QUANTAL TIMING: AN INVESTIGATION OF GAMMA APPARENT MOTION

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Abstract

A study of Apparent Motion (AM) of Gamma type is presented which extends previous findings (Geissler, Schebera & Kompass 1999) showing that a temporal parameter (ISI), critical for the perceptual transition AM -> flicker, exhibits discrete timing. The major empirical results, a set of four significant ISI modal values, having integer size ratios 3 : 4 : 6 : 8, and a regularity in the spacing of a larger collection of ISI modal values, support the Taxonomic Model of Quantal Timing by Geissler (1985, 1992). In this model a theoretical upper limit of mental timing in the range R1, which involves the time quantum Q_0 = 4.5 ms directly, is predicted at 145 ms. Critical ISI above this value require a transition to representations based on quantal units which are multiples of Q_0. The spacing of ISI modes in Gamma AM suggests a permanent transition to the quantum 9 ms. Assigning the same preferences of occurrence to multiples of this value as to multiples of Q_0 in Beta AM (Geissler et al. 1999) disagrees to the empirical observations, however. This raises the question how representations in the neighboring temporal ranges R1, based on Q_0, and R2, based on $2*Q_0$, interact.

In the present paper an experiment on Gamma Apparent Motion (AM) is reported which is a logical continuation of a previous study in long-range AM of beta type (Geissler, Schebera & Kompass 1999). This earlier study revealed a discrete structure in perceptually critical temporal stimulus parameters. More specifically a set of preferred ISIs at 4.5, 9.5, 18, 22, 27, 37, 44, 54, 107 and 145 msec, critical for the transition from AM to perceived flicker, was found which has large overlap with the set of periods extracted from v. Békésy's (1936) data on the absolute threshold of the perception of very low sounds. Every member of the set exhibits nearly integer ratios to at least three others. Taken together with a number of other psychophysical results (Latour, 1967; Kristofferson, 1967, 1980, 1990; Treisman et al., 1990; Dehaene, 1993; Elliott & Müller, 1998; Petzold & Edeler, 1999) there is now a large body of evidence available indicating the action of universal laws of temporal organization of mental processes across different tasks and sensory modalities, which include a substantial amount of discretization.

The existence of such laws has long been hypothesized, first, to our knowledge by Fechner (1860) and the French psychologist Lalanne (1876), who noticed the equality of stimulus fusion frequencies in the auditory, visual and tactile senses. Since then, investigation of such laws has been attractive to many scientists because their understanding may become a powerful tool for the analysis of mental processes in general. Different models were proposed to account for laws of discrete mental timing, many of which rely on synchronization of mental oscillations with a central clock (e.g. Stroud, 1955; Treisman, 1963; Treisman et al.

1990) or on coupling of different such oscillations via nonlinear interactions (Wiener 1968). Apart from the fact that such a clock has not been identified so far there is also psychological evidence against it (Allport 1968).

As an alternative, Geissler (1985, 1992; Geissler et al. 1999) formulated a taxonomic model of quantal timing (TQM) which is based on the entrainment of temporal intervals. The inspection of v. Békésy's data (of one subject), lead to the observation that all distinct times are multiples of a small value of about 4.6 ms. This value, slightly corrected to 4.5 - 4.6 ms, is postulated to represent an absolute quantum Q_0. Multiples of it, called operative quanta, can be concatenated to form mental representations of intervals. Beside suggesting a much smaller elementary period (which corresponds to 220 Hz in the frequency domain), TQM differs from early models of a central clock (Stroud 1955) by a limitation of entrainment which is thought to result from increasing loss of phase precision (Fig. 1a).
The assumption of limited coherence is derived from the principle that mental timing has to obey some sort of Weber Law. TQM consequently leads to an overlay between quantal and Weber Law - like precision of mental representation caused by the necessity to increase the operative quantum Q when the interval M * Q is exceeded. The famous result of Kristofferson (1980) who investigated discrimination of short intervals after prolonged training (Fig. 1b) shows that such an overlay actually exists. Mainly from Teghtsoonian's (1971) finding that on a subjective scale the Weber fraction, often called Ekman's Constant, is about 1/30 the estimate $M \approx 30$ for the concatenation of operative quanta was derived.
A third basic assumption of TQM is the formation of hierarchies of entrained intervals (Fig. 1c). It can lead to preferences of multiples of the quantum, composed of simple primes like 24, which are inherent in the empirical data on discrete timing (Geissler 1992, Kompass 1999). As a first approach in this direction the system of preferences of multiples given in Fig. 1d was derived simply by counting all hierarchies $\leq$ M containing a given multiple.

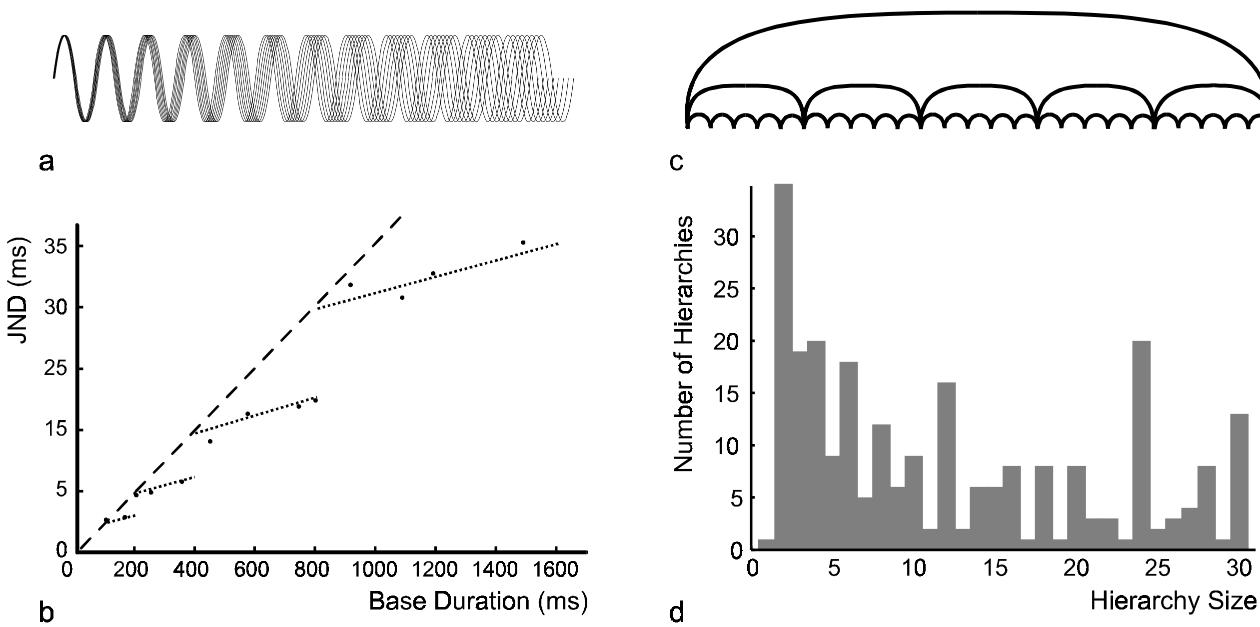

Figure 1. a. Illustration of limited coherence. **b.** Step function of discriminability of short intervals by Kristofferson (1984). **c.** Illustration of hierarchies of concatenated intervals. **d.** Preferences of multiples of Q_0.

TQM imposes restrictions upon the sets of discrete intervals, which can alternatively be observed in a mental task. Provided experimental paradigms are found which allow for the observation of many closely related discrete temporal values the hypotheses of TQM can be tested. The experiment on Long Range Beta AM (Geissler et al. 1999) is important in this respect since it is the first that, based on significance tests, lead to the extraction of a large set of such values. The basic TQM predictions were met by the Beta AM data. Discrete critical ISI (cISI) are very close to the multiples (1, 2, 4, 5, 6, 8, 10, 12, 24 and 32) of a period of 4.49 ms. An independent derivation of Q_0 based on measures of local variation of ISI yielded the estimate 4.56 ms (Kompass 1999), again in favor of the quantization hypothesis. The set of all cISI spans the interval $[0, 32 * Q_0]$ which is in support of the hypothesis of limited coherence with $M = 32$.

The reported experiment on Gamma AM was performed to test whether discrete timing is observable also in other illusions of motion. A second goal of the study was the investigation of range formation. The concept of ranges, resulting both from quantization and limited coherence, is a basic issue within TQM, which is not yet completely understood. Representation of intervals larger than $M * Q_0$ requires transition to other operative quanta, thus a series of ranges $R1 = \{i * Q_0 \mid i \le M\}$, $R2 = \{i * (2*Q_0) \mid i \le M\}$, ... emerges. The overlap of successive ranges leads to ambiguities of representation of intervals contained in their intersection. In duration discrimination tasks like the one performed by Kristofferson (1980) in order to achieve maximal precision the principle that the smallest possible range is used for representation should hold. But this principle need not rule timing in other mental tasks, e.g. the representation of a dynamic percept like AM. An attractive alternative is the stability of a range throughout all variations of a cognitive demand. Generally, it is not clear how much beyond their granularity representations in alternative ranges should differ at all.

For the follow-up study of discrete timing gamma AM was chosen for two main reasons, first, because its similarity to the Beta type of motion seemed promising to also gain a rich set of discrete mental intervals and, second, because from experiments by Holt-Hansen (1973, 1974) it was known that critical temporal parameters span ranges larger than R1.

Method

Forty six subjects, the same as with Beta AM, underwent two sessions of about 40 minutes duration comprising of 2×12 trials of determination of perceptually critical ISI in a method of limits. The sequence of stimuli used to invoke perception of AM and flicker is presented in Fig. 2a. A vertical bar having a constant angular size (AS) of 3° in the first and of 6° in the second session alternated with a small square, which served as a fixation point. Exposure duration (ED) of the bar was constant during the trials. Each of 12 different values (3, 20, 40, ..., 180, 200, 250 ms) was used once in the first half of a session. After a short break all trials were repeated in the same order. Within a trial slow reduction of the ISI, so called in analogy to the experiment on Beta AM, led to perception of contraction and extension of the bar, first with a period of rest in between, which then vanished to give way to smooth Gamma Motion, until this percept switched to flicker, often perceived as forth and back movement of the bar in depth. Flicker had to be reported verbally, the operator then registered the cISI and finished presentation.

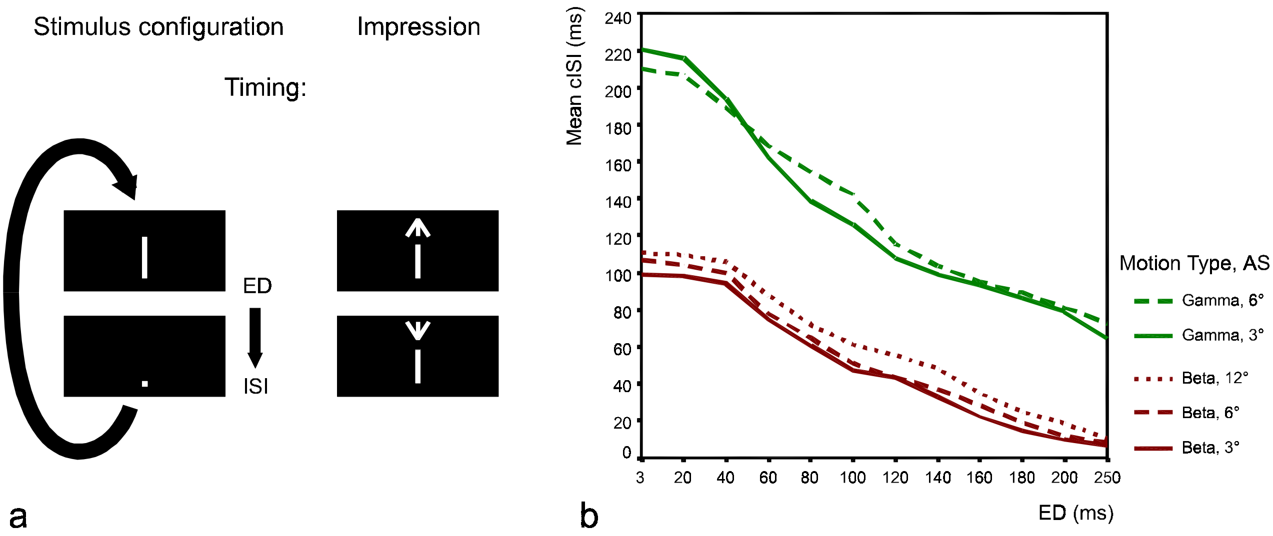

Figure 2. a. Stimulus sequence used in the experiment. **b.** Mean cISI as function of ED and angular size of the bar.

Results and Discussion

Similarly to Beta AM increase of ED led to smaller values of ISI, critical for transition to flicker. The mean cISI for each ED and AS of the bar are presented in Fig. 2b, together with corresponding results of the Beta AM study. In both experiments the relation of ED and cISI is roughly linear. Its slope is about the same while the intercept in Gamma AM is about twice that of Beta AM.

Occurrence of discrete timing could be statistically proved with a straightforward as well as with a more complicated approach. Analyses were based on the distribution of all cISI which is shown in Fig. 3a (kernel density estimate with normal kernel, $\sigma = 2$ ms). All cISI values are contained in the Range R2, about 57 % of them also in R1.

In a first step of analysis modal values were identified using a method called SiZer (Chaudhuri & Marron 1998), which statistically evaluates local increases and decreases of density at different resolutions. The results are plotted in Fig. 3b. Statistically significant local maxima of density are 77, 103 and 154 ms. Restriction of simultaneous testing to cISI contained in R2 only revealed an additional mode at about 210 ms. All these numbers show the simple integer size relations 3: 4: 6: 8 which is a clear indication that they result from laws of discrete mental timing. The most prominent mode at 103.5 ms deviates less than 5 % from its counterpart in Beta AM (108 ms) and is therefore considered to have the same basis in the mental representation $24 * Q_0 = 12 * (2*Q_0)$. The alternative $23 * Q_0$ would not only violate the above size relation, it also would contradict to the empirical observation (Geissler 1992, Kompass 1999) that simple multiples of the quantum are preferred.

In a second step an attempt was made to assess quantal properties of all cISI modes, including those which are not significant, taken as single values. For this purpose distances of these modes to the most prominent one were computed modulo the assumed operative quantum $2*Q_0 = 9$ ms. The set of modes, selected by the criterion to have a second derivative of the density estimate in figure 5 below -0.5, being {59.2, 66.9, 76.7, 85.6, 93.1, 122.0, 134.5, 144.1, 153.7, 175.2, 184.7, 191.1, 199.8, 210.4 and 221.0 ms, yielded the distances {0.8, -0.6, 0.2, 0.1, -1.4, 0.5, 4.0, -4.4, -3.8, -0.3, 0.2, -2.4, -2.7, -1.1 and 0.5} whose absolute values have the average 1.5 ms which is significantly (z-value 2.2 , $p \approx 0.015$) below 9 ms / 4 = 2.25 ms which is expected in the case of randomness of the modes. The other modes thus contribute to the argument that a period of 9 ms is involved in the perceptual timing. The presence of this period even in the spacing of modes contained in R1 (see fig. 3a) supports the hypothesis that formation of R2 and its usage for mental representations is relatively stable across changing temporal stimulus conditions.

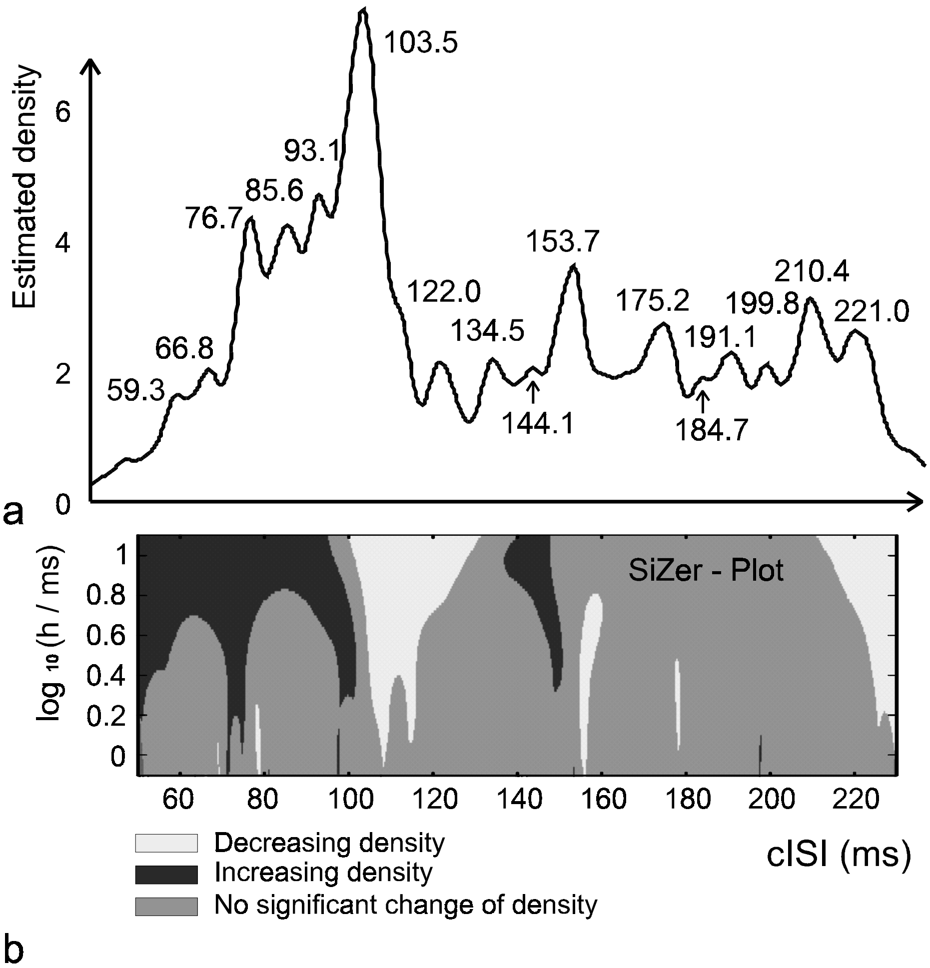

Figure 3. a. Kernel density estimate of all cISI and modal values. **b.** Result of an analysis with SiZer.

A simple transformation of hierarchies in R1 to R2 by doubling all periods should result in the same preferences, now of multiples of 9 ms. However, the empirical data do not support this idea. The preferences derived from cISI densities in Gamma and Beta AM exhibit gross differences. Only the latter are similar to the predictions in Fig. 1d.

To resume, there is strong evidence for discrete timing mechanisms acting in the perception of gamma AM and support for the TQM in general. A theoretical system of preferences within TQM should consider interactions of hierarchies of discrete timing contained in different ranges. Further theorizing and more experimentation are needed to capture this aspect of discrete timing.

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