ASSIMILATION BETWEEN TWO NEIGHBORING TIME INTERVALS MARKED WITH TACTILE STIMULI

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Abstract

The aim of this study was to examine whether and how the perception of an empty time interval marked by two brief tactile stimuli, S, is influenced by the duration of the preceding time interval, P. In each trial, three electric pulses, each lasting 20 ms, were successively delivered to the right hand of participants, the first two pulses marking P and the last two marking S. S was fixed at 240 ms while P was 160, 240, or 320 ms. In addition, there was a control condition where S was presented in isolation (without P). Perceived duration of S was estimated with the method of constant stimuli. Results showed that participants underestimated S when P was 160 ms. This underestimation appeared as a kind of perceptual assimilation between P and S, but indeed S was not overestimated when it was preceded by a longer interval (P = 320 ms). The underestimation was rather regarded as the time-shrinking illusion which had been tested with visual and auditory stimuli.

One of the main issues in time perception studies has been whether or not the brain has a single dedicated time-keeping device, called a *central* clock, which processes duration in general irrespective of the sensory modality of inputs (e.g., Grondin, 2010). This device is assumed to consist of two modules, one emitting neural pulses which are accumulated in the other; the amount of accumulated pulses determines the perceived duration of intervals. The beginning and end of accumulation are triggered by sensory inputs while the accumulation process, per se, is not affected by the property of sensory inputs (e.g. Gibbon et al., 1984). However, this notion is being challenged by some empirical findings. For example, Grondin and Rousseau (1991) indicated that sensitivity to time differs between sensory modalities. In their experiment, intervals were better discriminated (the Weber fraction was lower) when they were marked by auditory stimuli than when marked by visual or tactile ones, and the discrimination was even much lower when an empty interval was marked by two brief signals delivered from different sensory modalities. This finding is inconsistent with that expected from the internal-clock hypothesis; if inputs from different modalities were processed by a single dedicated device, discrimination levels should be relatively constant regardless of marker modalities.

On the other hand, the internal-clock hypothesis would receive empirical support would one find a common time-perception phenomenon occurring in different sensory modalities. In other words, a phenomenon should occur in more than one modality if its occurrence is attributed to the central-clock mechanism that is independent from stimulus modalities. Indeed, there is an illusion that appears in both visual and auditory modalities. This illusion, called *time shrinking*, has been first reported by Nakajima and ten Hoopen (1988), and it has been investigated mainly in the auditory modality (see ten Hoopen et al., 2008 for a review). When three successive short sounds mark two neighboring time intervals (t_1 and t_2), the subjective duration of the second interval (t_2) can be shortened by a considerable degree under certain time conditions: when t_1 is shorter than t_2, and this difference is smaller than about 100 ms. Time shrinking appears maximally for short durations, i.e., when $t_1 < 200$ ms. Since in most cases the subjectively shortened t_2 approaches the subjective duration of t_1, time shrinking can be considered to be a type of temporal assimilation between two neighbouring time intervals (Nakajima et al., 2004). A later study by Arao et al. (2000) showed that time shrinking can appear also when the time intervals are marked by short flashes (although the time condition in which time shrinking takes place differed: it took place for a wider range of time conditions in vision compared to audition). Their results indicated that the visual system, like the auditory one, can assimilate the second interval to the first one. The fact that time shrinking appears for both auditory and visual stimuli suggest that the processing of temporal information in the auditory and the visual system relies on a single device.

Given that several perceptual phenomena take place in more than one modality (e.g., the *tau* and *kappa* effects; see Jones & Huang, 1982), it seemed reasonable to predict that time shrinking can occur in other sensory modalities. In the present study, we investigated whether or not time shrinking takes place in tactile modality. Since this was the first time that time shrinking was examined with tactile stimuli, we included an experimental condition which would cause time shrinking in both audition and vision, i.e., $t_1 = 160$ and $t_2 = 240$ ms. If it is shown that time shrinking occurs also for tactile stimuli, it will suggest that the timing system for auditory, visual, and tactile modalities share a single device.

Method

Participants

Twelve participants (9 females and 3 males) were recruited at Laval University. The mean age was 27.8 years (SD = 7.02). Each participant was paid CAD$28.

Stimuli and Apparatus

Each tactile stimulus was a 20-ms electric signal, delivered to the right hand of the participant. The intensity of the stimuli was adjusted to a comfortable level for each participant. The stimulus patterns are illustrated in Figure 1.

In the Experimental condition, the standard pattern consisted of three successive stimuli, the first and the second marking the preceding time interval (P), and the second and the third marking the standard time interval (S). In the control condition, the standard pattern consisted of two successive stimuli marking S. In both cases, the comparison interval (C) was marked by two successive stimuli.

S was fixed at 240 ms, and P was 160, 240, or 320 ms. The condition /160/240/ (slashes denote short markers delimiting P and S, as /P/S/) was the temporal pattern in which considerable underestimation occurred in both the auditory and the visual modality (Nakajima et al., 2004; Arao et al., 2000). The number of conditions was 4 (3 P-durations + 1 control). The duration of C was 100, 140, 180, 220, 260, 300, 340, or 380 ms. A computer application (E-prime) was used to generate the stimuli and to make a program steering the course of the experiment. The stimuli were presented from electrodes fixed to the back of the participant's right hand, one between the index finger and the middle finger, and the other between the ring finger and the pinky. The electrodes were connected to a computer (IBM Netvista) via an amplifier (Solutions Temps Reel).

Procedure

The method of constant stimuli was used. Participants were instructed to judge whether C was subjectively shorter or longer than S, and to respond "shorter," "longer," or "unsure" by pressing a button with their left hand (we instructed the participants to try to respond "shorter" or

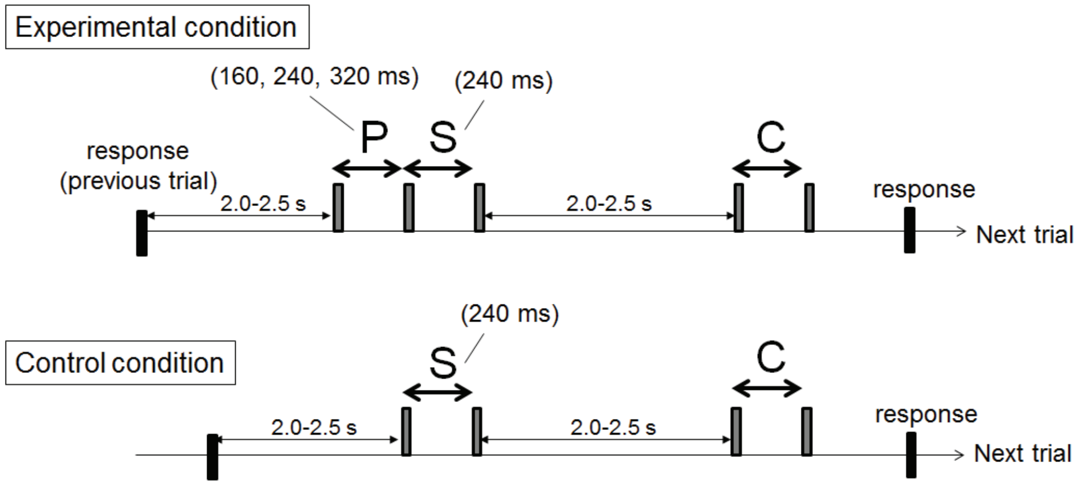

Figure 1. Stimulus presentation chart for the experiment. The durations of P, S, and C correspond to the temporal distance between the beginning of one marker and the beginning of the subsequent marker.

"longer" and to try not to respond "unsure" when possible). For each condition, the 8 durations of C (100-380 ms) were presented in random order.

Each condition was blocked together to be conducted in one of four experimental sessions: one for /160/240/, one for /240/240/, one for /320/240/, and one for the control condition. There were 240 trials per session (8 C-durations × 30 repetitions), and these trials were divided in 3 blocks of 80 trials. Participants were able to take a break between blocks.

The order of the three experimental conditions was counterbalanced (there were 6 possible orders). Half of the participants did the three experimental conditions first and then moved on to the control condition, while the other half of the participants started with the control condition and then moved on to the three experimental conditions. Thus, there were 12 possible orders: 6 for the experimental condition × 2 for the order of experimental and control.

Results

There were 11,520 responses in total (4 conditions × 8 C-durations × 30 repetitions × 12 participants). The number of "unsure" responses was 359, and they were split evenly between "longer" and "shorter" responses. For each condition and each participant, a psychometric function was obtained by plotting the probability of responding that C was "longer" against the C-duration. Figure 2 shows the psychometric functions using the "longer" probabilities averaged across participants.

The cumulative normal distribution was fitted to the psychometric function. The duration of C which corresponded to a probability of 0.5 for responding that C was "longer" was considered as the *point of subjective equality* (*PSE*) of S. The standard deviation was also calculated for each curve. A lower standard deviation means a steeper slope of the curve, and thus indicates better discrimination (see Grondin, 2008). Thus, the PSE and the standard

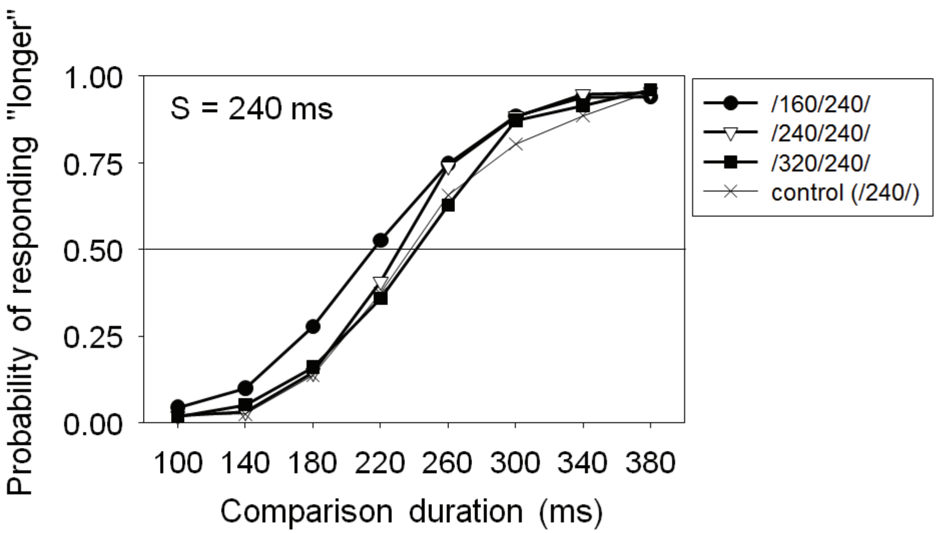

Figure 2. Probability of responding that the comparison interval was longer than the standard (240 ms) in each condition. Each data point is based on 360 responses (30 responses by each of the 12 participants).

deviation were obtained for each condition for each participant. The PSE was smallest when P = 160 ms, and increased as P became longer.

To eliminate experimental bias and to compare the effect of the P durations, we calculated the amount of overestimation of S for the three experimental conditions by subtracting the PSE for the control condition from the PSE for the experimental conditions (i.e. PSEexp – PSEcont) for each participant.

Figure 3 shows the mean overestimation of the 12 participants. The overestimation was negative (i.e., S was underestimated) when P = 160 ms, and the underestimation decreased as P lengthened.

A one-way repeated-measures ANOVA with P-duration as factor was performed using the amounts of overestimation. The effect of the P-duration was significant, $F(2, 22) = 6.649$, $p < .01$, $\eta_p^2 = .377$. Bonferroni post-hoc test revealed that the difference between P = 160 ms and P = 240 ms, and between P = 160 ms and P = 320, ms were significant ($p < .05$).

Discussion

The results of the experiment clearly showed that, when two time intervals neighbor each other, the subjective duration of the second interval can be influenced by the first one. When the first time interval was equal to or shorter than the second, the duration of the second time interval was underestimated (Figure 3).

The underestimation of S was in line with the previous studies on time shrinking; time shrinking in the auditory modality was said to take place typically when (1) $0 \leq S - P \leq 100$ ms, and (2) $P < 200$ ms (e.g. ten Hoopen et al., 2008). In our experiment, the time condition in which maximum time shrinking took place, /160/240/, was within this range (e.g., Nakajima et al., 2004). For this condition, time shrinking had been reported also in the visual modality (Arao et al., 2000). We hereby demonstrated that time shrinking occurs also in the tactile modality for the same time condition.

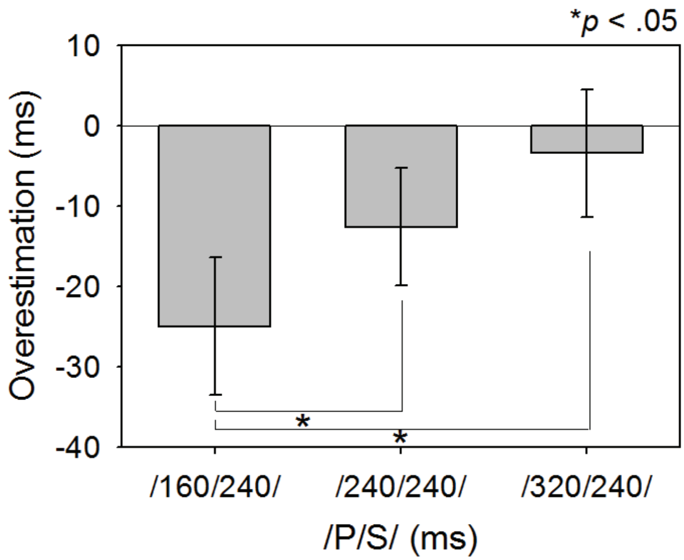

Figure 3. Mean overestimation of S in each experimental condition (PSEexp – PSEcont). Negative overestimation indicates time shrinking. Error bars show the standard error of mean (SEM). Results of multiple comparisons based on Bonferroni's method are also shown.

The underestimation of the S when /160/240/ must have made the subjective duration of S approach the subjective duration of the shorter P. In other words, this underestimation could be understood as perceptual *assimilation*.

It was interesting that S was underestimated even when P and S had the same physical duration (see the /240/240/ condition in Figure 3). Although underestimation of S may seem unnecessary in terms of temporal assimilation when P = S, underestimation of S in such conditions had been shown repeatedly in the figures of previous auditory and visual experiments, especially when the preceding interval was short (e.g., Arao et al., 2000; Miyauchi & Nakajima, 2005; Nakajima et al., 2004). It could be possible that, when P = S, P is already slightly underestimated, so the following S must be shortened to approach the subjective duration of P (Miyauchi & Nakajima, 2005).

It should be noted that, when P was longer than S, perceptual assimilation did not occur: if assimilation had taken place, the S should have been overestimated to approach the subjective duration of the longer P. However, such overestimation of S did not appear (see the /320/240/ condition in Figure 3). This is interesting, for in both /160/240/ (in which assimilation occurred) and /320/240/ (in which assimilation did not occur), the difference between the duration of P and S was 80 ms. It seems that the range in which temporal assimilation occurs is asymmetric, as in the auditory modality (-80 ms $\leq$ [P – S] $\leq$ 40 ms; ten Hoopen et al., 2008).

In summary, we found that time shrinking, an illusion in temporal perception that had been reported mainly in auditory modality, takes place also with tactile stimuli. The occurrence of time shrinking (temporal assimilation) was similar to that reported previously for auditory and visual modalities, which may indicate that the timing system for auditory, visual, and tactile modalities share a similar process to some extent. It should be interesting to investigate the occurrence of time shrinking further with a wider range of time intervals, which could allow more thorough comparison between modalities.

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