References

Brown, C.P., Fitch, R.H., & Tallal, P. (1999). Sex and hemispheric differences for rapid auditory processing in normal adults. *Laterality, 4(1),* 39-50.

Brown, S. & Nicholls, M.E.R. (1997). Hemispherical asymmetries for temporal resolution of brief auditory stimuli. *Perception and Psychophysics, 59 (3)*, 442-447.

Costa, C.J., Silva, I., & Florentine, M. (in revision). Frequency-specific correlations between temporal resolution and speech perception in noise. *Ear & Hearing.*

Efron, R., Yund, E.W., & Nichols, D. (1985). An Ear asymmetry for gap detection following anterior temporal lobectomy. *Neurophysiology*, 23: 43.

Florentine, M., Buus, S., & Geng, W. (1999). Psychometric functions for gap detection in a yes-no procedure. *Journal of Acoustical Society of America, 106*, 3512-3520.

Florentine, M., Buus, S., & Geng, W. (2000). Toward a clinical procedure for narrowband gap Detection 1: A psychophsysical procedure. *Audiology, 39*, 161-167.

Nicholls, M.E.R., Schier, M., Stough, C.K.K., & Box, A. (1998). Psychophysical and Electrophysiological Support for a Left Hemisphere Temporal Processing Advantage. *Neuropsychiatry, Neuropsychology, and Behavioral Neurology, 12*, 11-16.

Oxenham, A.J. (2000). Influence of spatial and temporal coding on auditory gap detection. *Journal of the Acoustical Society of America, 107,* 2215-2223.

Sininger, Y.S. & de Bode, S. (2008). Asymmetry of temporal processing in normally hearing and unilaterally deaf subjects. *Ear & Hearing, 29*(2)*,* 228-238.

Sulakhe, N., Elias, L.J., & Lejbak, L. (2003). Hemispheric asymmetries for gap detection depend on noise type. *Brain and Cognition, 53*, 372-375.

Vroon, P.A., Timmers, H., & Tempelaars, S. (1977). Attention and performance VI: Procedings of the sixth international symposium on attention and performance, 231-235.

FILLED INTERVALS ARE PERCEIVED AS LONGER THAN EMPTY ONES: THE EFFECT OCCURS EVEN WITH A BETWEEN-SESSION DESIGN

Marilyn Plourde, Pierre-Luc Gamache, and Simon Grondin
École de psychologie, Université Laval, Québec, Canada

Abstract

The timing literature usually reveals that, for a same physical duration, filled intervals are perceived as being longer than empty ones. This effect is known to occur when filled and empty intervals are randomized within a same block of trials. In the present experiment, the magnitude of the effect was tested with three experimental designs: filled and empty intervals grouped by sessions, by blocks, or randomized within blocks. The results tended to show that filled durations are perceived as longer than empty intervals, and this potential effect does not seem to be reduced by the use of a between-session design. Finally, higher sensitivity was observed with empty intervals, which is inconsistent with a portion of the literature.

The structure of a time interval, i.e., whether it is marked by two distinct sensory signals (empty) or by a continuous signal (filled) influences time judgements. However, demonstrations of its influence have been very heterogeneous, since researchers have used various duration ranges and "filling" methods for investigating the phenomenon (Wearden, Norton, Martin, & Montford-Bebb, 2007; for a review see Grondin, 2003).

A relatively consistent finding though is that filled intervals are perceived as being longer than empty ones (Wearden et al., 2007). In the context of temporal discrimination tasks, this effect is generally observed when filled and empty intervals are compared directly, that is, when both types of signals are presented within an experimental block. In order to understand the cause of the difference between filled and empty intervals for perceived duration, we used three different contexts, i.e., three different experimental designs in which both types of signals were randomized within blocks, grouped by blocks, or grouped by sessions. In other words, we wanted to know to what extent the temporal proximity of these interval types influences their relative estimates.

We expected that the filled-empty difference would be governed basically by the same mechanisms as those observed, for instance, for the auditory-visual difference reported in the memory-mixing model proposed by Penney, Allan, Meck and Gibbon (1998; see Gamache & Grondin, 2008). This model implies the creation of a common memory reference generated from the temporal information issued from both temporal types. If only one interval type is presented within a session, there should be no influence of interval type on the other, and the perceived duration should be the same in both structure conditions. Therefore, we anticipated that the filled-empty difference would be greater with a within-block design; minimal, if any, with a between-session design; and intermediate with a between-block design.

Method

Participants

Seven 20- to 26-year-old volunteer students at Université Laval, 3 females and 4 males, participated in this experiment. They were paid CAN$25 for their participation.

Apparatus and stimuli

The temporal intervals were marked either by a continuous visual signal (Filled condition) or by two successive 10-ms visual signals (Empty condition). These signals were produced by a circular red light emitting diode (LED: Radio-Shack # 276-088) laid out at a distance of one meter in front of the participant, underlying a visual angle of approximately .57°.

Each observer was seated in a chair in a dimly lit room and asked to respond either "short" or "long" on the corresponding button on the response box. The presentation of the stimuli and the recording of the participants' responses were computer controlled.

Procedure

The single-stimulus method was employed. According to this method, only one interval is presented during a given trial and the participant has to decide whether it belongs to the "short" or "long" category. There were eight comparison intervals presented to participants, located around a 250-ms implicit standard duration: 208, 220, 232, 244, 256, 268, 280 and 292 ms. The intervals were presented randomly but equiprobably within each block of 80 trials. A 2-s feedback was presented 200 ms after the response, followed by a 1-s inter-trial interval. In the case of filled intervals, participants were asked to time the total duration of the visual signal; for empty ones, they were asked to time the period between the offset of the first marker and the onset of the second marker.

There were two independent variables: the structure of the interval (empty or filled) and the delay separating the presentation of these structures. Three delays were under investigation. The structure of the intervals was grouped by sessions (Session), grouped by blocks (Block) or randomized within blocks (Trial).

There were five types of experimental sessions (Table 1). All participants were conducted first in the between-session condition for two sessions, four being presented with the filled intervals in Session 1 and the empty intervals in Session 2; and other participants being conducted in the reverse order. All participants were conducted in the between-block condition during Sessions 3 and 4, one for each of filled and empty intervals (with participants assigned to the same order as for Sessions 1 and 2). Finally, all participants were conducted in the within-block condition during Sessions 5 and 6.

Table 1. List of Experimental Conditions and Number of Trials per Block with Empty (E) and Filled (F) Intervals

Session	Delay	Practice	Block 1	Block 2	Block 3	Block 4	Block 5
1 or 2	Between-session	E: 16	E: 80	E: 80	E: 80	E: 80	-
1 or 2	Between-session	F: 16	F: 80	F: 80	F: 80	F: 80	-
3 or 4	Between-block	E: 16	E: 80	F: 80	E: 80	F: 80	E: 80
3 or 4	Between-block	F: 16	F: 80	E: 80	F: 80	E: 80	F: 80
5 and 6	Within-block	E: 8	E: 40	E: 40	E: 40	E: 40	-
		F: 8	F: 40	F: 40	F: 40	F: 40	

Data Analysis

For each participant and each of the six experimental conditions (2 Structures x 3 Delays), an eight-point psychometric function was traced, plotting, on the *x* axis, the eight comparison intervals and, on the *y* axis, the probability of responding "long". Each point of the psychometric function represents forty observations.

The cumulative normal distribution was fitted to the resulting curves. Two indices of performance were extracted from these functions and kept for analysis: the bisection point (BP), used to evaluate perceived duration, and one standard deviation (SD – the variability of the function), an index of temporal sensitivity. The BP can be defined as being the value on the *x* axis corresponding to a probability of 50% of long responses. The higher the BP is, the shorter is perceived duration. Finally, SD is an index often used to estimate temporal sensitivity (Getty, 1975; Grondin, Meilleur-Wells, & Lachance, 1999; Killeen & Weiss, 1987).

Results

The psychometric functions for the averaged group results in all structure and delay conditions, for each comparison interval, are plotted in Figure 1. Figures 2 and 3 illustrate the mean bisection points and mean standard deviations, respectively, for the empty and filled interval conditions in each of the three delay conditions. The goodness-of-fit of participants' responses (R^2) varies between .81 and .98, the total average being .90.

In order to detect any significant structure difference on the BP that would be specific to a delay, three t-tests were conducted, one for each delay condition (see Figure 2). The BP is significantly higher for empty intervals in the Session delay condition, $t(6) = 2.05$, $p < .05$, while there is no significant difference in the two other delay conditions, Block : $F(1, 6) = 1.4$, $p = .11$; Trial : $F(1, 6) = .83$, $p = .22$.
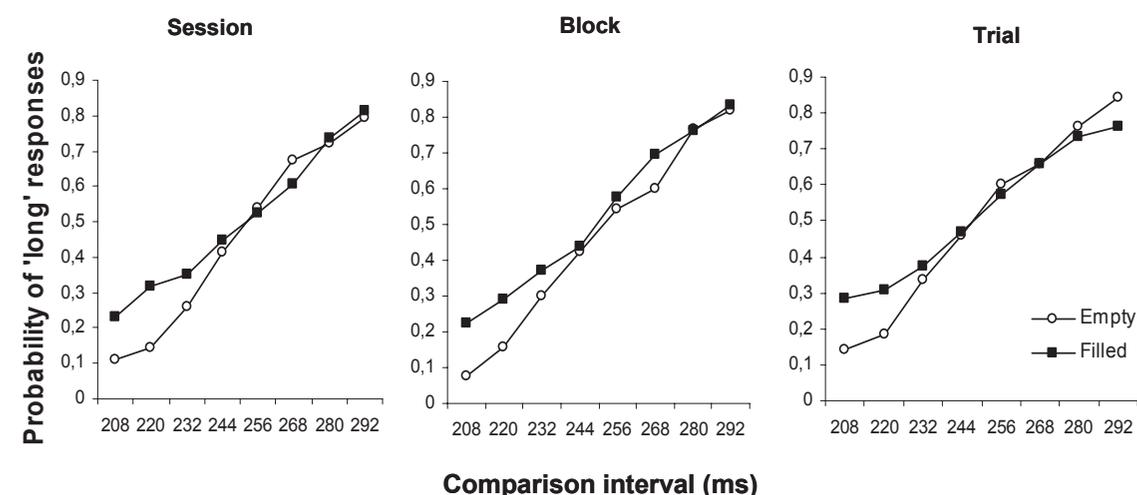

Figure 1. Mean probability of responding "long" for each comparison interval and for each experimental condition.

For SD (see Figure 3), an analysis based on t-tests revealed a significant difference for structure in the Block delay, $t(6) = 1.97$, $p = .043$, and in the Trial delay conditions, $t(6) = 5.50$, $p = .001$, but not in the Session delay condition, $t(6) = 1.67$, $p = .07$. In general, discrimination is much better with empty than with filled intervals.
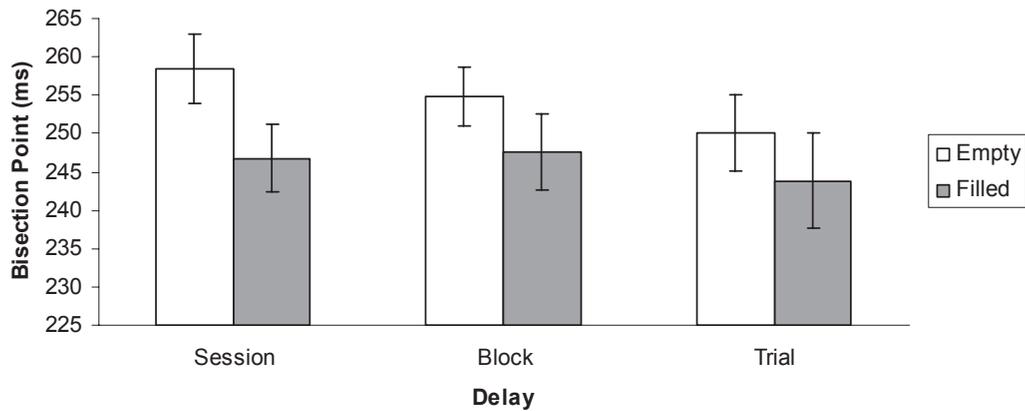
Figure 2. Bisection Point (ms) as a function of the delay condition (± standard-error)
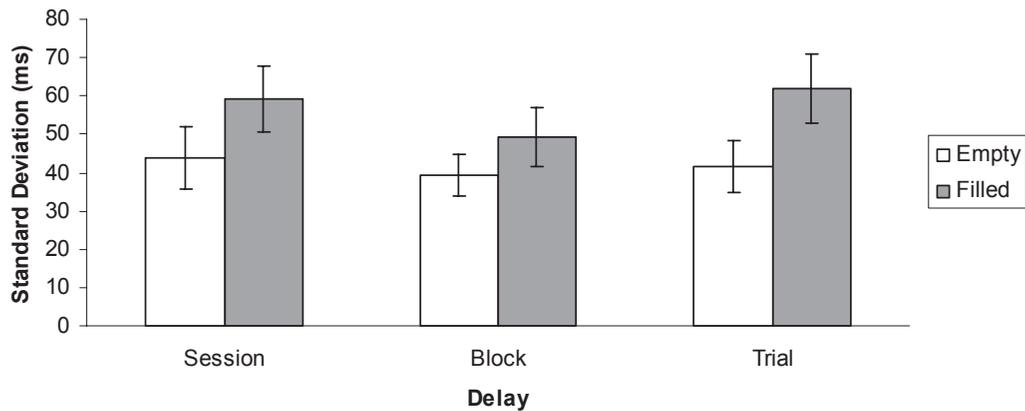

Figure 3. Standard deviation (ms) as a function of the delay condition (± standard-error).

Discussion

The aim of this experiment was to use a well-known perceptual effect for studying the mnemonic trace left by previously encoded temporal information. The studied effect refers to the fact that for the same physical duration, filled intervals are generally perceived as being longer than empty intervals (Grondin, 2003). Interestingly, the largest BP difference observed between empty and filled intervals occurred in the between-session condition, not in the within-block (Trial) condition. Indeed, the difference was significant only in the between-session condition. Under this condition, the structure effect was expected to be minimized, since empty and filled intervals were not delivered adjacently and had to be memorized in separate sessions.

As to why the filled-empty difference might be stronger in the between-session than in the within-block condition, it might be posited that the processing of the signals differs from one delay condition to another. According to the internal marker hypothesis (see Grondin, 1993), participants can process the empty gap between two markers as the relevant interval

when they attend specifically to that type of stimuli (i.e., to empty intervals): The timekeeping period occurs from the offset of the first marker to the onset of the second marker (see Grondin, Ivry, Franz, Perreault, & Metthé,1996; or, for physiological evidence, see Tse & Penney, 2006). This would happen as well in the within-block or within-session conditions. On the other hand, when both interval structures are mixed within a block, participants start timing the interval as soon as the first marker appears, as this signal's onset might also mark the beginning of a filled interval (50% of the trials). In that case, the subjective shortening of the empty intervals would be compensated by the inclusion of additional sensory information (the first signal) in the timekeeping period.

While this hypothesis accounts for the failure to observe a filled-empty difference in the within-block condition, it does not totally explain the between-session effect. Why did participants respond "long" more often with filled intervals? Two possibilities come to mind: on the one hand, an intrinsic stimulus-response compatibility for "long-filled" and "short-empty" and, on the other hand, a gradual disinvestment of attention as the session progresses, with a greater impact on the processing of empty intervals. In the latter case, we might suggest that the continuity of the filled signals facilitates the allocation of sustained attention throughout the interval. In other words, implicit standard and comparison intervals would be processed with the same amount of attention, while during the trials held later in the session, empty target intervals would receive less attention than the implicit standard, which would result in more "short" responses. That said, it cannot be totally excluded that the difference between the delay conditions regarding the magnitude of the filled vs. empty difference is partly due to some order effect since the within-clock trials were performed in the last (5 and 6) sessions of the experiment.

Finally, the significant SD difference obtained for the structure effect is inconsistent with a portion of the literature on the subject (e.g. Rammsayer & Lima, 1991; Rammsayer & Skrandies, 1998; Skrandies & Rammsayer, 1995; see also Plourde, Meilleur-Wells, Gamache, Dionne, & Grondin, 2008). However, other studies, mostly from our lab, have shown a higher temporal sensitivity with empty intervals than with filled ones when short durations were being investigated (< 500 ms; Grondin, 1993; Grondin, Meilleur-Wells, Ouellette & Macar, 1998; Plourde et al., 2008). This inconsistency between results might be explained partly by the fact that when a 2AFC procedure is adopted (which was not the case here), some confusion might occur with a series of 4 markers where three intervals (if one includes the inter-stimulus interval) rather than two are generated by the sequence.

References

Getty, D. (1975). Discrimination of short temporal intervals: A comparison of two models. *Perception and Psychophysics, 18*, 1-8.

Gamache, P.-L. & Grondin, S. (2008). Temporal limits of memory for time. In B. Schneider (Ed.). *Fechner Day 2008: Proceedings of the 24th Annual Meeting of the ISP* (this volume). Toronto: The ISP.

Grondin, S. (1993). Duration discrimination of empty and filled intervals marked by auditory and visual signals. *Perception & Psychophysics*, *54*, 383-394.

Grondin, S. (2003). Sensory modalities and temporal processing. In H. Helfrich (Ed.), *Time and mind II* (pp. 75–92). Gottingen, Germany: Hogrefe & Huber.

Grondin, S., Ivry, R., Franz, E., Perreault, L., & Metthé, L. (1996). Markers' influence on the duration discrimination of intermodal intervals. *Perception & Psychophysics*, *58*, 424-433.

Grondin, S., Meilleur-Wells, G., & Lachance, R. (1999). When to start explicit counting in a time-intervals discrimination task: A critical point in the timing process of humans. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 993-1004.

Grondin, S., Meilleur-Wells, G., Ouellette, C., & Macar, F. (1998). Sensory effects on judgments of short-time intervals. *Psychological Research, 61*, 261-268.

Killeen, P. R., & Weiss, N. (1987). Optimal timing and the Weber function. *Psychological Review, 94*, 455-468.

Penney, T. B., Allan, L. G., Meck, W. H., & Gibbon, J. (1998). Memory mixing in duration bisection. In D. A. Rosenbaum & C. E. Collyer (Eds.), *Timing of behavior: Neural, psychological, and computational perspectives* (pp. 165 - 193). Cambridge, MA: MIT Press.

Plourde, M., Meilleur-Wells, G., Gamache, P.-L., Dionne, G., & Grondin, S. (2008). Relative sensitivity to filled vs. empty intervals depends on methods : Evidence from developemental data. In B. Schneider (Ed.). *Fechner Day 2008: Proceedings of the 24th Annual Meeting of the ISP* (this volume). Toronto: The ISP.

Rammsayer. T. H., & Lima, S. D. (1991). Duration discrimination of filled and empty auditory intervals: Cognitive and perceptual factors. *Perception and Psychophysics*, *50*, 565-574.

Rammsayer, T. H., & Skrandies, W. (1998). Stimulus characteristics and temporal information processing: Psychophysical and electrophysiological data. *Journal of Psychophysiology*, *12*, 1-12.

Skrandies, W., & Rammsayer, T. H. (1995). The perception of temporal structure and auditory evoked brain potential. *Biological Psychology*, *40*, 267-280.

Tse, C. Y., & Penney, T. B. (2006). Pre-attentive timing of empty intervals is from marker offset to onset. *Psychophysiology, 43*, 172–179.

Wearden, J. H., Norton, R., Martin, S., & Montford-Bebb, O. (2007). Internal Clock Processes and the Filled-Duration Illusion. *Journal of Experimental Psychology: Human Perception and Performance, 33* (3), 716–729.

Acknowledgements.

RELATIVE SENSITIVITY TO FILLED VS. EMPTY INTERVALS DEPENDS ON METHODS: EVIDENCE FROM DEVELOPMENTAL DATA

Marilyn Plourde, Ginette Meilleur-Wells, Pierre-Luc Gamache,
Ginette Dionne & Simon Grondin
École de psychologie, Université Laval, Québec, Canada

Abstract

Two experiments involving child participants were conducted to test the relative effect of nontemporal factors and age on duration discrimination. In Experiment 1, a method similar to the time test of the Seashore Measures of Musical Talents, which involves a forced-choice presentation of intervals and a 800-ms standard, was employed. Results showed that the discrimination is better with filled intervals (a continuous signal) than with empty intervals (a silent period between two brief signals). As well, discrimination gradually improved with age, from 9 years old to adulthood, and this was generally true with intervals presented both in the visual and in the auditory modes, with either filled or empty intervals. Experiment 2 showed that children, as reported in previous studies with adults, have better discrimination with empty than with filled intervals in conditions where a 250-ms standard, visual signals, and an adaptive procedure are employed. There was an apparent contradiction of the two experiments regarding the structure --filled vs. empty-- of the interval. The filled vs. empty difference may depend on the method (Seashore-like vs. adaptive), on the range of duration, or on the combination of both factors.

Time perception is often argued to depend on the output of an internal clock (see Grondin, 2001). This clock is most often described as composed of a pacemaker and an accumulator. The pacemaker emits pulses at some rate that are counted by the accumulator. The number of pulses accumulated over an interval of time depends on the rate of emission by the pacemaker, and is under the control of a switch (e.g. Church, 1984) triggered by the signals marking the beginning and end of the timing activity. It is the number of pulses that represents duration, and variations in temporal performance are assumed to depend mainly on the variability of this pulse accumulation process. When analyzing the variability of timing performances, it is important to determine what part of variance is due to the clock, and what part is nontemporal. The experiments presented below are focused on nontemporal factors, to examine how they influence time judgments.

The experimental task most employed in time psychophysics is probably duration discrimination. In such a task, a participant is asked to judge the relative duration of two or more time intervals. Discriminating a filled interval (marked by a continuous signal) instead of an empty interval influences performance. The literature shows that performance difference between these two types of intervals probably depends on the range of durations under investigation and on the method employed. For instance, with an adaptive procedure (i.e., a procedure where both a standard and a comparison interval are presented on each trial, and where the level of difficulty of the discrimination is adjusted after each trial with an appropriate change of the comparison interval), Grondin (1993) reported no difference between filled and empty auditory intervals for both the 50- and the 250-ms ranges of duration. However, in the visual modality, discrimination was better with empty than with filled intervals, for these two ranges of duration (see also Plourde, Gamache & Grondin, 2008). Moreover, with a single stimulus method of presentation of the intervals (i.e., one response after each presentation of an interval), empty intervals were better discriminated than filled intervals in both ranges of duration, and with both sensory modalities (visual and auditory; see also Grondin, Meilleur-