Experimental Study into the Time Taken to Understand Words when Reading Japanese Sign Language

Mina Terauchi
Polytechnic University
(Visiting Fellow of Kogakuin University)
Kodaira-shi, Tokyo, Japan
e-mail: terauchi@uitec.ac.jp

Keiko Watanabe Yuji Nagashima
Kogakuin University
Hachioji-shi, Tokyo, Japan
e-mail: ed13001@ns.kogakuin.ac.jp e-mail: nagasima@cc.kogakuin.ac.jp

***Abstract*— We are conducting research in areas such as linguistic and cognitive analysis of sign language, and animation, with the aim of assisting the hearing impaired with communication. It was already assumed that hearing-impaired people recognize the meaning of sign language words while the sign language movement is being performed. Based on the results of dialog-based analysis of sign language however, we predicted that hearing-impaired people would understand the meaning of sign language words during the "transition" stages. For the purposes of this paper, we compiled a series of experiment sentences and conducted an experiment to determine the timing with which hearing-impaired people recognized target words in each sentence. The results of the experiment indicated that hearing-impaired people recognized a high percentage of words during the "in-transition" stage. Based on these results, we can assume that hearing-impaired people understand sign language sentences by effectively utilizing hand shapes, movements and information such as expressions and intonation. The challenge for the future is how to harness this information to improve the comprehension abilities of students undergoing sign language education.**

Keywords- Sign Language, predict recognition, transition.

I. INTRODUCTION

We are in the process of conducting linguistic and cognitive research into sign language in order to assist the hearing impaired with communication.

For the purposes of this paper, we conducted an experimental study into the time taken for deaf people to predict and understand words at the ends of sentences when reading Japanese sign language. We divided the sign language sentences used in the reading experiment into three different types depending on the nature of the word at the end of each sentence (the "target word"). Type A sentences contained target words that enabled the reader to correctly interpret the meaning of the sentence. Type B sentences contained target words that were of the correct type syntactically, but that did not enable the reader to correctly interpret the meaning of the sentence. Type C sentences contained target words consisting of fabricated movements based on phonemes that are absent from Japanese sign language ("pseudowords"), making it impossible for the reader to interpret their meaning. We compiled these three types of sentences with assistance from a native signer. We filmed the sentences being signed and then edited the sign language clips for use in the experiment.

For the experiment itself, we asked 13 native signers to read sign language sentences following each of the three patterns. The results were as follows.

II. THE TEMPORAL STRUCTURE OF SIGN LANGUAGE

Sign language consists of two different types of signal; manual signals and non-manual signals. It is a visual language that uses both types of signal simultaneously and continuously. Manual signals (MS) are determined by handshapes, the direction of the palms, the position of the hands and other broad movements, and are used to form words. Non-manual signals (NMS) meanwhile consist of elements such as the shape of the mouth, the signer's eye line, expressions and nodding, and are used for semantic and syntactic purposes.

The temporal structure of sign language can be broadly divided into two categories; "signs" and "transitions". A "sign" starts when the signer has decided and formed the shape for a single sign language word. When the signer has finished moving, the sign then ends the moment before they release their handshape. A "transition" starts when the signer has finished the movements required for a single sign language word, and lasts until the moment before the signer starts to sign the next sign language word, as they move into position. Transitions can be further divided into two sub-categories; "in-transitions" and "out-transitions". An "in-transition" starts when the signer begins to create the manual signal for the target word, and ends when they have finished forming the relevant manual signal. An "out-transition" starts when the signer releases the manual signal for the target word, and ends the moment before they form the manual signal for the next word. Figure 1 shows the defined categories that make up sign language, with "signs" and "transitions" plotted along a timeline.

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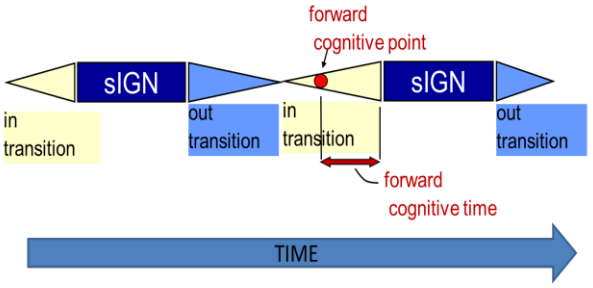

Figure 1. The temporal structure of sign language

III. COGNITIVE EXPERIMENT ON SIGN LANGUAGE WORDS

A. *Compiling experiment data*

We compiled the experiment data (sentences) with the aim of ascertaining the point at which the subjects recognized the target sign language word. Expressions in sign language have various different characteristics. The chosen method can therefore have a significant effect on the results of cognitive experiments. We carried out a preliminary experiment using selected sentences from KOSIGN Ver.2, a dialog corpus that includes 10 sign language words. As the sentences were parts of dialog however, their contents depended on questions asked by another person, which influenced reading of the sign language. Being dialog also meant that the sign language included elements such as agreement, denial and acknowledgement. This created further issues because it changed the position of the target word within the sentences. With that in mind, we began to look into conditions for the compilation of sentences that we could use in the main experiment.

1) *Exploring target words*

We started by determining the position of the target word, as the third word in each sentence. We were unable to position the target word at the start of the sentence because it would have included transitional movements from the initial position, making it impossible to ascertain the point during the out-transition or in-transition at which the subject recognized the word. In natural sign language, the choice of first words is also limited, because the first word in a sentence is often a referent word such as {I} or {you}, or a word indicating the tense of the sentence such as {today} or {yesterday}. The second word in a sentence is easily influenced by the first word, so that would also have limited the range of words available. Taking all of these factors into account, we decided to make the third word the target word, and to use sentences consisting of three or four words.

Next, we selected the target words. Many words in sign language are made up of two or more morphemes. The Japanese word {kazoku} (family) for example consists of the two morphemes {ie} (house) and {hitobito} (people). The in-transition for a word like this is likely to suggest a number of possible words, including {ie} (house) {yane} (roof) or {kazoku} (family). We therefore decided to use words consisting of a single morpheme as candidates for the experiment. We also decided to include sign language for the selected words, as detailed below.

a) One-handed sign language: {omou} (think)

b) Two-handed sign language: {hana} (flower)

c) Different sign language with each hand:

{odororku (surprise)

d) Sign language with changing handshape:

{nenrei} (age)

e) Sign language with classifier handshape:

{asa} (morning), {neko} (cat)

To enable the experiment to be carried out on both native signers and on non-native signers, we selected words that even a beginner just starting to learn sign language would know.

2) *Compiling experiment sentences*

The spatial structure of sign language consists of elements such as handshapes and articulatory gestures. To understand the way in which subjects recognize sign language words in practice, we looked at three different types of example sentences; Type A, Type B and Type C.

We selected the target words for Type A sentences so that the sentences would be grammatically and semantically correct in the context of sign language. We called these "correct sentences". The following is an example of the correct sentences used in the experiment. The words between curved brackets { } are sign language words. The words between speech marks " " give the meaning of the sentence in English.

Example correct sentence:
{fujisan} {miru} {asa} {kirei}
(Mount Fuji) (look) (morning) (beautiful)

English translation:
"Mount Fuji looks beautiful in the morning"

Type B sentences had the correct grammatical structure, but we selected target words that would affect how the sentence was interpreted. We called these "difficult to interpret sentences". For Type B sentences, we tried to select target words whose sign language movements were dissimilar to the target words used in the Type A sentences.

Example difficult to interpret sentence:
{ashita} {tenki} {ame}
(tomorrow) (weather) (candy)

English translation:
"Tomorrow the weather will be candy"

Type C sentences contained target words consisting of fabricated movements based on phonemes that are absent

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from Japanese sign language ("pseudowords"), making it impossible for the reader to interpret their meaning. We called these "pseudoword sentences". We complied the sign language movements for Type C sentences so that the transition from the second word to the target word resembled the equivalent transition in the Type A sentences.

Example pseudoword sentence:
{watashi} {ototo} {pseudoword 1}
(I) (younger brother) (pseudoword 1)

In this sentence, the sign language movement for "pseudoword 1" starts by moving from the cheek, as in the sign language word {shumi} (hobby), before opening and lowering the hand, as in the sign language word {hikari} (light). The aim of using a pseudoword is to check that the subjects are taking the reading experiment seriously.

3) Filming clips of example sentences

We compiled 226 correct sentences, 48 difficult to interpret sentences and 12 pseudo word sentences for use in the reading experiment. We then filmed a native signer signing the sentences. For the purpose of the reading experiment itself, we selected 20 correct sentences, two difficult to interpret sentences and one pseudo word sentence from the sign language sentences we had recorded. Table 1 shows the selected sentences.

We used the following procedure to edit the sign language sentences for the reading experiment.

a) We took the section from the start of the sentence to the first frame of the out-transition from the second word, immediately before the target word, and called it "Pattern 1" (Figure 2(a)). All Pattern 1 clips cut off at the out-transition from the second word.

b) Next, we added the next frame following on from Pattern 1 and called the resulting clip "Pattern 2" (Figure 2(b)). So Pattern 2 clips kept running for one frame longer than Pattern 1 clips.

c) We continued to produce similar patterns, by adding another frame at the out-transition from the second word, one frame at a time.

We continued this process of adding one frame at a time, all the way through to the out-transition from the target word. The final experiment clip was Pattern n, which showed the target word in its entirety.

Figure 2 shows the progression through the different patterns used for the experiment clips. If subjects had been given a long time to think, they might have worked out the end of the sentence. We therefore edited the clips so that the patterns played through continuously, one after another. As subjects required some thinking time however, we edited the clips with a three-second countdown between each pattern.

B. Experiment procedure

We explained to the subjects in advance that we wanted them to recognize the third word in each sentence. To prevent subjects from working out the answers from the context, and from being influenced by the Japanese language, we asked them to watch each clip and then give their answers in sign language during the countdown before the next clip. We then recorded the experiment to determine at what point (pattern) the subjects were able to read the target word. If a subject was unsure about the target word or gave an incorrect answer, we continued to play the clips until they gave the correct answer. We recorded subjects' answers even if they were incorrect. Correct, difficult to interpret and pseudoword sentences were shown in a random order, rather than the order listed in TABLE I (next page).

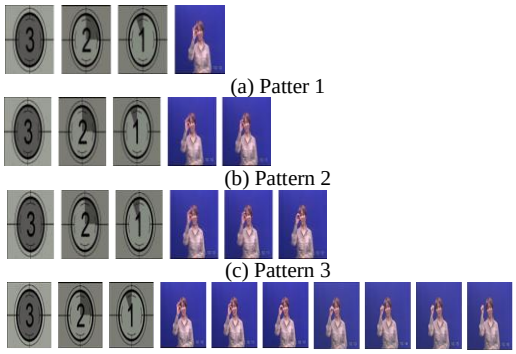

Figure 2. Example patterns for the experiment sentences

C. Subjects

A total of 13 native-signers took part in the experiment as subjects, as outlined in TABLE II. It is difficult for to the cooperation of the experiment for a hearing impaired people. In addition, this experiment takes long time. Therefore I have become 13 people in this article.

TABLE II. LIST OF SUBJECTS

Subject	Age group	Gender	Age when Subject Lost Hearing
A	60s	Female	0
B	30s	Female	4
C	20s	Male	3
D	50s	Female	5
E	60s	Female	0
F	40s	Male	3
G	40s	Female	0
H	60s	Male	1
I	60s	Female	0
J	20s	Male	0
K	40s	Female	0
L	50s	Female	0
M	50s	Female	0

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TABLE I. LIST OF SENTENCES USED IN THE EXPERIMENT

Sign language words		1st	2nd	3rd	4th
Correct sentences	1	fujisan (Mount Fuji)	miru (look)	asa (morning)	kirei (beautiful)
	2	kore (this)	yoi (good)	omou (think)	
	3	isshokenmei (to the best of one's ability)	sagasu (search)	shikashi (however)	nakatta (not there)
	4	taberu (eat)	ato (after)	tsugi (next)	nani (what)
	5	ima (now)	kyuryo (salary)	sukunai (low)	
	6	kino (yesterday)	neko (cat)	shinu (die)	kanashii (sad)
	7	ima (now)	nani (what)	tsukuru (make)	anata? (you)
	8	moshikomi (application)	ashita (tomorrow)	made (by)	daijyobu? (OK)
	9	watashi (I)	okane (money)	nai (not have)	watashi (I)
	10	kyo (today)	miru (watch)	dake (only)	owaru (end)
	11	anata (you)	kao (face)	odoroku (surprise)	nani? (what)
	12	massugu (straight ahead)	iku (go)	mura (village)	aru (there is)
	13	hon (book)	kasu (lend)	kamawanai (OK)	
	14	watashi (I)	suiei (swimming)	tokui (good at)	watashi (I)
	15	anata (you)	chichi (father)	toshi (age)	ikutsu? (how old)
	16	senshu (last week)	doyobi (Saturday)	shibai (play)	mita (see)
	17	anata (you)	suki (like)	hana (flower)	nani? (what)
	18	sono (that)	heya (room)	tabako (cigarette)	dame (forbidden)
	19	kino (yesterday)	yoru (night)	msuume (daughter)	kaetta (returned)
	20	anata (you)	shuwa (sign language)	dekiru (can do)	
Semantically unconventional sentences	1	ashita (tomorrow)	tenki (weather)	ame (candy)	
	2	watashi (I)	musuko (son)	neko (cat)	kaicho (chairman)
Phonologically unconventional sentences	1	watashi (I)	ototo (younger brothre)	shumi(opening hand from fist as in {hikari}(light) (hobby)	gemu (video games)

IV. COGNITIVE EXPERIMENT ON SIGN LANGUAGE WORDS

Table III shows the point at which the 13 subjects recognized the target word in each of the sign language sentences. The position of the out-transition and in-transition stages was determined by the native signer who compiled the example sentences.

Table III shows that, when faced with correct sentences, subjects answered most target words correctly between the out-transition from the second word and the in-transition to the third word.

Figure 3 shows the cumulative rate of recognition of target words at three points in time; during the in-transition, out-transition and word movement.

As Figure 3 clearly shows, most of the subjects recognized the target word before the target word movement. The rate of recognition also increased dramatically during the first 80% (approx.) of the time following the start of the out-transition from the second word. During the first 30% (approx.) of the time following the start of the in-transition to the target word meanwhile, the rate of recognition was over 50%.

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TABLE III. RECOGNITION TIMES FOR TARGET WORDS

Example sentences	Target word	Result (recognition)		
		Out-transition from second word	In-transition to third word	Movement for third word
Correct sentences	asa (morning)	0	1	12
	omou (think)	13	0	0
	shikashi (however)	1	7	4
	tsugi (next)	1	9	2
	sukunai (low)	1	12	1
	shinu (die)	7	6	0
	tsukuru (make)	3	9	1
	made (by)	13	0	0
	nai (not have)	13	0	0
	dake (only)	13	0	0
	bikkuri (surprise)	0	9	4
	mura (village)	0	13	0
	kamawanai (OK)	13	0	0
	tokui (good at)	8	5	0
	toshi (age)	7	6	0
	shibai (play)	8	5	0
	hana (flower)	0	5	8
	tabako (cigarette)	7	6	0
	musume (daughter)	0	9	4
	dekiru (can do)	13	0	0
Semantically unconventional sentences	ame (candy)	0	10	3
	neko (cat)	1	10	2
Phonologically unconventional sentences	Non-sign language (shumi (hobby))	0	4	9

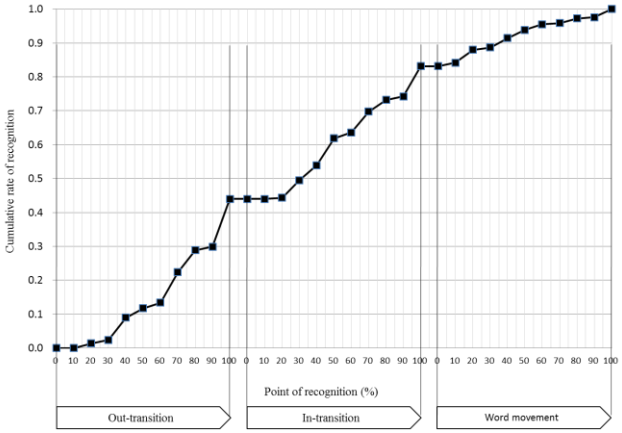

Figure 3. Cumulative rate of recognition in correct sentences

We also ran the experiment using difficult to interpret and pseudoword sentences, to examine how subjects were able to recognize words during the transition stages. In the case of difficult to interpret sentences, 3% of subjects recognized the target word during the out-transition, 67% during the in-transition, and 30% during the word movement, indicating that 70% of subjects still recognized the target word during the transition stages. The target words in the difficult to interpret sentences were sign language words whose meaning was unpredictable. It is therefore to be expected that recognition amongst the subjects would be slightly slower than normal. Although there were few correct answers during the out-transition from the second word in the case of difficult to interpret sentences, the rate of recognition shot up to 67% during the in-transition to the target word. This suggests that native signers are able to recognize words based on the transition, even when dealing with difficult to interpret sentences.

If we look at incorrect answers given in response to correct sentences, we see that the subjects incorrectly recognized very similar words as the target. The following section examines two typical examples in sign language.

Example incorrect answer 1:

{asa} → {mitomeru} {mata}
(morning) → (recognize) (again)

In the first example, the movement for the in-transition is similar. This is probably why many of the subjects recognized the target word during the word movement for the third word.

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Example incorrect answer 2:

{sukunai} → {yasui} {mata} {binbo}
(few/low) → (cheap) (again) (poor)

The second example contains a different movement for the in-transition. The sign language for the target word was supposed to be the following.

Example incorrect answer 3:

{ima} {kyuryo} {sukunai}
(now) (salary) (low)

English translation:

"My current salary is low"

It is likely that the subjects inferred from the second word {kyuryo} (salary) that the next word would be {yasui} (cheap) or {binbo} (poor).

At the same time, there were some words that more or less all of the subjects recognized during the out-transition from the second word. The words in question – {made} (by), {dake} (only), {nai} (not have), {kamawanai} (OK) and {dekiru} (can do) – all have characteristic word movements that are easy to recognize.

Based on these results, we can assume that native signers predict the next word in a sentence partway through the transition stages, based on information such as expressions and intonation.

V. CONCLUSION AND CHALLENGES FOR THE FUTURE

This paper is an experimental study into the time taken for deaf people to predict and understand words at the end of sentences when reading Japanese sign language.

We divided the sign language sentences used in the reading experiment into three different types depending on the nature of the word at the end of each sentence (the "target word"). Type A sentences ("correct sentences") contained target words that enabled the reader to correctly interpret the meaning of the sentence. Type B sentences ("difficult to interpret sentences") contained target words that were of the correct type syntactically, but that did not enable the reader to correctly interpret the meaning of the sentence. Type C sentences ("pseudoword sentences") contained target words consisting of fabricated movements based on phonemes that are absent from Japanese sign language ("pseudowords"), making it impossible for the reader to interpret their meaning.

For the experiment itself, we asked native signers to read sign language sentences following three different patterns. The results showed that, in the case of correct sentences, over 80% of the subjects predicted and correctly understood the target word before the word itself was signed. In the case of difficult to interpret sentences meanwhile, 70% of subjects predicted the target word before the word itself was signed and were able to interpret the sentences in spite of their unconventional meanings. When dealing with pseudoword sentences however, the subjects were unable to predict the signer's movements until the fabricated movement for the target word was performed.

Based on these results, we can assume that deaf people predict words and understand sentences by effectively utilizing the information required to form correct sentences, including expressions and intonation.

The challenge for the future is whether this method of reading information can be learnt through sign language education. With the clarification of ascertaining the point at which the subjects recognized the target sign language word, that can be helpful in generating sign language animation.

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