Taken together, the results of the present study suggest that practice affects specifically the processes taking place before the gap occurrence since the slopes of the production functions varied with practice. Intercepts of these functions were stable and CVs of produced intervals did not vary notably, suggesting that the representation of the target interval itself was not modified significantly by practice. Similarly, produced intervals in practice trials performed at the beginning of experimental sessions appeared to be unaffected by practice (see Table 1).

Previous studies suggest that two main factors are responsible for the effect of varying gap location in time production with gaps: attention sharing between timing and monitoring for the gap signal while it is expected during the pregap period (Fortin & Massé, 2000), and preparation to interrupt timing, which also takes place during the pregap period (Bherer et al., 2007). Attention sharing as well as preparation may have both contributed to make the effect of gap location vary in the present study. For example, practice may have increased the degree of certainty about the time of gap occurrence, influencing the amount or duration of attention sharing before the gap. Similarly, practice may have allowed the participants to better prepare to interrupt timing as soon as the gap signal occurs, thus increasing gradually the strength of the gap location effect in the first 10 experimental sessions. After a certain number of experimental sessions however, additional practice in trials with gaps would not increase further the degree of certainty concerning the possible values of gap location so that the gap location effect stabilizes. This would explain why, in the last 10 experimental sessions, the slopes of the functions relating produced intervals to gap location remained relatively stable.

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References

Brown, S. W. (1998). Automaticity versus timesharing in timing and tracking dual-task performance. *Psychological Research, 61,* 71-81.

Brown, T. L., & Carr, T. H. (1989). Automaticity in skill acquisition: Mechanisms for reducing interference in concurrent performance. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 686-700.

Bherer, L., Desjardins, S., & Fortin, C. (2007). Age-related differences in timing with breaks. *Psychology and Aging, 22*(2), 398-403.

Fortin, C., Bédard, M.-C., & Champagne, J. (2005). Timing during interruptions in timing. *Journal of Experimental Psychology: Human Perception and Performance, 31*(2), 276-288.

Fortin, C., & Massé, N. (2000). Expecting a break in time estimation: Attentional time-sharing without concurrent processing. *Journal of Experimental Psychology: Human Perception and Performance, 26*(6), 1788-1796.

Macar, F. (2002). Expectancy, controlled attention and automatic attention in prospective temporal judgments. *Acta Psychologica, 111*(2), 243-262.

Niemi, P. & Näätänen, R.(1981). Foreperiod and simple reaction time. *Psychological Bulletin, 89*, 133-162.

EXPLORATION OF THE FILLED-TIME ILLUSION WITH AN INTERVAL PRODUCTION TASK

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Abstract

The filled-duration illusion, or divided time illusion, refers to the fact that intervals filled with one or multiple intervening sensory events are perceived as being longer than undivided intervals of the same physical duration. The range of durations for investigating this illusion is most often restricted to very short durations (less than a second). Two experiments involving temporal production were conducted, in which participants used a finger-tapping method to produce series of .8- to 3-s target intervals (Experiment 1) or 1- to 1.4-s target intervals (Experiment 2). In Experiment 1, the addition of a divider leads to longer productions only in the short-target conditions but to shorter and more precise productions in the long-target conditions. In Experiment 2, the number of dividers varied from 0 to 3. The results showed that the constant error was larger at 1 than at 1.4 s and larger when more dividers were used, which is attributed to an increase in the information processing load.

The segmentation of temporal intervals can induce a bias in the evaluation of their duration. Indeed, a classical phenomenon called the “filled-time illusion” or “filled-duration illusion” refers to the fact that intervals filled with stimuli are perceived as longer than empty intervals of equal physical duration (Hall & Jastrow, 1886). Although this phenomenon has been investigated by several researchers (see ten Hoopen, Miyauchi, & Nakajima, in press), some questions remain unanswered, given the large number of parameters to consider with regard to this illusion (e.g. the type and the number of dividers, the duration range examined, the sensory modality marking time…).

Several solutions have been proposed to account for the observed overestimation of filled intervals (e.g. Adams, 1977; Nakajima, 1987; Thomas & Brown, 1974). For instance, Buffardi (1971) reported that the overestimation is directly due to the number of dividing sounds occurring during an interval. On the other hand, Nakajima’s (1987) model proposes a simple and straightforward solution: The magnitude of the overestimation is proportional to the number of subdivisions, plus a constant, which can be represented by the following formula:

$$\tau(t) = k(t + \alpha),$$

$\tau(t)$ being the subjective duration of a time interval as a function of its physical duration t, a scaling constant k, and a ‘supplementary’ constant, which would represent the mental time required to process the interval. The value of α is estimated at 80 ms (Nakajima, 1987). For example, if we apply this formula to an empty interval divided by 2 sounds (thus, 3 subintervals to process), the total perceived duration should be equal to $k(t1 + 80ms) + k(t2 + 80ms) + k(t3 + 80ms) = k(t1 + t2 + t3 + 240ms)$. Suppose that we set k at 1 (k =1) for this example; we would then observe a 240 ms overestimation of the subjective duration compared to physical time, 160 extra ms being a direct consequence of the segmentation. While Nakajima did not do the test to validate this model, a close look at Buffardi (1971) reveals that the reported results provide support for this explanation (ten Hoopen et al., in press).

The purpose of the following experiments is to directly test to what extent the model proposed by Nakajima (1987) can predict the perceived duration of subdivided intervals from different duration ranges. We anticipated that the insertion of dividing signals would generate longer production times for short durations, and that each additional subinterval would lengthen productions by about 80 ms.

In addition to this tendency to produce intervals that are longer than the real value of the standard, we expected the segmented intervals to be reproduced with less variability. This prediction rests on the fact that using a segmentation strategy leads to less variable time estimations for relatively long time intervals (e.g. Getty, 1976; Grondin, 1992; Grondin, Ouellet, & Roussel, 2004; Grondin, Meilleur-Wells, & Lachance, 1999; Wearden, Denovan, Fakhri, & Haworth, 1997).

Experiment 1

Method

Participants
Twenty-four 21- to 51-year-old volunteers, 10 females and 14 males, participated in this experiment. All participants were paid CAN$10 for their participation.

Apparatus and stimuli
The experiment was under the control of a Zenith micro-computer, which was linked to a response box that contained the pushbutton used to produce the intervals. The auditory markers defining the target interval that the participant had to produce were a 15-ms, 5-kHz tone. Each sound dividing the target interval was a 15-ms, 1-kHz tone.

Procedure
Each trial started with the presentation of a series of 11 successive auditory markers defining 10 examples of the target intervals to be produced. In the segmented-target condition, the target interval was interrupted by one divider, which subdivided the target into two equal subintervals. The task of the participant was to produce a series of taps separated by a duration equal to the target interval.

There were 24 experimental conditions, 2 input types (segmented vs. nonsegmented) times 12 targets (.8, 1, 1.2, 1.4, 1.6, 1.8, 2.0, 2.2, 2.4, 2.6, 2.8, and 3.0 s). Each participant completed two sessions, one for each input type (segmented vs. nonsegmented). Twelve participants completed the nonsegmented input session first, and the 12 others were tested in the reverse order. The order of the target conditions varied for each participant. One participant had the following order: .8, 1.0, 1.2, … 3 s; another started with 1.0, 1.2, 1.4 s and ended with 2.8, 3 and .8 s; a third started with 1.2 s and ended with 1 s; and so on. The order of the target duration for a given participant was the same in the segmented and nonsegmented conditions. For each experimental condition, there were two trials, i.e., a series of inputs followed by 31 taps, and another series of inputs followed by 31 taps. After the inputs were presented, participants were free to start the production task at any time.

Each of the twenty-four experimental conditions was conducted twice and the best of two performances was retained for the final analysis. The best performance was the smallest number resulting from the following formula: Standard Deviation * | Mean Production Interval - Target Duration | (i.e., SD * | MPI - TD |).

Results

Two dependent variables are tested: the constant error of productions (CE = MPI – TD) and the coefficient of variation as an index of sensitivity (CV = SD / MPI). Mean CEs and CVs are presented in Figures 1 and 2. We conducted a 2 x 12 ANOVA with repeated measures on each dependent variable (2 Segmentation x 12 Target Duration).

The segmentation variable was found to have a significant effect on the CE, *F*(1, 23) = 4.51, *p* < .05. There was no significant effect for the target duration, but there was a significant interaction for Segmentation x Target Duration, *F*(11, 253) = 3.24, *p* < .001. Multiple comparisons performed with *t* tests indicated that significantly longer intervals were produced in the nonsegmented condition at 2.8 s, *t*(23) = 2.13, *p* < .02, and at 3 s, *t*(23) = 3.51, *p* < .001. In these cases, the differences were composed of a mixture of produced intervals briefer than the target in the segmentation condition and longer than the target in the nonsegmentation condition.

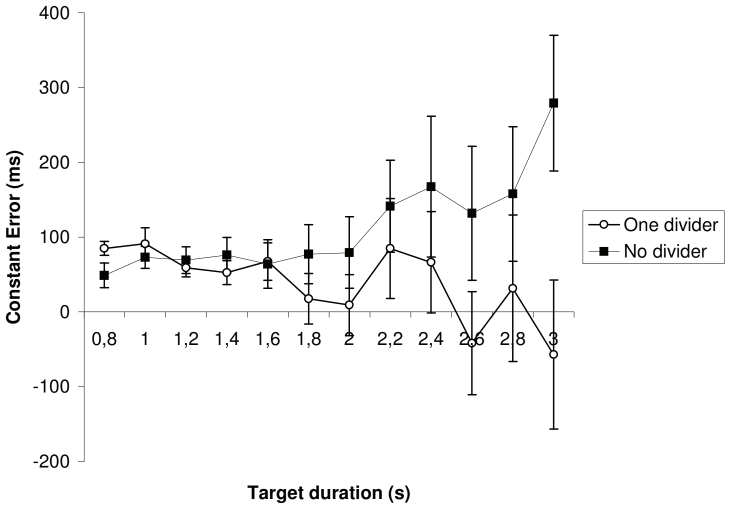

Figure 1: Constant error (± standard error) as a function of the target duration and the segmenting condition

With regard to the CV, the segmentation condition had a significant impact, *F*(1, 23) = 15.34, *p* < .01. The CV is akin to the Weber fraction and should be constant assuming that Weber's law is correct. Figure 2 shows that, for the nonsegmented condition, the CV varies very much according to the target's length. The CV decreases from .8 to 1.2 s, a finding that might be accounted for by the *Generalized form of Weber's law*. This decrease is followed by a step from 1.2 to 1.4, and by some constancy from 1.4 to 2.2 s. However, beyond 2.2 s, there is an important increase in the CV. On the other hand, in the segmented condition, the CV is constant from 1 to 1.8 s, but beyond this value, CVs become much higher.

The target duration also has a significant effect on the CV, *F* (11, 253) = 12.33, *p* < .01. The Segmentation x Target Duration interaction is also significant, *F*(11, 253) = 2.71, *p* < .001. Multiple comparisons performed with *t* tests revealed significant differences between the segmented and non segmented conditions at 1.4 s, *t*(23) = 2.46, *p* = .01, at 1.6 s, *t*(23) = 2.766, *p* = .006, at 1.8 s, *t*(23) = 3.057, *p* = .003, at 2.0 s, *t*(23) = 1.996, *p* = .029, at 2.8 s *t*(23) = 3.520, *p* = .001, and at 3.0 s, *t*(23)= 3.741 *p* = .0005. In the non-segmented condition, the difference between data points was not significant when 1 and 1.2 s were compared, *t*(23) = 1.337, *p* = .10 but it was when 1.2 and 1.4 s were compared, *t*(23)= 3.601, *p* = .0008.

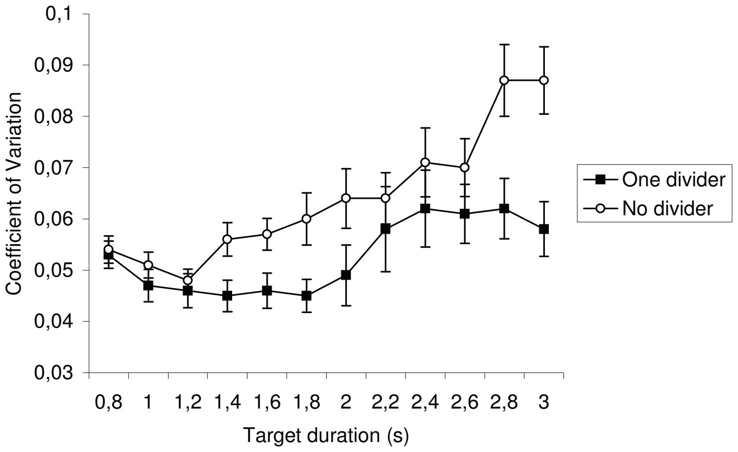

Figure 2: Coefficient of variation (± standard error) as a function of the target duration and the segmenting condition

Experiment 2

Method

Participants
Twenty-four volunteers participated in this experiment. All participants were students at Université Laval and were paid CAN$10 for their participation.

Apparatus and stimuli
The apparatus and stimuli are the same as in Experiment 1.

Procedure
The procedure is essentially the same as in Experiment 1. However, some parameters were changed. Firstly, the target durations to be reproduced were 1.0, 1.2, or 1.4 s. Secondly, the number of targets presented before production was manipulated; there were either 3 or 9 examples. Finally, there could be either 1, 2, 3 or 4 (equal) subintervals within a target duration. Hence, each participant was tested in 24 experimental conditions (3 target durations x 2 numbers of presentations before production x 4 divider conditions).

Results
Mean CEs and CVs are illustrated in Figures 3 and 4. Two 2 x 3 x 4 ANOVAs were conducted, one on each dependent variable. The CE was significantly influenced by the target duration $F(2, 46) = 7.32$, $p < .001$ and by the number of dividers, $F(3, 69) = 9.55$, $p < .01$. The number of target presented before production did not have a significant influence and no significant interaction was found between the 3 independent variables.

The CV was also influenced by the target duration, $F(2, 46) = 16.62$, $p < .001$ and the number of dividers, $F(3, 69) = 3.220$, $p < .001$. The interaction between these two variables was significant, $F(6, 138) = 2.651$, $p = .018$. There was no significant effect of the number of dividers.

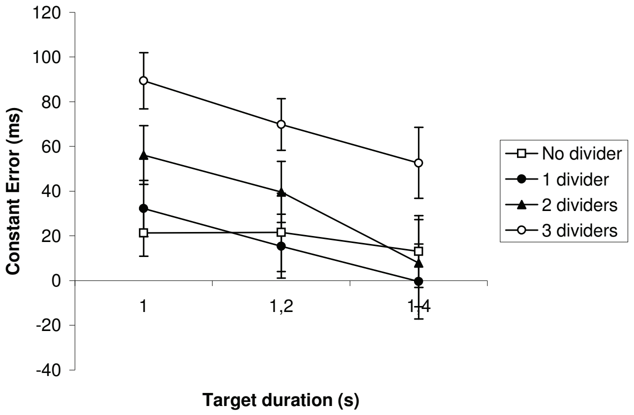

Figure 3: Constant error (± standard error) as a function of the target duration and the number of dividers

Conclusion

The aim of the two experiments presented here was to further understand the underlying mechanisms of the filled-time illusion. The results show two noteworthy features. Firstly, adding only one interval does not necessarily increase time productions (Experiment 1). Secondly, using many dividers generates overestimations when 1.0- to 1.4-s intervals are produced (Experiment 2).

As predicted by Nakajima’s (1987) model, there is a linear increase ($r^2 = .99$), in Experiment 2, in the length of temporal productions as a function of the number of subintervals if we average production times for the three target durations; however this increment only applies when increasing the number of subintervals from two to three and three to four. Indeed, the insertion of only one divider doesn’t impact the duration of time reproductions. We suggest that the cost associated to the processing of additional subintervals, which reflects increased mental time requirements, is only apparent if the information load contained in the interval is too great. Moreover, the addition of three and four subintervals results respectively in 24 ms and 25 ms overestimations, which is much smaller than the 80 ms value predicted by the model.

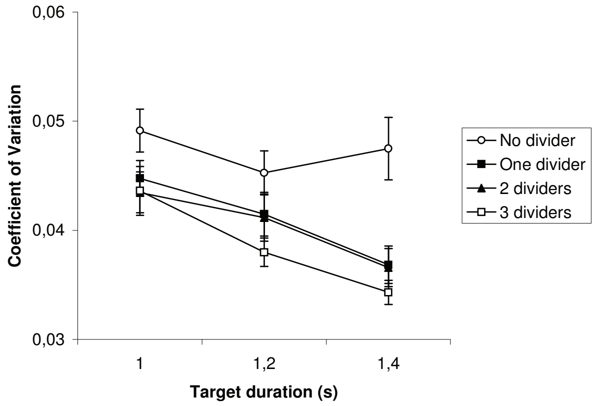

Figure 4: Coefficient of variation (± standard error) as a function of the target duration and the number of dividers

The results of Experiment 1 have another interesting implication for the filled-time illusion: it seems to reach a temporal limit for intervals that are longer than 2.4 s. In this case, instead of leading to overestimations, segmenting intervals helps to stay closer to the target. Without segmentation, there seems to be a tendency to overestimate when reproducing longer target durations. The segmentation strategy, in this case, seems to be beneficial in that it appears to prevent this tendency. Actually, the benefits from segmentation are not only apparent with regard to mean target production, but also in terms of variability. In both experiments, there was a step in the function linking variability and time when targets increased from 1.2 to 1.4 s. In addition, while there was no variability difference between the segmented and nonsegmented conditions for durations inferior to 1.2 s, a significant difference occurred at 1.4 s.

With regard to these observations, one might suggest that the extra mental time required to process each subinterval might depend on their length rather than on their number. Indeed, it would seem to take extra time to process very short subintervals, while it would be cost-free to process longer durations. This explanation could conciliate the fact that there is some overestimation when multiple dividers are inserted, but no additional overestimation with only one divider. The shorter productions (CE closer to 0) in the segmented condition for long intervals are interpreted as a result of the beneficial effects of segmenting time. In terms of variability, there seems to be a beneficial impact if intervals are longer than 1.2 s.

References

Adams, R. D. (1977). Intervening stimulus effects on category judgments of duration. *Perception and Psychophysics, 21,* 527–534.

Buffardi, L. (1971). Factors affecting the filled-duration illusion in the auditory, tactual, and visual modalities. *Perception & Psychophysics, 10,* 292–294.

Getty, D. (1976). Counting processes in human timing. *Perception & Psychophysics*, *20*, 191-197.

Grondin, S. (1992). Production of time intervals from segmented and nonsegmented inputs. *Perception & Psychophysics, 52*, 345-350.

Grondin, S., Ouellet, B., Roussel, M.-E. (2004). Benefits and Limits of Explicit Counting for Discriminating Temporal Intervals. *Canadian Journal of Experimental Psychology, 58,* 1-12.

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 by humans. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 993-1004.

Hall, G.S. & Jastrow, J. (1886). Studies of rhythm. *Mind, 11*, 55-62.

Nakajima Y, (1987). A model of empty duration perception. *Perception, 16*(4) 485-520.

ten Hoopen, G., Miyauchi, R., & Nakajima, Y. (in press). Time-based illusions in the auditory mode. In S. Grondin (Ed.). *Psychology of time*. Emerald Publisher.

Thomas, E. A. C., & Brown, I. (1974). Time perception and the filled duration illusion. *Perception & Psychophysics, 16,* 449–458.

Wearden, J. H., Denovan, L., Fakhri, M., & Haworth, R. (1997). Scalar timing in temporal generalization in humans with longer stimulus durations. *Journal of Experimental Psychology: Animal Behavior Processes, 23,* 502–511.

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.

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EAR ASYMMETRIES IN GAP DETECTION

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Abstract

Some research suggests a right-ear advantage for the ability of normal listeners to detect brief gaps (pauses) in noise, whereas other research does not. This experiment uses a narrowband gap detection procedure to assess a possible right-ear advantage in two frequency regions (500 Hz and 4 kHz) using a cued yes-no method of maximum likelihood (MML). The gaps were carried by 786-ms noises set at 85 dB SPL and started at 250-ms after the onset of the noise. Thirty right-handed normal listeners were presented stimuli in mixed order in the presence of a band-stop masker to prevent audible cues from spectral splatter. There were no significant differences between the data from left and right ears at either frequency region as indicated by analysis of variance for repeated measures. Present results and data from the literature suggest that the type of stimulus plays a role in ear asymmetries in gap-detection tasks.

Because central auditory processing disorders can be identified with temporal tasks and adequate temporal processing is highly likely to be related to the ability to understand speech in noise, there has been a quest to find a simple and reliable measure of temporal processing that can be used with individual listeners in clinical settings. One such measure that has offered promise is the ability to detect a pause, or gap, in a noise. Florentine, Buus, and Geng (2000) examined a possible clinical procedure for a narrowband gap-detection test that is simple, frequency specific, and reliable. Results were encouraging. A subsequent study showed a significant correlation between this task and the ability of normal-hearing listeners to understand speech in narrowband noise (Costa, Silva, and Florentine, in revision).

One aspect that needs to be considered in any clinical gap-detection task is the possibility of a right-ear advantage in temporal tasks. Whereas a right-ear advantage has been found in some gap-detection tasks (Varoon, Timmers, and Tempelaars, 1977; Brown and Nicholls, 1997; Nicolls, Schier, Stough, and Box, 1998), it is not universally observed (Efron, Yund, and Nichols, 1985; Oxenham, 2000; Sulakhe, Elias, and Lejbak, 2003; Sininger and de Bode, 2008). The purpose of the present study was to measure gap-detection thresholds in the left and right ears of a group of normal listeners to determine the presence or absence of a right-ear advantage in the clinical gap-detection task proposed by Florentine *et al*. (2000).

Method

Listeners. Thirty normal-hearing listeners (15 males and 15 females) participated in the experiment. They ranged in age from 19 to 32 years. Only two listeners had prior experience with gap-detection tasks. All listeners were right handed and were paid for their participation.

Stimuli and Procedures. The stimuli and procedures were the same as those used by Florentine *et al*. (2000). The stimuli were gaps in bandpass narrowband noises presented at 85 dB SPL at two center frequencies (500 Hz and 4 kHz). Each bandpass noise that carried the gap was 786 ms and had a 20-ms rise and fall time. The gap occurred 250-ms after the onset of the noise. The initial gap duration was clearly audible for all listeners.