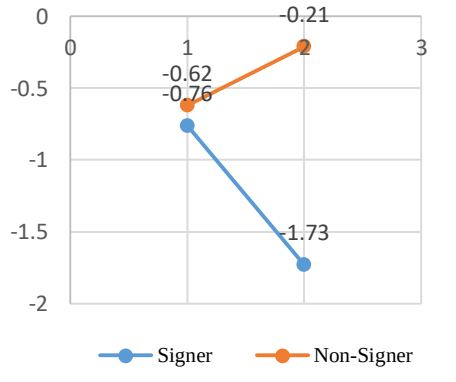
Correct response score for handshape [1] – [X]				
		within		across
	HIT	d'	HIT	d'
D1	15	-0.27	2	0
D2	6	-1	3	0.67
D3	12	-0.48	2	0
D4	9	-0.76	2	1.28
D5	9	-0.67	3	0
D6	4	-1.25	1	-0.67
Non-signer	**55**	**-0.7**	**13**	**0.1**
H1	21	0.132	2	0
H2	12	-0.43	5	0.97
H3	11	-0.51	6	1.28
H4	14	-0.34	2	0
H5	17	-0.13	1	-0.67
H6	14	-0.28	5	0.97
H7	14	-0.28	6	1.28
H8	19	0	3	0.67
Signer	**122**	**-0.22**	**30**	**0.67**

	within	across
Non-signer	-0.7	0.1
Signer	-0.2	0.67



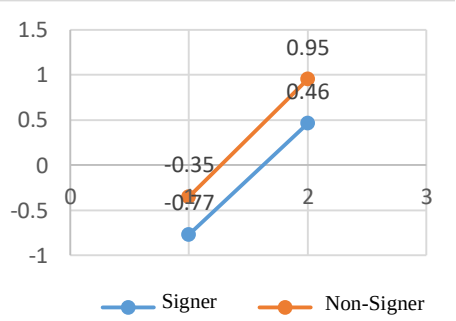
Correct response score for handshape [5] – [Open B]				
		within		across
	HIT	d'	HIT	d'
D1	9	-0.7165	0	-1.28155
D2	10	-0.63364	1	-0.67449
D3	12	-0.5244	0	-1.28155
D4	9	-0.67449	0	-1.28155
D5	6	-1.00315	0	-1.28155
D6	5	-1.11896	0	-1.28155
Non-signer	**51**	**-0.75981**	**1**	**-1.73166**
H1	15	-0.26699	1	-0.67449
H2	9	-0.7165	2	0
H3	10	-0.58946	3	0
H4	4	-1.25212	1	-0.96742
H5	10	-0.58946	1	-0.67449

	within	across
Non-signer	-0.76	-1.73
Signer	-0.62	-0.21



H6	15	-0.26699	3	0.67449	
H7	7	-0.89943	3	0.67449	
H8	10	-0.63364	1	-0.67449	
Signer	**80**	**-0.62293**	**15**	**-0.21043**	
Correct response score for handshape [B] – [Open B]					
		within		across	
	HIT	d'	HIT	d'	
D1	6	-0.96742	5	0.967422	
D2	9	-0.67449	4	0.430727	
D3					
D4	24	0.336038	3	0.67449	
D5	0	-1.28155	3	0	
D6	1	-1.91451	4	0.430727	
Non-Signer	**40**	**-0.77294**	**19**	**0.463708**	
H1	16	-0.13971	5	0.967422	
H2	13	-0.35549	6	1.281552	
H3	14	-0.33604	3	0.67449	
H4	8	-0.76471	4	0.430727	
H5	17	-0.21564	1	1.281552	
H6	12	-0.43073	5	0.967422	
H7	16	-0.13971	6	1.281552	
H8	11	-0.50849	4	0.430727	
Signer	**107**	**-0.35122**	**34**	**0.951278**	

	within	across
Non-Signer	-0.77	0.46
Signer	-0.35	0.95



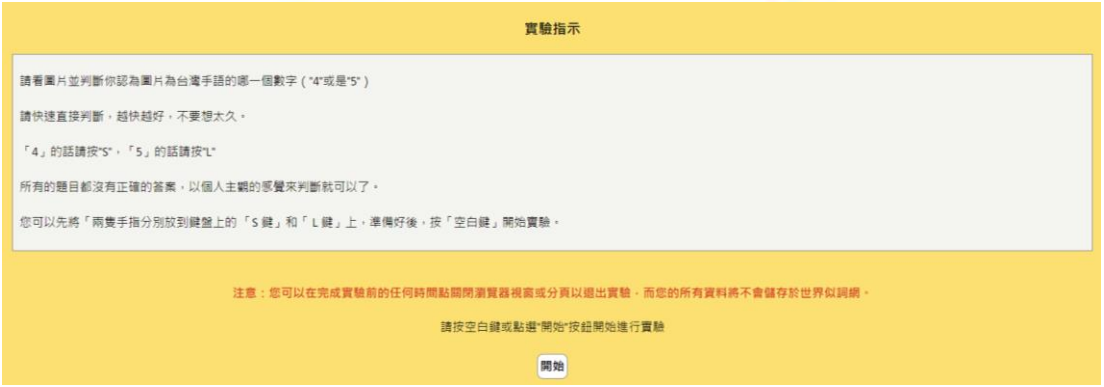
Appendix C. Experiment 2: Screen Shot of the Experiment procedure

(1) Experiment Description

(2) Informed Consent

(3) Background Information

(4) Experiment Instruction



(5) Example of the Experiment Content

四 (S)　　五 (L)

Appendix D. Boundary location of each continua by participant

Handshape [1]-[X]			
Signer group		Non-signer group	
Participant	Boundary	Participant	Boundary
1	8.5	1	8
2	8	2	8
3	9	3	7.5
4	8.5	4	10
5	9.5	5	7.5
6	7.5	6	8.5
7	9.5	7	8.5
8	7.5	8	9.5
9	9	9	9.5
10	9.5	10	9
11	9.5	11	5
12	9	12	8
13	8	13	9.5
14	10	14	7.5
15	8.5	15	8.5
16	8.5	16	9
17	9.5	17	7.5
18	8.5	18	7
19	6.5	19	6
20	9.5	20	8
21	9	21	10
22	8	22	6.5
23	8.5	23	7
24	7.5	24	8.5
25	8.5	25	8.5
26	7	26	8
27	7.5	27	7.5
28	8.5	28	5.5
29	9.5	29	10
30	7	30	8.5
31	9	31	5
32	9	Average	8.2

33	8.5	Min~max	5~10
Average	8.6		
Min~max	6.5~10		

Handshape [Curved V]-[V]			
Signer group		Non-signer group	
Participant	Boundary	Participant	Boundary
1	6.5	1	5.5
2	4.5	2	5.5
3	5.5	3	7.5
4	6.5	4	5.5
5	3.5	5	5.5
6	5.5	6	6.5
7	4.5	7	5.5
8	6.5	8	6
9	4.5	9	5.5
10	5.5	10	5.5
11	5.5	11	6.5
12	7.5	12	4.5
13	4.5	13	5.5
14	5.5	14	8.5
15	4.5	15	5.5
16	5.5	16	5.5
17	4.5	17	6.5
18	5.5	18	5.5
19	5.5	19	7.5
20	4.5	20	5.5
21	5.5	21	3.5
22	5.5	22	7.5
23	6.5	23	7.5
24	6.5	24	6.5
25	6.5	25	5.5
26	4.5	26	6.5
27	5.5	27	5.5
28	4.5	28	5.5
29	4.5	29	4.5

30	5.5	30	5.5
31	4.5	31	7.5
32	4.5	average	5.9
33	5.5	Min~max	3.5~8.5
average	5.2		
Min~max	3.5~7.5		

Handshape [5-curved-pinky]-[5]			
Signer group		Non-signer group	
Participant	Boundary	Participant	Boundary
1	7.5	1	6.5
2	8.5	2	8.5
3	9.5	3	7.5
4	8.5	4	7.5
5	7.5	5	8.5
6	8.5	6	7.5
7	8.5	7	6.5
8	8.5	8	8
9	7.5	9	10.5
10	8.5	10	7.5
11	8.5	11	8.5
12	8.5	12	7.5
13	7.5	13	9.5
14	7.5	14	7.5
15	8.5	15	7.5
16	9.5	16	8.5
17	8.5	17	8.5
18	8.5	18	9.5
19	7.5	19	8.5
20	8.5	20	8.5
21	8.5	21	10.5
22	7.5	22	9.5
23	8.5	23	7.5
24	6.5	24	6.5
25	8.5	25	8.5
26	8.5	26	8.5

27	7.5	27	7.5
28	7.5	28	9.5
29	8.5	29	9.5
30	7.5	30	8.5
31	3.5	31	8.5
32	9.5	average	8.4
33	8.5	Min~max	6.5~10.5
average	8.1		
Min~max	3.5~9.5		