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Perception of acoustically presented time series with varied intervals

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ABSTRACT

Data from three experiments on serial perception of temporal intervals in the supra-second domain are reported. Sequences of short acoustic signals ("pips") separated by periods of silence were presented to the observers. Two types of time series, geometric or alternating, were used, where the modulus $1+\delta$ of the inter-pip series and the base duration T_b (range from 1.1 to 6 s) were varied as independent parameters. The observers had to judge whether the series were accelerating, decelerating, or uniform (3 paradigm), or to distinguish regular from irregular sequences (2 paradigm). "Intervals of subjective uniformity" (ISUS) were obtained by fitting Gaussian psychometric functions to individual subjects' responses. Progression towards longer base durations ($T_b = 4.4$ or 6 s) shifts the ISUS towards negative δs, i.e., accelerating series. This finding is compatible with the phenomenon of "subjective shortening" of past temporal intervals, which is naturally accounted for by the lossy integration model of internal time representation. The opposite effect observed for short durations ($T_b = 1.1$ or 1.5 s) remains unexplained by the lossy integration model, and presents a challenge for further research.

1. Introduction

Standard methods of experimental research in time perception usually operate on single time intervals (production, estimation), or pairs of successively presented time intervals (reproduction, discrimination), which are marked by sensorially perceivable events (e.g. acoustic or visual). However, in real-world settings we often perceive series of events forming a temporal pattern, e.g. musical rhythms, sound sequences produced by mechanical devices, and movement patterns in sports or physical exercises. Identification of a global temporal pattern must somehow rely upon elementary discrimination of its constituting intervals, but how these two levels of perception are related is still an open question.

The relevance of musical rhythms for understanding time perception was early recognized by the now "classic" authors in the field (Fraisse, 1958; Mach, 1922), and perception of musical rhythms has become a special topic of its own (Boltz, 1989; Handel, 1992; Hirsh, Monahan, Grant, & Singh, 1990; Povel, 1977, 1981). Musical rhythms are acoustic patterns consisting of integer multiples or simple fractions of a base duration, which is specified by the tempo and lies in the sub-second or circa-second domain. Musical rhythms are thus only very special instances of serial events. In other situations, intervals between single events may vary continuously—e.g. perception of "acceleration" of a bouncing ball losing its kinetic energy.

The study of serial events with longer base durations may provide further insights on specific characteristics of time perception in the supra-second region. Perception of durations longer than 2–3 s shows a remarkable "subjective shortening" (Wearden & Ferrara, 1993) of past intervals, which is revealed (i) by an asymmetry of the discrimination function in pairwise comparisons of time intervals (Hellström, 1977, 1985; Wackermann & Späti, 2006), and (ii) by progressive shortening of the response with longer standards in the reproduction task (Eisler & Eisler, 1992; Ulbrich, Churan, Fink, & Wittmann, 2007; Wackermann & Ehm, 2006; Wackermann, Späti, & Ehm, 2005). However, empirical evidence should be mentioned suggesting that the "subjective shortening" effect is variable and partly dependent on the range of presented durations (Lejeune & Wearden, 2009; Noulhiane, Pouthas, & Samson, 2009). In any case, we may expect the "subjective shortening" also to affect perception of series of events. In fact, such an effect was described succinctly by Ernst Mach in his *Analysis of Sensations* (1922, chap. XII, §9):

> "The phenomenon is perfectly analogous to that which we observe in the province of the space-sense […]. In walking forwards, we have a distinct sensation that we are moving away from a starting-point, but the physiological measure of this removal is not proportional to the geometrical. In the same manner, elapsed physiological time is subject to perspectival contraction, its single elements [i.e., events] becoming less and less distinguishable."

In other words, as multiple events ("elements" in Mach's parlance) recede to the past, the intervals separating the singular events seem subjectively to shrink, thus creating an impression of "perspectival contraction".

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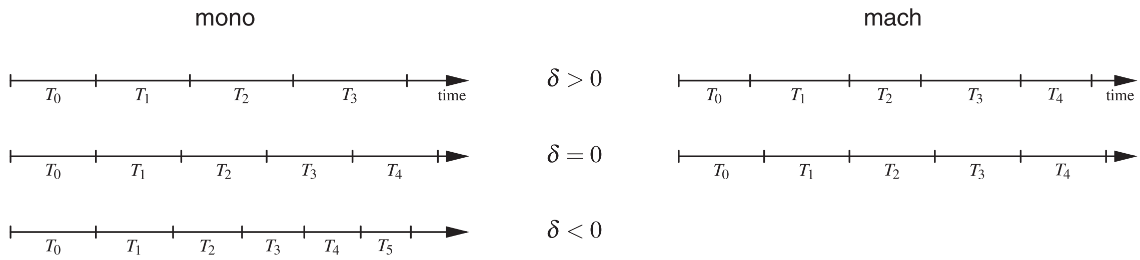

Fig. 1. Monotonic (left) and alternating (right) pips sequences for different values of δ.

These observations motivated our study of serial discrimination of acoustically presented intervals in the supra-second domain using two types of stimuli: (i) series of monotonically increasing or decreasing intervals, resulting in a global judgment of accelerating, decelerating, or uniform sequence, and (ii) series of alternating intervals, resulting in a global judgment of regular or irregular sequence.

2. Methods

2.1. Apparatus and stimuli

Series of acoustic events ("pips") were generated by a program running under BSD Unix on a portable iBook G4 (Apple Inc.) computer, using the system clock for the interval timing and the console beeper as a sound source. The acoustic signal from the computer was fed via an amplifier (Sony TA-FE310R) to a pair of headphones (Sennheiser HD 201). Pips of a nominal frequency of 2000 Hz and a duration of 20 ms were used in all reported experiments. The inter-onset intervals between subsequent pips were varied to form either geometric series (mode mono), or alternating series (mode mach[1]), using the formulae:

$$T_n = T_\mathrm{b}(1+\delta)^n \qquad \text{(mono)}$$
$$T_n = T_\mathrm{b}\left(1+(-1)^n\frac{\delta}{2}\right) \qquad \text{(mach)}$$

where $n = 0,1,2,\ldots$ is an ordinal index of the interval, T_b denotes the "base duration", and δ is a parameter modulating the series. In the mono mode, the base duration was identical to the first interval presented ($T_0 = T_\mathrm{b}$) while in the mach mode, the base duration was the mean value of subsequent, alternating durations (Fig. 1). T_b and δ were two control parameters determining the temporal structure of the stimulus which were varied according to experimental designs described below.

2.2. Participants

Participants were students from the University of Freiburg recruited by advertisement. All participants were reportedly of good health and with no known neurological or psychiatric problems. The participants signed an informed consent before the beginning of the session and received a moderate financial compensation when the session was completed. Twenty-four observers, 12 women and 12 men in the age range 21–33 years (mean age 25.8 years) participated in Experiment 1. Eighteen observers, 9 women and 9 men in the age range 21–29 years (mean age 24.4 years) participated in Experiment 2. Twelve observers, 6 women and 6 men in the age range 21–28 years (mean age 24.7 years) participated in Experiment 3.

[1] Mach (1865) was the first to use acoustic series with alternating intervals in a study of temporal discrimination.

2.3. Procedures

In each trial, the observer listened to the pips series played through the headphones. Duration of the pips series was limited to a maximum of 1 min. However, the observer could interrupt the stimulus presentation by pressing a button on a pointing device ("mouse") before the time limit was reached.[2] Thereafter a list of possible judgments was displayed on the monitor, from which the observer had to choose her/his response. In the mono mode (3), the three response categories were "accelerating", "uniform", and "decelerating". In the mach mode (2), the two response categories were "regular" and "irregular". In Experiments 1 and 3 only monotonically modulated series were used. In Experiment 2 both types of stimuli, mono and mach were used.

2.3.1. Experiment 1

($N = 24 = 2 \times 12$ subjects.) Three blocks, each consisting of twelve trials, were run with different base durations in a fully permuted order, using $T_\mathrm{b} = 1.5, 3, 6$ s for a sub-group of twelve subjects, and $T_\mathrm{b} = 1.1, 2.2, 4.4$ s for the other twelve subjects. Each block consisted of two parts. In part 1, δ varied from -0.05 to $+0.05$ in steps of 0.02, following a simple up/down or down/up staircase scheme with two repetitions for each δ value. A point of subjective uniformity (PSU) was roughly estimated from the data, and a new range of δs distributed symmetrically around the PSU with halved steps of 0.01 was used in part 2, following the same scheme. This two-phase procedure was designed to adapt the δ-sampling scheme to the subject's individual performance.

2.3.2. Experiment 2

($N = 18 = 2 \times 9$ subjects.) Each session consisted of two blocks, one block with monotonic series (mode mono) and the other block with alternating series (mode mono). Two base durations were used in each block, $T_\mathrm{b} = 2.2$ or 4.4 s with nine subjects, and $T_\mathrm{b} = 3$ or 6 s with the other nine subjects, in a permuted order. A mono block consisted of 26 trials, with δ that varied from -0.06 to $+0.06$ in steps of 0.01, and two repetitions for each δ value. A mach block consisted of 22 trials, with δ that varied from 0 to 0.25 in steps of 0.025 for base durations 2.2 s and 3 s, or a doubled range up to 0.5, and doubled steps of 0.05 for base durations 4.4 s and 6 s. These settings were based on a series of pilot experiments showing that the discrimination in the mach mode was definitely inferior to that in the mono mode. An interleaved up/down or down/up staircase scheme was used, in which the full δ-range was traversed four times with different starting points and interleave factor four. This resulted in a pseudo-random, from the participants' point of view unpredictable sequence.

[2] This allowed the observer to give her/his response as soon as s/he arrived at a firm judgment, thus speeding up the experiment and reducing the participants' boredom. Only in Experiment 3, where the number of presented intervals n_P was fixed for each trial (and varied across blocks of trials) the observer had to listen to the entire sequence, and the stopping option was disabled.