

the same way as the gap transfer illusion and the illusory auditory completion. The present argument is not at all meant to disprove the conventional explanation of the continuity illusion, but to view the same phenomenon from an alternative angle. It is possible that more than one mechanism is involved in the above illusions. I thus showed the outline of our attempt to understand some auditory phenomena from a unified viewpoint.

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SHORT STORIES ABOUT AUDITORY TIME AND RHYTHM

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Abstract

The length of time intervals is fundamental for organizing auditory perception. The present text offers an overview of different experiments conducted in my lab on the sensitivity of humans for discriminating such intervals. Various ways for testing sensitivity to time and for keeping track of time are proposed. It will be shown to what extent the number of intervals presented determines the level of discrimination; whether Weber's law for time applies under both of the following conditions –single vs. multiple (rhythm) interval discrimination; how segmenting time improves performance; and how sensitive humans are to temporal variations in music and language.

Number of Intervals in a Sequence

There have been many proposals about the functional nature of the mechanism(s) involved in perception of time. One general proposal is that relative judgments about the duration of events are based on an interval-by-interval comparison strategy (Keele, Nicoletti, Ivry & Pokorny, 1989; Killeen & Weiss, 1987). This proposal is central to a conventional view of timing where timekeeping is reported to be based on an internal, single clock mechanism consisting of a pacemaker-counter device (Grondin, 2001). An alternative perspective on timing, known as the beat-based approach, is that people pick up the implied beat generated by a series of successive events when it is available (Large & Jones, 1999; McAuley & Jones, 2003). For tasks where intervals have to be compared to one or multiple presentations of a standard interval, both of these perspectives on timing suggest that duration discrimination should improve when multiple standards, instead of a single standard, are presented. From an interval-based perspective, explaining better discrimination with multiple (standard) interval presentations in the first sequences places the locus of threshold improvement in memory (multiple-look model: Drake & Botte, 1993).

In an experiment designed to test the effect of the number of intervals on duration discrimination, participants were presented with two sequences, each consisting of 1 or 4 intervals (marked by 2 or 5 signals), and asked to indicate whether the interval(s) of the second sequence was (were) shorter or longer than the interval(s) of the first (Grondin & McAuley, 2007). Figure 1 shows the effect of the sequence length in conditions where the standard (= 500 ms) is presented first (left panel) or second (right panel). The results generally reveal that more intervals in Sequence 1 increase sensitivity but not when the standard is presented second and Sequence 2 has only one interval. However, having four intervals instead of one in Sequence 2 leads to better performances (see also Miller & McAuley, 2005). Indeed, additional investigations by Grondin and McAuley with different sensory modality conditions have shown that increasing the number of comparison (variable) intervals is a determinant factor. In other words, sensitivity level is not simply linked to increasing the number of intervals in the first sequence in order to reduce memory variance. Finally, it should be noted that the order of the intervals (standard in Sequence 1 vs. 2) is also a critical factor.

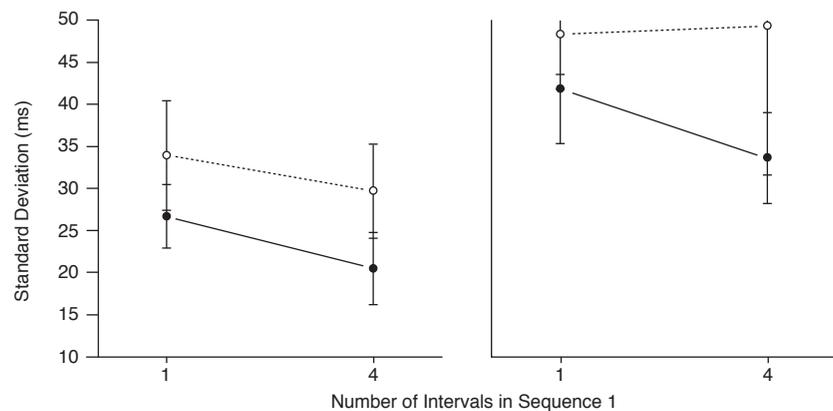


Figure 1. Standard deviation as a function of the number of intervals in Sequence 1 and in Sequence 2. Open circles: Sequence 2 = 1 interval; Filled circles: Sequence 2 = 4 intervals. Left panel: Standard – Comparison order; Right Panel: Comparison – Standard order. Bars represent standard error. (data from Grondin & McAuley, 2007)

In another experiment from the lab designed to test Weber's law, time intervals were presented in sequences marked by brief auditory signals (standard values = 1, 1.3, 1.6 and 1.9 s). Whether Weber's law holds for multiple as well as for single interval discrimination remains unclear (Drake & Botte, 1993; Friberg & Sundberg, 1995). Participants were asked to indicate whether, in a presentation of two series of 1, 3 or 5 intervals, with each series being marked by 2, 4, or 6 signals, the intervals of the second sequence were shorter or longer than those of the first. In addition to showing that discrimination was poorer when only one interval was presented, but remained about the same regardless of whether 3 or 5 intervals were presented, the results demonstrated that the Weber fraction (difference

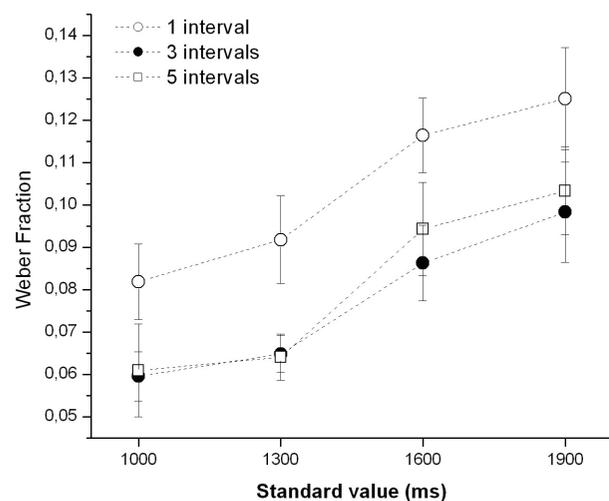


Figure 2. Weber fraction as a function of the standard value in a discrimination task involving single and multiple interval presentations (from Grondin, in preparation).

threshold/standard) is not constant: the fraction is significantly larger at 1.6 than at 1.3 s, and this effect does not interact with the number-of-interval variable. These results are argued to demonstrate that single and multiple interval discriminations are based on a similar mechanism.

Segmenting to Reduce Weber Fraction

The increase observed in the Weber fraction for time as duration gets longer is not surprising when one considers that there is a simple and infallible trick to prevent this increase: counting. Grondin, Meilleur-Wells and Lachance (1999) have reported that benefits can be anticipated for auditory interval discrimination when a counting strategy is adopted with intervals as brief as 1.2 s (see Figure 3).

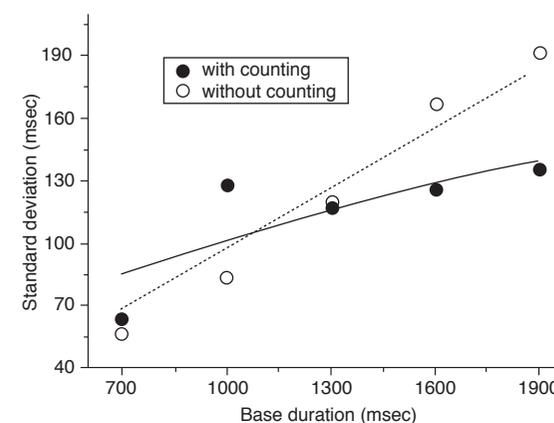


Figure 5. Standard deviation as a function of time. Each point is estimated on a basis of psychometric function in which points are the summation of all individual scores. The line through data points is obtained from Equation 7 with $A = C = 0$ (continuous line: with counting) and with $B = C = 0$ (dotted line: without counting)

Figure 3. Taken from Grondin et al., 1999 – Figure 5.

Indeed, counting means adopting a rhythmic activity. While different forms of segmentation strategy have been adopted for keeping track of time, Grondin and Killeen (2006, in preparation) have explored whether singing is as efficient as or even better than counting for keeping track of time. In one experiment, they asked participants to reproduce one of four standard (target) intervals: 6, 12, 18 and 24 s. In one trial, the target duration was presented and the participant was instructed to adopt a counting strategy or to sing a song (*Au clair de la lune*) in order to keep track of time. During the reproduction phase, the participant was told to produce an interval of the same duration by pressing the spacebar to initiate and terminate the reproduction, and to keep track of time with counts or with the song. The Weber fraction remained quite constant at roughly 9 to 10%, and was over 25% when no segmentation strategy was adopted (i.e. when participants were told not to count, tap or adopt any spontaneous way of dividing the interval) (see also Hinton & Rao, 2004).

Recently, skilled musicians were asked to complete this reproduction task (6 to 24 s intervals) with either a counting or a singing strategy. The preliminary data (based on five

participants) are presented in Figure 4. In the counting or singing conditions, the capacity of musicians to keep track of long intervals was much better than that of normal participants. The Weber fractions were roughly 5 to 7%.

Finally, while the deviation from target by musicians was close to 0 in the 6-s condition, the deviation, with either counting or singing, was about 150 to 200 ms below the target duration in the other target conditions.

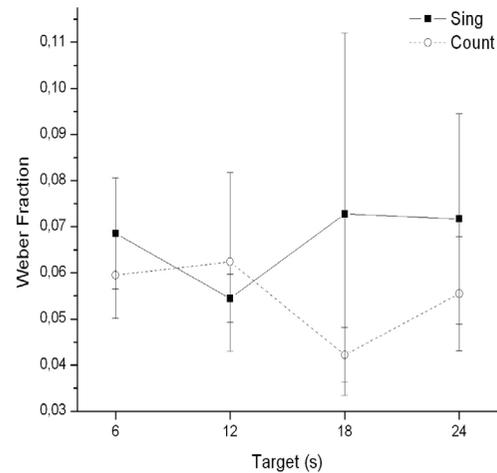


Figure 4. Mean Weber fraction in a long interval reproduction task by musicians who are counting or singing to keep track of time (Preliminary data).

Discriminating Intervals in “Natural” Conditions

Musicians' high levels of sensitivity to time were also reported in a lab experiment where a musical excerpt was manipulated (Grondin & Laforest, 2004). Participants had to judge slight tempo variations in the excerpt. The Weber fraction of musicians for this task was about 1%, even when gradual tempo changes were involved. Interestingly, non-musicians also exhibit great sensitivity to slight tempo changes in music. Indeed, more natural conditions (i.e. instead of a series of discrete tones) seem to favour higher sensitivity to temporal variations.

In order to investigate the possibility of having a particularly fine sensitivity to temporal variations with natural stimuli, an experiment was recently conducted in the lab where slight temporal variations were introduced in sentences. In this experiment, there were two types of tempo induced in the stimuli (sentences or sound sequences): 3-3-3-3 or 4-4-4. The sentences were delivered in French (the main language of participants), or in a foreign language (Slovenian), totally unfamiliar to the participants, by one male and one female speaker in each language.

The French sentences were:

1. Il avait demandé à sa sœur de l'aider. (3-3-3-3)
2. Les invités sont arrivés lundi matin. (4-4-4)

The Slovenian sentences were :

1. Pridite, popoldne, do nase, hisice (3-3-3-3)
2. Solnce sije, kladvo bije, zgodnje ure (4-4-4)

These neutral declarative sentences were recorded in the recording studios of Université Laval's faculty of music. All sentences were twelve syllables in length and contain

no major pauses or differences associated with the gender of the speaker. To compare tempo discrimination in language with non-language discrimination, a similar condition was presented using electronically produced auditory tones. Two series of 12 tones were presented, with the interonset intervals set at the mean of the intersyllable intervals in the recorded sentences. The intersegment intervals were also reflected to maintain 3-3-3-3 and 4-4-4 rhythmic sequences for each series respectively. There were two other “tone” conditions. In one, the twelve tones were equally spaced, and in the other one, twelve filled intervals were spaced by 11 brief silences.

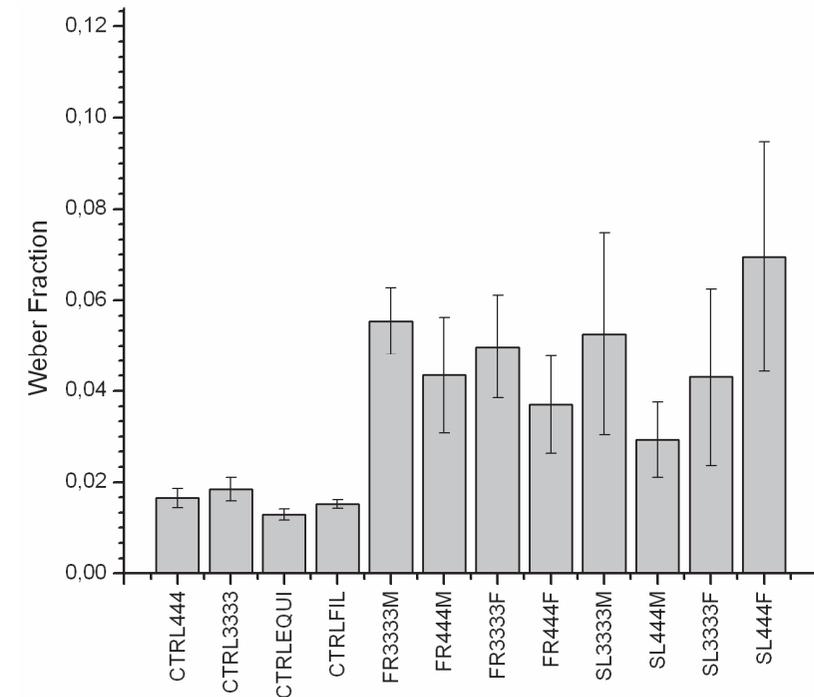


Figure 5. Mean Weber Fraction in a duration discrimination task involving simple sounds (CTRL), sounds of a familiar (French) language (FR) and sound from a foreign language (ET). H: Male voice; F: Female voice. Bars are SE. (Preliminary data from 10 participants).

The stimuli were presented to participants in a two alternative forced choice paradigm (2AFC). At each trial, the standard (St) is presented first, followed by one of the eight electronically accelerated or decelerated comparison stimuli (Co).

Figure 5 shows the Weber fraction in each condition. Surprisingly, discrimination was much better in the tone conditions. The differences between tone and language conditions are statistically significant. Within the tone conditions, having internal rhythms, either 3-3-3-3 or 4-4-4, did not lead to better discrimination than having 11 equal intervals. The preliminary results also tend to reveal a rhythm x language interaction, which would indicate that sensitivity to the temporal characteristics of a sentence varies according to a combination of the tempo adopted to deliver the sentence and a person's ability to understand the sentence.

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RHYTHMS EMERGE FROM THE PERCEPTUAL GROUPING OF ACOUSTIC COMPONENTS

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Abstract

To have a rhythm, one has to have a succession of distinct units. Usually we take the existence of auditory units for granted, because we have created them. We think of them as separated by silences, but there is hardly ever total silence in a complex auditory scene. However, the auditory system has mechanisms that find units within it. A unit not only contains acoustic energy that stretches over time but over the spectrum. Various acoustic factors favour the integration of energy into the same auditory unit. Once formed, these units have to be bound together sequentially to form an auditory stream. To a first approximation, a rhythm emerges within a stream. Although the ideal function of a stream is to represent a particular source of sound, in practice there is not always a one-to-one correspondence between streams and sources. Research and demonstrations will be presented to illustrate these ideas.

The relation between auditory scene analysis (ASA) and rhythm is not unique, but is an instance of a more general rule: "Every perceived quality of sound is affected by perceptual organization". Examples of perceived qualities are position in space, loudness, and pitch.

Perceived spatial position, loudness, and pitch

The spatial position of sounds can be affected by ASA. I will illustrate this by mentioning the unpublished research of two of my students, Yuko Tagami and Melissa Rapoport at McGill.

In both studies, the two ears of the listener received the identical sound (a pure tone binaurally matched in frequency, phase, and intensity). Normally this should be heard as a single centred sound. However, in both these experiments the sound at one ear was longer, starting before and ending after the sound in the other ear. During the period in which they coincided, they were identical in all respects. Nonetheless, due to the asynchrony of onset, they were often heard as two sounds, one at each side of the head (violating the common belief that a single frequency cannot be heard in two places at the same time). In Tagami's research, listeners described the number of sounds they heard and their positions by choosing among a set of visual icons representing alternative percepts. In Rapoport's study, they adjusted the interaural intensity of a binaural reference tone to match the position at which they had heard the shorter of the two tones. Both experiments showed that the faster the rise time of the shorter tone, the more segregated it was from the longer tone and the more it was lateralized to one side. The longer the temporal overlap of the two tones, the more they tended to fuse and be heard as a single centred tone.

Perceived loudness can also be affected by perceptual organization. Suppose a soft steady noise burst, A1, is on for a brief period, and then suddenly is replaced by a louder version of itself, A2, and then the soft sound, A1, returns (all without silences or breaks). In certain conditions, listeners will hear two sounds. One of them is the soft sound A1, which is heard as continuing unchanged during the louder period and continuing after the loud period ends. The loud period (A2) is heard as the occurrence of a second sound, B, superimposed on the unchanging A1. In other words the loud sound, A2, is perceptually interpreted as the sum