
Bilateral Assimilation of Two Neighboring Empty Time Intervals

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In many sensory dimensions, assimilation of characteristics of perceived events can be found. In the present study, we examined whether assimilation appeared also in time perception, employing time intervals shorter than 300 ms marked by tone bursts. In Experiment 1, we measured points of subjective equality of two neighboring empty time intervals, $t1$ and $t2$. The perceived durations approached each other when the difference between $t1$ and $t2$ was small. That is, bilateral assimilation took place. In Experiment 2, we measured points of subjective equality of $t1$ in smaller steps and across a wider durational range than in Experiment 1. We found that $t1$ was overestimated slightly when it was a bit shorter than $t2$, and $t1$ was underestimated slightly when it was a bit longer than $t2$. The overestimation and the underestimation were considered as typical assimilation. The results also showed that the perception of $t1$ changed from assimilation to contrast when the difference between $t1$ and $t2$ exceeded the range $-80 \leq t1 - t2 \leq 40$ ms.

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WE report a new type of perceptual assimilation related to time perception. In many sensory dimensions, it has been observed that, when some objects or events are spatially and temporally close together, characteristics of these events can approach one another (e.g., Brown & Mueller, 1965; Helson, 1963). This phenomenon is called assimilation. In experiments with auditory stimuli, it was reported that sound sequences were classified into rhythmic categories at simple integral ratios (e.g.,

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Desain & Honing, 2003; Drake, 1993; Povel, 1981; Repp, Windsor, & Desain, 2002), and assimilation appeared also in speech perception (e.g., Repp, 1978; Shigeno & Fujisaki, 1979). It is often thought that these assimilations take place when a single continuous dimension is mapped into perceptual categories (e.g., rhythmic and phonemic categories) and does not occur directly with regard to the dimension constituting the stimulus pattern. A study of time perception (Sasaki, Nakajima, & ten Hoopen, 1998), however, suggested that assimilation in points of subjective equality (PSEs) of duration appeared when two empty time intervals were adjacent. This may indicate that assimilation takes place in the dimension of time itself.

When two neighboring empty time intervals were presented and the second time interval was longer, the duration of the second time interval was underestimated considerably in some conditions (e.g., Nakajima, ten Hoopen, & van der Wilk, 1991; ten Hoopen et al., 1993). This phenomenon has proved to be highly stable (e.g., Suetomi & Nakajima, 1998). Nakajima, ten Hoopen, Hilkhuysen, and Sasaki (1992) argued that this illusory phenomenon was a kind of assimilation, and named it "time-shrinking." They assured that time-shrinking, as assimilation, was asymmetric in time and unilateral, because the illusion appeared only when t_2 was longer than t_1 , and only the perception of t_2 was affected.

Sasaki et al. (1998) measured the PSEs of two neighboring empty time intervals and confirmed the idea that time-shrinking was unilateral assimilation. A closer look at their data shows that a different assimilation also seems to have appeared outside of the range in which the unilateral assimilation took place. When t_1 was 105 ms, and t_2 was 75 ms, t_1 was underestimated, and t_2 was overestimated significantly. That is, bilateral assimilation might have taken place. Their experiment, however, was not designed to check this particular issue systematically. In this report, we establish that bilateral assimilation takes place widely in auditory temporal patterns consisting of two neighboring empty time intervals that are mainly shorter than 200 ms.

Experiment 1

The direct aim of Experiment 1 was to examine whether bilateral assimilation would take place systematically in stimulus patterns in which the tendency had appeared, but not significantly in most cases, in the previous research (Sasaki et al., 1998). We recruited a larger number of participants and measured PSEs of two neighboring empty time intervals, t_1 and t_2 , employing the method of adjustment.

METHODS

Participants

Sixteen participants with normal hearing, ranging in age from 20 to 29 years, took part. Thirteen participants were male, and three were female. All were students at the Kyushu Institute of Design. They had received basic training in music and technical listening training for acoustic engineers (Iwamiya, Nakajima, Ueda, Kawahara, & Takada, 2003).

Stimuli and Design

Each stimulus pattern in the experimental conditions (Figure 1b and Figure 1c) comprised two neighboring empty time intervals, $t1$ and $t2$ in this order ($t1/t2$), followed by a comparison time interval, C . The time between the beginning of the standard time interval, either $t1$ or $t2$, and the beginning of C was randomly varied in a range between 3000 and 3500 ms. The sound markers that delimited $t1$, $t2$, and C were pure tone bursts of 1 kHz. Their duration was 10 ms, including a rise and a fall time of 3 ms. Their sound level was 89 dBA when a continuous tone of the same amplitude was measured by a precision sound level meter (Brüel & Kjær 2209), mounted with an artificial ear (Brüel & Kjær 4152). The total duration of $t1$ and $t2$ combined was 120, 180, 240, or 360 ms, and we divided the total duration into two durations of a simple integral ratio, namely, [1:3], [1:2], [5:7], [1:1], [7:5], [2:1], or [3:1]. We did not use the ratio at both ends when the total duration was 120 ms, because the physical duration of $t1$ or $t2$ would have been too short in these cases. Thus, when $t1 + t2$ was 120 ms, $t1$ was varied from 40 to 80 ms in steps of 10 ms. When $t1 + t2$ was 180 ms, $t1$ was varied from 45 to 135 ms in steps of 15 ms. When $t1 + t2$ was 240 ms, $t1$ was varied from 60 to 180 ms in steps of 20 ms. When $t1 + t2$ was 360 ms, $t1$ was varied from 90 to 270 ms in steps of 30 ms. The change in dura-

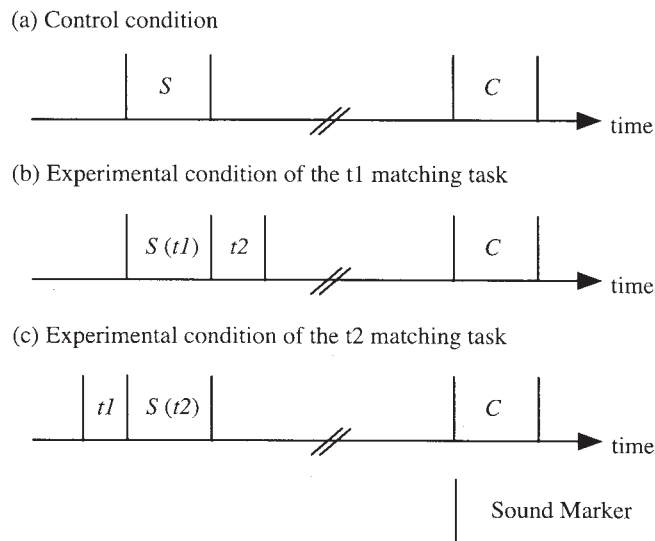


Fig. 1. Time charts of the stimulus patterns in Experiments 1 and 2. S indicates the standard time interval, C indicates the comparison time interval, $t1$ indicates the preceding time interval, and $t2$ indicates the succeeding time interval. The task of the participant was to adjust C to the same subjective duration as that of S . In Experiment 1, we used patterns (a), (b), and (c). In Experiment 2, we used patterns (a) and (b).

tion of $t2$ was complementary to that of $t1$ for each total duration. In total, there were 26 combinations of $t1$ and $t2$ for the experimental conditions [5 ($t1 + t2 = 120$ ms) + 7 ($t1 + t2 = 180$ ms) + 7 ($t1 + t2 = 240$ ms) + 7 ($t1 + t2 = 360$ ms)].

Each stimulus pattern in the control conditions (Figure 1a) comprised an isolated empty time interval followed by C . The durations of the empty time interval were the same as those of $t1$ and $t2$ in the experimental conditions, so there were 19 control conditions.

The adjustments were done both in ascending and descending series. The initial duration of C was sufficiently short (ascending series) or long (descending series) compared with $t1$ and $t2$. In total, [26 experimental conditions + 19 control conditions] \times 2 (ascending/descending series) constituted a single measurement block of 90 trials. We divided these 90 randomized trials into eight sessions. One session contained 11 or 12 measurement trials plus 2 warm-up trials.

Procedure

There were two different tasks, a $t1$ -matching task and a $t2$ -matching task. In the $t1$ -matching task (Figure 1b), the participant matched C to the subjective duration of $t1$ as the standard time interval, S . In the $t2$ -matching task (Figure 1c), the participant matched C to the subjective duration of $t2$ as S . A stimulus pattern was presented as many times as the participant requested by clicking a mouse button in a "presentation" pane on a computer screen. The duration of C could be changed freely by clicking a "shorten," "shorten (roughly)," "lengthen," or "lengthen (roughly)" pane. If the participant clicked the "shorten (roughly)" or "lengthen (roughly)" pane, the step size for changing C was larger than those achieved by clicking the "shorten" or "lengthen" pane. The participant could change the duration of C as many times as he/she wished. The participant could finish the trial by clicking a "finish" pane when he/she was satisfied with the adjustment of C . The final duration of C was recorded as the PSE.

Each participant took part in the experiment on five separate days. The first day consisted of four training sessions only. Each of the last 4 days consisted of four measurement sessions of the same task. Half of the participants did the $t1$ -matching task in the initial 2 days, and the $t2$ -matching task in the last 2 days. The other participants performed the two tasks in the reverse order. The experiment took about 10 hours in total.

Apparatus

The stimuli were computer-generated (DEC VENTURIUS FX-2; sampling frequency = 44.1 kHz) and presented monaurally via headphones (STAX Lambda Nova Basic) to the participant through a D/A converter (TEAC D-T1), a low-pass filter (NF DV-8FL; cut-off frequency = 20 kHz), and a driver unit (STAX SRM-Xh) in a soundproof room. The level of the sound bursts was calibrated with a precision sound level meter (Brüel & Kjær 2209), mounted with an artificial ear (Brüel & Kjær 4152) and a microphone (Brüel & Kjær 4144).

RESULTS AND DISCUSSION

We averaged the two PSEs of each participant in each condition, and ran analyses of variance (ANOVAs) on these mean PSEs. We did eight ANOVAs, one for each $t1$ - and $t2$ -matching task of each total duration, which we will discuss in turn. When the total duration was 120 ms, we had a 2 (control vs. experimental conditions) \times 5 (S -duration) repeated measures design for each matching task. The main effect of control vs. experimental conditions was significant in the $t1$ -matching task, $F(1, 15) = 68.61$, $p < .001$, and in the $t2$ -matching task, $F(1, 15) = 47.61$, $p < .001$.

As a matter of course, the main effect of S -duration was significant in the $t1$ -matching task, $F(4, 60) = 92.38$, $p < .001$, and in the $t2$ -matching task, $F(4, 60) = 83.60$, $p < .001$. Because it was a statistical artifact of the duration, we will not discuss this variable any more in the following analyses. The interaction effect between control vs. experimental conditions and S -duration was significant in the $t1$ -matching task, $F(4, 60) = 37.29$, $p < .001$, and in the $t2$ -matching task, $F(4, 60) = 54.04$, $p < .001$. The difference between experimental and control PSEs depended on S -duration not only in the $t2$ -matching task but also in the $t1$ -matching task. Figure 2a, in which the mean PSEs of the experimental and the control conditions are plotted as a function of the total duration ($t1 + t2$) and the stimulus pattern ($t1/t2$), clearly shows that $t2$ was underestimated in the /40/80/, /50/70/, and /60/60/ patterns, and was overestimated in the /80/40/ pattern. The same interaction pattern appeared in similar stimulus patterns in previous research (Nakajima et al., 2004) and can be explained roughly in terms of a temporal illusion called *time-shrinking*. In addition, this time, an interaction effect appeared clearly also in the $t1$ -matching task. Overestimation of $t1$ took place in the /40/80/ pattern, and disappeared in the /50/70/ pattern. Then, it was replaced with underestimation in the /60/60/, /70/50/, and /80/40/ patterns.

When the total duration was 180 ms, we had a 2 (control vs. experimental conditions) \times 7 (S -duration) repeated measures design for each matching task. The main effect of control vs. experimental conditions was significant in the $t1$ -matching task, $F(1, 15) = 4.95$, $p < .042$, and in the $t2$ -matching task, $F(1, 15) = 362.55$, $p < .001$. The interaction effect between control vs. experimental conditions and S -duration was also significant in the $t1$ -matching task, $F(6, 90) = 3.88$, $p < .002$, and in the $t2$ -matching task, $F(6, 90) = 64.15$, $p < .001$. The difference between experimental and control PSEs depended on S -duration in both matching tasks. Figure 2b clearly shows interaction not only in the $t2$ -matching task but also in the $t1$ -matching task. In the $t2$ -matching task, underestimation of $t2$ took place in the range from the /45/135/ to /90/90/ pattern, and was replaced with overestimation in the /105/75/ and /120/60/ patterns. The overestimation disappeared in the /135/45/ pattern. In the $t1$ -matching task, overestimation of $t1$ took place in the range from the /45/135/ to /60/120/ pattern and disappeared in the /75/105/ pattern. Then, underestimation appeared in the range from the /90/90/ to /120/60/ pattern and disappeared in the /135/45/ pattern.

When the total duration was 240 ms, we had a 2 (control vs. experimental conditions) \times 7 (S -duration) repeated measures design for each matching task. In the $t1$ -matching task, the main effect of control vs. experimental conditions was not significant. The interaction effect between control vs. experimental conditions and S -duration was significant, $F(6, 90) = 4.50$, $p < .001$. In the $t2$ -matching task, the main effect of

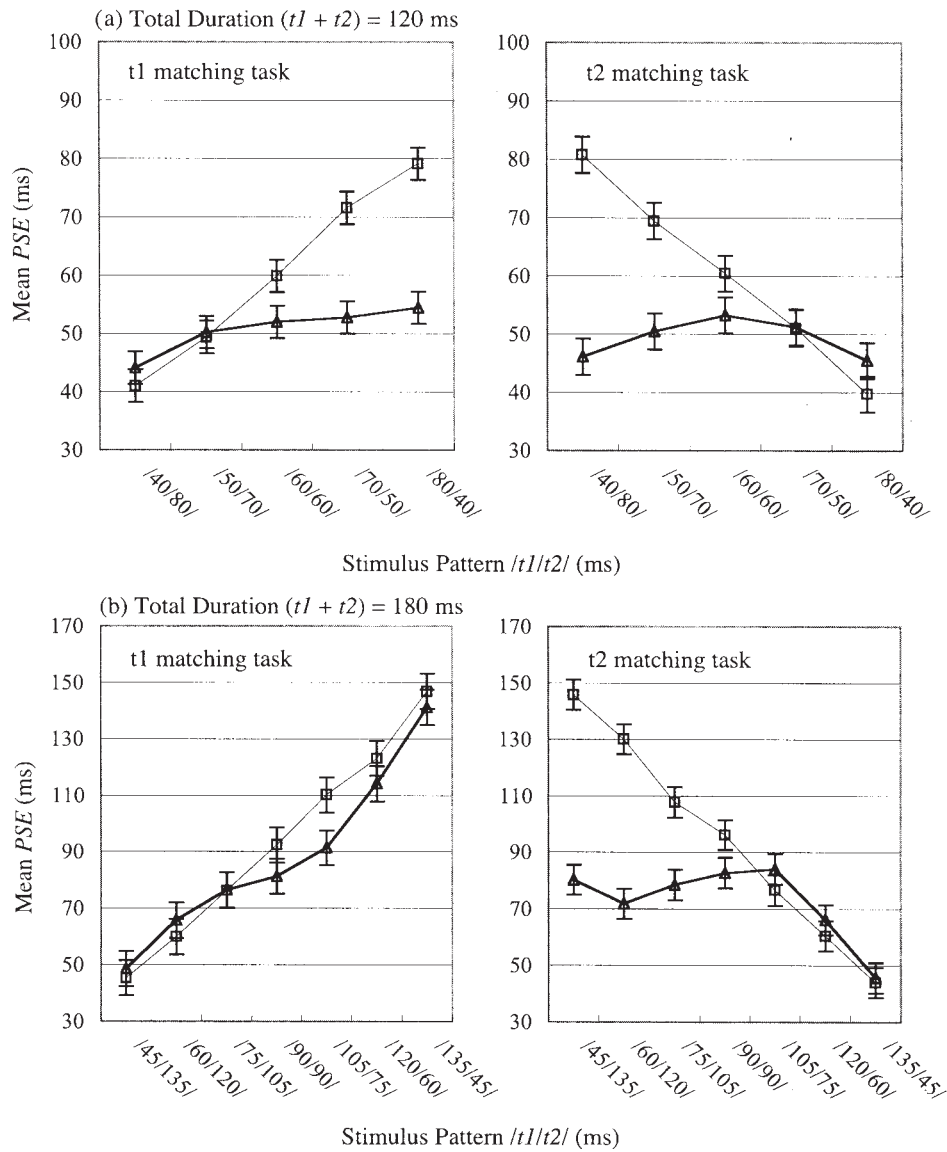
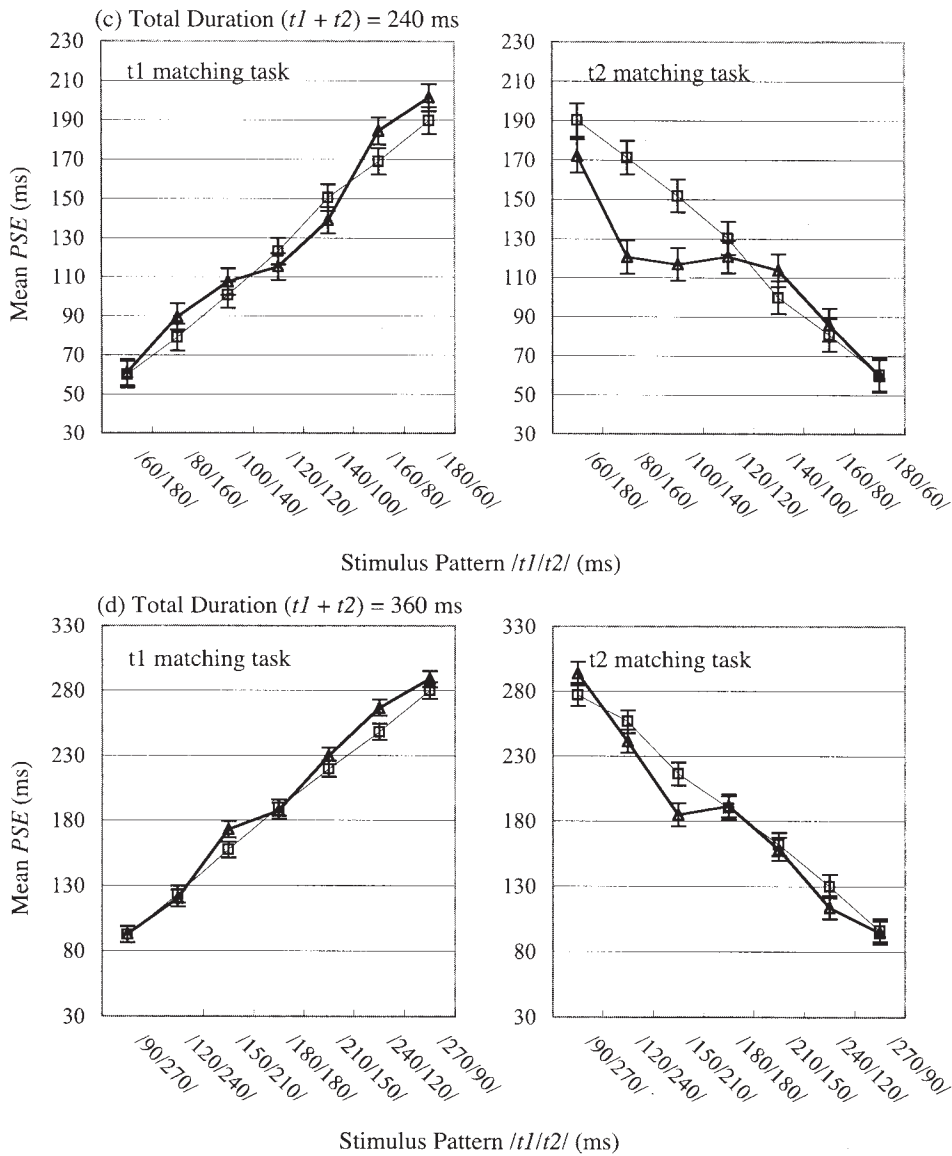


Fig. 2. Mean points of subjective equality (PSEs) of the experimental conditions (open triangles) and the control conditions (open squares) in Experiment 1 as a function of the total duration and the stimulus pattern condition, ($t1/t2$). The graphs on the left show the results of the $t1$ -matching task, and the graphs on the right show the results of the $t2$ -

control vs. experimental conditions was significant, $F(1, 15) = 25.30$, $p < .001$, and the interaction effect between control vs. experimental conditions and S -duration was also significant, $F(6, 90) = 14.52$, $p < .001$. The difference between experimental and control PSEs depended on S -duration in both matching tasks. Figure 2c shows that the pattern of interac-



matching task, for each total duration. The error bars show the 5% confidence intervals based on the 15-*df* error term from two-level (experimental condition vs. control condition) \times one-way (*S*-duration), within-subject analyses of variance applied to the data in each condition separately (Loftus & Masson, 1994).

tion was similar to that obtained when the total duration was 180 ms. In the *t2*-matching task, underestimation of *t2* took place in the range from the /80/160/ to /120/120/ pattern. Then, slight overestimation appeared in the /140/100/ pattern and disappeared in the /180/60/ pattern. In the *t1*-matching task, overestimation of *t1* took place in the /80/160/ and

/100/140/ patterns. Then, underestimation took place in the /120/120/ and /140/100/ patterns. The underestimation disappeared beyond the /140/100/ pattern and was replaced with overestimation in the /160/80/ and /180/60/ patterns.

When the total duration was 360 ms, we had a 2 (control vs. experimental conditions) \times 7 (*S*-duration) repeated measures design for each matching task. The main effect of control vs. experimental conditions was significant in the *t1*-matching task, $F(1, 15) = 6.50$, $p < .022$, and in the *t2*-matching task, $F(1, 15) = 8.70$, $p < .010$. The interaction effect between control vs. experimental conditions and *S*-duration was also significant in the *t1*-matching task, $F(6, 90) = 3.75$, $p < .002$, and in the *t2*-matching task, $F(6, 90) = 5.94$, $p < .001$. The difference between experimental and control PSEs depended on *S*-duration in both matching tasks. Figure 2d shows that underestimation of *t2* and overestimation of *t1* took place in the /150/210/ pattern. This time, underestimation of *t1* and overestimation of *t2* did not appear even when *t1* was slightly longer than *t2*, but overestimation of *t1* took place in the /240/120/ and /270/90/ patterns.

We calculated the overestimation in each experimental condition as the difference between the PSEs in the experimental condition and in the corresponding control condition (PSE_{exp} – PSE_{con}). Figure 3 shows these overestimations as a function of the total duration and the difference between the neighboring durations (*t1* – *t2*). Negative overestimations indicate underestimations. Figure 3 shows the same tendency across all total durations, except for a few conditions. When *t1* was slightly shorter than *t2*, *t1* was overestimated, and *t2* was underestimated. When *t1* was slightly longer than *t2*, *t1* was underestimated, and *t2* was overestimated, except when *t1* + *t2* = 360 ms. These overestimations and underestimations can be classified as bilateral assimilation. The bilateral assimilation disappeared when the difference between *t1* and *t2* was outside of the range $-100 < t1 - t2 < 50$ ms. This tendency indicates that the absolute difference between *t1* and *t2* is important in determining the occurrence and the degree of bilateral assimilation.

Thus, bilateral assimilation between the neighboring time intervals took place systematically. One issue was still left to be solved. The present experiment gave us no systematic information about how the PSEs would change when the difference between *t1* and *t2* was very large. Because we paid attention mainly to conditions in which bilateral assimilation could take place, we did not include conditions in which *t1* and *t2* were very different. In the /240/120/ pattern, however, *t1* was overestimated and *t2* was underestimated. This result suggested that contrast might have taken place. Nakajima et al. (2004) measured the PSEs of *t2* in similar conditions systematically, and showed that *t2* contrasted with *t1* when *t2* was longer than *t1* by 100 ms or more. The same kind of contrast might have taken place also in *t1* in the present experiment. We planned Experiment 2 to examine this issue.

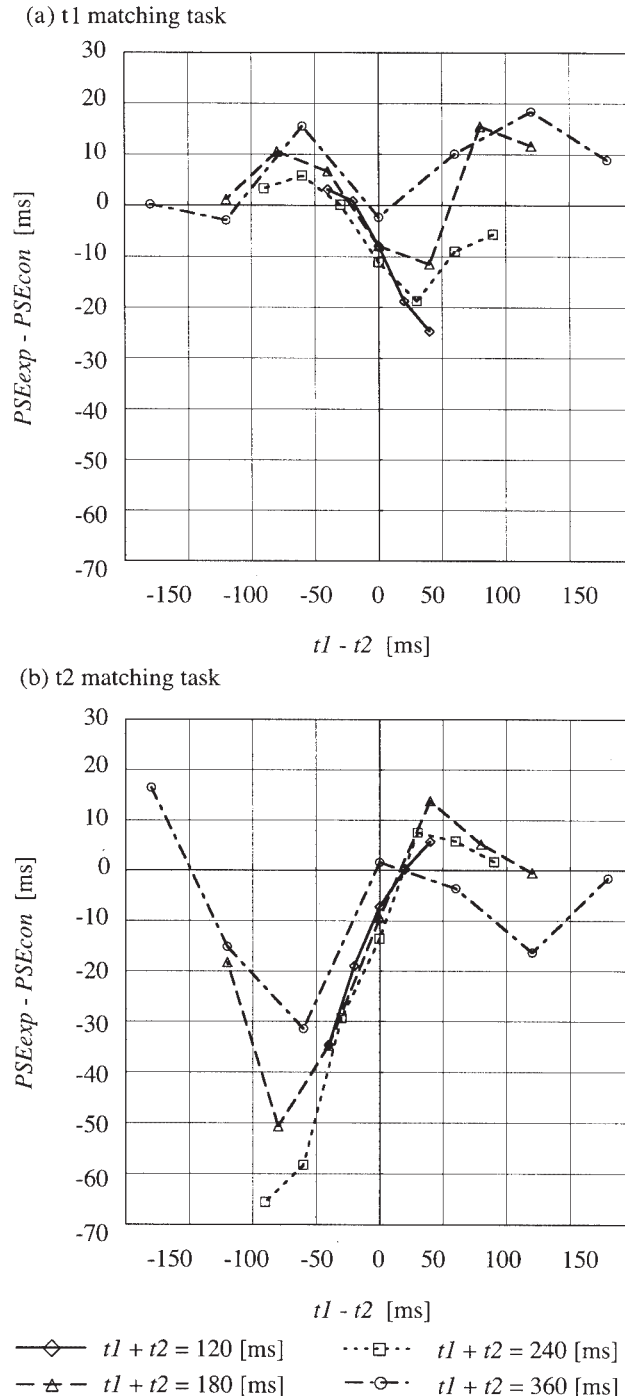


Fig. 3. Mean differences between the experimental and the corresponding control points of subjective equality ($PSE_{exp} - PSE_{con}$) in Experiment 1, for each total duration ($t_1 + t_2$), as a function of the difference between t_1 and t_2 , ($t_1 - t_2$).

Bilateral assimilation did not appear when $t1 > t2$ and $t1 + t2 = 360$ ms. This may be attributed to the large step-size of $t1$ and $t2$ used in these conditions. In future, we have to control the difference between two neighboring empty time intervals in smaller steps. The next experiment gives us some information on this point, but we will need another set of experiments to have a clearer picture.

Experiment 2

This experiment was designed in order to check whether the duration of $t1$ could be contrasted with that of $t2$ when $t1$ and $t2$ are very different. (It has been already clarified by Nakajima et al. (2004) that contrast takes place in $t2$.) Another purpose of this experiment was simply to measure the effect of $t2$ on the perception of $t1$ systematically, because we still did not have a sufficient amount of data of this kind. We used the same type of stimulus patterns as in Experiment 1, but changed the duration of $t1$ systematically in smaller steps and across a wider range. We measured the PSEs of $t1$ by using the method of adjustment.

METHODS

Participants

Four participants with normal hearing, ranging in age from 22 to 23 years, took part in Experiment 2. All were male and were students at the Kyushu Institute of Design. They had received basic training in music and technical listening training for acoustic engineers (Iwamiya et al., 2003).

Stimuli and Design

The stimulus patterns were similar to those used in Experiment 1 (Figure 1). The sound markers that delimited $t1$, $t2$, and C were the same as those in Experiment 1. The preceding time interval ($t1$) always served as the standard time interval, S , and was 40, 60, 80, 100, 120, 140, 160, 180, 200, 240, or 280 ms. The duration of $t2$ was 80, 120, or 160 ms. Combining the 11 durations of S and the 3 durations of $t2$ resulted in 33 experimental conditions. In the control conditions, only S was presented and varied in duration in the same 11 steps. The duration matching task was done both in ascending and descending series. In total, [33 experimental conditions + 11 control conditions] \times 2 (ascending/descending series) constituted a single measurement block of 88 trials. We divided these 88 randomized trials into eight sessions. One session contained 11 measurement trials plus 2 warm-up trials.

Procedure

The task of the participant was to match the duration of C to the subjective duration of S . Each participant went through two measurement blocks. The whole experiment consisted of five daily sessions. The first day consisted of four training sessions only. Each of the last four days consisted of four measurement sessions. The experiment took about 10 hours in total. The procedure was the same as in Experiment 1.

Apparatus

The stimuli were computer-generated (Dell Dimension L800r; sampling frequency = 44.1 kHz) and presented monaurally via headphones (Sennheiser HDA200) to the participant through a DAT deck that served as a D/A converter (TASCAM DA-30MK-II), a low-pass filter (NF DV-8FL; cut-off frequency = 8.3 kHz), and an amplifier (SANSUI AU-Alpha 607 NRA) in a soundproof room. The level of the sound bursts was calibrated with a precision sound level meter (Brüel & Kjær 2209), mounted with an artificial ear (Brüel & Kjær 4152) and a microphone (Brüel & Kjær 4144).

RESULTS AND DISCUSSION

We averaged the four PSEs of each participant in each condition, and ran ANOVAs on these mean PSEs. We did three ANOVAs, one for each duration of t_2 , which we will discuss in turn. When t_2 was 80 ms, we had a 2 (control vs. experimental conditions) \times 11 (S -duration) repeated measures design. As a matter of course, the main effect of S -duration was significant, $F(10, 30) = 581.42$, $p < .001$. Because it was a statistical artifact of the variable duration, we will not discuss this factor any more in the following analyses. The main effect of control vs. experimental conditions was not significant. The interaction effect between control vs. experimental conditions and S -duration was significant, $F(10, 30) = 4.35$, $p < .001$, which means that the difference between experimental and control PSEs depended on S -duration. We calculated the overestimation as the difference between the PSEs in each experimental condition and in the corresponding control condition ($PSE_{exp} - PSE_{con}$), and show these overestimations in Figure 4 as a function of the duration of t_2 and the difference between the neighboring durations ($t_1 - t_2$). Negative overestimations indicate underestimations. Figure 4a clearly shows the interaction pattern. In the range $-40 \leq t_1 - t_2 \leq 20$ ms, there was a steep increase in the amount of underestimation, and a sudden release from it at $t_1 - t_2 = 40$ ms. Assimilation of t_1 took place when $t_1 - t_2 \leq 20$ ms. Overestimation appeared, when $60 \leq t_1 - t_2 \leq 200$ ms, clearly indicating the existence of contrast.

When t_2 was 120 ms, we had a 2 (control vs. experimental conditions) \times 11 (S -duration) repeated measures design. The main effect of control vs. experimental conditions was not significant. The interaction effect between control vs. experimental conditions and S -duration was significant, $F(10, 30) = 2.86$, $p < .012$, which means that the difference between experimental and control PSEs depended on S -duration. Figure 4b shows an interaction pattern similar to that obtained when t_2 was 80 ms. In the range $-40 \leq t_1 - t_2 \leq 20$ ms, there was a steep increase of underestimation, and a sudden release from it at $t_1 - t_2 = 40$ ms. Then, overestimation appeared when $t_1 - t_2 \geq 60$ ms.

When t_2 was 160 ms, we had a 2 (control vs. experimental conditions) \times 11 (S -duration) repeated measures design. The main effect of control vs. experimental conditions was not significant. This time, the interaction

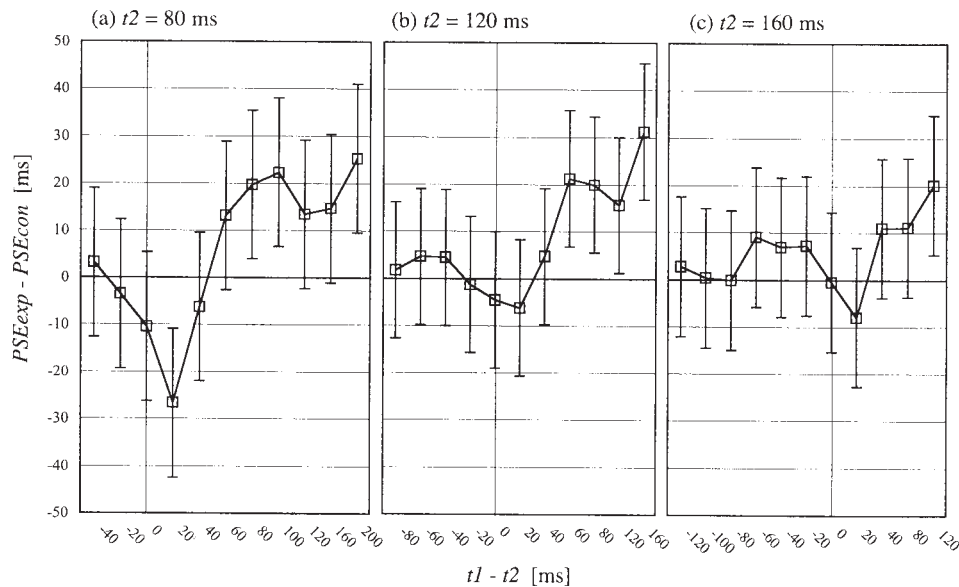


Fig. 4. Mean differences between the points of subjective equality (PSEs) in experimental and corresponding control conditions ($PSE_{exp} - PSE_{con}$) in Experiment 2 as a function of the duration of t_2 and the difference between t_1 and t_2 , ($t_1 - t_2$). The error bars show the 5% confidence intervals based on the error term for one-factor repeated measures analyses of variance of the differences between the experimental and the corresponding control PSEs ($PSE_{exp} - PSE_{con}$) applied to the data in each t_2 condition separately (Loftus & Masson, 1994).

effect between control vs. experimental conditions and S -duration was not significant either. Although the degree may have been small, Figure 4c shows an interactive tendency similar to that when t_2 was 80 or 120 ms. When $t_1 - t_2 \geq 40$ ms, contrast took place.

The data in Figure 4 as a whole showed a tendency for assimilation to take place when $-60 \leq t_1 - t_2 \leq 20$ ms. Clear contrast took place when $t_1 - t_2 > 40$ ms, and the appearance of assimilation and contrast was affected by t_2 .

General Discussion

The present experiments, combined with some previous experiments (Nakajima et al., 2004; Sasaki et al., 1998) indicated that the PSEs of t_1 and t_2 approached each other when $-80 \leq t_1 - t_2 \leq 40$ ms. That is, bilateral assimilation took place. When t_1 and t_2 were further separated, this assimilation disappeared, and their difference was enhanced perceptually. That is, contrast took place. In Experiment 1, bilateral assimilation did not appear in some conditions when $t_1 > t_2$, and $t_1 + t_2 = 360$ ms. It is possible that conditions in which assimilation could take place were not

included, because the step size, 60 ms, was larger than the upper boundary of the range in which bilateral assimilation operates. The absolute difference between $t1$ and $t2$ seems an important factor in determining the appearance of assimilation and contrast.

The range in which assimilation took place corresponds to the range where the neighboring durations were perceived in ratios very close to 1:1 in the experiments of Sasaki et al. (1998). They found that all patterns between /60/120/ and /105/75/ yielded nearly perfect 1:1 ratios perceptually, despite the change in physical temporal ratio between two neighboring time intervals. They argued that time-shrinking caused the category of 1:1 rhythms. Although their argument sufficed as a rough sketch, it could not explain why patterns such as the /105/75/ pattern were also perceived as in the 1:1 category. The present research has clarified this issue, showing that not only unilateral but also bilateral assimilation contributed to the formation of the 1:1 category.

An important point in the present results is that illusory changes took place also in $t1$. The pattern of the underestimation of $t2$ caused by $t1$ can be explained roughly in terms of a model of time-shrinking (Nakajima et al., 2004). This model states that the perceived duration difference between $t1$ and $t2$ is diminished as a consequence of reduced mental processing time for $t2$, but predicts nothing on the perception of $t1$. Thus, the bilateral assimilation must have taken place through a different mechanism.

The present results still leave an interesting issue to be investigated. Even when $t1 = t2$, that is, when there was no obvious basis for assimilation or contrast to take place, $t1$ and $t2$ were often underestimated. A related phenomenon was described by Nakajima et al. (2004), but only concerning $t2$. They managed to explain the underestimation of $t2$ in similar conditions by modifying their quantitative model. The modification is a little complicated and beyond the scope of the present article, but we would like to point out that the underestimation of $t2$ appeared to a similar degree in the present experiment. In addition, the underestimation of $t1$ also appeared to a similar degree. The duration of $t1$ may have been assimilated perceptually into the underestimated duration of $t2$. If this idea is correct, the bilateral assimilation must have taken place *after* the unilateral assimilation. This idea may serve as a guide to indicate a way to further investigate the underlying mechanisms of the perception of short sound sequences.¹

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