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Is pitch accent necessary for comprehension by native Japanese speakers? – An ERP investigation

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ABSTRACT

Not unlike the tonal system in Chinese, Japanese habitually attaches pitch accents to the production of words. However, in contrast to Chinese, few homophonic word-pairs are really distinguished by pitch accents (Shibata & Shibata, 1990). This predicts that pitch accent plays a small role in lexical selection for Japanese language comprehension. The present study investigated whether native Japanese speakers necessarily use pitch accent in the processing of accent-contrasted homophonic pairs (e.g., *ame* [LH] for 'candy' and *ame* [HL] for 'rain') measuring electroencephalographic (EEG) potentials. Electrophysiological evidence (i.e., N400) was obtained when a word was semantically incorrect for a given context but not for incorrectly accented homophones. This suggests that pitch accent indeed plays a minor role when understanding Japanese.

1. Introduction

Pitch accent, used in Japanese and Chinese, involves the relative prominence of pitch in a syllable or mora of a word. According to Shibata and Shibata (1990), about 14% of Japanese homophones are

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distinguished by pitch accent while this number is 71% in Chinese for tone (a distinct type of pitch accent). Given this great discrepancy in percentages, they suggested that tone in Chinese is used for distinguishing homophones while pitch in Japanese is not. Likewise, Kitahara (2006) pointed out that, in Japanese, homophonic minimal pairs (e.g., *ame* [Low (L) – High (H)] for 'candy' and *ame* [HL] for 'rain') include words that usually differ in frequency (i.e., one is much more frequent). Once frequency-divergent homophone pairs are excluded, the number of homophones which are strictly distinguished by pitch falls below 10% which corroborates the minor role of pitch accent in distinguishing homophone pairs (as proposed by Shibata & Shibata, 1990).

An electrophysiological component often used in the study of language is the N400. The N400 is a centro-parietal relative negativity peaking around 400 ms after stimulus onset (see: Kutas & Federmeier, 2011). The component in itself does not need to be negative; rather, the comparison between experimental conditions such as in the semantic violation: 'He spread the warm bread with socks.' versus its control 'He spread the warm bread with butter' (Kutas & Hillyard, 1980) tends to elicit a relative negative amplitude for the incongruent condition (coined the "N400-effect"). This effect has been observed for a wide range of word processing studies investigating differences in word frequency (van Petten & Kutas, 1990), word neighborhood size (Holcomb, Grainger, & O'Rourke, 2002), and cloze probability (Kutas & Hillyard, 1980, 1984). It has been suggested that the N400 is sensitive to the relative ease with which the meaning of a word is integrated into the surrounding context.

Results of N400 elicitation were reported in studies on the role of tone accent in (Beijing) Mandarin Chinese (Li, Yang, & Hagoort, 2008; Schirmer, Tang, Penney, Gunter, & Chen, 2005; Xi, Zhang, Shu, Zhang, & Li, 2010; Zhao, Guo, Zhou, & Shu, 2011) showing that a tone violation in monosyllabic or disyllabic homophones (e.g., 花/hua1/'flower' instead of画/hua4/'painting') elicited an N400 during spoken language comprehension. In the case of Chinese, the N400 therefore indicated that when an incorrectly accented word was embedded in a context indeed the erroneous lexical item had been selected from the mental lexicon. Similarly, in Japanese, Hayashi et al. (2001) found an N400 elicitation for pitch violations. This study used a question and answer correspondence task. Participants first were given a question such as: 'What color is the traffic light indicating stop?' Subsequently, one of three answers was presented: (1) a correctly-accented condition:/aka/(HL) meaning 'It is red.', (2) an incorrectly-accented homophone:/aka/(LH) meaning 'It is dirt.', and (3) a one-phoneme-changed semantically-mismatched word:/ama/(HL) meaning 'It is a nun.' However, it has been shown that contextual predictability also elicits an N400 (e.g., van Berkum, Brown, Zwitserlood & Kooijman & Hagoort, 2005; Delong, Urbach, & Kutas, 2005; Hagoort, Hald, Bastiaansen, & Petersson, 2004). For instance, Dutch trains are painted 'yellow', not 'white'. This predictability from world knowledge elicits an N400 in language comprehension when the target word 'white' deviates from the well-known fact that trains are 'yellow' (Hagoort et al., 2004). A 'red' traffic signal indicating stop is commonly-used all over the world. Thus, after presentation of the question, participants may have easily anticipated the upcoming word in this particular paradigm. It is possible that the N400 elicitation was caused by predictability arising from world knowledge, rather than a pitch accent violation.

Similarly, an N400 was found on pitch accent violation of verbs (Koso & Hagiwara, 2009; Koso, Ojima, & Hagiwara, 2011). Japanese is a head-final language (*head* referring to a verb), in which a verb is positioned at the end of the sentence. Various studies (e.g., Kamide, Altmann, & Haywood, 2003; Kamide & Mitchell, 1999) have indicated that, for processing sentences of such languages, speakers are able to incrementally construct syntactic structure prior to seeing the head verb. This is called *pre-head anticipation processing*. However, Koso and colleagues (Koso & Hagiwara, 2009; Koso et al., 2011) mainly used highly-predictable verbs (e.g., LHL-pitch *tabe-ru* for present tense 'eat', and HLL-pitch *tabe-ta* for past tense 'ate'). As such, prediction from sentential context could again have elicited an N400 (e.g., van Berkum et al., 2005). In addition, pitch accent for verb tense also follows rule-based regularities, rather than being an individual lexical property; therefore an N400 might also be caused by accent regularity on verb tense.

The current study would therefore like to substantiate and extend the earlier N400 findings obtained in Japanese. To do this we employed electroencephalography (EEG) to investigate whether native Japanese speakers necessarily activate pitch accent when accessing the concept of a lexical item in the processing of accent-contrasted homophonic pairs by embedding these words in simple sentences which are less susceptible to the possible alternative interpretations mentioned earlier. We also

included a non-homophonic semantic deviation to make sure that any absence of a N400-effect for incorrectly accented target words was not due to experimental factors.

To summarize, we expect an N400-effect for semantically incongruent words compared to correctly-accented words. Additionally, if Japanese speakers unequivocally process pitch accent when accessing meaning, we also expect an N400 effect for incorrectly-accented targets in context sentences (compared to correctly-accented words). However, if Japanese speakers do not use pitch accent for comprehension we hypothesize that the N400-effect will be absent.

2. Methods

2.1. Participants

Nineteen right-handed native Japanese speakers (8 female; mean age: 20.2 years, SD = 1.5) living in Aichi Prefecture (central part of Japan; classified as part of the Tokyo standard dialect region; Daijirin, 2013), participated in the experiment. All participants were university students at Nagoya University, and familiar with Tokyo standard pitch accent according to a questionnaire given prior to the experiment. No participant reported any neurological problems. Informed consent was obtained before the experiment.

3. Materials

Twenty-four matched words having the same sounds but different accents were embedded in the same sentence across three conditions. For example, as shown in Fig. 1, the first condition was a sentence with a correctly-accented target word in the Tokyo-standard accent such as: *Kinyuu kiki-de yooroppa zentai-no tsuuka-ga geraku shita* 'Due to the financial crisis, currency dropped throughout Europe'. In this condition, the underlined word *tsuuka-ga* [HLL-L] 'currency' was used as the correctly-accented target word.

To ascertain that the stimuli for the first condition were not particularly predictable (compared to Hayashi et al., 2001; Koso et al., 2011), we conducted a pilot paper-and-pencil prediction test for all 48 sentences. We tested 41 native Japanese university students (31 males; average age: 20 years, SD = 0.6; not included in EEG experiment). For example, a sentence with a bracket for a target word *Watashi-wa toshokan-de* ( )*-o yomuno-ga sukida*, meaning 'I like to read ( ) at the library' was presented to students. The target word of this sentence is 'a biography'. If a student filled in this word, it was counted as 1. The results revealed a low average predictability rate of 22.8% which discounts a great role for predictability regarding the stimuli used in the EEG experiment.

The second condition was the same sentence containing an incorrectly-accented target word that was minimally similar, yet had a different accent and *if accent is lexically distinctive* thus has a different meaning. In the case of the homophone target pair, *tsuuka-ga* [HLL-L] 'currency' would be changed to *tsuuka-ga* [LHH-H] 'passage' or 'transit', resulting in a sentence indicating: 'Due to the financial crisis, passage dropped throughout Europe'. The sound of the entire sentence is exactly the same as in the first condition except the accent of *tsuuka-ga* [LHH-H] 'passage'. The *tsuuka-ga* homophone pairs can be altered to the correct/incorrect accents to create congruent/incongruent sentence meanings. In this pair-matching approach, 24 paired target words were used to create 48 paired sentences. The third condition was the same sentence with a semantically-incompatible word, such as *huton-ga* 'futon', which contains the same number of morae (3) as *tsuuka-ga* 'currency' and 'passage'.

The underlined words in the example pair of Japanese sentences were the targets or "trigger" words, for which sound initiation was time-locked to the event-related potentials (ERPs) calculated in subsequent analyses. Since the 24 pairs of correctly and incorrectly accented homophones were reversed in correct and incorrect accents in sentences, these 48 sentences had identical word frequency ($M = 10.4$). Semantically incorrect words matched with these paired words had an average word frequency of 10.5. A one-way analysis of variance (ANOVA) was conducted on word frequencies across three conditions, indicating no main effect [$F < 1$]. The same ANOVA was conducted using a natural logarithm transformation from raw word frequencies (see Baayen, Feldman, & Schreuder, 2006; $M = 7.7$ for the paired conditions and $M = 8.3$ for the control condition). Sixteen sentences (8

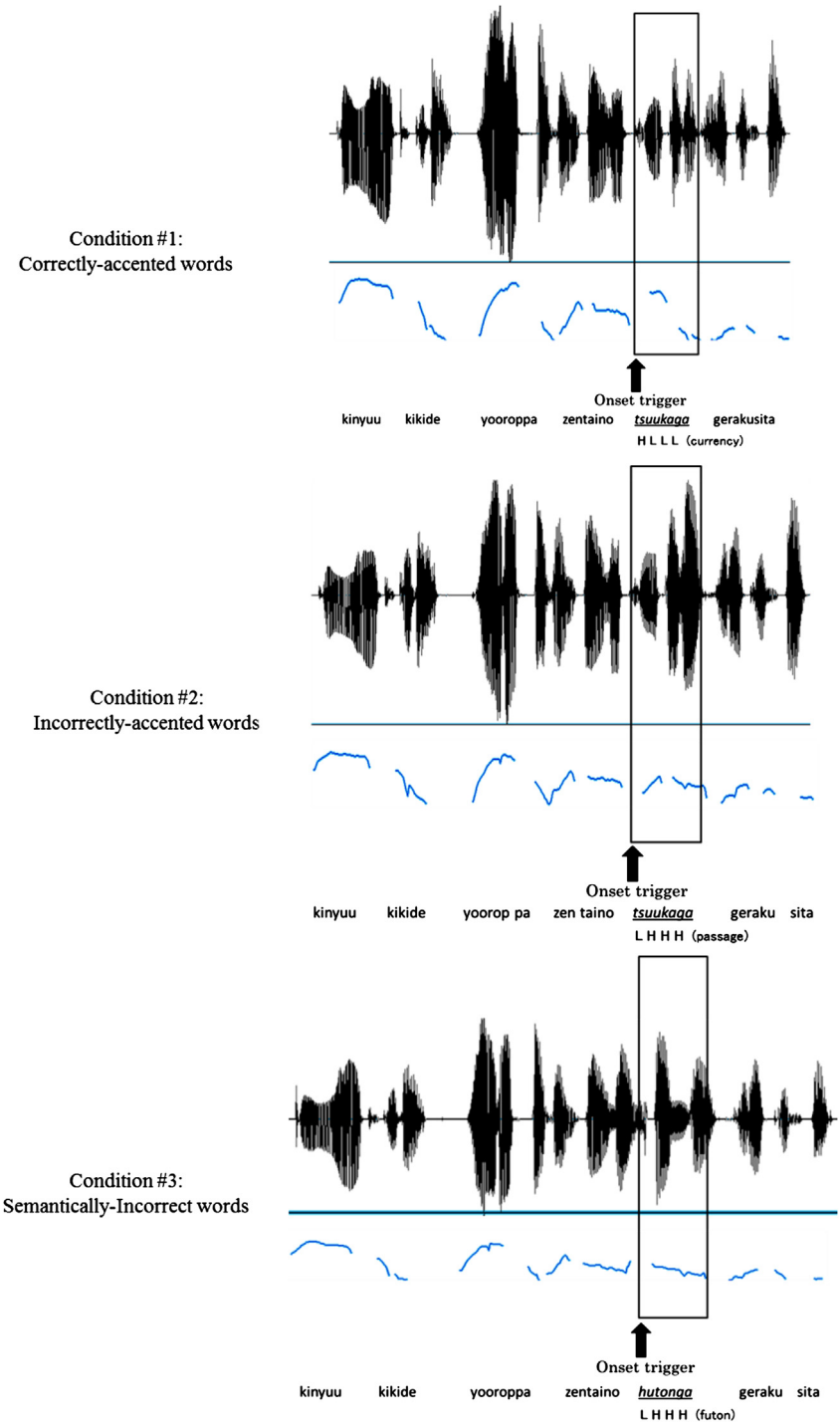

Fig. 1. Example for the three stimulus conditions.

correct, 8 incorrect; not included in experiment proper) were created to serve as practice sentences before the experiment started. The result also showed no main effect [$F(2, 141) = 1.88$, $p = .16$].

All sentences were recorded by Nobuhiro Saito (born in the Kanto area, Tokyo standard dialect speaker) a specialist in Japanese pitch accent patterns (see Saito & Uchibori, 2003) and are available at http://www.lang.nagoya-u.ac.jp/~ktamaoka/.

The sound durations of whole sentences across the three conditions were controlled to be equal, with a mean duration of 3.08 s for correctly-accented sentences, 3.09 s for incorrectly-accented sentences, and 3.12 s for sentences with control words. A one-way ANOVA revealed no significant differences between sentence sound durations [$F < 1$]. In addition, the sound durations of target trigger words across the three conditions were also controlled. The means were 1.58 s for correctly-accented sentences, 1.58 s for incorrectly-accented sentences, and 1.60 s for control sentences. A one-way ANOVA revealed no main effect of duration [$F < 1$].

In addition to the 144 sentences (48 sentences $\times$ 3 conditions) used for analysis, 46 filler sentences were added to divert attention from the experimental manipulation, totaling 48 target sentences $\times$ 2 pairs + 48 semantically-incorrect sentences + 48 filler sentences = 192 sentences. Examples of filler sentences are *Aki-ni Naruto-wa sanma-ga oisii desu-ne* 'In autumn, pike is tasty' and *Seishikina syorui-wa tegaki-de kaitekudasai* 'Please write an official document by hand'. The total of 192 sentences was presented pseudo-randomly to each participant (pseudo means that the same sentences could not follow each other).

4. Procedure

Participants were tested individually in a sound attenuated room and gave informed consent before the experiment started. First of all, EEG measurements were acquired on 32 scalp sites by attaching tin electrodes mounted in an electrode cap off-line referenced to the left and right mastoids. Using BioSemi Actiview continuous EEG sampling was performed at 512 Hz. Eye-blinks were measured with one electrode placed above and another underneath the left eye. Eye-movements were measured with two electrodes, one on the external canthi of each eye. We used E-prime 2.0 for stimulus presentation as well as putting marker data into the continuous EEG signal. Before the experiment proper started participants were given 16 practice trials to familiarize themselves with the experiment. The experiment consisted of three blocks with a small break between each block.

5. Design

A trial started with 1500 ms of fixation followed by an auditorily presented sentence. The ERPs were time-locked to the initiation of the critical target word embedded in the auditorily presented sentence. Since it is possible to perform the task by detecting an incorrectly-accented word before listening to the entire sentence, responses were to be made when a '?' was displayed which was 1 s after the sentence ended. Only accuracy but not reaction times were analyzed due to this delay in the response task.

6. Results

6.1. Accuracy data

Judgment accuracy was 97.0% for correctly rejecting sentences with semantically-incompatible words, 92.5% for correctly accepting sentences with correctly-accented words, and 87.7% for correctly rejecting sentences with incorrectly-accented words. An LME (linear mixed effect) model analysis showed a significant main effect [$F(2, 4128) = 37.22$, $p < .001$]. Multiple comparisons showed that the incorrect pitch accent condition was more difficult than the other two conditions. Although, native Japanese speakers showed very high accuracy rates across the three conditions, they made more errors rejecting incorrectly-accented words.

6.2. ERP data

The EEG data were corrected for eye-blink artifacts using the Gratton, Coles, and Donchin (1983) algorithm. Ocular and non-ocular artifacts were removed from further analyses. Filters (high-pass: 0.01 Hz/24 dB and low-pass: 40 Hz/24 dB) were applied. Epochs of 800 ms were computed with a 200 ms pre-stimulus baseline. Trials with artifacts were removed from the analysis (5.2% of the data). These artifacts were equally distributed over the conditions. The mean amplitudes of the remaining ERP trials was on average 46 (SD = 3.6) and were submitted to a repeated-measures ANOVA with Condition (correct-accent, incorrect-accent, and semantically-incongruent) and Localization (frontal: AF3, AF4, F3, F4, F7, F8, Fz versus central: C3, C4, Cz, FC1, FC2, CP1, CP2 versus posterior: P3, P4, P7, P8, PO3, PO4, Pz) as the independent factors. Time window selection was based on visual inspection: 100–200 ms and 250–700 ms (N400).

100–200 ms. There was neither a main effect of Condition [$F(2,36) = 1.88$, $MSe = 28.16$, *ns*] nor an interaction with Localization [$F < 1$].

250–700 ms. There was a main effect of Condition [$F(2,36) = 11.50$, $MSe = 58.66$, $p < .001$] which interacted with Localization [$F(4,72) = 5.12$, $MSe = 5.19$, $p < .005$]. Separate analyses for each brain region revealed a main effect of condition throughout all brain regions [frontal: $F(2,36) = 3.68$, $MSe = 26.45$, $p < .05$; central: $F(2,36) = 13.96$, $MSe = 23.03$, $p < .001$; posterior: $F(2,36) = 16.96$, $MSe = 17.40$, $p < .001$]. Planned comparisons demonstrated that the N400 revealed more negative amplitudes for the semantically-incompatible condition compared to both the correct-pitch accented condition [frontal: $F(1,18) = 3.68$, $MSe = 36.16$, $p < .05$; central: $F(1,18) = 13.96$, $MSe = 42.31$, $p < .005$; posterior: $F(1,18) = 16.96$, $MSe = 32.20$, $p < .001$] and the incorrect-pitch accented condition [frontal: $F(1,18) = 4.50$, $MSe = 63.41$, $p < .05$; central: $F(1,18) = 19.72$, $MSe = 53.25$, $p < .001$; posterior: $F(1,18) = 22.91$, $MSe = 39.37$, $p < .001$]. However, importantly, *the incorrectly-accented words did not differ from the correctly accented words* [frontal and central: $F < 1$; posterior: $F(1,18) = 1.40$, $MSe = 19.54$, *ns*]. The result that pitch accent deviation in Japanese did not produce an N400, as the correctly accented but semantically incongruent condition did, indicates that pitch-accent is not a critical factor in Japanese sentence comprehension (see Fig. 2).

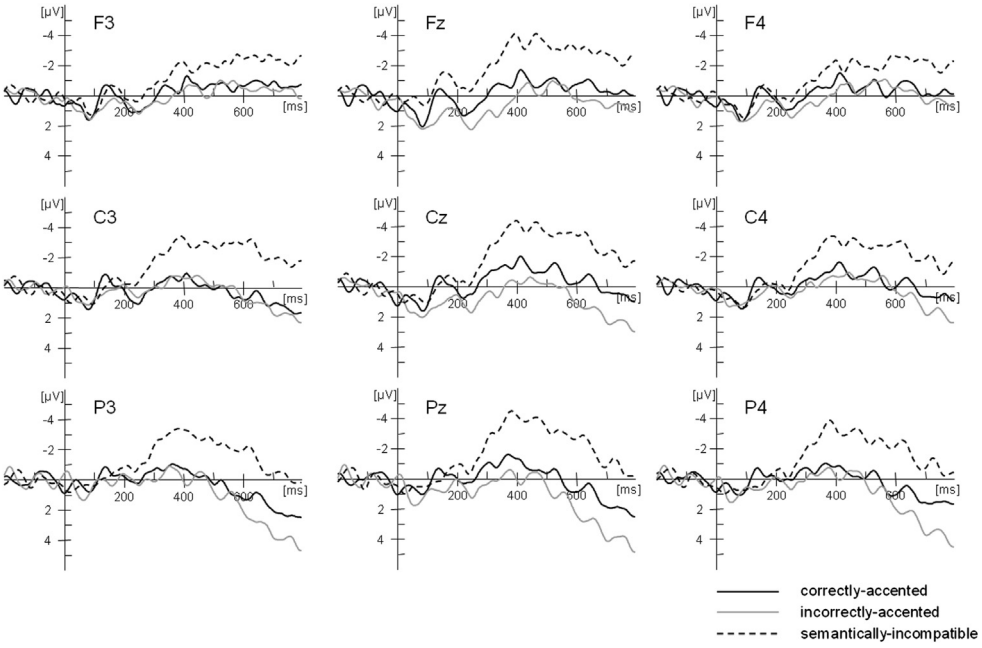

Fig. 2. Averaged stimulus-locked ERP waveforms for the conditions of pitch accent in Japanese spoken sentence comprehension.

7. Discussion

The present study did not find electrophysiological evidence (i.e., N400) for the involvement of pitch accent when processing incorrectly accented words during sentence comprehension. This absence is not the result of experimental attributes as semantically incongruent items did elicit the expected N400. Rather it is the result of retrieval of the *correct* item from the mental lexicon (although the word was incorrectly accented) for embedding in the sentence.

The absence of an N400 for incorrectly-accented items compared to correctly-accented items supports the claim made by Shibata and Shibata (1990) that Japanese pitch accents have little function in homophone distinction (opposite to Chinese where tone plays a crucial role). However, although the present study indicates that pitch accent in Japanese plays a minor role in lexical selection, previous studies (Hayashi et al., 2001; Koso & Hagiwara, 2009; Koso et al., 2011) did find neuro-correlational evidence for the distinguishing function of pitch accent. Hayashi et al. (2001) found an N400 elicitation between both pitch violation and phonemic violation in the processing of Japanese sentences. This result indicates that native speakers may still be using pitch accent to access the meaning of a homophone. However, as stated before, the N400 is confounded with high/low-predictability (Hagoort et al., 2004). Therefore, it is difficult to distinguish whether the N400 found by Hayashi et al. (2001) resulted from a violation of pitch accent or from the use of world knowledge to predict the response. It might be worthwhile to adapt the paradigm used in Hayashi's study (as well as the Koso & Hagiwara, 2009 and Koso et al., 2011 studies) by including less predictable stimuli to assess whether the N400 could still be obtained when anticipation plays a less prominent role.

It is important to note that in Japan, regional differences in pitch accent are abundant (e.g., Kindaichi, 1974; Kubozono & Ota, 1998; Sugito, 1982, 2012). Accents in the Osaka region often show pitch reversal compared to Tokyo-standard accent, such as the 4-mora utterance *boosi-ga* 'a hat', which is LHHH in Tokyo versus HLLL in Osaka. Sato (1999) reported that native Japanese speakers living in non-Tokyo-standard accent regions can comprehend Tokyo-standard accent sufficiently well to communicate with those from the region where Tokyo-standard dialect is spoken. Conversely, people from Tokyo standard dialect regions, having little knowledge of dialectic accents, can readily process the meanings from words with different accents from semantic context. In addition, there are even some dialects scattered throughout Japan which do not feature pith-accent, such as in Miyagi, Yamagata, and Fukushima prefectures (Daijirin, 2013). Speakers of these dialects can understand pitch-accent dialects spoken in other regions from Japan, unless they use completely different dialect-specific lexical items. As Japanese pitch accents diverge (or are absent) in different regional dialects of Japanese, pitch accent may not be a very reliable cue for lexical access during spoken word recognition. In summary, the present study indicated that Japanese pitch accent plays a minor role in lexical access during language comprehension. This result is consistent with existing calculations showing a low-ratio for accentual oppositions among homophones in Japanese (Shibata & Shibata, 1990). Japanese is therefore different from Chinese, in which the proportion for which homophones can only be distinguished in tone is much greater. We therefore conclude that the processing of pitch accent in Japanese and Chinese differ as a result of the number of accentual oppositions in each language.

Appendix. A. Examples of experimental target stimuli

1-1 Correctly-accented, *ju u da i* 'important' LHHH
この国会で税金を上げるかどうかは重大だ。
Kono kokkaide zeikin-o ageruka doo-ka wa juudai da.
It is serious whether a tax is raised in this parliament.

1-2 Incorrectly-accented *ju u da i* 'teens' HLLL, but sounded LHHH
この国会で税金を上げるかどうかは十代だ。
Kono kokkaide zeikin-o ageruka doo-ka wa juudai da.
It is teens whether a tax is raised in this parliament.

1-3 Semantically-incorrect *ju u de n* 'charge' LHHH
この国会で税金を上げるかどうかは充電だ。
Kono kokkaide zeikin-o ageruka doo-ka wa juuden da.
It is charge whether a tax is raised in this parliament.

2-1 Correctly-accented, *de n ki* 'biography' LHH
私は図書館で伝記を読むのが好きです。
Watashi-wa toshokan-de denki-o yomunoga sukidesu.
I like reading biographies in the library.

2-2 Incorrectly-accented *de n ki* 'light' HLL, but sounded LHH
私は図書館で電気を読むのが好きです。
Watashi-wa toshokan-de denki-o yomunoga sukidesu.
I like reading the light in the library.

2-3 Semantically-incorrect *ta ta mi* 'Tatami (Japanese traditional carpet)' LHH
私は図書館で畳を読むのが好きです。
Watashi-wa toshokan-de tatami-o yomunoga sukidesu.
I like reading the tatami in the library.

3-1 Correctly-accented, *bu do o* 'grape' LHH
こんなに甘くておいしいブドウは初めてです。
Konnani amakute oishii budoo-wa hajimete desu.
I ate the grape which is so sweet and delicious for the first time.

3-2 Incorrectly-accented *bu do o* 'the martial arts' HLL, but sounded LHH
こんなに甘くておいしい武道は初めてです。
Konnani amakute oishii budoo-wa hajimete desu.
I ate the martial arts which is so sweet and delicious for the first time.

3-3 Semantically-incorrect *ko to shi* 'this year' LHH
こんなに甘くておいしい今年は初めてです。
Konnani amakute oishii kotoshi-wa hajimete desu.
I ate this year which is so sweet and delicious for the first time.

4-1 Correctly-accented, *ta i yo o* 'sun' HLLL
東の空から少しずつ太陽が出てきた。
Higashi no sora-kara sukoshizutsu taiyoo-ga detekita.
The sun came out of the east sky little by little.

4-2 Incorrectly-accented *ta i yo o* 'ocean' LHHH, but sounded HLLL
東の空から少しずつ大洋が出てきた。
Higashi no sora-kara sukoshizutsu taiyoo-ga detekita.
The ocean came out of the east sky little by little.

4-3 Semantically-incorrect *ho n da na* 'bookshelf' HLLL
東の空から少しずつ本棚が出てきた。
Higashi no sora-kara sukoshizutsu hondana-ga detekita.
The bookshelf came out of the east sky little by little.

5-1 Correctly-accented, *ka n ji* 'Chinese character' LHH
中国で発明された漢字は日本にも伝わった。
Cyuugoku-de hatsumei sareta kanji-wa nihon-nimo tsutawatta.
The Chinese character invented in China reached Japan.

5-2 Incorrectly-accented *ka n ji* 'secretary' HLL, but sounded LHH
中国で発明された幹事は日本にも伝わった。
Cyuugoku-de hatsumei sareta kanji-wa nihon-nimo tsutawatta.
The secretary invented in China reached Japan.

5-3 Semantically-incorrect *ta nu ki* 'raccoon dog' HLL
中国で発明されたタヌキは日本にも伝わった。
Cyuugoku-de hatsumei sareta tanuki-wa nihon-nimo tsutawatta.
The raccoon dog invented in China reached Japan.

6-1 Correctly-accented, *i shi* 'stone' LH
この庭にはたくさんの石が置いてある。
Kono niwa-niwa takusan no ishi-ga oite aru.
Many stones are put in this garden.

6-2 Incorrectly-accented *i shi* 'will' HL, but sounded LH
この　庭にはたくさんの意志が置いてある。
Kono niwa-niwa takusan no ishi-ga oite aru.
Many wills are put in this garden.

6-3 Semantically-incorrect *u ta* 'song' LH
この庭にはたくさんの歌が置いてある。
Kono niwa-niwa takusan no uta-ga oite aru.
Many songs are put in this garden.

7-1 Correctly-accented, *ka ki* 'persimmon' LH
昔、裏山の寺で柿を取って食べました。
Mukashi urayama no tera-de kaki-o totte tabemasita.
I took the persimmon in the temple of the distant mountain and ate it in old days.

7-2 Incorrectly-accented *ka ki* 'oyster' HL, but sounded LH
昔、裏山の寺で牡蠣を取って食べました。
Mukashi urayama no tera-de kaki-o totte tabemashita.
I took the oyster in the temple of the distant mountain and ate it in old days.

7-3 Semantically-incorrect *i ki* 'breath' HL
昔、裏山の寺で息を取って食べました。
Mukashi urayama no tera-de iki-o totte tabemashita.
I took the breath in the temple of the distant mountain and ate it in old days.

8-1 Correctly-accented, *ka n sa i* 'west area in Japan' HLLL
私は中学生まで、関西に住んでいました。
Watashi-wa cyuugaku-made kansai-ni sunde imashita.
I lived in Kansai until junior high.

8-2 Incorrectly-accented *ka n sa i* 'pay in full' LHHH, but sounded HLLL
私は中学生まで、完済に住んでいました。
Watashi-wa cyuugaku-made kansai-ni sunde imashita.
I lived in pay in full until junior high.

8-3 Semantically-incorrect *te n sa i* 'genius' LHHH
私は中学生まで、天才に住んでいました。
Watashi-wa cyuugaku-made tensai-ni sunde imashita.
I lived in genius until junior high.

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