ACOUSTICAL LETTER

About optimal timing and stability of Weber fraction for duration discrimination

Simon Grondin, Bastien Ouellet and Marie-Ève Roussel

École de Psychologie, Université Laval,
Québec, Qué, G1K 7P4, Canada,
e-mail: simon.grondin@psy.ulaval.ca

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1. Introduction

The Weber function is fundamental in the study of sensory processing. This function relates the difference threshold ($\Delta\phi$) in discrimination tasks to the magnitude of the stimulus (ϕ) under investigation. The ratio $\Delta\phi/\phi$ is called the Weber fraction, and when this ratio remains constant for a given range of ϕ values, the Weber's law is reported to hold. Such Weber function analyses are also critical in studying the mechanisms underlying time perception [1].

In the field of time perception, this functional relationship between difference threshold and time is often reported to be well accounted for by some generalized form of the Weber's law [2]. However, there are several empirical reports, especially in the context of interval discrimination marked by series of brief auditory stimuli (rhythm), in which a special form of violation to the Weber's law is reported. Essentially, these reports suggest that there is, for given ϕ values, a range of duration for which sensitivity is as its maximum (i.e., timing is optimal or, in discrimination tasks, the Weber fraction is at its lowest). Drake and Botte [3] reported maximum sensitivity for intervals ranging from 0.3 to 0.8 s, but maximum sensitivity was reported for 0.5-s intervals by Friberg and Sundberg [4] and for 0.6-s intervals by Fraisse [5]. On the other hand, Mishima [6] (in Fraisse [7]) found a preferred tempo at 560 ms for audition, and one at 680 ms for vision.

The present experiment was designed to search for an optimal value for duration discrimination around 600 ms. Five standard durations, from 500 to 740 ms, were under investigation. By using standard values that were close to each other, the conditions were laid for possibly observing optimal timing at some point. Moreover, to make it possible to compare sensory modes, a search for optimal timing was conducted with intervals marked by either auditory or visual signals. For each experimental condition, the thresholds were estimated with two variations of an adaptive procedure, i.e., with ascending and descending trials.

2. Method

2.1. Participants

Sixteen adult volunteer subjects participated in the experiment. They were paid $25 (Canadian).

2.2. Apparatus and stimuli

Each participant was seated in a chair in a dimly lit room. The ambient light was kept constant. The visual signal consisted of a circular red LED (Radio-Shack No. 276–088). The LED was located at about 1 m in front of the participant, subtending a visual angle of 0.57 degree. The auditory stimuli used in the present experiment was a 1-kHz complex tones generated by the computer and presented binaurally through a headphone (Sony MDR-V600). The intensity of sounds was about 70 dB. Finally, the experiment was controlled by a Zenith micro-computer.

2.3. Procedure

One trial consisted of presenting both the standard duration and a comparison interval, in random order. The participant had to indicate, by pressing the appropriate button, if the first interval was shorter or longer than the second interval. The empty intervals were marked by two 10-ms signals. The first and second intervals were separated by a 1.5-s interval. A 1.7-s visual feedback was provided to participant, and there was no warning signal. The next trial started 2 s after presentation of the feedback.

With the adaptive procedure, the difficulty of the discrimination was adjusted after each trial. Specifically, after each correct response, the duration of the comparison interval was made more similar to that of the standard interval by a factor of X, and, after each wrong response, the duration of the comparison interval was made more different from that of the standard interval by a factor of 3X. This technique, a weighted up-down method, provides an estimate of the difference threshold at which participants are correct on 75% of the trials [8,9].

There were 10 experimental conditions: 2 sensory modes marking the intervals, auditory or visual, and 5 standard durations (500, 560, 620, 680, and 740 ms). For each condition, two types of procedure were adopted for estimating difference thresholds, one with ascending values of the comparison interval, and one with descending values.

Each threshold estimate was based on a run of 50 trials. These 50 trials were composed of three blocks of 10, 20, and 20 trials. Within each block, the size of the adjustment step (X) was held constant, and between blocks, the step size was decreased. The duration of the first comparison interval was, for standards from 500 to 740 ms respectively, 250, 280, 310, 340, and 370 ms in the ascending trials; and 750, 840, 930, 1,020, and 1,110 ms. For both ascending and descending trials, step sizes for Block 1 were, for standards from 500 to 740 ms respectively, 30, 34, 38, 42, and 46 ms. For all conditions, step sizes for Block 2 and 3 were 12 and 4 ms.

The adjustment procedure was constrained so that the duration of the comparison interval could not be higher than or equal to the duration of the standard interval. Thus, there were instances in which the duration of the comparison interval was identical for successive trials.

For each standard, there were four marker-type conditions: 2 sensory modalities (Visual or Auditory) by two types of procedure (ascending and descending). Their order of presentation was balanced between participants according to a Latin square.

There were five sessions, one for each standard condition. Eight participants were conducted in the following standard condition order: 500, 560, 620, 680, and 740 ms; and the other eight participants followed the reverse order. In each session, for one given sensory mode, if there was more than a 50% difference between the difference thresholds in the ascending and descending conditions, and if the Weber fraction in this condition was larger than 30% in the visual-marker condition, and more than 20% in the auditory-marker condition, the threshold estimate observed in the worst condition was estimated a second time and that value was kept for analysis.

3. Results

The dependent variable of interest is the Weber fraction. It was calculated by estimating first the difference threshold, which was estimated by subtracting 1) the average of the comparison intervals in the last 10 trials from the value of the standard (Descending trials) or 2) the value of the standard from the average of the comparison intervals in the last 10 trials (Ascending trials). The Weber fraction was the ratio of the difference threshold on the standard duration.

Figure 1 illustrates the mean Weber fraction for each experimental condition at each standard duration. The fractions are lower in the auditory (about 9%) than in the visual modality (about 14%) but, for both sensory modes, there is no sign of optimal timing (lower Weber fraction) for one given standard.

The difference between the means was tested with a randomized block factorial analysis of variance (2 Sensory Modes $\times$ 5 Durations $\times$ 2 Directions—Ascending vs. Descending). There was no significant Duration effect ($p = 0.90$), but the Mode effect, $F(1, 285) = 80.46$, $p < 0.01$, and the Direction effect, $F(1, 285) = 5.92$, $p < 0.05$, were significant. No interaction effect was significant, but note the Mode $\times$ Direction effect, $F(1, 285) = 2.14$, $p = 0.15$.

4. Discussion

The main result of the present experiment is the stability of the Weber fraction when difference thresholds are estimated for five different standard values from 500 to 740 ms. With optimal timing somewhere in this range, a lower Weber fraction, in one given sensory mode, should have been observed. The present results do not support the notion of better timing for intervals lasting about 600 ms [5] or 500 ms [4], in either the auditory or the visual mode. In other words, if there is any optimal range on the physical time continuum for a timing performance, it is a range limited to individual preferences, or limited to particularities of a method for presenting or producing time intervals. On the other hand, at this point, it cannot be excluded that optimal timing could be shown with intervals shorter than 0.5 s of longer than 0.74 s.

The significant difference between Weber fractions with ascending and descending trials has theoretical interest. It is consistent with the Weber function which predicts higher difference threshold with longer intervals. In the analysis of the present experiment, the Weber fractions for both descending and ascending trials were computed on the basis

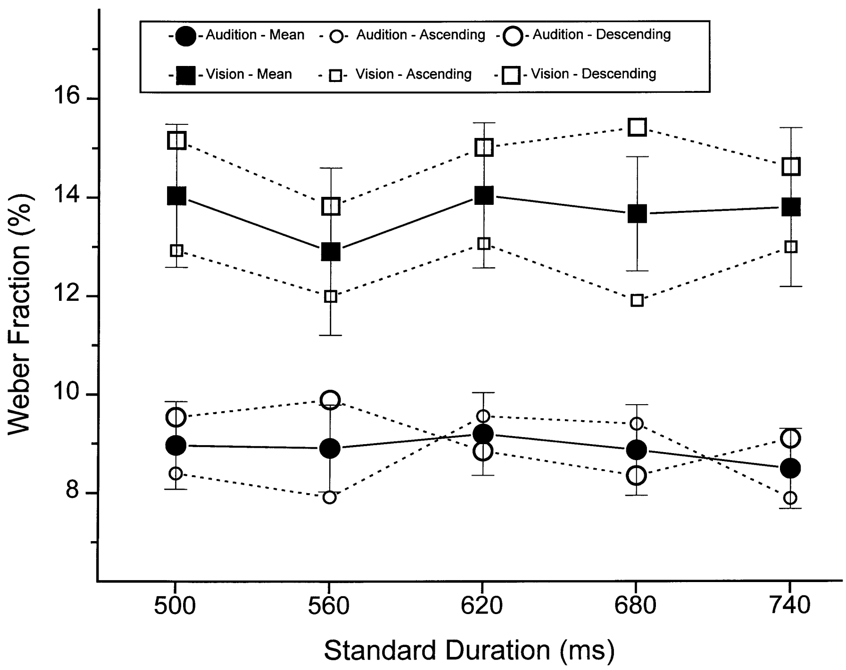

Fig. 1 Weber fraction as a function of standard duration (error bars are standard errors for the mean fraction of ascending and descending trials).

of the same standard value. In other words, a Weber fraction effect reveals that difference thresholds were higher with the descending procedure (i.e., with comparison intervals longer than standards) than with the ascending procedure (i.e., with comparison intervals shorter than the standards).

Finally, the performance levels reported here for audition are higher than those reported for vision. This is consistent with previous reports on interval discrimination where Weber fractions can increase from 5% in audition to 10% in vision [10], or from 10% in audition to 15% in vision [11]. In point of fact, the exact fraction values depend very much on the method and operational definition used to define thresholds, and on the range of durations under investigation.

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