ORIGINAL ARTICLE

Audiovisual Temporal Recalibration for Speech in Synchrony Perception and Speech Identification

Kaori ASAKAWA^{*,†}, Akihiro TANAKA^{**,***,‡} and Hisato IMAI^{*}

^{*} Division of Psychology, Graduate School of Humanities, Tokyo Woman's Christian University,
2-6-1 Zempukuji, Suginami-ku, Tokyo 167-8585, Japan

^{**} Department of Psychology, Faculty of Letters / Graduate School of Humanities and Sociology, University of Tokyo,
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan

^{***} Waseda Institute for Advanced Study, 1-6-1 Nishi Waseda, Shinjuku-ku, Tokyo 169-8050, Japan

Abstract: We investigated whether audiovisual synchrony perception for speech could change after observation of the audiovisual temporal mismatch. Previous studies have revealed that audiovisual synchrony perception is re-calibrated after exposure to a constant timing difference between auditory and visual signals in non-speech. In the present study, we examined whether this audiovisual temporal recalibration occurs at the perceptual level even for speech (monosyllables). In Experiment 1, participants performed an audiovisual simultaneity judgment task (i.e., a direct measurement of the audiovisual synchrony perception) in terms of the speech signal after observation of the speech stimuli which had a constant audiovisual lag. The results showed that the “simultaneous” responses (i.e., proportion of responses for which participants judged the auditory and visual stimuli to be synchronous) at least partly depended on exposure lag. In Experiment 2, we adopted the McGurk identification task (i.e., an indirect measurement of the audiovisual synchrony perception) to exclude the possibility that this modulation of synchrony perception was solely attributable to the response strategy using stimuli identical to those of Experiment 1. The characteristics of the McGurk effect reported by participants depended on exposure lag. Thus, it was shown that audiovisual synchrony perception for speech could be modulated following exposure to constant lag both in direct and indirect measurement. Our results suggest that temporal recalibration occurs not only in non-speech signals but also in monosyllabic speech at the perceptual level.

Keywords: audiovisual temporal integration, speech perception, temporal recalibration, simultaneity judgment, the McGurk effect

1. INTRODUCTION

People can encounter a temporal mismatch between audio and visual signals due to technical limitations in a live satellite broadcast, video streaming or video calls via the Internet. Previous psychophysical studies have found that audiovisual temporal asynchrony is tolerated to some extent. This characteristic for audiovisual temporal integration, including synchrony perception, has been examined using various kinds of stimuli (e.g., a circle and tone [1], a video and sound of object action [2, 3], music [3, 4], or speech [1-9]) and tasks (e.g., simultaneity judgment [1, 8], temporal order judgment [3, 4, 7, 9], or speech identification [5-8]). Some studies have argued that the characteristics of audiovisual synchrony perception depend on various properties of the stimuli (e.g., complexity, duration [3]) and tasks (e.g., simultaneity / temporal order judgment, speech identification [7, 10]) (see [11] for review).

Recent studies have shown that the characteristics of audiovisual synchrony perception are recalibrated after adaptation to a constant timing difference between auditory

and visual signals. Previous studies showing this temporal recalibration have demonstrated that the participants could adaptively shift their perception of audiovisual synchrony following exposure to a series of desynchronized simple audiovisual pairs toward the exposure lag [12, 13]. These results suggest that exposure to an audiovisual temporal mismatch could modulate the characteristics of audiovisual synchrony perception and diminish the conflict of the exposed lag.

The above studies [12, 13] used simple non-speech pairs of sound and light. However, the signals that we encounter in the real world are more complex (e.g., speech, music, or action). In particular, speech signals play an important role in daily communications. In fact, the characteristics of audiovisual temporal integration for speech have been shown to be different from those for non-speech in some previous studies (e.g., [2], but see also [1, 14]). Given these aspects of speech, in order to reveal the temporal recalibration of audiovisual speech, it is appropriate to use a speech signal, not a simple non-speech signal.

Several studies have investigated temporal recalibration using a speech signal [10, 15, 16]. Vatakis et al. [16] conducted a study in which participants were required to make a temporal order judgment (TOJ) regarding vowel-consonant-vowel (VCV) speech-sounds and visual-speech gestures presented with various stimulus onset asynchro-

[†] Present affiliation: Research Institute of Electrical Communication and Graduate School of Information Sciences, Tohoku University,
2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan

[‡] Corresponding author: akih.tanaka@gmail.com

nies (SOA). They were asked to render TOJs under two adaptation conditions that involved presentation of a continuous and co-occurring background (i.e., an on-line adaptation method) consisting of an audiovisual speech stream of words. One adaptation condition presented the background stream in audiovisual synchrony, whereas in the other adaptation condition, the background auditory speech stream lagged behind the visual speech stream. Participants performed the TOJ task in either a single task condition (i.e., dedicated to performing the TOJ task) or a dual-task condition (i.e., performed the TOJ task in parallel with counting the number of male names included in the background speech stream). A significant difference of synchrony perception between adaptation conditions was observed in the direction of the adaptation (background speech) stimulus only when participants made a TOJ in the dual-task condition. This result suggests that synchrony perception of audiovisual speech is drawn toward the monitoring asynchrony only during a dual-task situation.

Although the above studies [10, 15, 16] using the on-line adaptation method have demonstrated temporal recalibration of a speech signal, more consideration appears to be necessary in order to elucidate the temporal recalibration for speech. First, the results of these studies were limited to a dual-task situation. This suggests that the factor responsible for inducing the observed temporal realignment may involve the attention paid to background speech in the on-line adaptation method. However, it is also possible that a decline of some attentional resource for the target stimulus affects the temporal recalibration. In the latter case, the results from the on-line adaptation method might tap a mechanism different from recalibration results (described earlier) in which adaptation stimuli are presented prior to a pair of target audiovisual items (i.e., off-line adaptation paradigms). An off-line adaptation method presumably would allow participants to focus more effectively on target stimuli. Thus, using the off-line adaptation method for speech stimuli may provide a significant advantage that should help reveal critical aspects in temporal recalibration for speech.

A second limitation of past research on temporal recalibration for speech is the ubiquitous use of direct measures of perceived simultaneity. Most studies have required participants to directly judge simultaneity. Because most of the information in any direct task is open to conscious inspection, the resulting judgments of asynchronies can easily reflect deliberate response strategies rather than a perceptual process (see [12, 17]). In order to reduce this possibility, it is useful to supplement direct measures with an indirect (implicit) measure. If the temporal recalibration of speech were observed using both direct and indirect measures, then this would strongly support the idea that

recalibration is based upon a perceptual change and is not due to cognitive bias.

In this study, we investigated the modulation of the characteristics of audiovisual synchrony perception (i.e., temporal recalibration) for speech following exposure to asynchrony using both direct and indirect measures. As a direct measure, in Experiment 1 we used a simultaneity judgment task; as an indirect measure, in Experiment 2 we used a speech identification task. Specifically, in the latter we used a phenomenon known as the McGurk effect [18]. In this case, the McGurk effect relies upon dubbing of an auditory /pa/ onto a visual /ka/. Using these syllables, in Experiment 2, participants experiencing this clip should hear /ta/ if they can integrate an auditory /pa/ with a visual /ka/. The greater the perceived audiovisual synchrony of these speech elements, the stronger the McGurk effect [6, 8].

2. EXPERIMENT 1

2.1 Methods

Ten participants (mean age of 23.4 years) took part in Experiment 1. All had normal hearing and normal or corrected-to-normal visual acuity. All were native Japanese speakers. They gave informed consent to participate in the study according to the Declaration of Helsinki.

Stimuli were based on digital audio and video recordings of a female native Japanese speaker. The visual materials were recorded using a DV camera (HDR-A1J, Sony). Auditory stimuli were collected using a condenser microphone (ECM-77B, Sony). The audio uttering of /pa/ was dubbed onto an audio track of a video uttering of /ka/ (frontal view, including head and shoulders) using Sound Forge 8.0 (Sony) to achieve precise timing of onsets of these two stimulus items. The video clip (640 × 480 pixels, Cinepak Codec video compression, 30 frames/s) and the auditory speech (16-bit and 48-kHz audio signal digitization) were synthesized and desynchronized using Adobe Premiere Pro 2.0. The duration of the original (i.e., synchronized) clip was 1468 ms. A still image was extracted from the first and the last frame of the video clip and added to the beginning and end of the video clip to fill the blank field.

The experiment had two conditions that functioned as within-subject variables. One condition was adaptation lag which involved an audio delay of speech sounds relative to visible speech of either 0 or 233 ms. The other condition was stimulus onset asynchronies (SOAs) between the visual-speech element and a speech-sound in the test stimuli. Here, as with adaptation lag, the onset of the visual stimulus preceded that of the sound by a variable audio delay that assumed seven levels (0, 66, 133, 166, 233, 300, 433 ms). That is, we considered only SOAs

involving audio (not visual) delays in the interest of ecological validity, given that these asynchronies are the most common ones.

The experiment was conducted in a soundproof room. The participants were seated wearing headphones (HDA 200, Sennheiser) at a distance of approximately 50 cm from a 17-inch CRT monitor (CPD-E220, Sony). The speech-sound was presented at a sound pressure level of approximately 65 dB. Pink noise overlapped the speech-sound at 65 dB (i.e., S/N 0 dB) in order to decrease the intelligibility of the auditory stimulus and to enhance the McGurk effect [19] in Experiment 2. The video clip was presented on a black background using Real Player Ver. 10.5 (RealNetworks).

Each session started with an adaptation phase of 3 min (see Figure 1). This phase was characterized by a constant time lag (0 or 233 ms) between the visual speech and the speech sound. After this adaptation phase, test trials were conducted. Each test trial was preceded by a 10-s re-adaptation phase (with lags of either 0 or 233 ms). The McGurk token described above was presented 96 times in an adaptation sequence (i.e., 3 min.) and 5 times in each re-adaptation sequence (i.e., 10-s). The interstimulus interval (ISI) between each token in the (re-)adaptation phase was varied either 0, 400, or 800 ms in pseudorandom order. After a 2-s red-tinted still image, which was a cue of the test trial, a test stimulus was presented based on one of the seven possible SOAs. The participants' task was to judge whether auditory and visual stimuli were presented synchronously or asynchronously. Participants were instructed to respond accurately (rather than quickly) by encircling one of two choices on the response sheet. In

each session, the various test SOAs were randomly presented using the method of constant stimuli. An experimental session, which lasted approximately 20 minutes, consisted of 42 test trials (6 repetitions of the 7 SOAs). Four experimental sessions were run for each adaptation condition. The participants took part in one adaptation condition per day. The experiment was conducted for two successive days. The adaptation conditions were counterbalanced across participants.

2.2 Results

Figure 2 shows the percentages of “simultaneous” responses as a function of adaptation lag and SOA. The percent of response choices for simultaneity decreased as SOA increased¹. Table 1 (left side) shows the average number of “simultaneous” responses in each condition. Two-way analysis of variance (ANOVA) revealed a significant influence of SOA on “simultaneous” responses [$F(6, 54) = 135.39, p < .01$]; however, the main effect of adapted lag was only marginally significant [$F(1, 9) = 3.45, p < .10$]. The interaction between adaptation lag and SOA was significant [$F(6, 54) = 6.26, p < .01$]. Importantly, a post-hoc multiple comparison (Bonferroni-corrected t test) revealed that the participants gave more judgments of synchrony for an adaptation lag of 233 ms than for one of 0 ms when SOAs reflected audio delays of 166 ms and 233 ms ($p < .05$). These results show that synchrony perception in subsequent test stimuli is affected by adaptation to the timing of an audio delay during an immediately preceding adaptation phase.

The results of Experiment 1 suggest that the characteristics of synchrony perception for speech can be modulated

Figure 1: Schematic image of a session. In the 0 ms adaptation condition, auditory and visual stimuli in the (re-)adaptation phase were always presented in synchrony. In the 233 ms adaptation condition, visual stimuli always preceded auditory stimuli by 233 ms in the (re-)adaptation phase. The test stimulus in both adaptation conditions was presented based on one of seven possible SOAs (i.e., 0, 66, 133, 166, 233, 300, 433 ms).

in the direction of an adapted lag as reflected by a direct measure of perceived synchrony (i.e., simultaneity judgment). In Experiment 2, we used an indirect measure to reduce the possibility that this modulation of synchrony perception resulted from post-perceptual influences.

3. EXPERIMENT 2

3.1 Methods

Eight participants (mean age of 22.3 years) took part in Experiment 2. The apparatus and materials were identical to those of Experiment 1. The participants' task was to choose one of several syllables utterances they heard while viewing a video presentation of a mouth. They were to register their choice by encircling one of four choices on the response sheet for answers of pa, ta, ka, or other. Otherwise, the design and procedure were identical to Experiment 1.

3.2 Results

To indirectly measure perceived synchrony, we adopted the /ta/ responses as a typical McGurk illusion which emerges from a perceptual integration of an auditory /pa/ and a visual /ka/ (see [8])². The audio speech intelligibility (i.e., /pa/ responses to /pa/ sound) was 58.3% in post-test session. This intelligibility rate was comparable to that of a previous study [19], which reported that Japanese participants' intelligibility of audio-alone /pa/ sound was 56% at S/N 0 dB. Figure 3 shows the percentages of /ta/ responses (the McGurk illusion) as a function of adapted

lag and SOA. The percentage of /ta/ responses representing the audiovisual integration decreased as SOA increased, along with the percentage of "simultaneous" responses in Experiment 1. In addition, overall, the percentage of /ta/ responses was higher with an adaptation audio lag of 233 ms than with one of 0 ms. Table 1 (right side) shows the average number of /ta/ responses in each condition. Two-way ANOVA revealed significant effects of adaptation lag [$F(1, 7) = 8.31, p < .05$] and of SOA [$F(6, 42) = 24.55, p < .01$] on /ta/ responses. In contrast, the interaction of these two variables was not significant [$F(6, 42) = 1.75, p = .13$].

These results suggest that adaptation to audio delay timing alters the McGurk illusion. Participants reported more /ta/ responses in audio-delay lag following a non-zero timing lag in the adaptation phase. Our results showed that the characteristics of synchrony perception changed not only with the direct measurement but also with the indirect measurement (i.e., speech identification). This finding supports the idea that temporal recalibration for speech could be regarded as a perceptual phenomenon, not a post-perceptual change, because temporal recalibration occurred with both direct and indirect measures.

4. DISCUSSION

In this study, we investigated the temporal recalibration for audiovisual speech following an immediately preceded-

Table 1: Average percentage of responses in each condition. In Experiment 1, the number in each cell indicates the average percentage of "simultaneous" responses. In Experiment 2, the number in each cell indicates the average percentage of /ta/ responses.

	Experiment 1								Experiment 2							
	test condition								test condition							
	0 ms	66 ms	133 ms	166 ms	233 ms	300 ms	433 ms		0 ms	66 ms	133 ms	166 ms	233 ms	300 ms	433 ms	
adaptation condition																
0 ms	89.17	83.33	74.58	59.17	25.83	7.92	2.08		57.29	66.15	52.60	47.40	28.65	22.92	16.67	
233 ms	80.83	87.92	86.25	73.33	41.25	9.58	1.67		75.00	71.88	61.46	64.58	37.50	32.81	22.40

Figure 2: Percentages of "simultaneous" responses as a function of adapted lag and audio delay in Experiment 1.

Figure 3: Percentages of /ta/ responses as a function of adapted lag and audio delay in Experiment 2.

ing exposure to asynchrony (i.e., using an off-line adaptation method). We used both a direct measure of perceived synchrony (i.e., the simultaneity judgment) and an indirect measure (i.e., the McGurk identification). The temporal characteristics of “simultaneous” responses appeared to shift in a direction toward the adapted lag in Experiment 1. In Experiment 2, the results can be interpreted in two ways. First, the number of /ta/ responses increased in all SOAs. Second, the temporal tolerance for audiovisual speech integration (i.e., /ta/ responses) broadened after an adaptation to 233 ms, compared to 0 ms. Due to the consideration under regulated condition in present study, it could not be determined whether the pattern of the results in Experiment 1 and 2 were actually different. In both cases, nevertheless, the results showed that the characteristics of synchrony perception for audiovisual speech were modulated after adaptation to audio-delay timing. These results suggest that the audiovisual temporal recalibration following exposure to audio-delay timing occurs not only for non-speech signals but also for speech signals at the perceptual level.

In several respects, our results are consistent with those of Fujisaki et al. [12], which demonstrated temporal recalibration using simple non-speech signals. First, both studies showed that the characteristics of synchrony perception changed after adaptation to constant audiovisual lag, using an off-line adaptation method (also see [13] regarding this point). Second, both studies revealed that temporal recalibration occurs using both direct and indirect measures. Fujisaki et al. adopted simultaneity judgment as a direct measure and stream/bounce illusion [20] as an indirect measure. As a result, they concluded that temporal recalibration of the non-speech signal was induced at the perceptual level because the audiovisual synchrony perception changed in both measures. The similarity in the results of these studies suggests that audiovisual temporal recalibration occurs perceptually for both simple non-speech and speech. However, it is unclear whether the characteristics of synchrony perception in direct and indirect measures actually shift or widen following adaptation. As such, it remains to be elucidated whether the manner of temporal recalibration for speech is similar to that for non-speech. Future studies should attempt to clarify whether the characteristics of synchrony perception shift toward the adapted lag and/or widen.

Using the off-line adaptation method, our results showed that the characteristics of synchrony perception change even in a single-task situation, in which a participant's performance in the experimental task is not disrupted by any other task. A previous study using the on-line adaptation method has shown that audiovisual synchrony perception changes under a dual-task but not a single-task

condition [16]. This apparent discrepancy between these results points to a potentially critical factor involved in the induction of temporal recalibration for speech. In this previous study [16], participants in the single-task condition devoted themselves to the TOJ task and did not pay attention to the adaptation stimuli (i.e., background speech stream). On the other hand, participants in the dual-task condition had to divide their attention between the target stimuli and adaptation stimuli. Given these findings, it appears that a critical factor determining this pattern of finding involves attention. A change in audiovisual synchrony perception can result either from reduced attentional resources for the target stimuli or from increased attentional resources devoted to the adaptation stimuli. If the former were to be true, we predicted that the temporal recalibration should not have occurred in our off-line adaptation experiments. However, this prediction was not supported. Thus it seems implausible that the reduced attention toward target stimuli was the critical factor for temporal recalibration in speech. Taken together with the above, our results suggest that attention toward the adaptation stimulus is necessary to induce temporal recalibration for speech signals.

In summary, we investigated temporal recalibration for audiovisual speech following exposure to asynchrony using both a simultaneity judgment task and the McGurk identification task. The results showed that the characteristics of synchrony perception were modulated in both direct and indirect measures. These results suggest that temporal recalibration occurs for speech signals at the perceptual level. Our findings imply that people observing audiovisual speech contents with a constant temporal mismatch can adaptively change their perception of audiovisual synchrony and the identification for that speech after observation for a relatively short period of time (3 minutes in this study).

ACKNOWLEDGEMENTS

A part of this work was supported by a Grant-in-Aid for Specially Promoted Research No. 19001004 from the MEXT, and by the JSPS Fellowship No. 21-8191.

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Kaori ASAKAWA

Kaori Asakawa was a Ph. D student of Advanced Acoustic Information Systems Laboratory at Research Institute of Electrical Communication and Graduate School of Information Sciences, Tohoku University, Japan. She received her M. A. degree from the Tokyo Woman's Christian University in 2008, and Ph.D in Information Sciences from Tohoku University in 2011. Her research interests are audiovisual perception and cognition underlying speech communication. She was a research fellow of Japan Society for the Promotion of Science.

Akihiro TANAKA

Akihiro Tanaka is an Assistant Professor of Psychology at Waseda Institute for Advanced Study, Waseda University, Japan. He received his PhD in Experimental Psychology from the University of Tokyo in 2004. He worked as a researcher at Tohoku University, the University of Tokyo, and Tilburg University. His research interest focuses on the cognitive mechanisms underlying linguistic and affective communication. Specifically, his recent work concerns audiovisual perception of speech. He joined the editorial board of *Cognitive Studies* (Journal of Japanese Cognitive Science Society) in July 2007. He won the best presentation award from the Japanese Society of Cognitive Psychology in 2007.

Hisato IMAI

Hisato Imai is a Professor of Department of Psychology at Tokyo Woman's Christian University, Tokyo Japan. He also worked as a visiting scholar of Department of Psychology at Boston University from 2010 to 2011. He received his Ph.D in Experimental Psychology from the University of Tokyo in 1998. His research interest focuses on conscious and unconscious processes of memory; specifically, his current research interests are implicit memory, voluntary and involuntary remembering, retrieval-induced forgetting, and remembering awareness.

¹ We did not fit any curve to our data because there was no certainty that a peak of response distribution could be obtained at synchrony (i.e., SOA 0 ms). Thus, the validity of estimated values resulting from the curve fitting would not have been guaranteed if we had adopted the curve estimation.

² We obtained similar results when we used not only /ta/ but also /ka/ responses for analysis. Namely, as a result of two-way ANOVA, significant main effects of adaptation lag [$F(1, 7) = 6.19, p < .05$] and of SOA [$F(6, 42) = 23.43, p < .01$] were revealed. The interaction of these two variables was not significant [$F(6, 42) = 0.55, n.s.$].