SCALAR TIMING (EXPECTANCY) THEORY: A COMPARISON BETWEEN PROSPECTIVE AND RETROSPECTIVE DURATION

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Abstract

One hundred and twenty human subjects participated in both a prospective and a retrospective duration reproduction experiment. A scaling approach to the collected data can be found in A. D. Eisler, Eisler, and Montgomery (2004). In the present part of the comprehensive project the data were treated according to the requirements of Scalar Timing (Expectancy) Theory (SET). For both the prospective and the retrospective data sets the distribution of the ratio reproduction/standard durations proved skewed to the right, and the coefficient of variation decreased with the durations rather than being constant. Both findings are at variance with SET, which assumes the validity of Weber's law and agreement between subjective and chronometric time. However, the outcome could be predicted from the generalized Weber law (common for many continua, see H. Eisler, 1965) and a nonlinear psychophysical function for duration. The symmetric distributions obtained from animals are explained by stimulus error. From the point of view of SET, as opposed to the scaling approach, except for greater scatter, the retrospective durations did not differ from the prospective in any essential way.

Key words: Chronometric time; duration; neural loops; psychophysics; scaling; subjective time; Weber law

Scalar Timing (Expectancy) Theory (SET) is a quantitative model that describes the behavior of organisms in temporal tasks (e.g., Church & Gibbon, 1982; Gallistel & Gibbon, 2000; Machado & Arantes, 2006). The oldest reference to scalar timing seems to be Gibbon (1971), which deals with operant conditioning. The model was originally developed for animal subjects. More recently, its applicability has been investigated for human subjects, too. An excellent and comprehensive survey of both the theoretical development of the model and pertinent experiments is given by Allan (1998). In principle, the model consists of three components: (1) an "internal clock," that is, a timer or pacemaker-accumulator, (2) a memory, or memories, and (3) decision processes, e.g., a comparator. The output from the pacemaker is assumed to be Poisson-distributed pulses ("ticks"). They are collected in the accumulator resulting in a count proportional to chronometric time. Furthermore, SET builds on Weber's law for duration. Accordingly, central values of responses should be proportional to presented standards (target durations) in, e.g., identification tasks, as the peak procedure, and the distributions of temporal responses should be (almost) symmetrical and congruent when normalized by the different standard durations. The coefficient of variation, s/m, should be constant, that is, the same for all standard durations.

Retrospective and Prospective Subjective Durations

Time perception studies distinguish between two paradigms. In a prospective paradigm, the researcher informs the subject beforehand that s/he will be required to make duration judgments. In a retrospective paradigm, on the other hand, the subject is unaware of the fact that s/he will be required to make duration judgments. Only after the presentation of a duration will the experimenter ask the subject to judge it. For example, the subject can be asked unexpectedly to reproduce a presented duration or to estimate it verbally. It follows that a retrospective duration judgment can be obtained only once from a given subject because s/he is then alerted to the task being actually concerned with *time* perception.

A Time Perception Study on Retrospective Duration Reproduction

A comprehensive comparative study of retrospective and prospective subjective duration, using psychophysical scaling approaches (duration reproduction and verbal estimation, among others), has been carried out. A detailed description of experimental methods, data analyses, and results can be found in A. D. Eisler, Eisler, and Montgomery (2004). In that study data were treated according to the ***Parallel-Clock model***, developed by H. Eisler (1975).

It was found that subjective duration in the second range, not only prospective, but also retrospective, can be described by the psychophysical power function $\Psi = \kappa(\Phi - \Phi_0)^{\beta}$, where Ψ denotes subjective and Φ physical (clock) duration. The difference between prospective and retrospective subjective duration could be attributed to different values of the subjective zero Φ_0, with unchanged values of the exponent β and the proportionality constant κ. The detailed description of theory and results can be found in A. D. Eisler et al. (2004).

Our intention in the present paper is to explore *retrospective* duration reproductions in the vein of the *Scalar Timing Model*. The two models are not entirely incompatible; two of the components, namely the internal clock and a decision-making device, are more or less the same in terms of their function. However, the Parallel-Clock Model disposes of any memory for the duration reproduction task. The aim of this paper is to investigate the extent to which our duration reproductions agree with SET, and whether prospective and retrospective durations differ in that respect. Of particular importance in this study is that, to our knowledge, no studies have previously examined retrospective duration data in accordance with SET. Before proceeding to the method section, a number of differences should be noted between the present experiment and common SET experiments. First, both human and animal experiments pertinent for SET require some kind of a learning phase with repetitions, whereas both retrospective reproductions and the prospective reproduction used in this study are single responses. Second, SET is based to a large extent on the investigation of scatter. However, such investigations are most informative if the scatter is obtained from the same organism, that is, *intra*individual. *Inter*individual scatter, which is all that is obtainable from our data, may be "diluted" in the sense that human subjects' parameter values always show a large range; even in animals there are noticeable individual differences (A. D. Eisler, 2003; A. D. Eisler & Eisler, 1994; A. D. Eisler, et al., 2004; H. Eisler, 1984a,b, 1989, 2003; H. Eisler & Eisler, 1991; Zeiler & Hoyert, 1989). Thus, our scatter necessarily includes individual differences.

Method

For experimental details (of the comprehensive project) see A. D. Eisler et al. (2004). For the present part of the study see the following description.

Apparatus. The experiment was conducted on a Swedish microcomputer (ABC80) equipped with a loudspeaker, which presented the standard durations and registered the reproduced durations, both indicated by noise.

Subjects. One hundred and twenty subjects (96 female and 24 male; mean age 28.5 years) participated individually in the experiment; most of them were students. All the subjects reported normal hearing. None of the subjects had previously participated in perception experiments. Their task was to reproduce the standard duration.

Stimuli. The sound-pressure level of the noise that indicated the durations, both standards and reproductions, was 50 dB. There were ten different standard durations, ranging from 1.3 to 20 s in logarithmic steps (1.3, 1.8, 2.5, 3.3, 4.5, 6.0, 8.1, 11.0, 14.8, 20.0 s).

Procedure. At the start of the experiment each subject was told that s/he would be participating in a sound perception experiment in which s/he would hear a sound and then would be asked to rate its degree of pleasantness/unpleasantness. Then the standard duration (one of the ten), indicated by noise, was presented. After its offset the subject was told that the same sound would resume and that s/he should terminate it by pressing a button when s/he experiences that this second noise had lasted as long as the first (retrospective paradigm).

Before the start of the prospective task the subject was told that s/he is participating in a time perception experiment and would hear a sound again (it was the same standard duration as for the retrospective reproduction) and should again reproduce its duration (prospective paradigm). Thus, each of the 120 subjects reproduced one of the ten standard durations, once retrospectively and once prospectively, so that twelve prospective and twelve retrospective reproductions of each of the ten standard durations were obtained. (As mentioned earlier, in a retrospective design a subject can make only one judgment, since s/he then knows that the experiment concerns time.) It should be mentioned that the comprehensive experiment included judgments of the pleasantness of the sound and of the speed of time as well as a verbal estimation of the duration. For two-thirds of the subjects, one or two of these judgments intervened between their retrospective reproduction and the prospective reproduction task. No significant difference between these three groups was found (A. D. Eisler et al., 2004), indicating that the prospective reproductions were not affected by the experimental tasks preceding them. Furthermore, no systematic deviation could be observed between the present prospective reproductions and corresponding ones from previous experiments which had used a prospective paradigm only (e.g., A. D. Eisler, 1992; A. D. Eisler & Eisler, 1994; H. Eisler & Eisler, 1992).

Results

Figure 1, upper panels, shows histograms of the ratio reproduction/standard duration for the prospective and retrospective data. Both distributions are clearly skewed to the right, in accordance with Wearden's (1999) statement regarding human subjects. Table 1 shows the skewness values (also with the two outliers in the prospective data omitted); their significance is beyond all our tables of the normal distribution. The mode does not agree with the standard in either plot; it is at a lower value than that of the standard for both the prospective and the retrospective data. This is opposed to SET, though to be expected, because reproductions typically differ systematically from the standards (e.g., H. Eisler, 1975). As an alternative denominator of the ratio Wearden (1999) suggested the contents of long-term memory. Since duration reproduction, according to the Parallel-Clock Model (A. D. Eisler & Eisler, 1994, 2001; A. D. Eisler et al., 2004; H. Eisler, 1975, 2003), disposes of any memory, we used instead the mean of each of the ten sets of the 12 reproductions as the denominator; the corresponding histograms are shown in the bottom panels. The skewness is somewhat less, but remains.

Table 1

Skewness of Normalized Reproductions

	Repr. /standard duration	Reproduction/mean
Prospective	4.01	2.60
Prospective without outliers	1.83	1.18
Retrospective	1.16	0.91

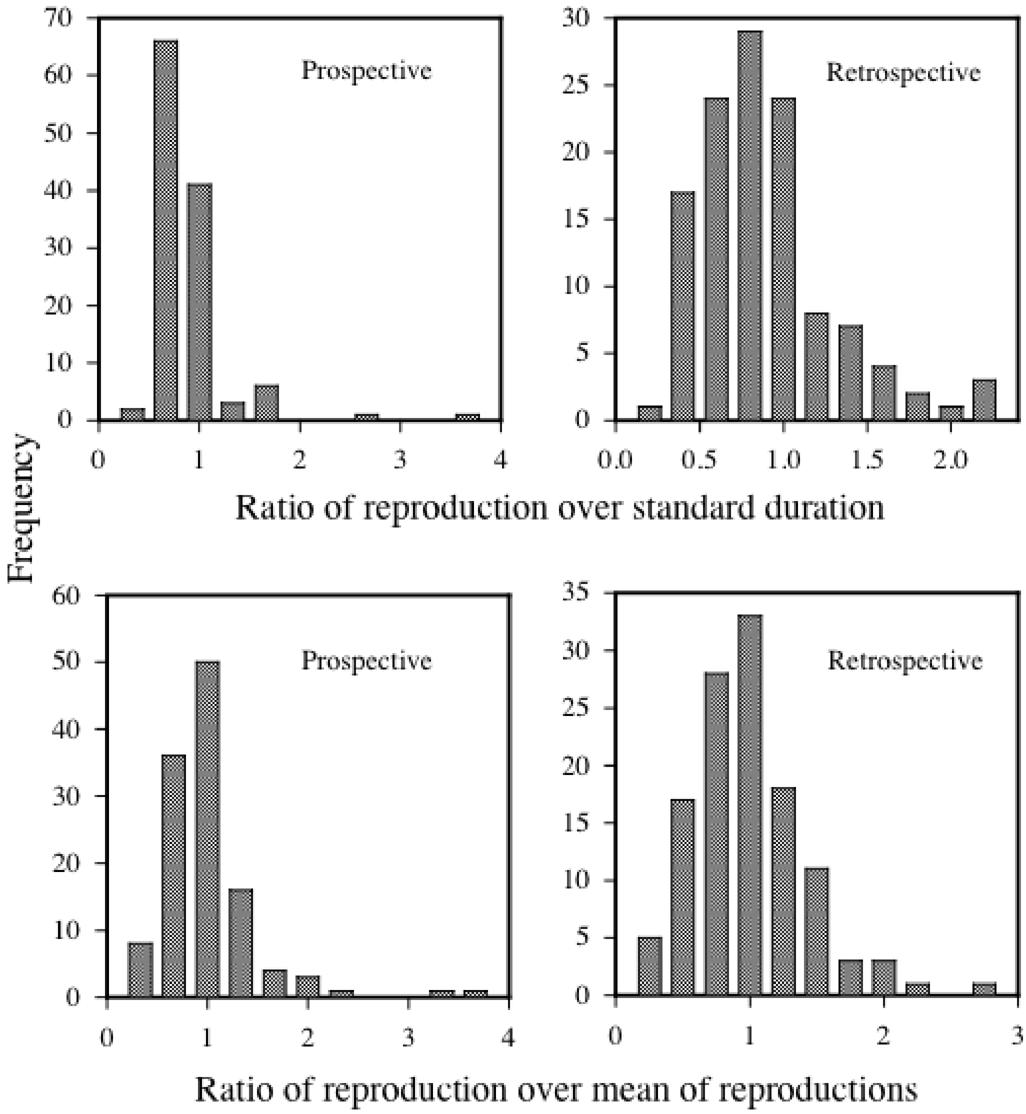

Figure 1. Histograms for prospective and retrospective duration reproductions. Top panel: Frequency against the ratio of reproduction over standard duration; Bottom panel: Frequency against the ratio of reproduction over the reproduction means.

Table 2
Sum of Squared Residuals for Fitted Coefficient of Variation (N=240)

		Fitted Function	
		y = a+b/x	y =c
Independent Variable	Standard durations	.50	.68
	Mean of reproductions	.54	.67

Figure 2 shows the coefficients of variation (based on the interindividual standard deviations) plotted against the standard durations (upper panel) and against the mean reproductions (lower panel). SET requires constancy, which may be found for the longer standards but not for the whole range. To illustrate a well-known trend (see below), we fitted a hyperbola of the form $y = a + b/x$ for both prospective and retrospective data together. Such a hyperbola is dealt with theoretically by Killeen and Weiss (1987), who also found empirical support from a number of time perception studies. However, the hyperbolical trend of coefficients of

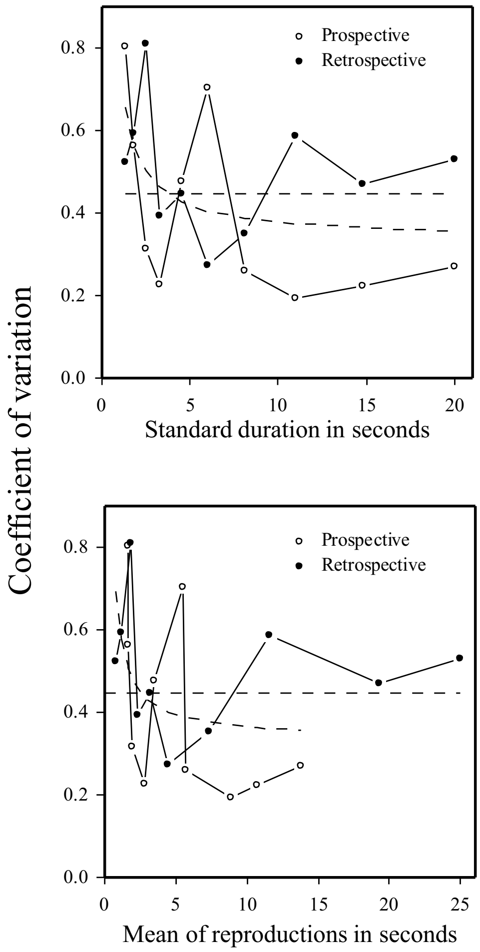

Figure 2. Coefficients of variation for prospective and retrospective reproductions plotted against the standard duration (top panel) and against the mean reproductions (bottom panel). The curved broken lines are hyperbolas fitted simultaneously to both sets of data points, the horizontal broken lines are at the mean of all points.

variation in data collected by psychophysical methods is by no means limited to time perception. Coefficients of variation from 16 experiments (H. Eisler, 1965) for different continua (none of them duration) show exactly the same trend. These experiments also illustrate the differences between intra- and interindividual and "mixed" SDs, and thus between coefficients of variation. We recognize there the "time perception" hyperbola, as well as the point of maximum sensitivity discussed by Grondin (2001). This finding is a reminder that time perception shares quite a few psychophysical features with other perceptual continua. In order to compare the constant coefficient of variation required by SET with the hyperbola we computed the sum of the squared residuals after fitting the two models, see Table 2.The fit is clearly better for the hyperbola, which, on the other hand, requires two parameter values, versus only one for a constant coefficient of variation. In Figure 2 both models are indicated by broken lines. The great scatter makes any clear decision difficult.

Discussion

The hyperbolic function for the coefficient of variation plots is easily described by the well-known generalized form of Weber's law, replacing $\sigma = k\ \mu$ by adding a constant γ: $\sigma = k\ \mu + \gamma$, that is, $\sigma/\mu = \gamma/\mu + k$ (cf. Killeen and Weiss, 1987). Another, similar, point is SET's postulation of proportionality—or even veridicality—of subjective and chronometric time. The neurophysiological model presented below will explain the psychophysical function for time, and also question the common claim that pulses emitted by a pacemaker are Poisson distributed. Consider pacemakers consisting of neural loops (Thatcher & John, 1977). The pacemaker emits one tick or pulse after each passage through the loop, and each subsequent passage of the loop requires more (clock) time than the previous one, perhaps because of a lengthened refractory period. From the retarding rate of "ticks" an exponent for subjective duration < 1 can be derived (A. D. Eisler & Eisler, 1994; H. Eisler, 1996; H. Eisler & Eisler, 1991). Empirically, the exponent is about .9 for adults, much smaller for children, and about .5 for rats (H. Eisler, 1976, 1984a, b). A consequence from the neural-loops model is that, because of the increasing refractory periods, the pulses are not independent, and thus incompatible with a Poisson distribution. We may conclude that the SET model's requirement of a constant average rate for the pacemaker's ticks has to be abandoned. The psychophysical function for duration is not linear. Therefore, the distributions are skewed and the means deviate from the standards (Figure 1). Wearden (1999) attributes the difference in skewness in the animal and human distributions to different decision rules. We are rather inclined to interpret the skewness difference to a criterion change. Due to the verbal instructions and no feedback, the human data express sensed duration as is, and thus they are based on the nonlinear psychophysical function for duration. In contrast, animals are taught to commit the stimulus error (cp. H. Eisler, 1996, p. 69), that is, react to veridical (chronometric) duration values, by being reinforced at standard durations. The feedback teaches animals "to correct" their immediate memory (or corresponding mechanisms) to achieve veridicality—change of decision criterion. Thus the procedure of feedback necessarily results in a linear duration function, entailing symmetric and congruent normalized distributions. One could say that feedback generates a bias towards veridicality. In sum, not all that surprisingly, the retrospective data show more scatter than the prospective, though the latter do contain two clear outliers. Both data sets are skewed to the right, at variance with SET. A second observation is that the coefficients of variation seem to display a hyperbolic trend like other continua, rather than the constancy required by SET. The generalized form of Weber's law and a non-proportional subjective duration function can explain these findings. Furthermore, in regard to SET, as opposed to the scaling approach, and on the basis of interindividual scatter, there is no fundamental difference between prospective and retrospective duration perception.

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