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Studying the Processing of Multimodal Brief Temporal Intervals with an Equisection (Bisection) Task

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Abstract

Several studies have investigated the influence of auditory and visual sensory modalities on the variability and perceived duration of brief time intervals. However, few studies have investigated this influence when the two intervals to be discriminated share the same stimulus, and none of these have included the tactile modality. The aim of the present study was to investigate, in multimodal conditions, the capability to discriminate two adjacent intervals, using an equisection and adjustment method. Participants had to adjust the second of three brief successive signals marking two empty intervals until they were subjectively perceived as equal. The experiment included nine modality conditions and intervals between Markers 1 and 3 lasted 0.5, 1, 1.5, or 2 s (four standard conditions). The results show that the adjustment is better (lower variability) with three auditory (A) than with three visual (V) or tactile (T) markers, and these three conditions are better than when Marker 2 differs from Markers 1 and 3 (all intermodal conditions). Differences also emerged in the perceived duration of intermodal conditions. In TVT and VTV conditions, intervals marked by a tactile–visual (TV) sequence are perceived as longer than VT intervals, and in AVA and VAV conditions AV intervals are perceived as longer than VA intervals. Finally, AT intervals are perceived as longer than TA intervals, but only in the short standard conditions. In addition to replicating the classical variability increase when short intermodal intervals are used, the study shows the influence on perceived duration of the speed of processing of a visual signal.

Keywords

intervals discrimination, multimodality, perceived duration, Weber fraction

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1. Introduction

Many aspects of the perceptible world are specific to a single sensory modality (e.g., water temperature, sound intensity or color), while others are not (e.g., the duration of an interval). In time perception, the discrimination of short intervals is usually a task where the influence of these aspects can be experienced. However, temporal estimation is not always accurate and precise, and can be influenced by both temporal (e.g., duration of interval and stimulation) and nontemporal (e.g., sensory modality) factors. In the present study, a specific version of an equisection task, namely a temporal bisection task, is proposed to study the processing of short time intervals marked by very brief multimodal intervals. In this study, both the mean bisection points and their variability will be of interest.

1.1. Duration Discrimination

An important part of the timing literature focuses on the variability and perceived duration of subsecond intervals using a discrimination task. Typically, two intervals are presented and a brief pause between the stimulus marking the end of the first interval and the stimulus marking the beginning of the second interval (Grondin, 2001). In this case, no stimuli are shared between the two intervals. This task is usually performed by presenting a standard interval first, followed by a comparison interval, i.e., the reminder method (Lapid *et al.*, 2008; Macmillan and Creelman, 2004). The participant is asked to state whether the duration of the comparison interval is shorter or longer than that of the standard interval.

1.1.1. Variability

It is well known that with short empty time intervals, the discrimination is easier, i.e., sensitivity to small differences between intervals is greater, when they are marked by two auditory (AA) than by two visual (VV) (Grondin and McAuley, 2009; Fornaciai *et al.*, 2018; Fraisse, 1952; Williams *et al.*, 2019) or tactile (TT) (Azari *et al.*, 2023; Mayer *et al.*, 2014; Villalonga *et al.*, 2021; Williams *et al.*, 2019) signals. Regarding the VV *vs* TT intervals, some results show better discrimination (less variability in judgments) of TT intervals (Azari *et al.*, 2020; Bresciani *et al.*, 2008; Tomassini, 2011; Villalonga and Sekuler, 2023; Villalonga *et al.*, 2021; Williams, 2019), while others show better discrimination with VV intervals (Grondin, 2003; Grondin and Rousseau, 1991). These results suggest that auditory stimuli cause less nontemporal noise than visual or tactile stimuli. However, the noisy properties of the signals delivered from different sensory modalities are not the only cause of the different discrimination levels observed in AA, VV, and TT conditions. In any intermodal condition, i.e., when the stimuli marking a brief empty interval are coming from different sensory modalities, even if one of the stimuli is

A, the discrimination level is lower than in VV or TT conditions (Azari *et al.*, 2020; Grondin *et al.*, 2005; Rousseau *et al.*, 1983). Furthermore, the difference in discrimination levels in intra- *vs* intermodal conditions is much more pronounced for very short (300 ms) than for long (900 ms) intervals (Azari *et al.*, 2020, 2023).

1.1.2. Perceived Duration

The sensory modalities employed to mark intervals to be discriminated may also influence their perceived duration. In intramodality, it is known that AA intervals are perceived to be longer than VV (Ulrich *et al.*, 2006) and that TT intervals are judged to be longer than those delimited by VV (Tomassini *et al.*, 2011; van Erp and Werkhoven, 2004). A part of the differences in perceived duration could be explained by the sensory trace that a signal might leave, assuming the timekeeping period of an empty interval begins once the trace left by the sensory signal disappears. If a visual stimulation leaves a longer sensory trace than an auditory or a tactile signal, the beginning of the period to be timed might be more delayed with a visual signal, resulting in a decrease in the perceived duration of the interval. Such an interpretation would also explain why intervals marked by a visual stimulus followed by an auditory stimulus (VA) are perceived as shorter than AV intervals (Azari *et al.*, 2020; Grondin *et al.*, 1996). In this VA *vs* AV example, the different perceived durations may also be related to the speed of detection of the second stimulus signal. Considering that the detection speed of an auditory stimulus is faster than that of a visual stimulus, an interval is expected to be perceived as shorter when the stimulus marking the end of the interval is auditory rather than visual.

1.2. Duration Discrimination Using Three Successive Stimuli

Less studies have examined the variability and perceived duration of the discrimination of two intervals sharing the same stimulus, i.e., a sequence of three successive brief stimuli delimiting two intervals (e.g., AAA). Using this type of sequence enables the participant to judge the relative position of the second stimulus in relation to the first or third, i.e., whether it is temporally centered or not. For example, this type of sequence has been used to observe the effect of stimulus duration on temporal judgments (Hasuo *et al.*, 2011; Kuroda *et al.*, 2016), the effect of simultaneous or delayed presentation of two stimuli delivered from two different modalities in adults (Burr *et al.*, 2009) and between adults and children (Gori *et al.*, 2012), and differences in spatiotemporal processing in blind and nonblind participants (Gori *et al.*, 2014).

1.2.1. Variability

Research shows that the variability of temporal judgments for short intervals from a sequence of three stimuli is lower when sequences are auditory (AAA) rather than visual (VVV) (Fraisse, 1952; Kuroda *et al.*, 2014). In his experiment, Fraisse (1952) aimed to observe whether temporal processing is based on what he called the organization of successive stimuli or rather based on a measurement of the temporal extent of the intervals. He compared performances in intra- (AAA and VVV) and intermodal (VAV and AVA) sequence conditions (1 s between the first and third stimuli). If judgments are based on the organization of successive stimuli, then an intermodal sequence should disturb the organization and discrimination should be impaired, resulting in greater variability. Fraisse effectively observed that the variability of temporal judgments of intramodal intervals is lower than that for intermodal intervals. In addition, he observed less variability in the discrimination of intervals delimited by an AVA sequence compared to a VAV sequence. Other results in the same range of duration, from Kuroda *et al.* (2014), are in line with those of Fraisse (1952) as it shows less variability in AAA than in VVV conditions. However, in Kuroda *et al.*, the variability observed in AVA sequences tends to be close to that observed with AAA intramodal intervals and is even slightly better than that in VVV. Therefore, there is no systematic intra- *vs* intermodal effect. The decreased performance in the VAV condition, compared to the VVV condition, is probably caused by the possibility to rely on the organization of successive intramodal stimuli in VVV. Such an interpretation though makes the results in AVA very surprising. One potential explanation relies on the possibility that the V stimulus in the AVA structure was transferred in an auditory code (Kanai *et al.*, 2011).

1.2.2. Perceived Duration

As previously mentioned, the influence of sensory modality on perceived duration also varies according to the modality employed. However, for two intramodal intervals sharing the same stimulus, research indicates that the effect of auditory and visual sensory modalities on perceived duration does not differ between them (Fraisse, 1952; Hocherman and Ben-dov, 1979; Kuroda *et al.*, 2014). The results of Kuroda *et al.* (2014) reveal no difference between intra- and intermodal conditions. However, their results show that the perceived duration of the second interval tends to be longer in the VAV condition than in the AVA condition. Similarly, Hocherman and Ben-dov (1979) show that, in the AVA and VAV conditions, intervals beginning with the auditory modality and ending with the visual modality (AV) are perceived as longer than intervals where the order of the modalities is reversed (VA).

1.3. The Present Study

Most investigations about the capability of processing brief time intervals involved decisional processes consisting of determining which one of two intervals is shorter or longer, or if the interval presented is closer to the shorter or to the longer interval previously presented; the latter task is referred to as the 'bisection' method (see Note 1). Clearly, using a sequence where a stimulus is shared between two intervals, instead of a classical duration discrimination procedure, changes the conclusion that one can draw about the effect of intermodality on the processing of brief time intervals. What is proposed here is to study the processing of brief time intervals, and more specifically the intra- and intermodality topic, with a different method, a method involving a different way to compare intervals.

The retention of intervals and the decisional processes are known to contribute to the variance observed in the processing of temporal information. In the information-processing version of the scalar expectancy theory (SET) (Gibbon *et al.*, 1984), or in the attentional gate model (AGM) (Zakay and Block, 1995), there are three main sources of error when judgements with regard to time are made: the clock, the memory processes, and the decisional processes. The clock is described as a pacemaker-counter device, with the pacemaker emitting pulses at a certain frequency that are accumulated in the counter. Accumulation can take place *via* a switch, directly associated with the mechanisms of attention, which may or may not let them through. In this model, errors in a duration discrimination task may result from the variance in the pacemaker's rate of emission of pulses, or may occur at the memory or decisional level.

What is proposed in the present study is to use a bisection method, with the term bisection here referring to what is known in psychophysics as an equisection approach, an approach often used to study psychological scaling (Plateau, 1872 — Note 1). In other words, participants will not be asked to assign on each trial a single interval to a short or long category. The bisection here, applied to time intervals, will be to locate a third brief stimulus, between two brief stimuli marking a time interval, so that the two newly generated intervals will be perceived as being of equal duration.

The bisection (equisection) task is not used here to study scaling, but to study the relative length of multimodal brief intervals and, even more importantly, to study, with this different approach, the variability of internal time. On each trial, participants are asked to bisect a temporal interval but are allowed to make a few adjustments before reporting the perceived bisection point. After a series of trials, the mean and variability of the perceived bisection points are kept for analyses. It is assumed here that the memory and decisional processes involved in the task will differ from what is used with the duration discrimination method or with the bisection method involving the use of short and long standards. Indeed, participants may search for a point that would allow for a regular rhythmic pattern (organization of successive stimuli), instead of isolating two intervals. In this context, it will be informative to determine to what extent intra- *vs* intermodal differences could be replicated, and to what extent the different intermodal conditions resulting from combinations of A, T, and V stimuli will differ.

Assuming that participants' attention will be focused on the moment of appearance of the second stimulus rather than on the duration of the two intervals, we posit the hypothesis that variability will be similar between intramodal conditions but will be lower for conditions involving mostly auditory modality. Furthermore, if the rhythmic aspect of sequences is considered more than the duration of intervals, the influence of nontemporal factors should influence the perceived duration of intermodal intervals: it is posited that the intervals beginning with an auditory signal will be perceived as longer than those beginning with a visual or tactile signal. Indeed, if attention is directed more towards the second marker, then the effect of the sensory modality corresponding to this marker should be greater than if attention were more directed towards the duration of the interval.

2. Method

2.1. Participants

Twenty-four participants from Laval University were recruited. Twelve men and twelve women aged between 20 and 42 ($M = 25.38$) took part in the experiment. The participants had no known neurological disorders and had normal or corrected vision. They consented to their participation by signing a form approved by the institutional ethics committee and received compensation of $20 CAD at the end of the experiment.

2.2. Material and Stimuli

The experiment was programmed using E-Prime 3.0 software. An Alienware screen with a diagonal of 25 inches was used, with a resolution of 1080×1920 pixels (120 Hz refresh rate). Participants were seated approximately 70 cm from the screen and responded to the task using '1', '3' and 'Enter' on the keyboard.

The auditory stimuli (A) were 1-kHz sound tone emitted by Logitech loudspeakers (Model Z200 Stereo) on both sides of the screen, approximately 70 cm from the participant. Sound intensity was 65 dB SPL. Visual stimuli (V) came from a 5-mm diameter red light-emitting diode (LED) located approximately 70 cm in front of the participant. The LED was attached to the lower frame of the screen. Tactile stimuli (T) came from two skin electrodes placed 1 cm apart on the back of the nondominant hand between the index and the thumb. The signal transmitted by the electrodes came from a transcutaneous electrical nerve stimulator. Tactile stimuli transmit an electric pulse at a stable frequency of 50 Hz. The intensity of the tactile stimulation was adjusted by the participant to perceive it clearly and comfortably.

Three stimuli were presented successively in each sequence to delimit two empty time intervals. Stimuli lasted 10 ms. For all sequences, stimuli were derived from one or two modalities: a main (X) and two secondary (Y or Z). Overall, one intramodal sequence (XXX) and two intermodal sequences (XYX, XZX) were presented in each session.

2.3. Procedure

The experiment consists of three sessions, each lasting around 30 min. Sessions could be completed on different days depending on the participant's schedule. If at least two sessions were completed one after the other, a break of at least ten minutes was required between sessions. There was a session where AAA, AVA, and ATA stimuli were presented; one where VVV, VAV, and VTV stimuli were presented; one where TTT, TAT, and TVT stimuli were presented. Each session begins with an intramodal condition, followed by two intermodal conditions. For each condition, four standard durations were used as interval lengths: 250, 500, 750, and 1000 ms. The order of presentation of the three sessions of the four standard durations within a session, and of the two intermodality conditions within a session, were counterbalanced using Latin squares.

The equisection method, in conjunction with the adjustment method, was used for this experiment. In other words, participants were first exposed to a sequence of two unequal intervals, and then had to adjust the moment of apparition of the second stimulus between the first and third, until they perceived the two intervals as equal (see Figure 1). The '1' key on the keyboard was used to decrease the duration of the first interval, and thus increase the duration of the second, by $\pm 8\%$ compared with the standard duration (see Table 1). The '3' key was used to make the opposite adjustment. Equal step sizes were used between the adjustments. However, the adjustments were $\pm 4\%$ when the participants were close to the standard, i.e., a two-interval sequence ($\pm 4\%$ of the standard) could be perceived just before the presentation of the standard interval sequence. For example, if the first interval of the sequence presented is 310 ms, and the participant wants to decrease the duration of this interval until the two intervals are equal (250-250 ms), they will have to go through the sequences where the first interval is 290 ms (-8%), 270 ms (-8%), 260 ms (-4%), then 250 ms (-4%).

After each adjustment, the adjusted sequence was presented to the participant. When participants perceived the intervals as equal, they pressed the 'ENTER' key, which recorded the duration value of the first interval and completed a trial. Before the beginning of trials in each session, participants completed a training phase with three practice trials in the AAA condition to familiarize with the task, where the standard interval was 600 ms. Then, they had eight trials in each level of standard duration. On each new trial,

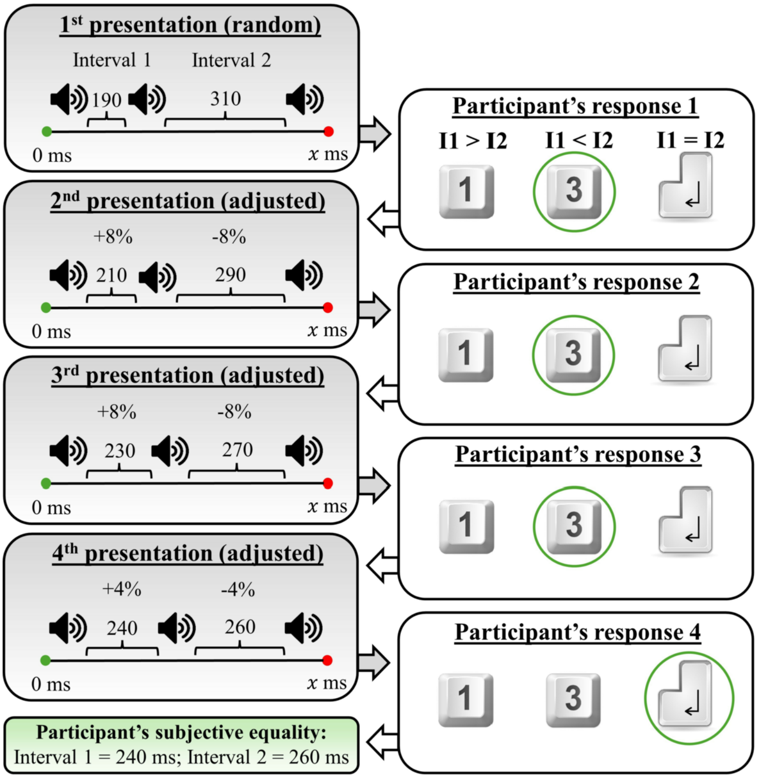

Figure 1. Example of a trial in the AAA condition with a standard duration of 250 ms.

sequences of three brief stimuli delimiting only unequal intervals were presented, i.e., the second stimulus appeared x ms after the offset of the first stimulus. The value of x corresponded to 68% to 92%, or 108% to 132%, of the standard duration. These sequences of unequal intervals were presented randomly and without replacement. Participants were not informed that intervals are always unequal at the beginning of a trial. Standard duration changed when the eight trials were completed. The auditory modality, known to provide better discrimination, was used for task familiarization to favour the best possible understanding of the task.

2.4. Data Analyses

For each experimental condition and standard duration condition, the mean value of the bisection point (BP) and the standard deviation (SD) were calculated for each participant. In this experiment, the BP is defined here as the mean value of the first interval of each sequence judged to be equal to the second. If the BP is smaller than the standard, it means that the second interval has

Table 1.
Range and step size of the first interval as a function of the standard interval length

Standard interval length (ms)	Step size of the 8% and 4% adjustment (ms)	Range of the 8% and 4% intervals (ms)
250	20; 10	170–330; 240–260
500	40; 20	340–660; 480–520
750	60; 30	510–1000; 720–770
1000	80; 40	680–1320; 960–1040

to be longer to appear equal to the first; therefore, BP smaller than the standard means that the first interval is being perceived as longer than the second.

Two dependent variables are of interest: the Weber fraction and the relative constant error (rCE). The Weber fraction corresponds to the SD divided by the standard duration value (250, 500, 750 and 1000 ms). A high fraction corresponds to higher variability (lower precision) in temporal judgments, while a low fraction corresponds to lower variability (greater precision). The rCE corresponds to the BP divided by the standard duration value: rCE = BP/standard. Using rCE rather than BP as the dependent variable enables direct comparisons of the perceived duration in the different standard conditions. rCE can be negative (Marker 2 closer to Marker 1 than to Marker 3, therefore the first interval is being perceived as longer than the second) or positive (Marker 2 closer to Marker 3 than to Marker 1, therefore the first interval is being perceived as shorter than the second). A rCE of zero represents no influence on perceived duration. The closer the rCE is to zero, the more accurate the participants' judgments. In order to compare rCE differences according to the modality of the second stimulus, it is important to analyse together the three conditions where the first and third stimuli come from the same modality.

For each condition, factorial-design ANOVAs with repeated measures and paired-samples t-tests were performed on Weber fraction and on rCE. A Tukey correction for multiple comparisons was applied for each of the *post-hoc* tests. In addition, Bayesian repeated-measures ANOVAs and Bayesian paired-samples t-tests, with correction to account for multiple comparisons, were performed to compare the fit of the data under the alternative hypothesis, compared to the null hypothesis (see tables of Bayesian factors in Appendix). An alpha level of 0.05 was used in all analyses.

3. Results

3.1. Variability (Weber Fraction)

3.1.1. Intramodality vs Intermodality

First, an overall comparison (pooled data) of inter- *vs* intramodal conditions was performed. In this analysis, the intramodal condition refers to the AAA, VVV, and TTT conditions, and the intermodal condition refers to the AVA, ATA, VAV, VTV, TAT, and TVT conditions for each standard duration. Figure 2 shows the mean Weber fraction in intra- and intermodal conditions at 250, 500, 750, and 1000 ms. A 2 (intra/inter) × 4 (duration) repeated-measures ANOVA revealed that there was a significant main effect for modality, $F_{1,23} = 262.30$, $p < 0.001$, $\eta_p^2 = 0.919$, and for duration, $F_{3,69} = 71.60$, $p < 0.001$, $\eta_p^2 = 0.757$. The interaction between duration and modality factors was significant, $F_{3,69} = 18.10$, $p < 0.001$, $\eta_p^2 = 0.440$.

Post-hoc analyses between intra- and intermodal condition at 250, 500, 750 and 1000 ms revealed that the Weber fraction was significantly lower in the intra- than in the intermodal condition ($p_s < 0.001$).

Post-hoc analyses between each duration in the intramodal condition revealed that the Weber fraction was significantly higher at 250 than at 750 ($p = 0.029$) and 1000 ms ($p < 0.001$), and higher at 500 than at 750 ($p = 0.029$) and 1000 ms ($p = 0.003$). The differences between 250 and 500 ms ($p = 0.955$), and between 750 and 1000 ms ($p = 0.237$), were not significant. In the intermodal condition, Weber fraction was significantly higher at 250 than at 500 ($p < 0.001$), 750 ($p < 0.001$), and 1000 ms ($p < 0.001$), higher at 500 than at 750 ($p < 0.001$) and 1000 ($p < 0.001$) ms, and higher at 750 than at 1000 ms ($p = 0.034$) ms.

3.1.2. Conditions AAA vs VVV vs TTT

Figure 3 shows the mean Weber fraction in AAA, VVV, and TTT conditions, at 250, 500, 750, and 1000 ms. A 3 (modality) × 4 (duration) repeated-measures ANOVA revealed that there was a significant main effect for modality, $F_{2,46} = 7.90$, $p = 0.001$, $\eta_p^2 = 0.256$, and for duration, $F_{3,69} = 14.29$, $p < 0.001$, $\eta_p^2 = 0.383$. The interaction between duration and modality was significant, $F_{6,138} = 12.47$, $p < 0.001$, $\eta_p^2 = 0.352$.

Post-hoc analyses between each duration in the AAA condition revealed that the differences were not significant between the 250-ms condition and the 500- ($p = 0.997$), 750- ($p = 0.950$) and 1000-ms ($p = 0.094$) conditions, between the 500-ms condition and 750- ($p = 1.000$) and 1000- ($p = 0.509$) ms condition, and between the 750- and 1000-ms ($p = 0.393$) conditions. In the VVV condition, Weber fraction was significantly higher at 500 ms than at 250 ($p = 0.049$), 750 ($p = 0.007$), and 1000 ms ($p = 0.021$). The

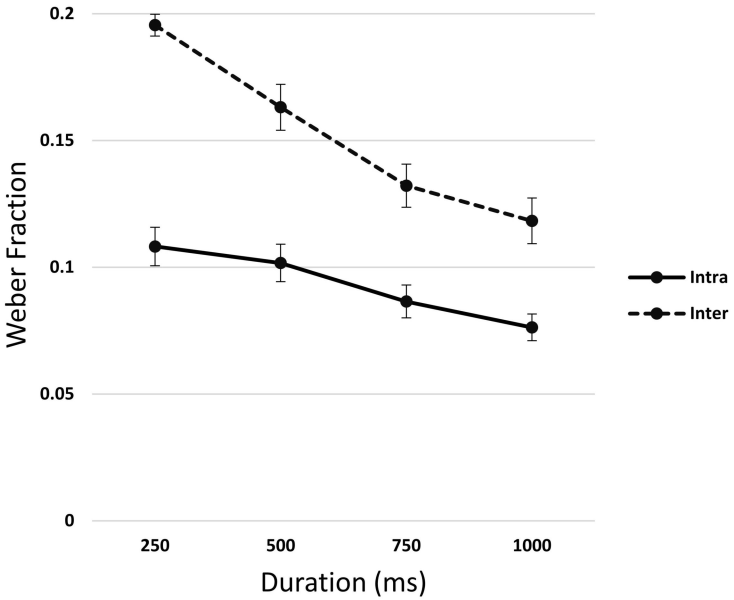

Figure 2. Weber fraction in the intra- *vs* intermodal conditions at each standard duration. Bars represent standard error.

differences between the 250-ms condition and the 750- ($p = 1.000$) and 1000-ms ($p = 1.000$) conditions, and between the 750- and 1000-ms ($p = 0.996$) conditions, were not significant. In the TTT condition, Weber fraction was significantly higher at 250 ms than at 500 ($p < 0.001$), 750 ($p < 0.001$), and 1000 ($p < 0.001$) ms. The differences between the 500-ms condition and the 750- ($p = 0.813$) and 1000-ms ($p = 0.134$) conditions, and between the 750- and 1000-ms ($p = 0.987$) conditions, were not significant.

Post-hoc analyses between each modality at 250 ms revealed that the Weber fraction was significantly higher in the TTT condition than in the AAA ($p < 0.001$) and VVV ($p < 0.001$) conditions. The difference between the AAA and VVV ($p = 0.998$) conditions was not significant. At 500 ms, Weber fraction in the AAA condition was not significantly different from that in the VVV ($p = 0.063$) and TTT ($p = 0.412$) conditions, and the difference between the VVV and TTT ($p = 0.947$) conditions was not significant. At 750 ms, Weber fraction in the AAA condition was not significantly different from that in the VVV ($p = 1.000$) and TTT ($p = 0.995$) conditions, and the difference between the VVV and TTT ($p = 1.000$) conditions was not significant. At 1000 ms, Weber fraction in the AAA condition was not significantly different from that in the VVV ($p = 0.871$) and TTT ($p = 0.449$) conditions, and the difference between the VVV and TTT ($p = 1.000$) conditions was not significant.

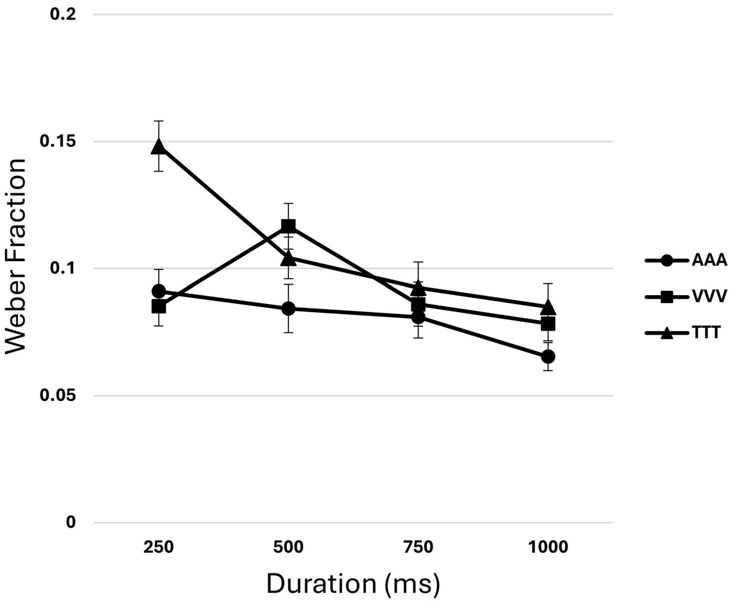

Figure 3. Weber fraction in the AAA, VVV, and TTT conditions at each standard duration. Bars represent standard error.

3.1.3. Conditions AAA vs AVA vs ATA

Figure 4A shows the mean Weber fraction in the AAA, AVA and ATA conditions at 250, 500, 750, and 1000 ms. A 3 (modality) × 4 (duration) repeated-measures ANOVA revealed that there was a significant main effect for duration, $F_{3,69} = 47.11$, $p < 0.001$, $\eta_p^2 = 0.672$, and modality, $F_{2,46} = 143.08$, $p < 0.001$, $\eta_p^2 = 0.862$. The interaction effect between factors was significant, $F_{6,138} = 7.23$, $p < 0.001$, $\eta_p^2 = 0.239$.

Post-hoc analyses between each duration in the AVA condition revealed that the Weber fraction was significantly higher at 250 ms than at 750 ($p < 0.001$) and 1000 ($p < 0.001$) ms, and higher at 500 ms than at 750 ($p = 0.003$) and 1000 ($p = 0.001$) ms. The differences between 250 ms and 500 ($p = 1.000$) ms, and between 750 ms and 1000 ($p = 0.533$) ms, were not significant. In the ATA condition, the Weber fraction was higher at 250 ms than at 500 ($p = 0.006$), 750 ($p < 0.001$) and 1000 ms ($p < 0.001$), and higher at 500 ms than at 1000 ms ($p = 0.010$). The differences between 500 and 750 ms ($p = 0.053$), and between 750 and 1000 ms ($p = 0.994$), were not significant.

Post-hoc analyses between each modality at 250, 500, 750, and 1000 ms revealed that the Weber fraction was significantly lower in the AAA condition than in the AVA and ATA conditions (p values < 0.001). The differences between the AVA and ATA conditions were not significant at 250 ($p = 0.856$), 500 ($p = 0.821$), 750 ($p = 0.999$) and 1000 ms ($p = 1.000$).

3.1.4. Conditions VVV vs VAV vs VTV

Figure 4B shows the mean Weber fraction in the VVV, VAV, and VTV conditions at 250, 500, 750, and 1000 ms. A 3 (modality) × 4 (duration) repeated-measures ANOVA revealed that there was a significant main effect for duration, $F_{3,69} = 36.80$, $p < 0.001$, $\eta_p^2 = 0.615$, and modality, $F_{2,46} = 70.60$, $p < 0.001$, $\eta_p^2 = 0.754$. The interaction effect between factors was significant, $F_{6,138} = 10.70$, $p < 0.001$, $\eta_p^2 = 0.318$.

Post-hoc analyses between each duration in the VAV condition revealed that the Weber fraction was higher at 250 ms than at 750 ($p < 0.001$) and 1000 ms ($p < 0.001$), and higher at 500 ms than at 750 ($p = 0.010$) and 1000 ms ($p = 0.002$). The differences between 250 ms and 500 ms ($p = 0.471$), and between 750 ms and 1000 ms ($p = 0.799$), were not significant. In the VTV condition, the Weber fraction was higher at 250 ms than at 500 ($p = 0.016$), 750 ($p < 0.001$), and 1000 ms ($p < 0.001$), and higher at 500 ms than at 1000 ms ($p = 0.043$). No significant difference was revealed between 500 and 750 ms ($p = 0.879$), and between 750 and 1000 ms ($p = 0.084$).

Post-hoc analyses between each modality at 250 ms revealed that the Weber fraction in the VVV condition was significantly lower than in the VAV ($p < 0.001$) and VTV ($p < 0.001$) conditions, significantly lower than in the VAV ($p = 0.012$) condition at 500 ms, significantly lower than in the VAV ($p = 0.042$) and VTV conditions ($p < 0.001$) at 750 ms, and significantly lower than in the VTV ($p < 0.001$) condition at 1000 ms. The differences were not significant between the VVV and VTV ($p = 0.056$) conditions at 500 ms, and between VVV and VAV ($p = 0.394$) conditions at 1000 ms. Weber fractions in VAV and VTV conditions at 250 ($p = 0.961$), 500 ($p = 0.991$), 750 ($p = 0.988$), and 1000 ms ($p = 0.983$), were not significantly different.

3.1.5. Conditions TTT vs TAT vs TVT

Figure 4C shows the mean Weber fraction in the TTT, TAT and TVT conditions at 250, 500, 750, and 1000 ms. A 3 (modality) × 4 (duration) repeated-measures ANOVA revealed that there was a significant main effect for duration, $F_{3,69} = 60.27$, $p < 0.001$, $\eta_p^2 = 0.724$, and for modality, $F_{2,46} = 48.79$, $p < 0.001$, $\eta_p^2 = 0.680$. The interaction effect between factors was not significant, $F_{6,138} = 0.75$, $p = 0.610$, $\eta_p^2 = 0.032$.

Post-hoc analyses between modalities revealed that the Weber fraction was significantly lower in the TTT condition than in the TAT ($p < 0.001$) and TVT ($p < 0.001$) conditions, and significantly lower in the TAT condition than in the TVT ($p = 0.021$) condition. *Post-hoc* analyses between durations revealed that the Weber fraction was significantly higher at 250 ms than at 500

($p < 0.001$), 750 ($p < 0.001$), and 1000 ms ($p < 0.001$); significantly higher at 500 ms than at 750 ($p < 0.001$) and 1000 ms ($p < 0.001$). The difference between the 750-ms and 1000-ms conditions ($p = 0.385$) was not significant.

3.2. *Perceived Duration (Relative Constant Error)*

3.2.1. *Intramodality vs Intermodality*

Figure 5 shows the mean rCE in intra- and intermodal conditions at 250, 500, 750, and 1000 ms. A 2 (modality) × 4 (duration) repeated-measures ANOVA revealed that there was a significant main effect for duration, $F_{3,69} = 3.44$, $p = 0.022$, $\eta_p^2 = 0.130$. The modality effect, $F_{1,23} = 2.15$, $p = 0.156$, $\eta_p^2 = 0.086$, and the interaction between factors, $F_{3,69} = 1.06$, $p = 0.371$, $\eta_p^2 = 0.044$, were not significant.

Post-hoc analyses revealed that the rCE at 500 ms was significantly lower than at 750 ($p = 0.015$) and 1000 ms ($p = 0.037$). The differences between 250 ms and 500 ($p = 0.099$), 750 ($p = 0.997$), and 1000 ms ($p = 0.955$), and between 750 ms and 1000 ms ($p = 0.534$), were not significant.

3.2.2. *Conditions AAA vs VVV vs TTT*

Figure 6 shows the mean rCE in AAA, VVV, and TTT conditions at 250, 500, 750, and 1000 ms. A 3 (modality) × 4 (duration) repeated-measures ANOVA revealed that there was a significant main effect for duration, $F_{3,69} = 3.47$, $p = 0.021$, $\eta_p^2 = 0.131$. However, *post-hoc* analyses with Tukey's correction revealed no significant difference between the durations (p values > 0.100). The modality effect, $F_{2,46} = 1.50$, $p = 0.232$, $\eta_p^2 = 0.061$, and the interaction effect between factors, $F_{6,138} = 0.23$, $p = 0.964$, $\eta_p^2 = 0.010$, were not significant.

3.2.3. *Conditions AAA vs AVA vs ATA*

Figure 7A shows the mean rCE in the AAA, AVA, and ATA conditions at 250, 500, 750, and 1000 ms. A 3 (modality) × 4 (duration) repeated-measures ANOVA reveals that there was a significant main effect for duration, $F_{3,69} = 5.13$, $p = 0.003$, $\eta_p^2 = 0.183$, and for modality, $F_{2,46} = 7.88$, $p = 0.001$, $\eta_p^2 = 0.255$. The interaction effect between factors was not significant, $F_{6,138} = 0.62$, $p = 0.713$, $\eta_p^2 = 0.026$.

Post-hoc analyses revealed that rCE was significantly higher and at 500 ms than at 750 ($p = 0.018$) and 1000 ms ($p < 0.001$). The differences between the 250-ms condition and the 500- ($p = 0.302$), 750- ($p = 0.965$), and 1000-ms ($p = 0.519$) conditions, and between the 750- and 1000-ms ($p = 0.169$) conditions, were not significant. Also, the difference between the AVA and AAA conditions was significant ($p < 0.001$). The differences between the AAA and ATA (p =0.138) conditions, and between the AVA and ATA ($p = 0.187$) conditions, were not significant.

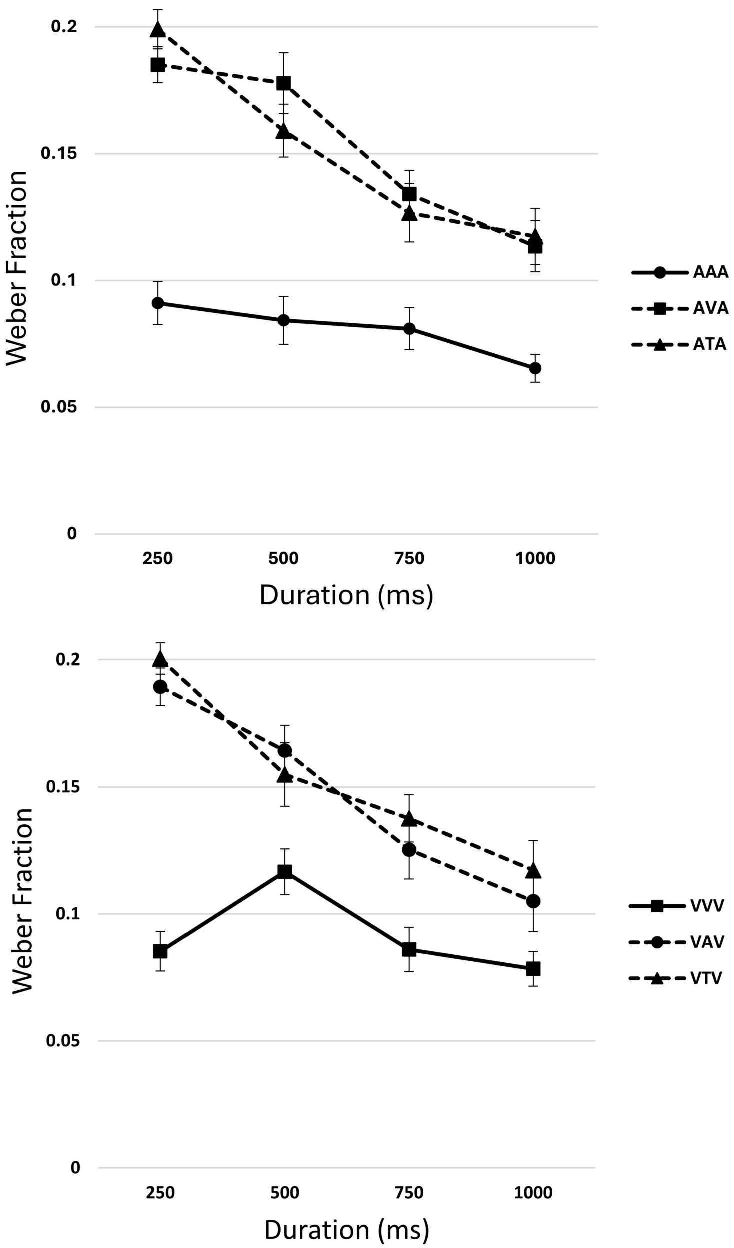

Figure 4. Weber fraction, for each standard duration, in the AAA, AVA and ATA conditions; VVV, VAV and VTV conditions; and TTT, TAT and TVT conditions. Bars represent standard error.

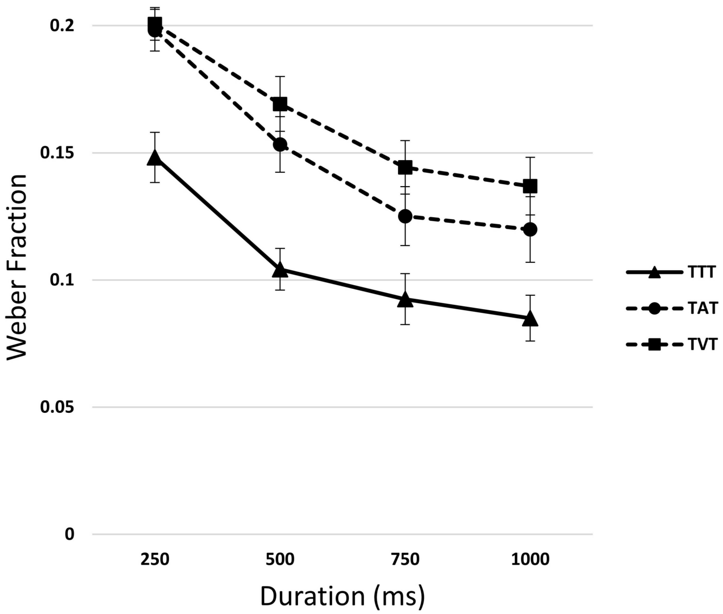

Figure 4. (Continued.)

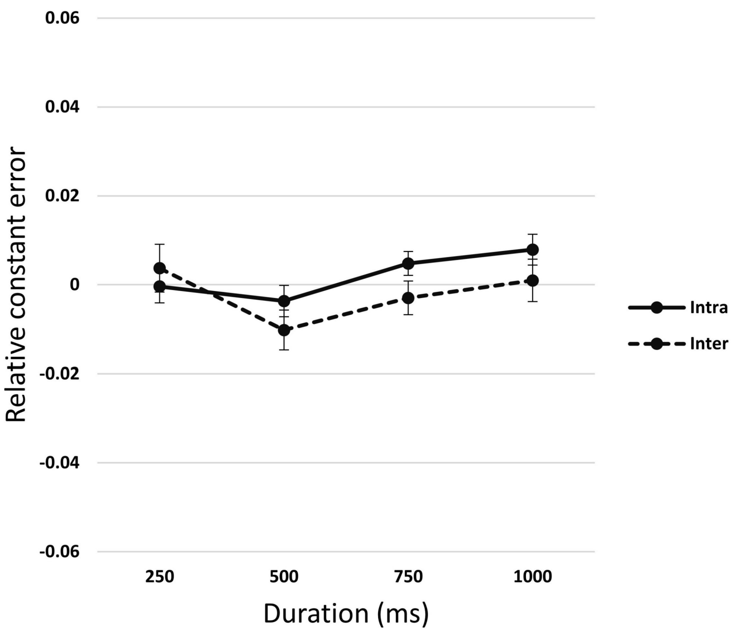

Figure 5. Relative constant error in the intra- *vs* intermodality conditions for each standard condition. Bars represent standard error.

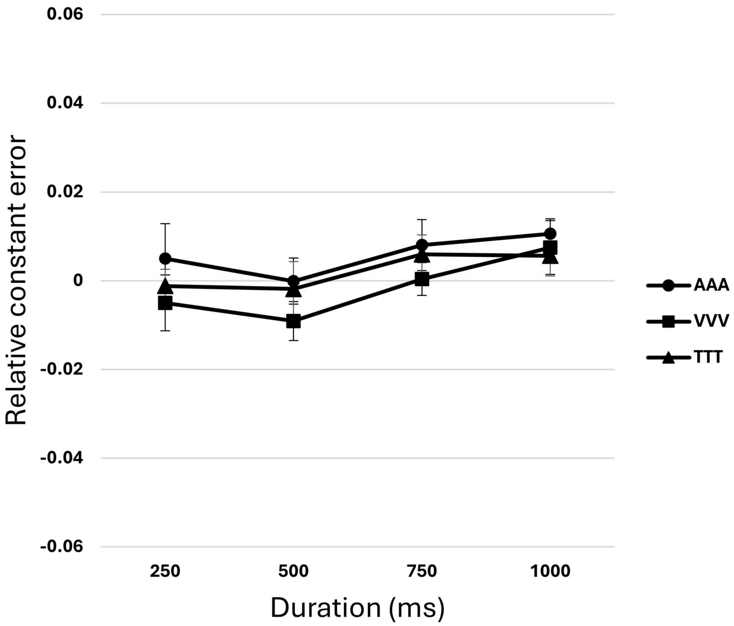

Figure 6. Relative constant error in the AAA, VVV, and TTT conditions for each standard condition. Bars represent standard error.

3.2.4. Conditions VVV vs VAV vs VTV

Figure 7B shows the mean rCE in the VVV, VAV, and VTV conditions at 250, 500, 750, and 1000 ms. A 3 (modality) × 4 (duration) repeated-measures ANOVA revealed that there was a significant main effect for modality, $F_{2,46} = 4.03$, $p = 0.024$, $\eta_p^2 = 0.149$, but the duration effect was not significant, $F_{2,46} = 2.26$, $p = 0.116$, $\eta_p^2 = 0.089$. The interaction effect between factors was significant, $F_{6,138} = 2.41$, $p = 0.030$, $\eta_p^2 = 0.095$. However, *post-hoc* analyses with Tukey's correction revealed no significant difference between the durations in each modality (p values > 0.100), and no difference between modalities for each duration (p values > 0.100).

3.2.5. Conditions TTT vs TAT vs TVT

Figure 7C shows the mean rCE in the TTT, TAT, and TVT conditions at 250, 500, 750, and 1000 ms. A 3 (modality) × 4 (duration) repeated-measures ANOVA revealed that there was a significant main effect for modality, $F_{2,46} = 8.26$, $p < 0.001$, $\eta_p^2 = 0.264$. The effect for duration, $F_{3,69} = 1.47$, $p = 0.231$, $\eta_p^2 = 0.060$, and the interaction effect between factors, $F_{6,138} = 1.85$, $p = 0.094$, $\eta_p^2 = 0.074$, were not significant.

Post-hoc analyses revealed that the rCE was significantly higher in the TVT condition than in the TTT ($p = 0.007$) and TAT ($p = 0.008$) conditions. The difference between the TTT and TAT condition was not significant ($p = 0.703$).

4. Discussion

In a three-session experiment, participants were presented with intra- and intermodal sequences of three stimuli (flashes, tones or electric pulse), delimiting two brief time intervals, and were asked to adjust the moment of appearance of the second stimulus in order to make the duration of the two intervals equal. The aim of this research was to determine whether the adoption of a totally different method of investigation would lead to the replication of the well-documented intra- *vs* intermodal differences observed when duration discrimination tasks are used. In the present study, both the variability of temporal judgments and the perceived duration of intervals were of interest. Overall, the results of the Bayesian analyses presented in Appendices A–E (Weber fraction) and F–J (rCE) support the frequentist results obtained and discussed in this study. Consequently, they will not be discussed in detail in this section.

4.1. Variability (Weber Fraction)

When intra- and intermodal conditions are compared, the results consistently show greater variability in temporal judgments in the intermodal conditions. These results are in line with previous research showing higher performance levels for the discrimination of short intramodal intervals than for the discrimination of short intermodal intervals presented separately (Azari *et al.*, 2020, 2023; Grondin and Rousseau, 1991; Grondin *et al.*, 2005). Therefore, overall, using a very different method for addressing the intra- *vs* intermodal issues in the processing of short time intervals does not change the take-home message: processing intermodal time intervals, within sequences or not, is much more difficult than processing intramodal temporal information.

The additional difficulty when intermodal intervals are used is apparently not located in the memory or decisional level of the models based on a pacemaker–accumulator theory (SET and AGM) but could lie in an earlier phase: the opening or closing of the switch within the clock process. Indeed, would the intra- *vs* intermodal difference be explained by variance associated to the contribution of decisional or memory mechanisms, the difference between intra- and intermodality in the present study would have been reduced considering this contribution is reduced by the use of the present equisection method.

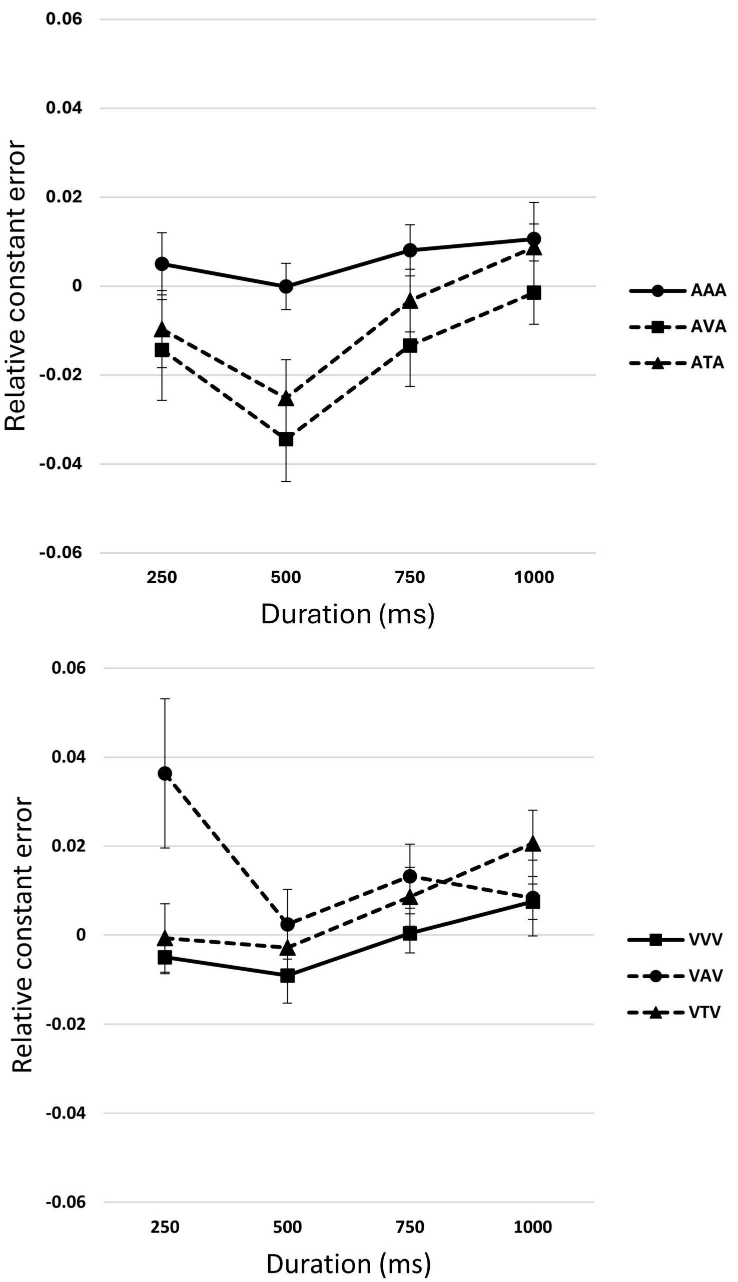

Figure 7. Relative constant error, for each standard condition, in the AAA, AVA and ATA conditions; VVV, VAV and VTV conditions; and TTT, TAT and TVT conditions. Bars represent the standard error.

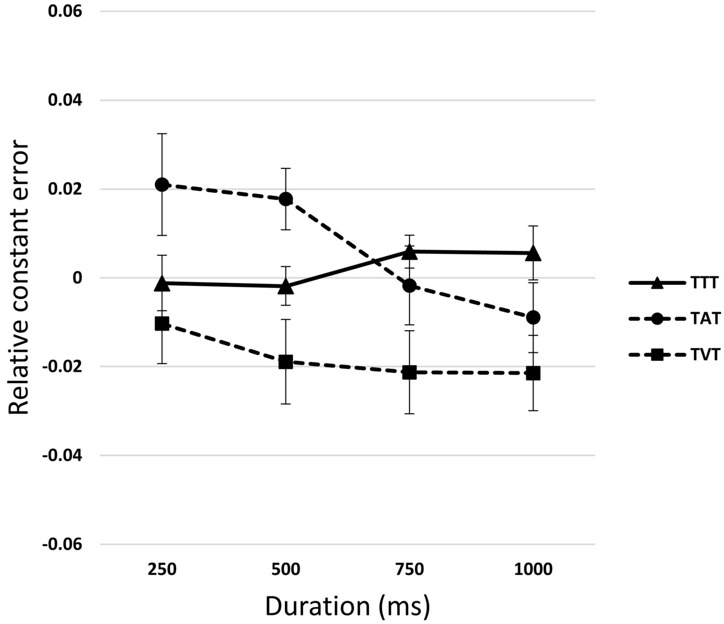

Figure 7. (Continued.)

That said, although no direct statistical analyses compared the VVV and AVA directly, it is relevant to note that in all four duration conditions, performances were better in VVV than in AVA. This result is inconsistent with what was reported by Kuroda *et al.* (2014) with the three-stimulus sequence method. While the results in Kuroda *et al.* were attributed to the possibility of substituting the middle V marker by an internal sound to favour some successive organization, another explanation could be given to their results. In their experiment, the first interval (standard) always lasted 500 ms, and the second one was shorter or longer than 500 ms. Therefore, the overall duration between the Markers 1 and 3 (both A), varied from trial to trial; to some extent it was possible to compare the overall duration between AA with the overall AA duration of previous trials. In other words, the task could have been performed without taking the V signal into account, which was not possible in the present experiment.

When the first and third stimuli are both auditory or both visual, there is no variability difference between the intermodal conditions, namely AVA *vs* ATA, and VTV *vs* VAV. However, when the tactile modality is presented as the first and third stimuli, the modality of the second stimulus has significant effect on intermodal interval variability, the TAT condition leading to better performance than the TVT condition. A better performance in TAT could be explained by a greater efficiency of stimulus A in the process, i.e., a dominance of auditory over visual signal in the integration of cross-modal sensory processing in time perception (Gori *et al.*, 2012; Song *et al.*, 2017) and a faster signal detection (Burr *et al.*, 2009). Also, the auditory signals are recognized for their efficient alerting property (Posner, 1978). Such an explanation, however, has a limitation: it would predict a difference between the VAV and VTV conditions, which is not what was observed. The lack of difference between VAV and VTV conditions could be explained by a hierarchy of signal detection speed, where auditory signals are detected faster than visual signals (Burr *et al.*, 2009; Fort *et al.*, 2002), and tactile signals are detected faster than visual signals (Spence *et al.*, 2001), but slower than auditory signals (Hoefer *et al.*, 2013). However, as most signals in the VAV and VTV sequences come from the visual modality, and the signal detection speed between A and T, and between V and T, is closer than the difference between A and V, this hierarchical effect of modality processing on the second marker could be attenuated. Based on the SET and AGM models, these results can be understood as an increase in the variability of switch closure or opening during detection of the second marker, due to the greater variability in the predominant processing of visual signals.

Regarding variability according to the order of duration used, although relatively stable compared to intermodality, the results show a slight decrease in variability as interval duration increases. In the auditory condition, variability remains stable despite a slight decrease. In the tactile condition, the level of variability decreases from 250 to 500 ms and declines slightly between 500 and 1000 ms. In this case, the results are consistent with a generalized version of Weber's law applied to duration: the poorer performance with shorter durations stems from the contribution of nontemporal factors to the total variance observed, these factors being the effectiveness of the stimuli used to delimit the start and end of intervals. The variability in the visual condition is more difficult to explain. In general, discrimination is higher in AAA than in VVV, but this is not the case at 250 ms. These results at 250 ms are inconsistent with what is generally observed when discrimination levels of short AA and VV intervals are compared. It cannot be ruled out that the similar levels observed in AAA and VVV at 250 ms under these conditions are the result of the research hazards (Note 3). It is also surprising at 250 ms to observe a large difference between the VVV and TTT conditions. Some studies suggest that there is not much difference between the TT and VV intervals in this duration range (Azari *et al.*, 2020; Grondin and Rousseau, 1991; van Erp and Werkhoven, 2004).

Concerning the effect of duration in intermodality, all conditions considered, the variability decreases more drastically from 250 ms to 1000 ms to reach a level of discrimination approaching that of intramodality. These observations are also consistent with a generalized version of Weber's law and with the results of Azari *et al.* (2020). The larger Weber fraction with very short intervals is compatible with the generalized version of Weber's law. This time, the nontemporal factors at play are not only the effectiveness of the stimuli in delimiting the beginning and end of the intervals, but also the fact that intermodality requires an attentional shift (Gontier *et al.*, 2013). That said, in cross-modal conditions where the tactile modality is presented as a second stimulus (ATA and VTV), there is a more pronounced decrease in the Weber fraction from 250 to 500 ms than in conditions where the tactile modality is not presented (AVA and VAV). However, in the absence of the tactile modality, a more pronounced decrease was observed between 500 and 750 ms. These results suggest that there is a greater affinity between auditory and tactile modalities, and even between visual and tactile modalities, in the processing of very short intervals than between auditory and visual modalities. The attentional shift could be therefore faster, or less impacted, for very short intervals in the presence of the tactile modality.

4.2. *Perceived Duration (Relative Constant Error)*

When the intra- *vs* intermodal conditions are compared, it appears that there is, overall, neither any difference between them, nor any interaction with duration (Figure 4). Indeed, there are two main avenues for interpreting these data: one is by looking specifically at intramodal intervals where the markers of both intervals are of the same modality, and the other is by comparing intermodal intervals where the markers are not identical.

In contrast to what is generally observed in the discrimination of intervals that share no common stimulus, there is no difference between the AAA, VVV, and TTT intramodal conditions, supporting Kuroda *et al.*'s (2014) findings about the perceived duration of AAA and VVV intervals. Indeed, the modality effect seems to be cancelled out in the successive presentation of three stimuli, probably because the effect of Markers 1 and 2 on the first interval is the same as that of Markers 2 and 3 on the second interval. While the intramodal conditions show essentially the same pattern, i.e., not much perceived duration differences in the different conditions, the picture is quite different with the intermodal intervals. The structure (modality of markers) composing the intermodal intervals has a major effect on the rCE (Figure 7). For instance, there is a huge negative rCE in the TVT condition with longer intervals. This means that for perceiving equal duration, the second marker (V) has to be much closer to the first than to the third marker. In other words, the second interval, VT, needs to be longer to look as long as the first interval, TV; therefore, TV is perceived longer than the VT interval. Interestingly, this is consistent with the fact that, in a VTV sequence, the results go in the opposite direction: the rCE is positive. This means that for perceiving equal duration, the second marker (V) has to be much closer to the third than to the first marker. In other words, the first interval, VT, needs to be longer to look as long as the second interval, TV. In brief, a TV interval is perceived longer than the VT interval. Therefore, it is much more that structure of the interval than their order within the sequence, that will determine perceived duration.

The same exercise could be made with another intermodal condition, that involving A and V markers. While the rCE values are positive in the VAV condition, they are negative in the AVA condition. In the VAV sequence, the second marker, A, is closer to the third marker than to the first marker: the AV interval is perceived as longer than the VA interval. In the AVA condition, the second marker, V, is much closer to the first than to the third marker. In other words, the second interval, VA, needs to be longer to look as long as the first interval, AV: AV is perceived as longer than the VA interval. This difference between the perceived duration of the VA and AV intervals is consistent with what was observed in Grondin *et al.* (1996) where the intervals compared shared no common marker (no three-stimulus sequence marking two intervals).

In both cases (AVA/VAV and TVT/VTV) involving visual signals, when the intervals begin with a visual marker, intervals are perceived as shorter, or said differently, when intervals end with a visual marker, they are perceived as longer. The opposite is also similar when the auditory modality is involved (ATA/TAT and AVA/VAV): when the intervals begin with an auditive marker, they are perceived as longer, and when intervals end with an auditive marker, they are perceived as shorter. However, if we look at the effect of tactile modality, the conclusion does not seem to follow the same logic: the influence of auditory and visual modality seems to prevail over tactile modality. For example, VT and TA intervals are perceived as shorter than AT and TV intervals. These results could be interpreted in the light of the internal-marker hypothesis (Grondin *et al.*, 1996): the beginning of the timekeeping activity (offset of the first marker of an interval) begins later with a visual signal, and sooner with an auditive signal, maybe once the sensory trace of the signal fades, and the end of timekeeping (onset of the second marker of an interval) occurs later with a visual signal, and sooner with an auditive signal. This makes sense with the rapid closing and opening of the switch in the models based on a pacemaker, and with the detection speed of the different modalities mentioned above. The effect of the tactile modality could be interpreted in the same way as the visual modality, but with a shorter fading of the sensory trace. The TAT and ATA conditions reflect participants' subjective perception that the intervals beginning with the tactile modality are perceived as shorter. What is interesting here is to observe that this sensory trace effect seems more pronounced with the visual signals than with the tactile signals, such as indicated by the results with the VTV and TVT conditions, where intervals beginning with the visual modality are perceived as shorter than those beginning with the tactile modality.

In general, the different effects of the succession of three markers on perceived interval duration can also be understood with the AGM mentioned in the introduction. Under intramodal conditions, the level of attention is assumed to remain relatively stable between each marker, thus regulating pulse accumulation for timekeeping. Indeed, the effect of Marker 1 on the following interval should be the same as the effect of Marker 2, and the effect of Marker 2 on the preceding interval should be the same as that of Marker 3. However, if we consider that the level of attention when timing intervals can be more or less affected depending on the sensory modality presented, then the number of pulses accumulated at the end of each interval, that is, the subjective duration, will differ according to the modality preceding the interval to be timed.

5. Conclusion

The aim of this study was to test the influence of auditory, visual, and tactile sensory modalities on the variability and perceived duration of temporal judgments *via* an equisection method in conjunction with an adjustment method. The experiment involved a sequence of three successive signals marking two intervals. Intra- and intermodal sequences of two intervals sharing the same stimulus were used. The results show that with the present method involving three successive stimuli, variability is much high in inter- than in intramodal conditions, and the magnitude of this difference depends on the duration range, the difference being much larger with very brief intervals. The results concerning the perceived duration of intramodal intervals show a time-order error that depends on the duration range. As for the perceived duration of intermodal intervals, it also depends very much on the pair of intermodal intervals compared.

Notes

1. This version of the 'bisection method' was used in animal timing research, and eventually became very popular in human timing research. A bisection point (point of subjective equality) is derived from a psychometric function drawn from a series of judgements. Researchers in the field of time perception have this interpretation in mind when using the term 'bisection'.
2. Referred to by Gescheider (1985).
3. Given the unexpected results in VVV, six new participants were recruited to see if the results would be replicated. They had eight trials per standard duration (250, 500, and 750 ms) in the VVV condition only. The results showed a Weber fraction of 0.123, 0.126, and 0.082, respectively.

Although higher at 250 ms compared with the observed data for the same standard duration (0.085), it remains surprisingly lower than that at 500 ms. Two of the six participants obtained a Weber fraction lower than 0.100 at 250 ms.

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Appendix A: Result of the Bayesian repeated-measures ANOVAs and of the Bayesian paired-samples *t*-tests for intra- *vs* intermodality conditions (Weber fraction)

Table A1.

Models	Bayes factor (BF_{10})
Null model (incl. subject)	1
Modality	$5.82*10^{10}$
Duration	$3.84*10^{16}$
Modality + Duration	$4.35*10^{27}$
Modality + Duration + (Modality × Duration)	$1.33*10^{35}$

Table A2.

Modality 1	Modality 2	Bayes Factor (BF_{10})
Intra	Inter	$1.16*10^{29}$

Table A3.

Duration 1	Duration 2	Bayes Factor (BF_{10})
250	500	175.23
	750	$9.89 * 10^{7}$
	1000	$4.27 * 10^{10}$
500	750	$1.22 * 10^{7}$
	1000	$8.27 * 10^{8}$
750	1000	248.40

Table A4.

Modality 1	Duration (ms) 1	Modality 2	Duration (ms) 2	Bayes Factor (BF_{10})
Intramodality	250	Intermodality	250	$2.81 * 10^{10}$
	500		500	$1.14 * 10^{8}$
	750		750	351671.27
	1000		1000	394531.73
	250	Intramodality	500	0.36
	250		750	23.50
	250		1000	886.02
	500		750	23.19
	500		1000	195.64
	750		1000	2.81
Intermodality	250	Intermodality	500	848.34
	250		750	$6.78 * 10^{7}$
	250		1000	$1.63 * 10^{9}$
	500		750	597602.20
	500		1000	$3.12 * 10^{6}$
	750		1000	19.92

Appendix B: Result of the Bayesian repeated-measures ANOVAs and of the Bayesian paired-samples *t*-tests for AAA *vs* VVV *vs* TTT conditions (Weber fraction)

Table B1.

Models	Bayes Factor (BF_{10})
Null model (incl. Subject)	1
Modality	28.3
Duration	19450.76
Modality + Duration	597192.56
Modality + Duration + Modality * Duration	$5.79 * 10^{14}$

Table B2.

Modality 1	Modality 2	Bayes Factor (BF_{10})
AAA	VVV	2.15
	TTT	92184.96
VVV	TTT	5.35

Table B3.

Duration 1	Duration 2	Bayes Factor (BF_{10})
250	500	0.23
	750	105.59
	1000	111596.92
500	750	30.46
	1000	16584.94
750	1000	3.14

Table B4.

Modality 1	Duration (ms) 1	Modality 2	Duration (ms) 2	Bayes Factor (BF_{10})
AAA	250	AAA	500	0.33
	250		750	0.51
	250		1000	13.36
	500		750	0.23
	500		1000	1.87
	750		1000	2.66
VVV	250	VVV	500	26.15
	250		750	0.21
	250		1000	0.27
	500		750	171.88
	500		1000	60.12
	750		1000	0.33
TTT	250	TTT	500	2311.25
	250		750	14048.14
	250		1000	$1.06 * 10^6$
	500		750	0.83
	500		1000	9.21
	750		1000	0.39
AAA	250	VVV	250	0.31
	500		500	20.09
	750		750	0.23
	1000		1000	0.70
	250	TTT	250	129259.59
	500		500	2.50
	750		750	0.34
	1000		1000	2.24
VVV	250		250	91734.48
	500		500	0.52
	750		750	0.25
	1000		1000	0.26

Appendix C: Result of the Bayesian repeated-measures ANOVAs and of the Bayesian paired-samples *t*-tests for AAA *vs* AVA *vs* ATA conditions (Weber fraction)

Table C1.

Models	Bayes Factor (BF_{10})
Null model (incl. Subject)	1
Modality	$1.32*10^{16}$
Duration	$3.95*10^{11}$
Modality + Duration	$9.53*10^{27}$
Modality + Duration + Modality * Duration	$1.56*10^{33}$

Table C2.

Modality 1	Modality 2	Bayes Factor (BF_{10})
AAA	AVA	$2.54*10^{22}$
	ATA	$1.04*10^{23}$
AVA	ATA	0.12

Table C3.

Duration 1	$Duration2$	Bayes Factor (BF_{10})
250	500	14.33
	750	$2.82 * 10^7$
	1000	$2.83 * 10^{12}$
500	750	3074.59
	1000	$2.89 * 10^6$
750	1000	14.00

Table C4.

Modality 1	Duration (ms) 1	Modality 2	Duration (ms) 2	Bayes Factor (BF_{10})
AAA	250	AVA	250	$1.83 * 10^8$
	500		500	264507.87
	750		750	8452.43
	1000		1000	11686.26
	250	ATA	250	$2.68 * 10^8$
	500		500	$2.53 * 10^7$
	750		750	3372.11
	1000		1000	5159.78
AVA	250		250	0.73
	500		500	0.81
	750		750	0.29
	1000		1000	0.23
	250	AVA	500	0.25
	250		750	1323.09
	250		1000	231458.62
	500		750	390.74
	500		1000	913.69
	750		1000	1.76
ATA	250	ATA	500	206.71
	250		750	20257.11
	250		1000	379835.76
	500		750	24.05
	500		1000	120.55
	750		1000	0.35

Appendix D: Result of the Bayesian repeated-measures ANOVAs and of the Bayesian paired-samples *t*-tests for VVV *vs* VAV *vs* VTV conditions (Weber fraction)

Table D1.

Models	Bayes Factor (BF_{10})
Null model (incl. Subject)	1
Modality	$6.04*10^{10}$
Duration	$1.58*10^{10}$
Modality + Duration	$1.82*10^{21}$
Modality + Duration + Modality * Duration	$4.94*10^{29}$

Table D2.

Modality 1	Modality 2	Bayes Factor (BF_{10})
VVV	VAV	$2.36*10^{11}$
	VTV	$2.6*10^{16}$
VAV	VTV	0.28

Table D3.

Duration 1	Duration 2	Bayes Factor (BF_{10})
250	500	0.69
	750	$1.39 * 10^6$
	1000	$8.4*10^8$
500	750	36205.07
	1000	$4.63*10^7$
750	1000	15.93

Table D4.

Modality 1	Duration (ms) 1	Modality 2	Duration (ms) 2	Bayes Factor (BF_{10})
VVV	250	VAV	250	$1.65 * 10^7$
	500		500	104.78
	750		750	30.25
	1000		1000	2.65
	250	VTV	250	$3.23 * 10^{11}$
	500		500	22.85
	750		750	9058.87
	1000		1000	195.68
VAV	250		250	0.48
	500		500	0.37
	750		750	0.38
	1000		1000	0.41
	250	VAV	500	2.09
	250		750	1546.45
	250		1000	88618.00
	500		750	129.60
	500		1000	656.90
	750		1000	0.87
VTV	250	VTV	500	77.44
	250		750	$3.342 * 10^6$
	250		1000	$2.031 * 10^6$
	500		750	0.68
	500		1000	29.97
	750		1000	15.15

Appendix E: Result of the Bayesian repeated-measures ANOVAs and of the Bayesian paired-samples *t*-tests for TTT *vs* TAT *vs* TVT conditions (Weber fraction)

Table E1.

Models	Bayes Factor (BF_{10})
Null model (incl. Subject)	1
Modality	$1.07^{*}10^{9}$
Duration	$3.05^{*}10^{15}$
Modality + Duration	$4.11^{*}10^{24}$
Modality + Duration + Modality * Duration	$2e05^{*}10^{23}$

Table E2.

Modality 1	Modality 2	Bayes Factor (BF_{10})
TTT	TAT	$3.83 * 10^{10}$
	TVT	$3.87 * 10^{15}$
TAT	TVT	6.58

Table E3.

Duration 1	Duration 2	Bayes Factor (BF_{10})
250	500	$1.75 * 10^{7}$
	750	$4.51 * 10^{12}$
	1000	$1.24 * 10^{13}$
500	750	3520.70
	1000	149307.25
750	1000	0.43

Table E4.

Modality 1	Duration (ms) 1	Modality 2	Duration (ms) 2	Bayes Factor (BF_{10})
TTT	250	TAT	250	4119.79
	500		500	1325.00
	750		750	5.14
	1000		1000	24.32
	250	TVT	250	239.33
	500		500	215364.87
	750		750	362.10
	1000		1000	775.74
TAT	250		250	0.22
	500		500	2.04
	750		750	1.38
	1000		1000	0.69
	250	TAT	500	170.69
	250		750	4634.93
	250		1000	2802.40
	500		750	16.95
	500		1000	10.22
	750		1000	0.25
TVT	250	TVT	500	4.89
	250		750	1484.40
	250		1000	838.68
	500		750	11.99
	500		1000	121.77
	750		1000	0.33

Appendix F: Result of the Bayesian repeated-measures ANOVAs and of the Bayesian paired-samples *t*-tests for intra- *vs* intermodality conditions (relative CE)

Table F1.

Models	Bayes Factor (BF_{10})
Null model (incl. Subject)	1
Modality	0.43
Duration	1.06
Modality + Duration	0.46
Modality + Duration + Modality * Duration	0.126

Table F2.

Modality 1	Modality 2	Bayes Factor (BF_{10})
Intra	Inter	0.353

Table F3.

Duration 1	Duration 2	Bayes Factor (BF_{10})
250	500	1.15
	750	0.15
	1000	0.18
500	750	5.52
	1000	7.86
750	1000	0.49

Table F4.

Modality 1	Duration (ms) 1	Modality 2	Duration (ms) 2	Bayes Factor (BF_{10})
Intramodality	250	Intermodality	250	0.26
	500		500	0.36
	750		750	0.74
	1000		1000	0.54
	250	Intramodality	500	0.31
	250		750	0.49
	250		1000	1.00
	500		750	2.34
	500		1000	1.90
	750		1000	0.37
Intermodality	250	Intermodality	500	1.03
	250		750	0.31
	250		1000	0.22
	500		750	0.72
	500		1000	1.05
	750		1000	0.37

Appendix G: Result of the Bayesian repeated-measures ANOVAs and of the Bayesian paired-samples *t*-tests for AAA *vs* VVV *vs* TTT conditions (relative CE)

Table G1.

Models	Bayes Factor (BF_{10})
Null model (incl. Subject)	1
Modality	0.23
Duration	0.87
Modality + Duration	0.21
Modality + Duration + Modality * Duration	0

Table G2.

Modality 1	Modality 2	Bayes Factor (BF_{10})
AAA	VVV	0.86
	TTT	0.19
VVV	TTT	0.20

Table G3.

Duration 1	Duration 2	Bayes Factor (BF_{10})
250	500	0.18
	750	0.31
	1000	1.23
500	750	1.30
	1000	5.93
750	1000	0.19

Table G4.

Modality 1	Duration (ms) 1	Modality 2	Duration (ms) 2	Bayes Factor (BF_{10})
AAA	250	AAA	500	0.28
	250		750	0.23
	250		1000	0.28
	500		750	0.55
	500		1000	2.41
	750		1000	0.23
VVV	250	VVV	500	0.26
	250		750	0.30
	250		1000	1.22
	500		750	0.36
	500		1000	1.58
	750		1000	0.45
TTT	250	TTT	500	0.22
	250		750	0.33
	250		1000	0.34
	500		750	0.58
	500		1000	0.31
	750		1000	0.22
AAA	250	VVV	250	0.39
	500		500	0.49
	750		750	0.32
	1000		1000	0.26
	250	TTT	250	0.25
	500		500	0.22
	750		750	0.23
	1000		1000	0.29
VVV	250		250	0.25
	500		500	0.33
	750		750	0.30
	1000		1000	0.23

Appendix H: Result of the Bayesian repeated-measures ANOVAs and of the Bayesian paired-samples *t*-tests for AAA *vs* AVA *vs* ATA conditions (relative CE)

Table H1.

Models	Bayes Factor (BF_{10})
Null model (incl. Subject)	1
Modality	10.19
Duration	6.64
Modality + Duration	71.57
Modality + Duration + Modality * Duration	5.47

Table H2.

Modality 1	Modality 2	Bayes Factor (BF_{10})
AAA	AVA	611.43
	ATA	3.09
AVA	ATA	0.39

Table H3.

Duration 1	Duration 2	Bayes Factor (BF_{10})
250	500	1.4
	750	0.14
	1000	0.46
500	750	8.83
	1000	665.04
750	1000	0.77

Table H4.

Modality 1	Duration (ms) 1	Modality 2	Duration (ms) 2	Bayes Factor (BF_{10})
AAA	250	AVA	250	0.75
	500		500	10.87
	750		750	2.80
	1000		1000	0.49
	250	ATA	250	0.62
	500		500	2.17
	750		750	0.39
	1000		1000	0.22
AVA	250		250	0.23
	500		500	0.35
	750		750	0.32
	1000		1000	0.38
	250	AVA	500	0.59
	250		750	0.22
	250		1000	0.29
	500		750	0.61
	500		1000	3.83
	750		1000	0.53
ATA	250	ATA	500	0.56
	250		750	0.25
	250		1000	0.42
	500		750	3.68
	500		1000	7.79
	750		1000	0.47

Appendix I: Result of the Bayesian repeated-measures ANOVAs and of the Bayesian paired-samples *t*-tests for VVV *vs* VAV *vs* VTV conditions (relative CE)

Table I1.

Models	Bayes Factor (BF_{10})
Null model (incl. Subject)	1
Modality	0.97
Duration	0.22
Modality + Duration	0.22
Modality + Duration + Modality * Duration	0.57

Table I2.

Modality 1	Modality 2	Bayes Factor (BF_{10})
VVV	VAV	3.47
	VTV	0.62
VAV	VTV	0.36

Table I3.

Duration 1	Duration 2	Bayes Factor (BF_{10})
250	500	0.56
	750	0.14
	1000	0.13
500	750	1.67
	1000	11.33
750	1000	0.21

Table I4.

Modality 1	Duration (ms) 1	Modality 2	Duration (ms) 2	Bayes Factor (BF_{10})
VVV	250	VAV	250	2.31
	500		500	0.35
	750		750	0.46
	1000		1000	0.22
	250	VTV	250	0.24
	500		500	0.26
	750		750	0.35
	1000		1000	0.83
VAV	250		250	2.03
	500		500	0.25
	750		750	0.25
	1000		1000	0.68
	250	VAV	500	0.80
	250		750	0.49
	250		1000	0.44
	500		750	0.51
	500		1000	0.25
	750		1000	0.25
VTV	250	VTV	500	0.22
	250		750	0.33
	250		1000	0.74
	500		750	0.65
	500		1000	12.28
	750		1000	0.46

Appendix J: Result of the Bayesian repeated-measures ANOVAs and of the Bayesian paired-samples *t*-tests for TTT *vs* TAT *vs* TVT conditions (relative CE)

Table J1.

Models	Bayes Factor (BF_{10})
Null model (incl. Subject)	1
Modality	25.32
Duration	0.1
Modality + Duration	2.73
Modality + Duration + Modality * Duration	2.15

Table J2.

Modality 1	Modality 2	Bayes Factor (BF_{10})
TTT	TAT	0.16
	TVT	222.07
TAT	TVT	463.71

Table J3.

Duration 1	Duration 2	Bayes Factor (BF_{10})
250	500	0.17
	750	0.27
	1000	0.45
500	750	0.20
	1000	0.27
750	1000	0.15

Table J4.

Modality 1	Duration (ms) 1	Modality 2	Duration (ms) 2	Bayes Factor (BF_{10})
TTT	250	TAT	250	0.56
	500		500	1.69
	750		750	0.28
	1000		1000	0.71
	250	TVT	250	0.33
	500		500	0.73
	750		750	3.66
	1000		1000	5.23
TAT	250		250	1.40
	500		500	25.41
	750		750	1.18
	1000		1000	0.38
	250	TAT	500	0.22
	250		750	0.51
	250		1000	0.98
	500		750	0.77
	500		1000	5.31
	750		1000	0.35
TVT	250	TVT	500	0.29
	250		750	0.32
	250		1000	0.32
	500		750	0.22
	500		1000	0.22
	750		1000	0.22