THE EFFECTS OF SENSORY MODALITY AND TYPE OF TASK ON DISCRIMINATION OF DURATIONS RANGING FROM 400 TO 1,400 MILLISECONDS

Thomas H. Rammsayer
Institute of Psychology, University of Bern, CH-3000 Bern 9, Switzerland
thomas.rammsayer@psy.unibe.ch

Abstract

In several studies, better acuity has been shown for temporal processing in the auditory compared to the visual sensory modality. More recently, experimental evidence has been provided for superior performance on duration discrimination with the reminder task than with the two-alternative forced-choice (2AFC) task. The present study was designed to further elucidate the influence of sensory modality and type of psychophysical task on temporal discrimination of intervals ranging from 400 to 1,400 ms. As an indicator of relative temporal sensitivity, Weber fractions were computed. Lower Weber fractions, indicating better discrimination performance, were obtained with the reminder task compared to the 2AFC task irrespective of sensory modality. Better temporal sensitivity could be also revealed for auditory compared to visual stimuli. In addition, a significant interaction between sensory modality and base duration indicated that the modality-dependent difference in temporal sensitivity was most pronounced at the shortest (400-ms) base duration.

Numerous studies consistently demonstrated effects of sensory modality on perceived duration indicating that auditory stimuli are perceived as longer than visual ones of the same physical duration. Unlike perceived duration, *duration discrimination* refers to the ability to discriminate small differences in duration between two stimulus intervals. Temporal sensitivity, as reflected by performance on duration discrimination, appears to be based on partially different mechanisms than perceived duration (Grondin & Rammsayer, 2003; Rammsayer, 2010). In contrast to the large number of studies on modality-specific effects on perceived duration, systematic investigations of the effects of sensory modality on performance on duration discrimination appear to be relatively scant (cf., Penney, 2003). The available data suggest better discrimination of auditorily compared to visually presented intervals (Grondin, 1993; Grondin, Meilleur-Wells, Ouellette, & Macar, 1998; Lapid, Ulrich, & Rammsayer, 2009) indicating higher temporal sensitivity in the auditory than in the visual domain. The present study aimed at providing a systematic investigation of modality-specific differences in temporal discrimination of auditorily and visually presented intervals with base durations ranging from 400 to 1,400 ms.

Two of the most commonly used psychophysical task for estimating the difference limen (*DL*) as an indicator of performance on duration discrimination are the reminder task and the two-alternative forced-choice (2AFC) task. Both types of task are variants of the method of constant stimuli (Gescheider, 1997; Macmillan & Creelman, 2005). In each trial of the reminder task, the participant is presented with two stimuli, the constant standard stimulus and a variable comparison. The comparison can be smaller, equal to, or larger than the standard and always follows the standard. At the end of each trial, the participant has to indicate whether the first or second stimulus was larger. The 2AFC task is similar to the reminder task except that the presentation order of the standard and comparison is random.

Although it is usually assumed that the both tasks yield identical *DLs*, Lapid, Ulrich, and Rammsayer (2008) have found that this assumption is not supported by experimental data. The 2AFC task consistently yielded larger *DLs*, in fact, the *DLs* are up to twice as large as the ones estimated by the reminder task.

Lapid et al. (2008) exclusively employed auditory and visual duration discrimination tasks with a 500-ms standard duration. Because the mechanisms underlying the processing of temporal information seem to differ as a function of base duration, it is uncertain whether their results generalize to other base durations. As early as 1889, Hugo Münsterberg put forward the idea of two distinct timing mechanisms involved in temporal information processing: a sensory mechanism for the processing of durations less than one third of a second and a non-sensory mechanism for processing of longer durations. Similarly, Michon (1985) argued that temporal information processing of intervals longer than approximately 500 ms is cognitively mediated, while temporal processing of shorter intervals are predicted to be highly perceptual in nature, parallel, and not accessible to cognitive control. Numerous subsequent theoretical accounts and experimental findings endorsed the notion of two distinct timing mechanisms – one for temporal processing of brief durations in the range of milliseconds and one for processing of longer durations (Buonomano & Merzenich, 1995; Fraisse, 1984; Lewis & Miall, 2003; Michon, 1985; Mitrani, Shekerdjiiski, Gourevitch, & Yanev, 1977; Münsterberg, 1889; Rammsayer, 1996, 1999; Rammsayer & Lima, 1991). Therefore, another major goal of the present study was to investigate whether the finding of higher *DLs* for the 2AFC than for the reminder task, reported by Lapid et al. (2008) for a 500-ms standard interval, also holds for other base durations.

Method

Participants

The participants were 52 male and 44 female adult volunteers ranging in age from 19 to 37 years (M = 22.3, SD = 3.46). All participants were undergraduate psychology students and received course credits for taking part in this experiment. They were randomly assigned to one of four experimental conditions with the restriction that males and females were evenly distributed across the four experimental conditions. All had normal hearing and normal or corrected-to-normal vision.

Experimental Design

The present study investigated the effects of Type of Task (reminder task and 2AFC task) and Sensory Modality (auditory and visual) as two between-subjects factors on performance on duration discrimination as a function of base duration. Base Duration was designed as a six-level within-subject factor (400-, 600-, 800-, 1,000-, 1,200-, and 1,400-ms standard intervals). Trials of a given standard interval were presented blockwise with order of blocks counterbalanced across participants. This design resulted in four independent experimental groups (reminder task, auditory intervals; reminder task, visual intervals; 2AFC task, auditory intervals; 2AFC task, visual intervals).

Apparatus and Stimuli

A PC-compatible computer controlled the presentation of the standard and the comparison stimulus as well as the recording of the participants' responses. The standard and the comparison stimuli were filled intervals. Filled auditory intervals were white-noise bursts

from a computer-controlled sound generator (Phylab Model 1) presented binaurally through headphones (Vivanco SR85) at an intensity of 67 dB. The visual stimuli were generated by a red LED (diameter 0.48°, viewing distance 60 cm, luminance 46 cd/m^2), which was attached 1 cm above the centre of the computer screen. The intensity of the LED was clearly above threshold, but not dazzling.

Procedure

Each block consisted of 64 trials, and each trial consisted of one standard interval (= base duration) and one comparison interval. The duration of the comparison interval varied according to an adaptive rule (Kaernbach, 1991) to estimate *x.25* and *x.75* of the individual psychometric function, that is, the two comparison intervals at which the response "longer" was given with a probability of .25 and .75, respectively. In each experimental block, one series of 32 trials converging to *x.75* and one series of 32 trials converging to *x.25* were presented. Trials from both series were randomly interleaved within a block. With the reminder task, the comparison interval always followed the standard interval, whereas with the 2AFC task, the order of presentation for the standard and the comparison interval was randomized and balanced, with each interval being presented first in 50% of the trials.

To estimate $x_{.75}$, the duration of the comparison interval was increased by Δ_+ ms if the participant had judged the comparison interval to be shorter, and decreased by Δ_- after a "long" judgment. The opposite step sizes were employed for $x_{.25}$. To increase efficiency of the adaptive procedure, a larger step size was applied for the initial Trials 1-6 than for Trials 7-32 (cf., Levitt, 1971). Because absolute precision of timing depends on the standard duration, the step sizes Δ_+ and Δ_- were adjusted for each base duration. Step sizes as well as the initial value of the comparison intervals for each base duration were chosen on the basis of the results of a prior pilot experiment.

Within each trial, the two intervals were presented with an interstimulus interval (ISI) of 900 ms. The participant's task was to decide which of the two intervals was longer and to indicate his or her decision by pressing one of two designated response keys. After each response, visual feedback ("+", i.e., correct; "–", i.e., false) was displayed on the computer screen. The next trial started 900 ms after the feedback. As an indicator of discrimination performance, half the interquartile ranges [(75%-threshold value – 25%-threshold value)/2], representing the difference limen, *DL* (Luce & Galanter, 1963), was determined for each base duration. With this psychophysical measure, better performance on duration discrimination is indicated by smaller values. For quantification of timing accuracy as a function of base duration, the Weber fraction (*DL*/standard duration) was computed for each experimental condition to obtain an indicator of relative temporal sensitivity (cf., Killeen & Weiss, 1987).

Results

For statistical analysis, a three-way analysis of variance was conducted with Type of Task (reminder task and 2AFC task) and Sensory Modality (auditory and visual) as two between-subjects factors, and Base Duration as a within-subject factor. There was a reliable main effect of Type of Task [$F(1,92) = 42.11$, $p < .001$] indicating better discrimination performance with the reminder task compared to the 2AFC task; mean Weber fractions (± SEM) were 0.12 ± 0.005 and 0.18 ± 0.009 for the reminder and the 2AFC task, respectively. A significant main effect of Sensory Modality [$F(1,92) = 51.73$, $p < .001$] revealed better discrimination performance for auditory than for visual intervals as indicated by mean Weber fractions of 0.12 ± 0.005 and 0.18 ± 0.008, respectively. Furthermore, Weber fractions significantly differed as a function of Base Duration [$F(5,460) = 2.46$, $p < .05$]. Post hoc

Tukey's HSD tests (cf., Kirk, 1995) confirmed that relative temporal sensitivity was much worse for the 400-ms base duration as compared to the longest 1,400-ms base duration ($p < .05$). No other differences in Weber fractions reached the 5% level of statistical significance.

The interaction between Sensory Modality and Base Duration was highly significant [$F(5,460) = 4,59$, $p < .001$]. Post hoc tests revealed that, for auditory intervals, discrimination performance as indicated by Weber fractions was not affected by base duration, whereas, for visual intervals, duration discrimination was reliably better with base durations longer than 800 ms than with the 400-ms base duration (see Figure 1). As can also seen from Figure 1, Weber fractions were significantly smaller for auditory than for visual intervals ranging from 400 to 800 ms. There was no indication for a statistically significant interaction of Type of Task and Base Duration [$F(5,460) = 1.59$, $p = .16$] and of all three factors combined [$F(5,460) = 0.85$, $p = .51$].

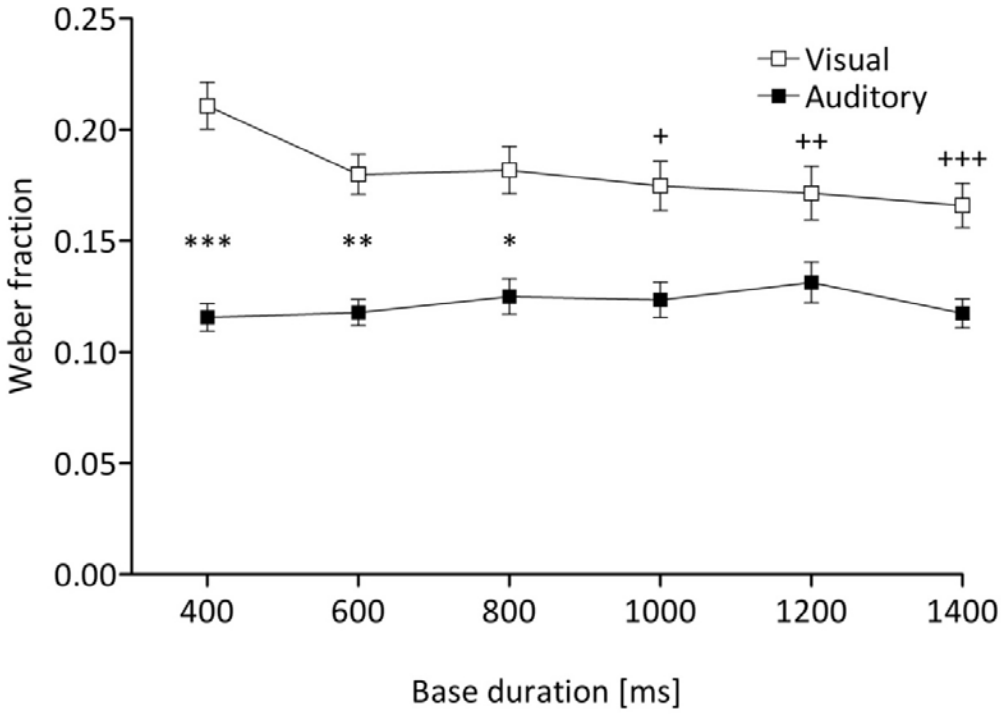

Figure 1. Relative temporal sensitivity, as indicated by Weber fractions, as a function of base duration and sensory modality.
Significantly different from the visually presented 400-ms base duration: $^{+}$: $p < .05$; $^{++}$: $p < .01$; $^{+++}$: $p < .001$.
Significantly different from the respective visually presented base duration: *: $p < .05$; **: $p < .01$; ***: $p < .001$.

Discussion

In a previous study, Lapid et al. (2008) showed that performance on auditory duration discrimination was much better when obtained by means of a reminder task than with a 2AFC task. The outcome of the present experiment confirms and extends these findings. Consistent with Lapid et al.'s (2008) data, temporal sensitivity was significantly higher when measured by the reminder task compared to the 2AFC task. In the present study, the average Weber

fraction obtained with the 2AFC task was 50% larger than the one obtained with the reminder task. This outcome definitively supports Ulrich's (2010) conclusion that the 2AFC task produces estimates of *DL* that are about 50% larger than those of the reminder task. In addition, this general effect of task was shown to hold for duration discrimination in both the auditory and visual sensory modalities. Eventually, since Lapid et al. (2008) only investigated temporal discrimination of intervals with a base duration of 500 ms, we speculated whether other base durations would produce a similar discrepancy. The present results unambiguously confirm that they indeed do.

Contrary to the common notion of superior sensitivity for temporal processing of auditory compared to visual intervals, the present findings clearly indicate that modality-specific effects appear to be differentially affected by base duration. While relative temporal sensitivity was shown to be independent of base duration for the discrimination of auditory intervals ranging from 400 to 1,400 ms, for visually presented intervals, temporal sensitivity was effectively modulated by the base duration of the intervals to be compared. More specifically, performance on visual duration discrimination was found to be reliably poorer for the 400-ms base duration than for base durations longer than 800 ms.

Although relative temporal sensitivity tended to be higher for the processing of temporal information in the auditory than in the visual domain, this modality-specific advantage was found to be limited to base durations not exceeding 800 ms. For longer base durations, temporal superiority of the auditory modality over the visual one decreased and no longer became statistically significant. The observed pattern of results could be accounted for by the assumption of a greater magnitude of constant sensory noise associated with temporal processing of visual compared to auditory stimuli.

Within the framework of duration discrimination, Weber's law states that the just noticeable difference in duration (i.e., *DL*) increases monotonically as a function of base duration. The generalized form of Weber's law (cf., Killeen & Weiss, 1987; Rammsayer & Grondin, 2000), however, assumes a constant sensory noise that interferes with the genuine timing process. This constant sensory noise represents a duration-dependent source of timing variability whose influence wears off with increasing base duration. At brief base durations, however, this noise component effectively boosts total timing variance and, thus, results in higher Weber fractions. While for temporal processing of auditory intervals, the effect of the noise component no longer is present at base durations longer than approximately 50 ms (Rammsayer, 2010), the present data suggest that, for temporal processing of visual intervals, this effect may still persist for base durations as long as 400 ms or even longer. This may be indicative of a more pronounced interfering effect of duration-dependent sensory noise on the timing of visual rather than auditory intervals.

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