TESTING THE SCALAR PROPERTY WITH INTERVAL REPRODUCTIONS

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Abstract

According to the scalar property for time, the variability to time ratio should be constant. The validity of this property was tested in a restricted range of durations (standard values from 1 s to1.9 s) with an interval reproduction method. Time intervals to be reproduced with finger tapping were presented with 2, 4, or 6 brief and successive auditory signals marking 1, 3, or 5 intervals, respectively. The variability to time ratio is not constant across the standard interval conditions (higher at 1.9 than at 1 s), and this violation to scalar timing does not interact with the number-of-interval variable.

One of the most popular models to account for capability to time intervals efficiency is the scalar expectancy theory (SET: Gibbon, 1977; see Grondin, 2001 or 2010a). According to SET, timing tasks or requirements are based on a central, amodal timekeeping device. Such a single timer, or internal clock, is described as a pacemaker-counter device. Time representation is based on the integration by an accumulator (or counter) of the temporal information—pulses—emitted by the pacemaker during a given period to be timed (see for instance Killeen & Weiss, 1987; Rammsayer & Ulrich, 2001).

According to SET, the variability of time estimates increases linearly with the duration of the interval to be timed. In other words, the variability to time ratio should be constant. This *scalar property* is known as Weber's law in psychophysics, and this ratio is the Weber fraction (WF). The WF is referred to below, as is sometimes the case in the timing literature, as the coefficient of variation (Grondin, 2008). Strictly speaking, the single-timer mechanism adopted in SET applies to all tasks (or methods of investigation) and to all ranges of durations. The main purpose of the present study was to conduct different tests of this scalar property with reproduction tasks. The tests were concerned with a narrow duration range (standards from 1 to 1.9 s) for which it was suspected that the WF might not be constant.

In its strict form, Weber's law for time does not hold. As is the case for many sensory continua, for little magnitude of sensation, the WF gets higher (see Grondin, 1993, for examples with interval discrimination). This tendency to have higher WFs for smaller values can be well accounted for by the generalized form of Weber law. However, there seems to be an increase of the Weber fraction as intervals get longer. Such observations would indeed be inconsistent with either Weber's law or its generalized form.

There are some evidences that the WF for timing and time perception increases as intervals get longer (see for instance Fraisse (1978), Figure 1; Gibbon, Malapani, Dale & Gallistel (1997), Figure 3; or Grondin (2003), Figure 3). These evidence include animal timing data (see Bizo, Chu, Sanabria, & Killeen, 2006; or Crystal, 2006), and observations with humans (Getty, 1975; Grondin, 2010b; Lavoie & Grondin, 2004). Indeed, "Within-task comparisons suggest that there may be an increase in the coefficient of variation between time values below 1-2s and those above" (Gibbon, et al., 1997, pp. 173-174).

In the present experiment, the reproduction task provides two different tests of the WF constancy: one with and one without the synchronization of the motor implementation (finger tapping) with the sounds marking time during the presentation of the interval to be reproduced. This experiment is identical to Experiment 2 in Grondin (in press), except for one condition, described below. Indeed, the present experiment is presented to show to what extent the results reported in Grondin's Experiment 2 can be replicated.

Method

Participants

Twelve participants (eight females and four males) recruited at Laval University participated in the experiment. The average age was 30.6 years (*SD* = 12.50). Each participant weas paid CAD$10.

Apparatus and stimuli

The intervals to be reproduced were silent durations between 20-ms auditory stimuli. Each auditory stimulus was a 1-kHz pure tone generated by an IBM Pentium IV micro-computer running E-Prime software. The computer was equipped with an SB Audigy 2 sound card, and the sounds were delivered binaurally through headphones (Sennheiser HD477) at an intensity of about 70 dB SPL.

The stimuli consisted of the presentation of two, four or six successive 20-ms tones, which yielded three interval types: 1-, 3- or 5-interval conditions, respectively. The interval duration was 1, 1.3, 1.6 or 1.9 s.

Procedure

Each participant was asked to complete a reproduction task. The experiment consisted of two sessions, each lasting approximately 30 minutes.

The first session was divided into twelve blocks of 10 trials each: one block for each type of experimental condition (3 number-of-intervals x 4 standards). In this session, participants were asked to wait until the end of the presented series of tones before beginning to reproduce the standard, empty, interval once. Participants were instructed to indicate the onset and the offset of the interval by a key press on the space bar on the computer keyboard.

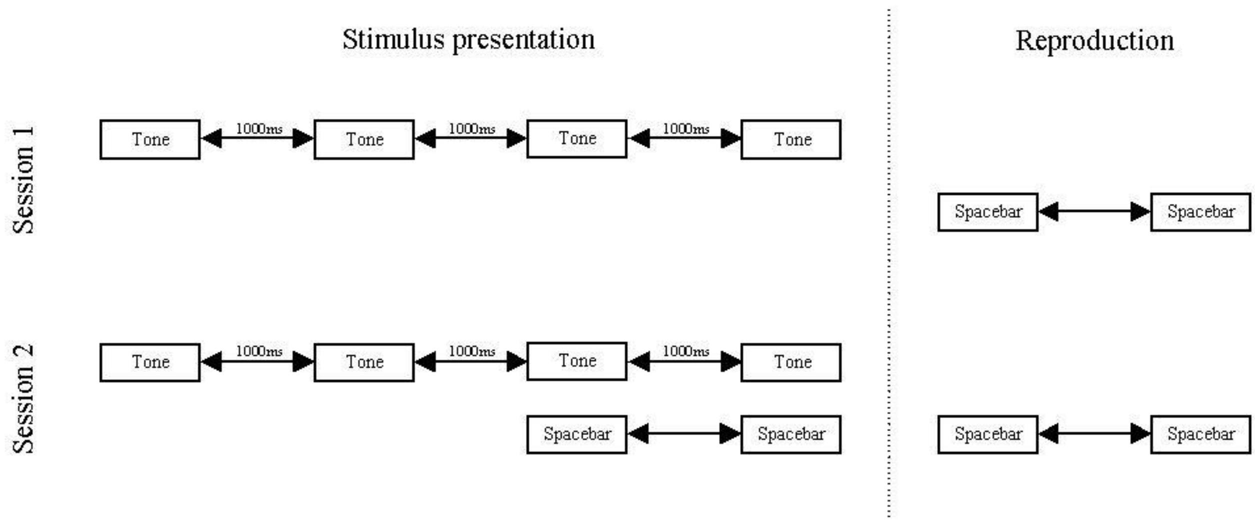

Figure 1. Example of two trials with the reproduction method, one for each session, of the three intervals, 1000 ms condition.

The second session was divided into eight blocks of 10 trials each. In this session, participants also had to reproduce one interval at the end of the presented stimuli. The difference between this session and the first one was that participants were asked to synchronize the pressing of the space bar with the presented tones. Participants were instructed to start this synchronization after the second tone was presented (i.e., with the third tone). Indeed, since participants needed at least two tones to evaluate the duration of one interval and synchronize their key pressing with the rest of the presented tones, there was no 1-interval condition in the second session. An example of two trials, one for each reproduction session, is presented in Figure 1.

It is important to note that, in Session 2, the parameters in the 1.6-s condition, with 3 intervals, were incorrect. Participants were presented 1.9-s instead of 1.6-s intervals. Therefore, the data analyses for Session 2 are restricted to the 1-, 1.3-, and 1.9-s conditions.

In Session 1, participants were asked to listen to the sounds and then to reproduce the interval. In Session 2, they received specific instructions regarding the need to synchronize, and were asked to continue to tap twice after the last the sound. In other words, there was continuity after the synchronization phase; after synchronizing with the standard sequence, participants still had to reproduce the interval. No specific instruction was given to participants regarding the duration between the last sound and the first tap without sound, although participants usually kept on tapping without interruption. For both sessions, the presentation order of interval types and standards was counterbalanced among participants. However since synchronizing is a specific strategy for approaching the reproduction task, synchronizing or not was not counterbalanced between Sessions 1 and 2.

Results

In order to directly compare the sensitivity levels in all conditions, the coefficient of variation (CV), i.e., the variability of the 10 reproduced intervals divided by the mean reproductions was used. Figure 2 illustrates the results in all conditions of Session 1. Generally, the figure shows

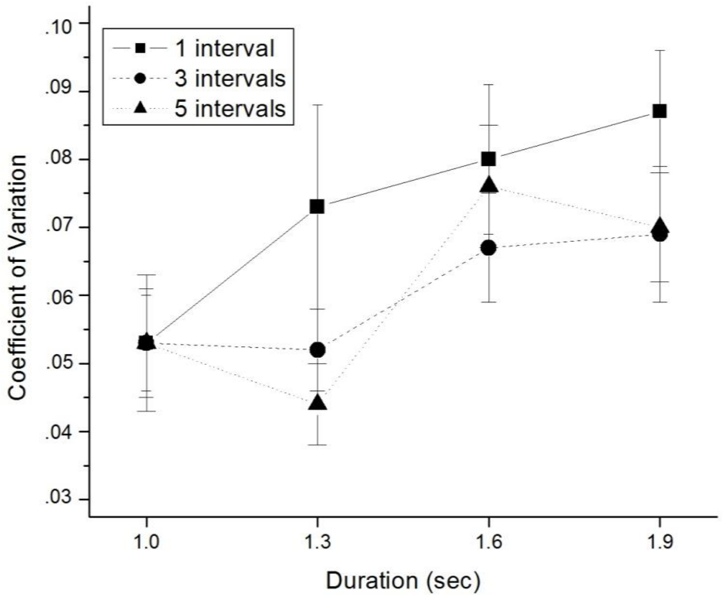

Figure 2. Average Coefficient of Variation (with standard error bars) as a function of the standard duration for each number-of-interval condition in Session 1

that the CV is lower in the 3- or 5-interval conditions than in the 1-interval condition. Moreover, in each number-of-interval condition, the WF does not remain constant from 1 to 1.9 s. A 3 (number of intervals) x 4 (standard duration) ANOVA with repeated measures was used to analyze the data. There was significant main effect for standard duration, $F(3, 33) = 12.39$, $p < .01$, $\eta_p^2 = .530$, but for the number of intervals, the effect was only marginally significant, $F(2,22) = 3.55$, $p < .068$, $\eta_p^2 = .244$. The interaction was not significant ($p = .374$).

For Session 2, there is also an increase of the CV as a function of time (Figure 3). A 2 (number of intervals) x 3 (standard duration) ANOVA with repeated measures was used to analyze the data. In other words, the 1.6-s condition was not included in the analysis. There were significant main effects for standard duration, $F(2, 22) = 9.88$, $p < .01$, $\eta_p^2 = .473$, and for the number of intervals, $F(1,11) = 7.14$, $p < .05$, $\eta_p^2 = .394$. The interaction was not significant ($p = .834$). The CV is lower in the 3- than in the 5-interval condition.

The other dependent variable of interest in this experiment is the CE, here defined as the mean productions minus the standard. For Session 1, the 3 x 4 ANOVA revealed no significant main or interaction effect. For Session 2, the 2 x 3 ANOVA also revealed no significant effect, but note that $p = .099$ for the standard duration effect, with the CE being much lower in the 1.9- (-59 ms) than in the 1- (-8 ms) or 1.3- (+2 ms) interval conditions.

Discussion

The main finding in the present experiment is the overall increase of the CV as a function of the base duration. The higher CV at 1.9 s than at 1 s was observed here in both Sessions 1 and 2, i.e. in conditions where synchronization preceded (Session 2) or not (Session 1) the reproductions. This finding is consistent with the one reported in Grondin (in press, Experiment 2), and is consistent with the ones also reported by Grondin (in press) when an interval discrimination

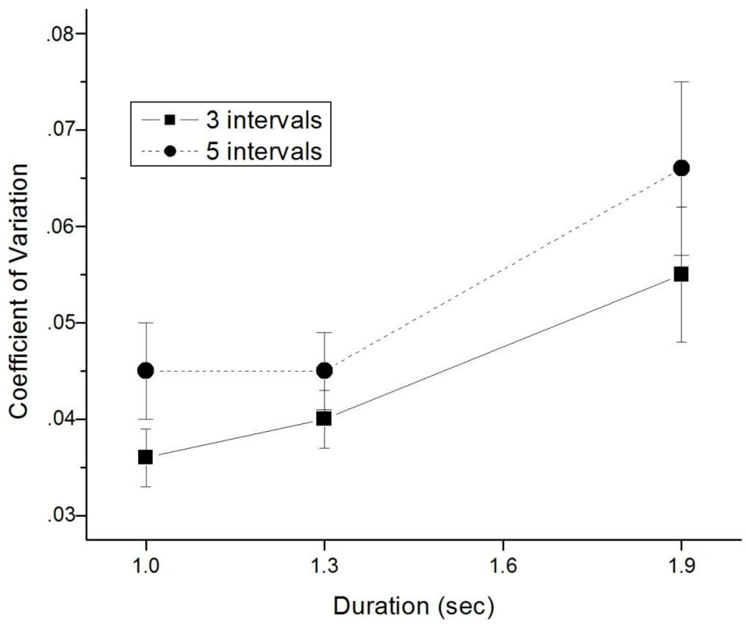

Figure 3. Average Coefficient of Variation (with standard error bars) as a function of the standard duration for each number-of-interval condition in Session 2

(Experiment 1) or categorization (Experiment 3) method is employed. Already in 1930, Woodrow showed that, with a reproduction task, the WF is higher at 2 s than at 1.5 s (and much higher for intervals beyond 2 s).

This main finding is a clear violation to the scalar property that is often reported to apply to time perception. Strictly speaking, this finding questions the notion of a central timekeeping system, this system being described as a pacemaker-counter device. On the other hand, observing the same discontinuity at the same moment (between 1 and 1.9 s) with different investigation methods (reproduction or perception) and this, with single and multiple interval conditions, could be interpreted as a sign that there is a common fundamental property, and therefore a common mechanism, for keeping track of time in each of these conditions.

The theoretical meaning of these results is discussed in Grondin (in press). Indeed, the psychological meaning of this non-constant WF between 1 and 1.9 s remains unclear, but some portions of the timing literature indicate that there could be a different temporal mechanism at play before or after 1.5 s (Gibbon et al., 1997). Along the same line, a maximum sensitivity for time is reported by Crystal (2006) for intervals lasting 1.2 s, a value over which it is also reported that it is preferable to adopt a different way (counting explicitly) for completing a duration categorization task (Grondin, Meilleur-Wells, & Lachance, 1999).

Finally, the present findings also reveal that the CV is lower in Session 2 than in Session 1, i.e., is lower with than without an explicit synchronization phase; as well, in Session 1, the CV is lower with multiple than with single interval presentations. These findings also replicate the ones reported by Grondin (in press) with the same method. However, observing lower CV in Session 2 in the 3- than in the 5-interval condition, as well as observing no significant difference for the CE, is not consistent with Grondin (in press). However, the strong tendency in Session 2 to obtain lower CE at 1.9 s than at 1 or 1.3 s is consistent with previous results.

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