Conclusion

The duration of the joyful excerpt (ratio > 1 with each method) was estimated as longer than that of the sad excerpt. This tendency is consistent with previous results on the effect of music on time estimation. For intervals lasting 2.5 minutes, Kellaris and Kent (1992) showed that the positively valenced music leads to an over-estimation of time. However, from a more global perspective, these findings are inconsistent with those reported by Hornik (1992), where an elated mood led to an underestimation of time. Clearly, more work is needed to clarify the impact of emotions on retrospective timing.

Moreover, compared to real time, the duration of the cognitive task was systematically underestimated, with an estimated duration to real time ratio much lower than 1 (approximately .8). This feature of the findings, as well as the relative estimated duration of joyful and sad excerpts, applies with each method used to estimate duration. However, the data also reveal some differences between methods. First, the duration in the sadness condition was estimated as longer than that in the neutral (cognitive) condition with the relative and verbal estimates conditions, but not with the standard condition. Moreover, the mean estimates for the three tasks are much lower than 1 with the judgments based on a standard and with the verbal estimates, and slightly above 1 with the other (relative estimates) method.

The present study showed that the method of relative estimates can be used and will reveal, as do verbal estimates, the main effects under investigation and the same type of distortions when used in a context where unequal intervals are to be estimated by the same participants. The method based on comparisons with a standard might lead to slightly different results.

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TEMPORAL LIMITS OF MEMORY FOR TIME

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Abstract

To further explore how memory influences time judgements, we will address the question of the life span of temporal representations in memory using the "memory-mixing" account of visual/auditory differences as a framework (Penney, Allan, Gibbon & Meck, 1998). In bisection tasks, these authors reported that the perceived duration of intervals differs according to the modality of the signals used for marking time. Modality differences only show up when there is a direct comparison of different marker-type intervals. In other words, the memory trace of previously processed intervals influences the perception of upcoming ones. In the present experiment, we manipulated the delay between auditory/visual signal presentations. In Condition 1, signals from the same modality were grouped by blocks of 60 trials; in Condition 2, visual and auditory signals were randomized across trials. Results show that the auditory/visual difference decreased when modalities were grouped by blocks, but remained present. In brief, 1) Penney et al.'s results were successfully replicated; 2) the critical role of memory for auditory/visual differences was highlighted by manipulating the delay; and 3) in this experimental context, the life span of a memorized interval is most likely inferior to the duration of a 60-trial block.

Researchers in the time perception field have recently shown increasing interest in the memory mechanisms that underlie time judgements (e.g. Droit-Volet, Tourret & Wearden, 2004; Ivry & Spencer, 2004; Penney, Allan, Gibbon & Meck, 1998; Penney, Gibbon & Meck, 2000). Indeed, memory representations of temporal information could explain an important part of the variability of time judgements (Gibbon & Church, 1984; Grondin, 2005; Jones & Wearden, 2004), even if some authors have reported that the suppression of memory demands during a time perception task does not eradicate all scalar variability (Allan & Gerhardt, 2001; Rodriguez-Girones & Kacelnik, 2001; Wearden & Bray, 2001). Although the importance of memory in time processing is well established, little is known about one of its potential, critical limitations: the decay of memorized temporal representations.

The importance of the persistence of the memory trace is highlighted in the memory-mixing model account of auditory (A) vs. visual (V) perceived duration differences, as described by Penney et al. (1998, 2000). These authors reported a series of temporal bisection tasks using A and V signals. Participants were assigned to one of two modality-mixing paradigms: 1) both modalities mixed within a session or 2) different subjects for different modalities. In the latter paradigm, no perceived duration difference was observed according to the signals' modality. However, when participants experienced both types of signals, psychometric functions were shifted toward the right for visual signals compared to those in the auditory mode. In other words, participants tended to judge auditory signals as being longer than visual ones for equivalent physical durations.

This subjective duration distortion is argued to depend on two factors: the differential effects of the signal's input modality on the accumulation process, and the creation of an amodal memory distribution used as a reference (Penney, 2003). The underlying cause of the first factor remains unclear. The longer perceived duration of auditory signals relative to visual ones would be due to a greater temporal accumulation in the former case. This greater

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accumulation could result either from the property of an internal clock which would run faster with auditory than with visual signals, or from a shorter latency to begin timing when auditory signals are used (Droit-Volet, Meck, & Penney, 2007). These two potential causes have different implications on A-V differences. The clock-speed account predicts that the magnitude of the A-V difference should be proportional to the length of the base duration. The latency explanation predicts an additive difference, one that should be constant across different base durations. Both explanations find empirical support, although the clock-speed explanation seems to be favoured in more studies (e.g. Penney et al., 1998, 2000; Wearden, 2006; Wearden, Edwards, Fakhri, & Percival, 1998).

The second factor is related to the use of a memory reference that is amodal, i.e., that is not specific to a sensory modality. The memory distribution is generated from the temporal information contained in both the auditory and visual signals that were processed previously. Consequently, since the auditory target intervals generate more pulses than the visual ones, and both signals are compared to a common distribution, auditory intervals are more often judged as being longer.

The aim of the present study is to determine the persistence of temporal representations in reference memory via Penney at al.'s (1998, 2000) memory-mixing model. In a bisection task, the memory distribution used as a reference depends on previously processed intervals. The question addressed here is as follows: What is the relative contribution of old and recent intervals to this distribution?

A bisection task involving auditory and visual signals like the one reported in Penney et al. (1998; 2000) was used in the present experiment. However, instead of randomizing auditory and visual signals from trial to trial, stimuli from one given modality were grouped in blocks in one condition. The analysis of the bisection point as a function of the number of elapsed trials should reflect changes within the reference distribution. In other words, we should be able to estimate if the memory distribution used at different moments of the experiment was generated on the basis of visual or auditory signals alone, or on both types of signals.

Method

Participants
Sixteen 20- to 28-year-old volunteer students at Université Laval, 10 females and 6 males, participated in this experiment. They were paid CAN$20 for their participation.

Apparatus and stimuli
The sensory signals marking time were either visual or auditory. The visual signals consisted of 5 cm^2 black squares appearing on the white background of a computer screen. The auditory signals consisted of 880Hz sinusoidal sounds generating 70 dB SPL and were presented through speakers.

Each observer was seated in a chair in a dimly lit room and asked to respond either "short" or "long" by pressing "1" or "3" on the computer keyboard. The delivery of the signals, the computing of participants' responses, and all other aspects of the experiment were computer-controlled, using E-prime 3.0 software.

Where applicable, feedback was delivered from a short sentence presented on the screen, indicating if the preceding signal was indeed short or long. The sentence was written in green characters following a good answer and in red following an error.

Procedure
Participants completed a bisection task with anchor durations set at 3 s (short: S) and 6 s (long: L), and were asked to judge whether a target interval was closer to the S or the L anchor duration.

Targets had the same duration as those reported by Penney et al. (2000; Experiments 1 and 2): 3.0, 3.67, 3.78, 4.24, 4.76, 5.34 and 6.0 s long. Their logarithmic spacing follows the assumption that the bisection point is located at the Geometric Mean (GM) (Allan & Gibbon, 1991). Note that 3.67 does not follow the log spacing but is the value reported by Penney et al. (2000). Given that signals can be visual or auditory, 14 types of intervals were delivered: 3s-V, 3.67s-V, 3.78s-V, 4.24s-V, 4.76s-V, 5.34s-V, 6s-V; 3s-A, 3.67s-A, 3.78s-A, 4.24s-A, 4.76s-A, 5.34s-A, 6s-A.

The experiment started with a training block, during which S and L intervals were presented three times in each modality, for a total of 12 presentations, and were always followed by feedback. The presentation order was randomized.

Two types of experimental sessions were used: *Trial-to-Trial* (TT) vs. *Block-to-Block* (BB). In the TT session, the 14 possible intervals were delivered randomly from trial to trial. There were four blocks of 60 trials each. Each 60-trial block was as follows: 5 x 3s-V, 4 x 3.67s-V, 4 x 3.78s-V, 4 x 4.24s-V, 4 x 4.76s-V, 4 x 5.34s-V, 5 x 6s-V; 5 x 3s-A, 4 x 3.67s-A, 3.78s-A, 4 x 4.24s-A, 4 x 4.76s-A, 4 x 5.34s-A, 5 x 6s-A.

In the BB session, intervals from one modality were grouped in blocks of 60 trials. There were two block sequences: A-V-A-V and V-A-V-A. Half the participants were assigned to each sequence order. For instance, Block 1 of Sequence 1 included a randomized presentation of the following intervals: 10 x 3s-A, 8 x 3.67s-A, 8 x 3.78s-A, 8 x 4.24s-A, 8 x 4.76s-A, 8 x 5.34s-A, 10 x 6s-A. Finally, in the TT or the BB session, each presentation of S or L was followed by the presentation of feedback.

All participants were tested in both types of sessions (TT and BB). At least 24 hours separated the two sessions. Half the participants began with the TT session, while the other half began with the BB session. All sessions consisted of four blocks of 60 trials, with a 20 s pause between the blocks.

Data Analysis
For each participant and for each experimental condition, a 7-point psychometric function was traced, plotting the seven target intervals on the x axis and the probability of responding "long" on the y axis.

The cumulative normal distribution was fitted to the resulting curves. Two indices of performance were estimated for each psychometric function, one for sensitivity and one for the perceived duration. One critical dependent variable is the bisection (BP). The BP can be defined as the x value corresponding to the .50 probability of "long" responses on the y axis. The observed shift of the BP for different experimental conditions can be interpreted as an indication of differences in perceived duration. Thus, longer perceived durations are reflected by smaller bisection point values (Grondin, 1998). In the present study, perceived duration is the most critical dependent variable.

As an indicator of temporal sensitivity, estimates of the standard deviation (SD) on the psychometric function were determined. For this purpose, the difference between the x values corresponding to .84 and .16 probabilities of "long" responses, on the y axis, was divided by 2. Using one SD (or variance) is a common procedure to express temporal sensitivity (Killeen & Weiss, 1987).

The two main independent variables tested are the modality (A vs.V) and the session delay (TT vs. BB). Two procedural variables are also taken into account: the order of the sessions (2 orders: TT-BB vs. BB-TT) and the rank of the session (1^{st} vs. 2^{nd}).

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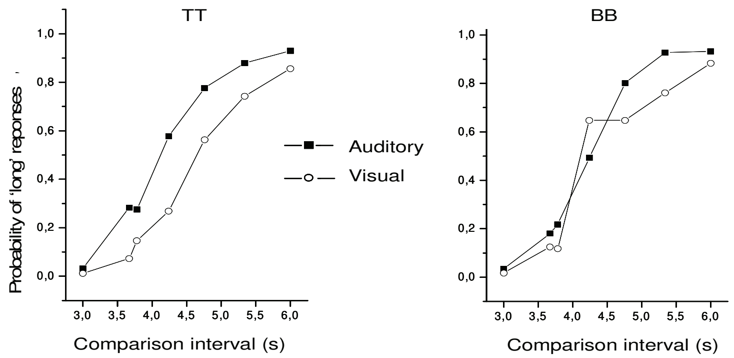

Figure 1. Averaged group functions for the probability of a long response for each modality condition in both Block-to-Block (BB) and Trial-to-Trial (TT) sessions.

Results

The functions for the averaged group results for each signal modality and each target duration are plotted in Figure 1. Table 1 summarizes the descriptive statistics. A two-factor (Modality x Session Delay) repeated measures ANOVA was conducted on each dependent variable, BP and SD. Results showed that the BP was significantly lower with auditory than with visual signals, F (1, 15) = 27.40, p = .0001, r = .32, p_{rep} = .996. The difference between the two session delays was also significant, F (1, 14) = 6.50, p = .02, r = .57, p_{rep} = .92. The BP was lower in BB session than in the TT session. The Modality X Session Delay was also significant, F (1, 14) = 23.62, p = .0002, r = .80, p_{rep} = 0.99.

A 2 x 2 x 2 split plot ANOVA (2 orders: BB-TT vs. TT-BB x 2 session ranks: 1st session vs. 2nd session x 2 modalities) revealed the presence of procedural effects (see Figure 3). The Order had a significant impact on the BP, F (1, 14) = 15.40, p = .002, r = .72, p_{rep} = .98. The eight participants who began with the BB session had lower bisection points than the other eight. The other main effect, the Rank variable, was not significant, F (1, 14) = 1.47, p = .25, but the Order x Rank interaction was significant, F (1, 14) = 7.75, p = .03, r = .60, p_{rep} = .91, just like the Order x Rank x Modality interaction, F (1, 14) = 12.8, p = .003, r = .69, p_{rep} =.97. The Order effect disappeared when only the first session of the participants was taken into account, F (1, 14) = 1.34, p = .27, r = .3, p_{rep} = 0.67. However, the effect was larger when

Table 1.
Mean (and standard error) Results for Bisection Point (*BP*), Standard Deviation (*SD*) and Goodness-of-Fit (R^2) for Auditory and Visual Conditions in Both Types of Sessions. BB = Block-to-Block; TT = Trial-to-Trial

Modality	Session	*BP* (s)	*SD* (s)	R^2
Auditory	TT	4.09 (.07)	.58 (.05)	.95 (.012)
	BB	4.19 (.04)	.55 (.03)	.97 (.009)
	Total	4.13 (.04)	.61 (.05)	.96 (.008)
Visual	TT	4.65 (.06)	.77 (.07)	.95 (.012)
	BB	4.29 (.04)	.67 (.09)	.89 (.021)
	Total	4.47 (.04)	.68 (.05)	.92 (.014)
Total	TT	4.37 (.41)	.68 (.08)	.95 (.010)
	BB	4.24 (.34)	.61 (.03)	.93 (.008)

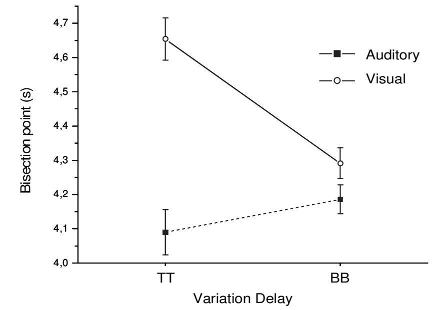

Figure 2. Bisection point (± standard-error) as a function of the modality and the variation delay. BB = Block-to-Block; TT = Trial-to-Trial

only the second session was taken into account, F (1, 14) = 19.98, p = .0005, r = .77, p_{rep} = .99. Moreover, the underestimation in the TT condition for the second session was significant with the auditory signals, t(14) = 2.95, p = .01, but not with the visual ones, t (14) = 1.36, p = .20.

For temporal sensitivity, a ANOVA 2X2 (Modality X Delay) ANOVA with repeated measures performed on the standard deviation of the psychometric functions revealed that the modality had a significant influence, the auditory trials generating less variability than the visual ones, F (1, 15) = 5.51, p = .03, R = .53, p_{rep} = .90. The effect of time, F (1,15) = 2.64, p = .13, and the procedural effects, as tested in a mixed ANOVA, were not significant (Rank: F [1,14] = 2.0, p = .18, Order: F (1,14) = .23, p = .64).

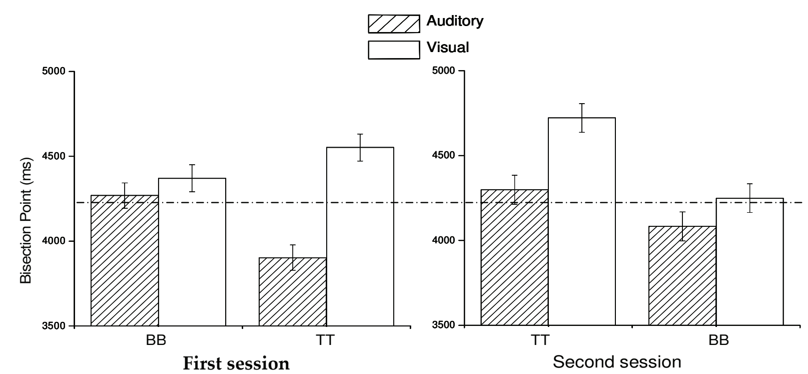

Figure 3. Mean bisection point (± standard error) observed in the first and second sessions as a function of the variation delay. BB = Block-to-Block; TT = Trial-to-Trial

Conclusion

Perceived duration was the central dependent variable in this experiment. As expected, the auditory intervals were considered longer than the visual ones. For the TT condition, the results were similar to those of Penney et al. (2000). The BP issued from the auditory signals was closer to the GM (4.24 s) than was the BP observed with the visual signals, indicating the preponderance of auditory signals in the formation of the memory reference.

Perhaps a more critical issue in the present experiment is the fact that the modality effect was strongly reduced when auditory and visual signals were delivered in unimodal blocks, rather than varied from trial to trial. This suggests that most of the memory trace left by the temporal representations has a persistence duration smaller than the duration of a 60-

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trial block (approximately eight minutes). Moreover, a long-term influence (24 h later) of previously processed information was also detectable through the analysis of the procedural variables. In other words, both global and local contexts influenced perceived duration (Jones & McAuley, 2005).

It is suggested that long-term indices were consolidated only once the experimental sessions were over and the cognitive resources needed for extensive treatment of residual temporal information were released. In the dynamic context of an experimental session, where the temporal data processing system is overloaded, local indices are the main source of information that determine the reference in memory.

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EFFECTS OF TEMPORAL DISTRIBUTION OF SOUND ENERGY WITHIN MARKER DURATION ON THE PERCEPTION OF EMPTY TIME INTERVALS

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Abstract

The aim of this study was to examine whether and how the temporal distribution of sound energy within markers affects the perception of empty time intervals marked by their onsets. We fixed the duration of sound markers to 60 or 100 ms, and manipulated the sound energy distribution by changing their rise and fall times. We used each of these markers as one of the two markers of an empty time interval of 120, 240, or 360 ms. The other marker was always a 20-ms marker with a fixed rise and fall time of 10 ms. We measured points of subjective equality (PSEs) of these time intervals. The results showed significant effect of sound energy distribution, but only in the shortest time interval of 120 ms. In this condition, a longer rise time, thus a shorter fall time, of the first marker decreased the subjective duration of the interval.

When two short sounds are presented successively, they mark an *empty time interval* as an *inter-onset interval (IOI)*. Our previous study has shown that lengthening one or both of the sounds, called markers, can cause the subjective duration of the empty time interval to increase (Hasuo & Nakajima, 2007). In the present study, we focused on the *temporal sound energy distribution* within markers as one of the factors that may have affected the perception of time intervals in our previous study. Changes in marker duration necessarily cause changes in sound energy distribution, i.e., the center of sound energy shifts away from the physical onset as the marker lengthens, and therefore, we were interested in investigating whether fixing the marker durations and changing only the distribution of sound energy would influence the perceived length of a time interval. In order to change the sound energy distribution within markers, we varied rise and fall times, and conducted an experiment using tones with different rise/fall times as first or second markers.

Method

Participants

Nine listeners (3 females and 6 males) with normal hearing participated. Their ages ranged from 22 to 30 years.

Stimuli

Each presentation consisted of two pairs of markers, the first pair marking the standard time interval, and the second pair the comparison time interval (Figure 1). The lengths of the silent sections before the standard interval and between the standard and the comparison were changed each time the stimulus pattern was presented, within the ranges of 2000-2500 ms

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