DOES FILLED DURATION ILLUSION TAKE PLACE FOR VERY SHORT TIME INTERVALS?

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Abstract

Subjective durations of filled time intervals (marked by the onset and offset of a sound) and empty time intervals (marked by onsets of two successive brief sounds) of 20-360 ms were measured, utilizing the method of adjustment. Whereas many previous studies employing longer intervals had reported that filled time intervals had been perceived as longer than empty time intervals of the same physical duration (filled duration illusion), the present results showed that this illusion occurred only for less than a half of the participants, and that, for the other participants, filled time intervals were perceived as shorter than empty time intervals.

We examined the *filled duration illusion* with very short time intervals. The filled duration illusion is a phenomenon that a *filled* time interval is perceived to be longer than an *empty* time interval of the same physical duration, and it has been demonstrated repeatedly in psychophysical studies (e.g., Craig, 1973; Zwicker, 1969/70; Wearden et al., 2007). We define a filled interval as the duration between the onset and the offset of a continuous sound, and an empty interval as the duration between two very brief sounds (e.g., Grondin, 2008).

Previous studies found clear filled duration illusion for intervals of about 300 ms or longer, but results were not very clear for shorter intervals (e.g., Wearden et al., 2007). We employed time intervals of 20-180 ms in Experiment 1 and 40-360 ms in Experiment 2, and observed whether the illusion occurred or not for such short intervals as had never been reported in previous studies.

Experiment 1

Method

Participants. Twenty-four undergraduate students of Department of Acoustic Design, Kyushu University, participated for course credits. All of them had received training in technical listening for acoustic engineers, and also basic training in music.

Stimuli. Each presentation consisted of a standard and a comparison in this order. The comparison began 2500-3000 ms (changed randomly) after the standard ended. There were three interval-type conditions: empty, filled, and control (see Figure 1 for details). The stimulus sounds of the comparison were the same as those in the control condition. All stimulus sounds were 1000-Hz pure tone bursts, and the total energy of each sound was kept constant. The presentation level of the 20-ms sound was 71 dBA, measured as the level of a continuous tone of the same amplitude. The standard duration was 20, 60, 100, or 180 ms.

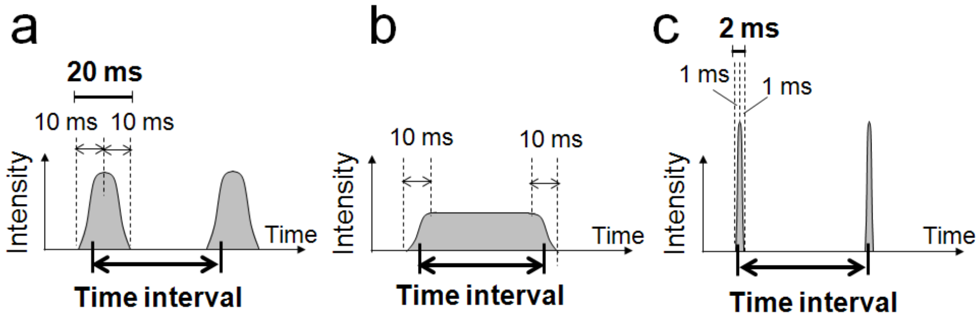

Figure 1. The illustration of stimuli in the empty (a), filled (b), and control condition (c). The temporal midpoints (or the beginnings depending on how we describe the patterns) of the rise and fall times were considered as the beginning and the end of a time interval. The envelope of the rise and fall portions was cosine-shaped in the intensity dimension.

Thus, there were 12 stimulus conditions (3 [filled, empty, and control] × 4 [standard durations]).

The stimulus patterns were generated digitally (16 bits; a sampling frequency of 44,100 Hz) on a computer (Asus EeePC 4G), and presented diotically via headphones (Sennheiser HDA200) to the participant in a soundproof room.

Procedure. Participants adjusted the comparison interval to make it subjectively equal to the standard interval. The final duration of the comparison interval in each trial was recorded as the *point of subjective equality*, PSE. The lower limit for the comparison interval was set to be 5 ms, for shorter intervals may cause the two sounds marking the comparison interval to be perceived as one sound rather than two distinct sounds (Plack, 2005). When the participant tried to adjust the comparison interval to be shorter than 5 ms, this intention was recorded, but the comparison interval in the next presentation was 5 ms. For each standard interval, there were an ascending series and a descending series, and the PSEs from these series were averaged for each participant. Thus, the total number of trials was 24 (12 [experimental conditions] × 2 [ascending and descending]).

Results and Discussion

Figure 2a shows the mean PSEs plotted as functions of the standard duration and the interval type (empty, filled, or control). The PSEs of the empty, the filled, and the control condition were very close to each other.

The filled duration illusion did not appear in Figure 2a; the mean PSEs in the filled interval condition were not larger than those in the empty or the control condition. This was unexpected, given that the overestimation of a filled interval had been reported repeatedly at least against offset-onset intervals (e.g., Craig, 1973; Zwicker, 1969/70; Wearden et al., 2007).

Although we did not find much difference between interval types in the mean PSEs, the standard deviations between participants were remarkably larger in the filled interval condition than in the other conditions. To examine whether the large variability in the filled interval condition was due only to task difficulty or to different listening strategies employed by each participant, we calculated the amount of overestimation of the filled interval [(filled PSE) – (control PSE)], and of the empty interval [(empty PSE) – (control PSE)], for each participant, and submitted their normalized values to a hierarchical cluster analysis. Clusters were determined by the Ward method, which analyzed the squared

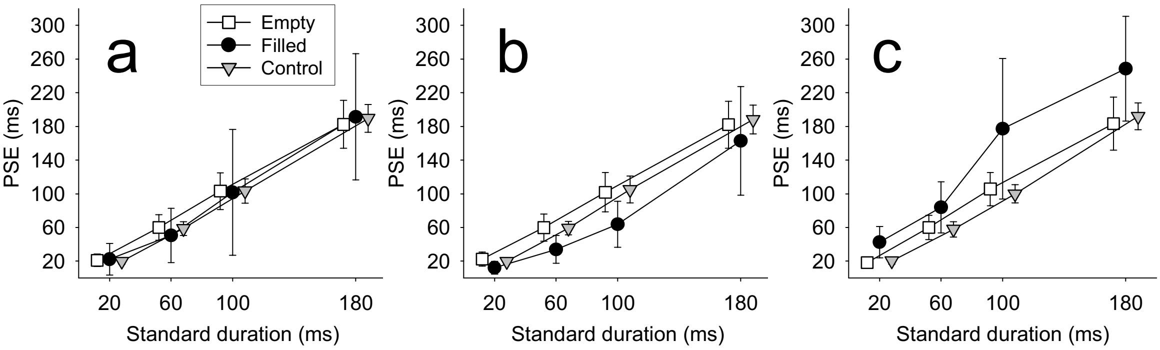

Figure 2. Mean points of subjective equality (PSEs) obtained in Experiment 1 plotted as functions of the standard duration and the interval type. Error bars represent the standard deviations between participants. (a) all participants (n = 24), (b) Cluster 1 (n = 16), and (c) Cluster 2 (n = 8).

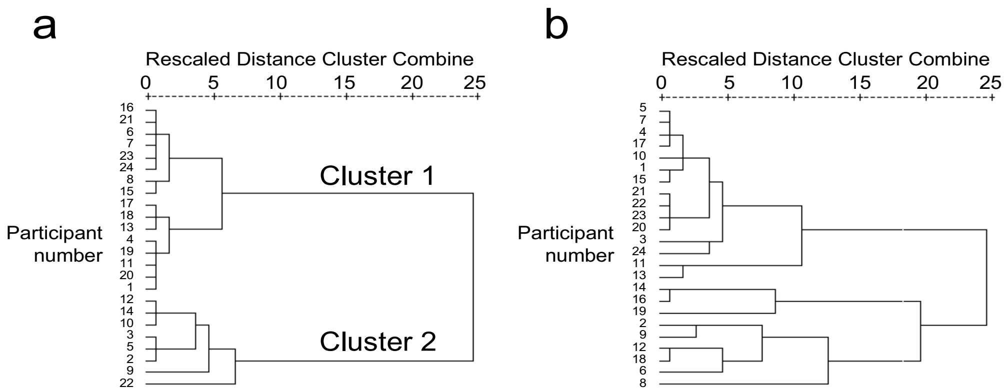

Figure 3. Dendrograms of 24 participants of Experiment 1 established by hierarchical cluster analysis in (a) filled interval condition and (b) empty interval condition.

Euclidean distance between points. For the filled interval condition (Figure 3a), participants were divided clearly into two groups, with 16 participants in one cluster (Cluster 1) and 8 participants in the other (Cluster 2). No such clear clusters appeared for the empty interval condition (Figure 3b).

We calculated the mean PSEs for Clusters 1 and 2 separately, and plotted them against standard duration (Figure 2b, c). The graphs showed clearly that participants in Cluster 1 underestimated the filled intervals, whereas participants in Cluster 2 overestimated. This tendency was consistent throughout all standard durations.

The main effect of the cluster difference was significant in the results of a two-way (cluster × standard duration) ANOVA, performed utilizing the PSEs of the filled interval condition, [F (1, 22) = 35.420, p < .001] (It was natural and trivial that PSEs changed as the standard duration changed). We also performed a two-way (interval type × standard duration) ANOVA for each cluster. For Cluster 1, the main effect of the interval type was significant, [F (2, 30) = 18.567, p < .001]. Dunnett's post hoc test was performed to compare the control condition with the empty and the filled interval condition, and revealed significant difference between the filled and the control condition (p < .001), but not between the empty and the control condition (p > .05). For Cluster 2, the main effect of the interval type was also significant, [F (2, 14) = 9.510, p < .05], and Dunnett's post hoc test revealed significant difference between the filled and the control condition (p < .001), but not between the empty and the control condition ($p > .05$). The interaction between the interval type and the standard duration in the two-way ANOVA was not significant ($p > .05$) in both clusters.

Summarizing, the filled interval condition was significantly different from the control, but the empty interval condition was not, in both clusters. The differences, however, were in different directions. For very short time intervals of 20-180 ms, some participants overestimated filled intervals, as had been reported in previous studies (e.g., Wearden et al, 2007; Zwicker, 1969/70), whereas the other participants underestimated them.

In Experiment 2, we tested whether the two clusters would also appear when the comparison intervals were marked by filled intervals (Experiment 2A), as well as by empty intervals (Experiment 2B), and when longer standards (40-360 ms) were employed.

Experiment 2

Method

Participants. Twenty-eight undergraduate students of Department of Acoustic Design, Kyushu University, participated for course credits. None had participated in Experiment 1. Twelve participants were assigned to take part in Experiment 2A, and the remaining sixteen to Experiment 2B.

Stimuli. We employed two interval-type conditions: empty and filled (Figure 1a, b). The comparison duration was marked by stimulus sounds that were the same as those in the filled-interval condition in Experiment 2A and as those in the empty-interval condition in Experiment 2B. The total energy of a filled-interval sound was equal to that of two 20-ms sounds together. The presentation level of a 20-ms sound was 71 dBA, measured as the level of a continuous tone of the same amplitude.

The standard duration was 40, 80, 120, 200, 280, or 360 ms. Thus, there were 12 experimental conditions (2 [filled and empty] × 6 [standard durations]) both in Experiment 2A and in Experiment 2B. Other aspects of stimuli as well as the apparatus were the same as in Experiment 1.

Procedure. The procedure was the same as in Experiment 1, except for the lower limit for the comparison interval, which was set to be 10 ms in Experiment 2A (filled comparison), and 20 ms in Experiment 2B (empty comparison); at least 10 ms was needed to keep the rise and the fall time of filled comparisons 10 ms in Experiment 2A, and at least 20 ms was needed to avoid overlap of the two markers of empty comparisons in Experiment 2B. For each standard interval, there were an ascending series and a descending series, and the PSEs from these series were averaged for each participant. Thus, the total number of trials was 24 (12 [stimulus conditions] × 2 [ascending and descending]).

Results and Discussion

Experiment 2A (filled comparison). As in Experiment 1, we calculated the amount of overestimation of the empty interval [(empty PSE) – (filled PSE)], and submitted their normalized values to a hierarchical cluster analysis (note that the filled-interval condition served as the control, since the comparison stimulus was the same as the filled standard). Participants were divided into two groups (Figure 4a), with 7 participants in one cluster (Cluster 1) and 5 participants in the other (Cluster 2).

Figure 5 shows the mean PSEs plotted as functions of the standard duration and the interval type (empty/filled). Participants in Cluster 1 overestimated the empty intervals when the standard was 40-120 ms (Figure 5b), whereas participants in Cluster 2 underestimated the empty intervals (Figure 5c).

Experiment 2B (empty comparison). We calculated the amount of overestimation of the filled interval [(filled PSE) – (empty PSE)], and submitted their normalized values to a hierarchical cluster analysis (note that the empty-interval condition served as the control, since the comparison stimulus was the same as the empty standard). Again, participants were divided into two groups (Figure 4b), with 11 participants in one cluster (Cluster 1) and 5 participants in the other (Cluster 2).

Figure 6 shows the mean PSEs plotted as functions of the standard duration and the interval type (empty/filled). Participants in Cluster 1 underestimated the filled intervals (Figure 6b), whereas participants in Cluster 2 overestimated (Figure 6c).

The results of Experiment 2 showed that participants were clearly divided into two groups; in one group, filled intervals were perceived as longer than empty intervals (i.e. usual filled duration illusion occurred), but, in the other group with the majority of participants, filled intervals were perceived as shorter than empty intervals. This was consistent with Experiment 1. However, the overestimation of empty intervals in the Cluster-2 participants disappeared when the standard duration was 200 ms or longer in Experiment2A (when the comparison interval was marked by filled intervals; Figure 5b).

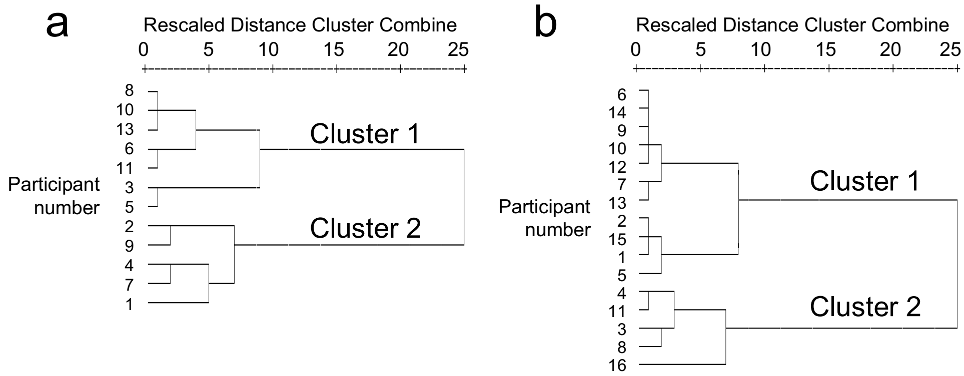

Figure 4. Dendrograms of participants of Experiment 2 established by hierarchical cluster analysis. (a) Experiment 2A (filled comparison). (b) Experiment 2B (empty comparison).

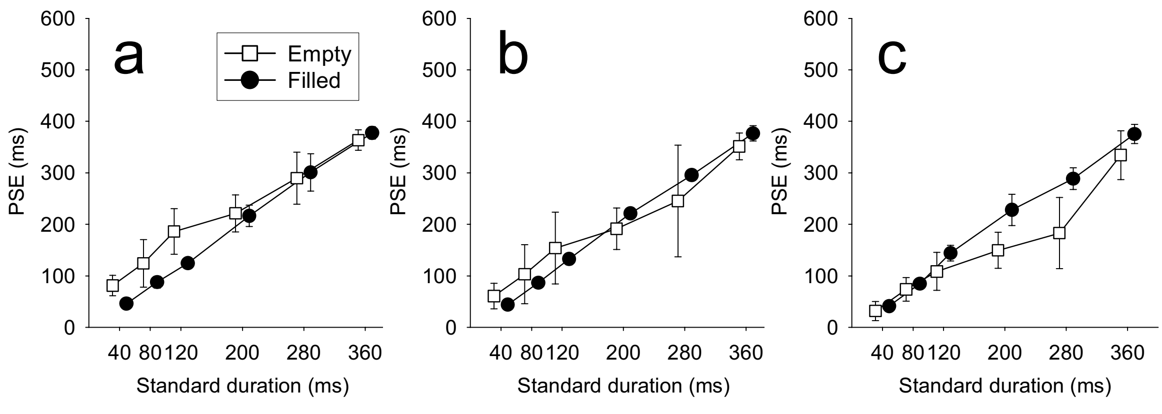

Figure 5. Mean points of subjective equality (PSEs) obtained in Experiment 2A (filled comparison). Error bars represent the standard deviations between participants. (a) all participants (n = 12), (b) Cluster 1 (n = 7), and (c) Cluster 2 (n = 5).

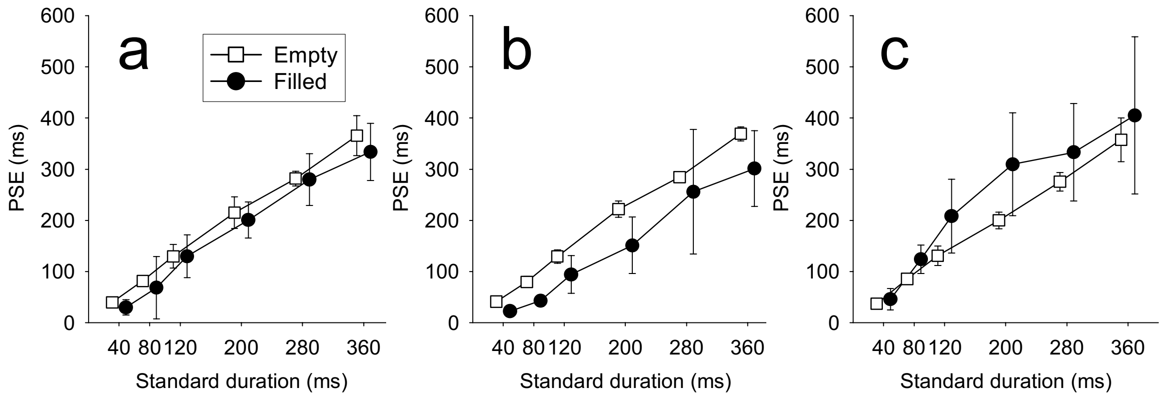

Figure 6. Mean points of subjective equality (PSEs) obtained in Experiment 2B (empty comparison). Error bars represent the standard deviations between participants. (a) all participants (n = 16), (b) Cluster 1 (n = 11), and (c) Cluster 2 (n = 5).

General Discussion

The well-established filled duration illusion did not take place for some participants when very short time intervals (20-360 ms) were employed. Surprisingly, these participants perceived filled intervals as shorter than empty intervals. This was the case regardless of the comparison stimulus, as far as the intervals were shorter than 200 ms (Figures 2b, 5b, 6b). However, the occurrence of such overestimation of the empty interval or underestimation of the filled interval for intervals of 200 ms or above seemed to depend on the comparison stimulus (compare Figures 5b and 6b). It is possible that the presentation order of the intervals (filled-empty or empty-filled) influences the way the listeners perceive the durations of the intervals when the intervals exceed 200 ms. It may be interesting to examine the occurrence of the filled duration illusion utilizing other methods, such as magnitude estimation, which do not require direct comparison between two stimuli.

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