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ANALYZING INDIVIDUAL DIFFERENCES IN REACTION TIME

Claude Bonnet* & Stephen W. Link*

* Laboratoire de Psychophysique Sensorielle, EP618 du CNRS, 12 rue Goethe, Strasbourg, France
* Department of Psychology, McMaster University, Hamilton, Ontario, L8S 4K1

Abstract

We introduce a new method for the analysis of reaction time (RT) data. The theory of reaction time, based on the Wave Theory of stimulus difference and similarity, assumes that performance is nearly perfect, if not entirely errorless. Relations between mean RTs are derived. The focus of this new method is the variability in RT measures as a function of practice and stimulus intensity. Data from a Choice RT experiment using five levels of stimulus contrast and 30 sessions illustrate the accuracy of theoretical predictions.

Variability is a challenging feature of psychophysical experiments. Variabilities are often considered a nuisance or unnecessary or uninformative "noise." The aim of the present paper is to suggest ways of taking these variabilities into account in the interpretation of psychophysical experiments. Two related aspects will be considered: global inter-individual variabilities and intra-individual variabilities. The latter are mostly related to practice, i.e. to the replication of experimental sessions. This question will be studied within the framework of Choice Reaction Time (CRT) experiments using the location and intensity of the stimulus as independent experimenter-controlled variables.

Every sensory modality provides ample evidence of a relationship between Simple Reaction Time and the intensity of the reaction stimulus. This relation, first established by Cattell (1902), attracted the attention of Piéron (1914, 1952) and Baird (1977). Piéron discovered a relation between RT and intensity (1) that satisfactorily fit the data. It will therefore be called the Piéron function:

$$RT = \beta I^{-\alpha} + t_0$$

where RT is the reaction time, \(t_0\) an asymptotic reaction time reached at high intensities, \(I\) the stimulus intensity, and \(\alpha\) and \(\beta\) are two parameters.

Extensive applications of the Piéron function revealed that parameters \(\alpha\) and \(t_0\) are metric characteristics of each modality. Recently Pins (1996) and Pins & Bonnet (1996)
demonstrated that the Piéron function also holds for CRT. When well trained subjects are used, the exponent \( \alpha \) remains unchanged between SRT and CRT although the asymptote \( t_b \) appears to increase with increasing difficulty of discrimination.

**Wave Theory and Reaction Times**

Our model is an application of the Wave Theory (Link, 1992) for reaction time experiments in which the major independent variable is stimulus intensity. The intensities are all supra-threshold so that the probability of detection is high if not equal to one. The main features of the model are summarized below and presented in more detail in the companion paper by Link and Bonnet (1998).

1) When a stimulus is presented neural signals generated by the stimulus vary from moment to moment. They appear within the background activity of the sensory system. Signal and Noise are assumed to be extracted from Poisson distributions. It is then assumed that the system accumulates, from moment to moment, the difference between the stimulus signals and the noise signals. That accumulation follows a *random walk process*. The higher the intensity of the stimulus, the faster the average rate of accumulation. That rate is a sensory parameter, as we shall see later. Its relation to the physical intensity of the stimulus will be discussed. Hanes & Schall (1996) show this model to be plausible at the neuronal level.

2) We assume that the response of the subject is initiated when a critical level of accumulation is reached. That level, called the resistance to respond, is a ‘response threshold’ under the subject’s control. It is presumed to be constant for a given subject within a given situation. The time taken to reach the response threshold, to overcome the resistance to respond, is the decision time. It follows that for a constant stimulus intensity, the greater the resistance to respond the longer the decision time.

3) On any given trial, the observed \( RT \) measures the time that the random accumulation process needs to reach the response criterion, the Decision Time \( (DT) \), plus non-decision components of the stimulus-response pathway, \( MT \). \( RT \) is the sum \( DT + MT \).

\( RT \) is determined by \( MT \) and at least two independent parameters: the rate of accumulation which depends on stimulus intensity, and the response threshold which depends on the subject’s readiness to respond. The explicit relation is

\[
RT = \frac{AI}{\mu} (2P_A - 1)c\Delta t + MT
\]  

(2)

where \( \mu \) increases with stimulus intensity, \( AI \) is the resistance to respond, \( MT \) is the non-decision process component of response time, and \( P_A \) is the probability of reaching the
response threshold, which for these supra-threshold stimuli is taken to be close to one. The value \( c \) is a constant of proportionality relating the \( \Delta t \) time epochs of the sensory system to the clock of the experimenter.

**Random Walk and Variability**

The accumulation process is a stochastic process. That assumption has important consequences for the variability of the data, both variability created by stimulus intensities and variability due to the subjects. The first source of variability results from the stochastic nature of the accumulation process. The time needed to reach a given accumulation level will vary from trial to trial for each subject. In fact, the greater the value of the response threshold, the greater the decision time variability.

If the response threshold of a subject is stable within an experimental session, it may nevertheless vary from session to session. In nearly every psychophysical experiment using multiple sessions, performance generally improves from session to session. For instance, across sessions Reaction Times tend to get shorter. What basic factor(s) is responsible for such a reduction in \( RT \)? Has sensitivity has improved? Or does only the subject’s response threshold change?

To answer these questions we focus on conditions employing supra-threshold stimuli generating very high correct response proportions. Equation (2) shows that when \( P_A \) is near one, mean \( RT \) depends primarily on \( AI \), \( \mu \), and \( MT \). Under these conditions,

\[
RT = \frac{AI}{\mu} c\Delta t + MT. \tag{3}
\]

Equation (3) bears a striking resemblance to the empirical relation discovered by Piéron. For a fixed stimulus intensity changes in \( RT \) are due primarily to changes in \( AI \), which may be a characteristic of a particular experimental subject. For fixed intensity, and values of \( P_A \) near one, \( RT \) increases linearly as \( AI \) increases. Also, when \( AI \) is fixed, and values of \( P_A \) are near one, increases in stimulus intensity cause \( RT \) to decrease as a function of the reciprocal of \( \mu \). Also, the values of \( \mu \) are often quite large, certainly far from the values typical of those generating many error responses.

For values of \( P_A \) near one, mean individual reaction times are a linearly increasing function of \( AI \). However, neither the value of \( AI \) nor the value of \( MT \) are known. Furthermore, unlike previous analyses of choice reaction time where the errors assist in testing predictions of the theory, the sparse number of errors precludes tests based on relations between \( RTs \) and correct and error response proportions.
We introduce a new technique applicable to the analysis of response times when error rates are very small if not zero. This theoretical analysis follows from empirical work on the relationship between mean response times across various experimental conditions and the response times within the individual conditions. In particular, we see in equation (3) that an estimate of the unknown value of $AIc\Delta t$ is obtained from

$$(RT - MT)\mu = AIc\Delta t. \quad (4)$$

For each experimental condition, $i = 1, ..., n$, in which a different stimulus intensity gives rise to a different value for $\mu_i$ equation (3) can be rewritten as

$$RT_i = \frac{AI}{\mu_i}c\Delta t + MT. \quad (5)$$

Substituting equation (4) into (5) provides a testable relation between the mean response time across the experimental conditions and each of the individual conditions.

$$RT_i = \frac{\mu}{\mu_i}(RT - MT) + MT$$

$$RT_i = \frac{\mu}{\mu_i}RT + \left(\frac{\mu_i}{\mu_i} - \frac{\mu}{\mu_i}\right)MT. \quad (6)$$

When there are few errors the values of $\mu_i$ are large and the slope of this equation must be near one. A feature of equation (6) is the transfer of emphasis from the slope in equation (5) to the intercept of this linear equation. The intercepts of the mean $RT$s from various experimental conditions that vary $\mu_i$ must vary around zero. More important, the intercept equals $MT$ times one minus the value of the slope. This relation provides an estimate of the unknown value of $MT$.

Plotting mean $RT$s from each experimental condition against the mean $RT$ of those conditions should produce a linear equation with slope near one and intercepts varying according to the vaules of $\mu_i$. Several sets of such results are necessary to obtain a test of this prediction. The various results must come from individual subjects who have relatively fixed values of $\mu_i$ but changes in their response threshold values, $AI$. For example, data from successive days of practice often show a reduction in mean $RT$ that may be attributed to changes in response threshold values, $AI$, rather than changes in sensory parameters such as $\mu_i$ or the value of $MT$. 
Experiment

These hypotheses were examined in the experiment on visual Choice Reaction Time (Saleh & Bonnet, 1998). Five subjects participated in the experiment. Three of the subjects were young emmetropics (P, N, D) who should produce very similar results. Subject J was 63 years old and presbyopic. The fifth subject (S) was a young albino with very poor vision, a nystagmus and photophobia. The latter subject should then have results very different from those of the emmetropic subjects. To investigate the assumed effects of changing the response threshold each subject engaged in 30 sessions of 200 trials each. A stimulus was a Gabor patch of various Spatial Frequencies presented either left or right of a central fixation point. Five Spatial Frequencies (SF) were combined with five levels of contrast of the stimulus. Each session contained 8 repetitions of 5 contrasts by 5 Spatial Frequencies.

Results

Figure 1 shows the mean RTs session by session, subject by subject. Average RTs decrease with practice. These declines, we believe, are a manifestation of the reduction in the value of $A_f$ as the experiment progressed. Because of large fluctuations and the small sample size, results were pooled over 5 successive sessions creating 6 1000-trial blocks per subject.

![FIGURE 1](image1.png)
**FIGURE 1**
Individual mean RTs as a function of session

![FIGURE 2](image2.png)
**FIGURE 2**
Individual mean RTs as a function of contrast

Figure 2 shows the decline in response time as a function of contrast averaged across the entire experiment. The decline as a function of contrast is characteristic of the effect of different values of $\mu_i$. 
We expect that in spite of their different characteristics with respect to values of $AI$ and $MT$ the sensory components of subjects P, N, D, and J are similar. Thus the values of $\mu_i$ will be comparable and lead to similar slope values in equation (6) for each subject. As a first step in this analysis, each mean $RT$ for each contrast was plotted against the mean $RT$ across all contrasts within each block of 1000 trials for each of these four subjects. The results in Figure 3 are quite acceptable, showing that the subjects all fall along the same linear function with slopes characteristic of contrast.

**References**


