THE EFFECT OF IRRELEVANT SOUNDS ON THE AUDITORY CONTINUITY ILLUSION

Maori Kobayashi[1,2] and Makio Kashino[2,3,4]
Department of Psychology, Rikkyo University[1],
NTT Communication Science Laboratories, NTT corpolation[2],
ERATO SHIMOJO Implicit Brain Function Project, Japan Science and Technology Agency[3],
and Department of Information Processing, Tokyo Institute of Technology[4].
Kitano,Niiza, Saitama Japan[1]; Morinosato, Atsugi, kanagawa Japan[2]
<maori@ais.riec.tohoku.ac.jp; kashino@avg.brl.ntt.co.jp >

Abstract

The effect of irrelevant sounds on the auditory continuity illusion was examined. Listeners judged whether a tone (inducee) that was repeatedly alternated with a band-pass noise (inducer) was continuous or discontinuous. A sequence of irrelevant sounds, that is, tone pips at a remote frequency from the inducee, increased the limit of illusory continuity in terms of maximum inducee level when the irrelevant sounds were synchronized with the onsets of the inducers. The effect of the irrelevant sounds depends on the timing relationship between the irrelevant sounds and the inducers. These results suggest that illusory continuity is not fully determined by local, pre-attentive processing in the auditory system.

The auditory continuity illusion is a compelling perceptual effect in which a sound (the inducee) interrupted momentarily by an extraneous sound (the inducer) is perceived as continuing through the inducer, even if the inducee is in fact physically absent during the inducer (Houtgast, 1972; Miller & Licklider, 1950; Warren, Obusek, & Ackroff, 1972; see Warren, 1999 for a review). This phenomenon is not only a powerful illusion, but represents an important ecological function of the auditory system that compensates for the effect of the masking by extraneous sounds often encountered in everyday situations.

Although the mechanism underlying the auditory continuity illusion is not fully understood, some clues have been obtained concerning the processing stage at which the illusion is created. First, the continuity illusion occurs only when there is no decrease in excitation at the frequencies of the inducee during the presence of the inducer (Houtgast, 1972; Warren, et al., 1972), suggesting that peripheral filtering in the auditory system plays a critical role. Second, the continuity illusion is sensitive to binaural disparity of the inducer and inducee (Kashino & Warren, 1996; Darwin, Akeroyd & Hukin, 2002), suggesting that illusory continuity is produced after binaural convergence at the level of the brainstem nuclei. Third, the continuity illusion affects the apparent loudness of the inducer (McAdams, Botte & Drake, 1998; Warren, Bashford, Healy, & Brubaker, 1994) and the pitch discrimination of the inducee (Plack & White, 2000), suggesting that the process responsible for the auditory continuity illusion should operate before the perceptual attributes of an auditory object are computed. Fourth, some studies employing a forced-choice task have shown that the continuity illusion can impair performance (Petkov, O'Connor, & Sutter, 2003), suggesting that the continuity illusion is an automatic and compulsory process, free from the voluntary control of listeners. Another line of evidence suggesting that the continuity illusion is an automatic process comes from a mismatch negativity (MMN) study, which showed that the illusion can occur outside the focus of attention (Micheyl, Carlyon, Shtyrov, Hauk, Dodson, & Pullver-

muller, 2003). Taken together, these findings indicate that the processing stage at which the continuity illusion is created is relatively early, local and pre-attentive.

However, this view has been challenged by a recent finding by Kobayashi, Osada & Kashino (2007), which demonstrated a transient visual stimulus that was synchronized with the onset of the noise inducer enhanced the auditory continuity illusion in most observers. The visual effect was larger when the asynchrony between the onset of the noise inducer and that of the visual stimulus was smaller. These results cannot be fully explained by the conventional theory that illusory continuity is created by the decomposition of peripheral excitation produced by the inducer. An alternative explanation is that the transient visual stimulus presented temporally close to the onset of the inducer captured attention, which otherwise would have been directed to the discontinuity of the inducee, resulting in the enhancement of the continuity illusion.

To further explore the validity of the attention hypothesis, here we examined whether the presentation of irrelevant sounds, rather than the transient visual stimuli, would also enhance the auditory continuity illusion. As "irrelevant" sounds, we used brief tone pips at a remote frequency from the inducee, assuming that such sounds are not likely to be grouped, or to interact peripherally, with the inducee or the inducer. The irrelevant sounds were presented in synchrony with the onset of inducers (Experiment 1), or at various timings (Experiment 2).

Experiment 1

Experiment 1 was conducted to examine whether the presentation of transient sounds would affect the auditory continuity illusion at all. The listener's task was to judge whether the inducee appeared continuous at various inducee levels while the inducer level was fixed. The continuity limit was defined as the highest inducee level at which an listener judged the inducee as continuous.

Method

Listeners. Eleven listeners (20-28 years of age) took part in this experiment. All had normal hearing (thresholds of 15 dB HL or better at 125-8000 Hz).

Apparatus and Stimuli. Testing was conducted in a darkened soundproof room. The stimuli were delivered to both ears through headphones (Stax SR-Λ PRO). An Apple Macintosh G5 computer was used to control the experiment and record listeners' responses. The target stimulus consisted of two sounds (an inducer and an inducee) that were presented in alternating fashion, as shown in Figure 1. The inducee was a 500-Hz sinusoidal tone, and the inducer was a one-third-octave noise band centered at 500 Hz. The duration of the inducee was 400 ms, and the duration of the inducer was 200 ms. To reduce switching transients, both inducee and inducer were gated on and off with a 10-ms raised cosine ramp. The ramps between successive sounds completely overlapped. The noise inducer was always presented at 60 dB SPL, whereas the inducee was presented in a range from 42 to 69 dB SPL on each trial. An irrelevant sound sequence consisted of seven 5000-Hz sinusoidal tone pips, of which duration was 30 ms including 10-ms cosine ramps.

Procedure. The listener judged whether the inducee was continuous or not. There were two conditions. In the *irrelevant sound* condition, the irrelevant sound was presented at each onset of the inducer. In the *control* condition, no irrelevant sound was presented. The continuity limits were measured using a method of limits procedure. On the beginning trial of an ascending series of judgments, the inducee was presented at 42 dB SPL, and the level was increased regularly in steps of 3 dB in successive trials until the listener detected discontinuity in the inducee. For a descending series of trials, the inducee was first pre-
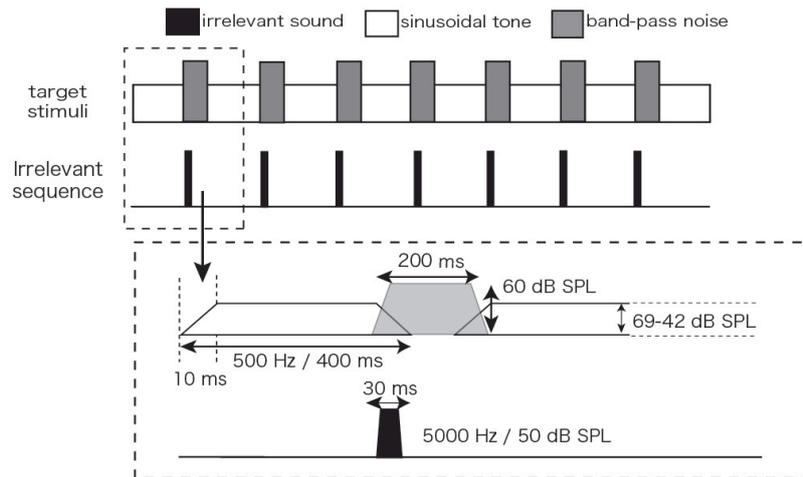
Figure 1. Stimuli used in Experiment 1. The target stimuli employed for measuring the continuity limits consisted of a 500-Hz sinusoidal inducee alternating with a 500-Hz, one-third-octave noise band inducer. The irrelevant sequence consisted of seven 5000-Hz tone pips.

sented at 69 dB SPL, and the level was decreased in 3-dB steps until the listener judged the inducee to be continuous. In each condition, the continuity measurement involved 12 series (6 ascending and 6 descending). The mean of all 12 stop points was taken as a continuity limit for the condition. The experiment lasted approximately 40 min, with a pause halfway through the session.

Results and Discussion
The continuity limits for the irrelevant sound condition ($M = 60.56$ dB SPL, $SE = 0.566$) were significantly higher than those for the control condition ($M = 57.98$ dB SPL, $SE = 0.568$) by approximately 2.5 dB SPL across listeners [$t(10) = 3.849$, $p < .05$]. These results indicate that the presentation of the irrelevant sounds enhanced the continuity illusion. Moreover, the irrelevant sound effect is as large as the visual flash effect in our previous study (Kobayashi, et al., 2007).

Experiment 2

Experiment 2 was conducted to examine the temporal selectivity of the irrelevant sound effect on the continuity illusion using the same method as in Experiment 1.

Method
   Listeners. New seven listeners (20-29 years of age) took part in this experiment. All had normal hearing (thresholds of 15 dB HL or better at 125-8000 Hz).
   Apparatus and Stimuli. The same as Experiment 1.
   Procedure. The same as Experiment 1, but seven conditions were tested: five stimulus onset asynchronies (SOAs) between the onset of the inducer and the irrelevant sound (-200, -100, 0, +100, +200 ms, where negative values indicate that the inducer preceded the irrelevant sound and positive values indicate that the inducer followed the irrelevant sound), a random condition, and a control condition. In the random condition, the SOA between an irrelevant sound and each inducer was randomly chosen from seven values between -396 and +396 ms in a sequence, so that the timing of the irrelevant sounds and the inducing noise bursts were not correlated.
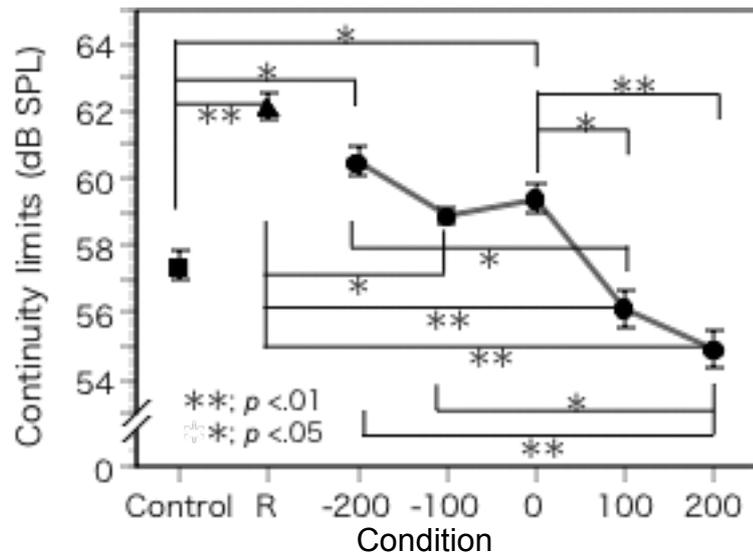
Figure 2. Continuity limits as function of the seven conditions in Experiment 2 (Control, the control condition; R, the random condition; the numbers are the stimulus onset asynchrony values, in milliseconds).

Results and Discussion

Figure 2 shows the mean continuity limits for all seven listeners. We conducted a repeated measures ANOVA on the mean continuity limits for all listeners, which revealed significant differences between the conditions [$F(6,41) = 11.28$, $p < .01$]. All pairwise comparisons, using the Tukey HSD test, revealed significant differences (see Figure 2).

These results indicate, first, that the irrelevant sounds affect the continuity illusion, confirming the result of Experiment 1. Second, the direction and the magnitude of this effect varied with the SOA between the inducer and the irrelevant sound. When the irrelevant sounds were presented before the inducers, the illusory continuity was enhanced. On the other hand, when the irrelevant sounds were presented after the inducers with the SOA of 200 ms, the illusory continuity was rather reduced. The SOA dependency demonstrated here is not similar to the previous findings on the visual effect on the auditory continuity illusion, where the largest effect was observed when the onset of the visual stimulus and that of the inducer were synchronous (Kobayashi, et al., 2007). Moreover, the continuity limit in the random condition was higher than the control condition by nearly 5 dB. This is quite different from the audiovisual case, where the effect of random visual flashes on the auditory continuity illusion was not significant (Kobayashi, et al., 2007).

General Discussion

In Experiment 1, we examined the effect of presenting irrelevant sounds synchronized with the onsets of the inducer on the auditory continuity illusion. The results of Experiment 1 showed that presenting irrelevant sounds affected the continuity illusion, and the effect was in the direction that enhances illusory continuity. These results are similar to the effect of a transient visual stimulus on the auditory continuity illusion (Kobayashi, et al., 2007). In Experiment 2, we examined the temporal tuning of the irrelevant-sound effect on the continuity illusion. The results of Experiment 2 showed that the direction and magnitude of the irrelevant-sound effect on the continuity illusion depended on the synchrony of the irrelevant sounds and the inducers. The continuity illusion was enhanced when the irrelevant sounds were pre-

sented before the inducers, but reduced when the irrelevant sounds were presented after the inducers. The largest enhancement occurred when the irrelevant sounds were presented at random timing. The results of Experiment 2 were quite different from the audiovisual case (Kobayashi, et al., 2007).

The present finding that presenting the irrelevant sounds affects the auditory continuity illusion, as well as the visual effect demonstrated in the previous study (Kobayashi, et al., 2007), cannot be fully explained by the conventional theory that illusory continuity is created by the decomposition of peripheral excitation produced by the inducer. The finding further supports the attention hypothesis that the transient stimuli presented temporally close to the onset of the inducer captured attention, which otherwise would have been directed to the discontinuity of the inducee, resulting in the enhancement of the continuity illusion. In other words, both visual and auditory irrelevant stimulus effects indicate that illusory continuity is not fully determined by local, pre-attentive processing in the auditory system.

The difference in the temporal tuning of the irrelevant stimulus effects between the present case and the audiovisual case (Kobayashi, et al., 2007) requires further consideration. A possible reason is the difference of temporal characteristics between within-modal and cross-modal attention. Investigations with additional experimental conditions are necessary.

It is not possible at this point to specify the exact neural sites where the auditory continuity illusion is created. A possible site would be the auditory cortex, because recent neurophysiological studies have revealed that many single-neuron responses in the primary auditory cortex (A1) of the awake macaque monkey closely follow the illusory continuity (Petkov, O'Conner, & Sutter, 2007) and that the spectrotemporal receptive fields of A1 neurons in the awake animal can dynamically adapt to the changing attentional focus (Fritz, Elhiali, David, & Shamma, 2007). Further research on the present effect using different approaches such as functional imaging may be promising to reveal neural mechanisms underlying the auditory continuity illusion.

Acknowledgements

References

Darwin, C.J., Akeroyd, M.A., & Hukin, R.W. (2002). Binaural factors in auditory continuity. In Nakatsu, R., & Kawahara, H. (Eds.), *Proceedings of the 8th Internarional Conference on Auditory Display* (pp. 259-262). Kyoto: ATR.

Darwin, C.J. (2005). Simultaneous grouping and auditory continuity. *Perception & Psychophysics*, **67**, 1384-1390.

Fritz, J.B., Elhilali, M., David, S.V., Shamma, S.A. (2007). Does attention play a role in dynamic receptive field adaptation to changing acoustic salience in A1? *Hearing Research*, **229**, pp. 186-203.

Houtgast, T. (1972). Psychological evidence for lateral inhibition in hearing. *Journal of the Acoustical Society of America*, **51**, pp.1885-1894.

Kashino, M., & Warren, R. M. (1996). Binaural release from temporal induction. *Perception & Psychophysics*, **58**, 899-905.

Kobayashi, M., Osada, Y., & Kashino, M. (2007). The effect of a flashing visual stimulus on the auditory continuity illusion. *Perception & Psychophysics*, **69**, pp. 393-399.

Miller, G. A., & Licklider, J. C. R. (1950). The intelligibility of interrupted speech. *Journal of the Acoustical Society of America*, **22**, pp. 167-173.

McAdams, S., Botte, M.C., & Drake, C. (1998). Auditory continuity and loudness computation. *Journal of the Acoustical Society of America*, **103**, pp.1580-1591.

Micheyl, C., Carlyon, R.P., Shtyrov, Y., Hauk, O., Dodson, T., & Pulvermuller, F. (2003). The neurophysiological basis of the auditory continuity illusion: A mismatch negativity study. *Journal of Cognitive Neuroscience*, **15**, pp.747-758.

Petkov, C. I., O'Connor, K. N., & Sutter, M. L. (2003). Illusory sound perception in macaque monkeys. *Journal of Neuroscience*, **23**, pp.9155-9161.

Petkov, C.I., O'Connor, K.N., & Sutter, M.L. (2007). Encoding of illusory continuity in primary auditory cortex. *Neuron*, **54**, pp.153-165.

Plack, C.J., & White, L.J. (2000). Perceived continuity and pitch perception. *Journal of the Acoustical Society of America*, **108**, pp.1162-1169.

Warren, R. M., Bashford, J. A., Jr., Healy, E. W., & Brubaker, B. S. (1994). Auditory induction: Reciprocal changes in alternating sounds. *Perception & Psychophysics*, **55**, pp. 313-322.

Warren, R. Obusek, C. J., & Ackroff, J. M. (1972). Auditory induction: Perceptual synthesis of absent sounds. *Science*, **176**, pp. 1149-1151.

Warren, R. M. (1999). *Auditory perception: A new analysis and synthesis*. Cambridge: Cambridge University Press.

Watanabe, K., & Shimojo, S. (1998). Attentional modulation in perception of visual motion events. *Perception*, **27**, pp. 1041-1054.

Author Note