STUDIES ON SUBJECTIVE DURATION

I. DIFFERENTIAL SENSITIVITY IN THE PERCEPTION OF REPEATED TEMPORAL INTERVALS

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INTRODUCTION

Exactly one hundred years ago the first experimental work on the Time Sense appeared. A doctoral dissertation by Höring published in 1864 was the first of a stream of publications about work started early in the 1860's by Mach, Vierordt, Höring and others. It was the era of the upsurge of psychophysics—Fechner's *Elemente der Psychophysik* appeared in 1860—and interest was concentrated on obtaining absolute and differential thresholds of all kinds of sensory dimensions \(^1\). One of the first things to do, of course, was to see whether Weber's law was fitting the results obtained. For duration it turned out not to hold within the range studied, which generally ran from about 300 msec up to about 10 or 20 sec. Except Fechner, who this time clearly fought for a lost case all authors agreed that Weber's law doesn't hold for perceived time (Nichols (6); Woodrow (14)). Later investigators (among them: Stott (10); Woodrow (13); Henry (2)) have essentially confirmed the early findings, although very recently Treisman (11) suggested that the maximum sensitivity point at 600 msec is an artefact. His argument is not very convincing however, because the way in which stimuli were presented facilitated motor learning of interval reproduction and order effects, in his experiments.

Some of the more reliable data are shown in fig. 1. The general shape of the (solid) curves shows a minimum at about 700 msec, with an increase to both longer and shorter intervals. The average sensitivity, expressed in \((100 \triangle t/t)\), is about 8. This level drops considerably under the influence of prolonged experience (Renshaw (8)).

In more recent times a number of publications appeared on the differential sensitivity to rates of intermittent stimulation. This research

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\(^1\) Although time is since long not considered any more as affecting the senses directly, it is psycho-physically still treated as a sensory dimension.
appears to be completely independent of the orthodox strain of time psychologists, because one can hardly find any cross reference in the publications from both sides. The procedure followed by these students of intermittency (notably Mowbray and Gebhard) is, to present a train of pulses (photic, auditory, electrical, tactile) to the subject, usually with a pulse-to-cycle fraction of 0.50, and have him compare this train with another of the same or a slightly different frequency. Although the authors are primarily interested in frequency (rate), the results can be used for interval studies, simply by inverting the stimulus frequencies. This has been done in the dashed curves of fig. 1, which give the original curves of Pollack (7) and Mowbray et al. (5) converted to a time scale.

The difference with the other type of investigation is clear. The shape of the curve is not too different, but maximum sensitivity has shifted to a point at about 110 msec. The question is, how to explain the difference between the two groups of studies.

The reason might be found in the difference in procedure: in most of the “interval” studies single intervals are presented and reproduced (or compared). In the “intermittency” studies trains of intervals are
presented and compared. This distinction explains the difference in overall level of sensitivity. Repeated presentation will have the same effect as prolonged experience, as we can see in fig. 1, by comparing the dashed curves with the Renshaw data. Why however the point of sensitivity should shift under the influence of repeated presentation is not clear at all.

To throw some light on this matter the present study has been carried out. Its purpose is, to establish carefully the differential sensitivity between 67 msec and 2.7 sec, with a rather narrow spacing of standard intervals. The results contain a warning against too much smoothing of curves fitting variable data.

**Method**

Differential thresholds were measured for interval-trains, marked by auditory clickes of very short duration and 45 dB above threshold. The experimental set up is shown in fig. 2.

![Diagram of the experimental apparatus.](image)

The low-frequency function generators (Hewell and Packard 202 A) were mutually calibrated by means of an oscilloscope. The subject was free to select standard of variable by means of the selector switch. The pulse shaper delivered 6 micro-sec pulses. Pulselength at the ear was
measured to be less than 1 msec. Twelve standard intervals were selected, as shown below:

<table>
<thead>
<tr>
<th>Interval (msec):</th>
<th>67</th>
<th>100</th>
<th>143</th>
<th>200</th>
<th>250</th>
<th>333</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (c.p.s.):</td>
<td>15.0</td>
<td>10.0</td>
<td>7.00</td>
<td>5.00</td>
<td>4.00</td>
<td>3.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Interval (mscc):</th>
<th>500</th>
<th>667</th>
<th>1000</th>
<th>1430</th>
<th>2000</th>
<th>2700</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (c.p.s.):</td>
<td>2.00</td>
<td>1.50</td>
<td>1.00</td>
<td>0.70</td>
<td>0.50</td>
<td>0.37</td>
</tr>
</tbody>
</table>

Measures were obtained by means of the "up and down" staircase method. Five trained observers, all male with normal hearing, took part in the experiment. Their average age was 27 years. Each subject was given five sessions, in which the differential threshold was established at every interval length in a completely random order. Each session took about one hour to complete. The experiment took place in a soundproof room, with about 60 dB attenuation of outside noise. Settings can be considered to be accurate within 0.5% at 2 c.p.s. or better. Stability of the low frequency function generators was well within the limits specified by the manufacturers. The final values in each of the five series can therefore be considered to be accurate to at least 0.2% at 2 c.p.s., or better (at higher and lower frequencies).

**RESULTS**

All results are presented as Weber fractions in percentages (100 $\Delta t/t$).

Inspection showed that much learning took place during the first four sessions. The average levels of sensitivity compared to that of the last series were 1.9, 1.7, 1.4, 1.0 respectively. No significant differences were found between the last two sessions for any of the subjects. t-tests on log-transformed data showed values ranging from $t = 0.94$ to $t = 1.34$ ($p > .20$). Fig. 3 shows the results of the last two series for each subject separately and in fig. 4 these results are taken together into one combined curve. The last curve shows average and SD of the results of fig. 3. The SD values cannot be distinguished from the 1% confidential limits.

Full data have been subjected to an analysis of variance after log-transformation. The results are shown in the table below.

The analysis of variance confirms the results shown by the diagrams. Both sessions and intervals are significantly different, but their interaction is not. This means that there is no significant change in the shape
Fig. 3. Results of fourth (○) and fifth (×) series of each of five subjects.

**Table 1**

Analysis of variance on log-transformed threshold values ($y = 1 + \log x$).

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>M.S.</th>
<th>$F$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>4</td>
<td>0.5704</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sessions</td>
<td>4</td>
<td>0.7138</td>
<td>13.29</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Subj. × Sess.</td>
<td>16</td>
<td>0.0537</td>
<td>8.80</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Intervals</td>
<td>11</td>
<td>1.7605</td>
<td>48.90</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Subj. × Interv.</td>
<td>44</td>
<td>0.0360</td>
<td>5.90</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Sess. × Interv.</td>
<td>44</td>
<td>0.0080</td>
<td>1.31</td>
<td>&gt; .05</td>
</tr>
<tr>
<td>Subj. × Sess. × Interv.</td>
<td>176</td>
<td>0.0061</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>299</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
of the individual curves throughout the experimental period. So the results of the \( r^{th} \) sessions can be transformed into the results of the \( n^{th} \) session by a simple multiplicative transformation. On the other hand, the significant first order interactions indicate that the shapes of the curves differ among subjects (Sub. \( \times \) Int.), and in the second place the rate of gain of sensitivity in successive sessions is different between subjects (Sess. \( \times \) Sub.).

Fig. 4 shows familiar features both in the shorter and the longer region. Actually, we appear to have a combination of the two types of curves we met in the introduction. The graph indeed suggests the operation of two different mechanisms, which supersede each other at an interval length between 200 and 300 msec. This is illustrated also by the relatively large SD in this region. The single subjects seems to adopt a rather stable criterion in this respect, but interindividual opinions disagree.

The shift between 200 and 300 msec is highly significant \( (p < .001) \). And thus we obtain a curve, which is a combination of the “interval-type” and the “intermittency-type” experiments.

**DISCUSSION**

Upon looking into the data given in literature more closely to find some affirmation for the present results, it turned out that this affirmation came right from the work mentioned before. Averaging procedures
or negligence, possibly because of wide stimulus spacing in the region under concern, seem to have obscured the details in the curves such as in fig. 1.

![Graph](image)

**Fig. 5.** Differential sensitivity for intermittent stimulation. Replotted results of Pollack (7): ○
Mowbray and Gebhard (4): ⊗
Gebhard *et al.* (1): +

Data are multiplied by arbitrary constants such as to coincide with Pollack's data at \( t = 0.1 \) sec. Dashed curve represents present results.

Some data of the modern "intermittency" work have been replotted in fig. 5. It will be clear that these data show a considerable discontinuity well within the expected range. The extent to which this shift in sensitivity has been neglected is demonstrated in a comparison of Mowbray and Gebhard (4) with Gebhard *et al.* (1). The "hunch" at about 5 c.p.s. is present in the first paper. Extensive further training took place, which resulted in the second paper, where the shift is still present although in a somewhat less conspicuous way.

Another example can be found upon comparison of the relevant graph of Pollack (7) and its adaptation by Mowbray *et al.* (5). In the latter study Pollack's data are presented so that they facilitate the fitting of a simple parabolic type curve. The two sets of numerical data can be found in table 2.

The early work represented in fig. 6 also shows a marked shift in sensitivity when separate subjects are considered. The experimental technique of both authors (Mach (3); Vierordt (12)) consisted of serial presentation of each of the intervals to be compared. Although there are
TABLE 2

Data on differential sensitivity for auditory flutter from Pollack (7) and the estimates of Pollack's values by Mowbray et al. (5).

<table>
<thead>
<tr>
<th>Interval length (sec)</th>
<th>Pollack (7) $\Delta t/t$</th>
<th>Pollack after Mowbray et al. $\Delta t/t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02</td>
<td>0.035</td>
<td>0.04</td>
</tr>
<tr>
<td>0.03</td>
<td>0.034</td>
<td>0.03</td>
</tr>
<tr>
<td>0.10</td>
<td>0.019</td>
<td>0.02</td>
</tr>
<tr>
<td>0.17</td>
<td>0.029</td>
<td>0.03</td>
</tr>
<tr>
<td>0.25</td>
<td>0.031</td>
<td>0.03</td>
</tr>
<tr>
<td>0.40</td>
<td>0.035</td>
<td>0.04</td>
</tr>
<tr>
<td>2.50</td>
<td>0.090</td>
<td>0.09</td>
</tr>
</tbody>
</table>

No data on intervals shorter than about 0.2 sec, there is nevertheless a marked shift found in each case, between 0.3 and 0.5 sec.

Fig. 6. Differential sensitivity for serial interval presentation. Some data of historical importance by Mach (3) and Vierordt (12). The two curves of Mach denote different subjects.

Obviously averaging over more subjects will increasingly obscure the pronounced shift, because of the rather large individual differences. This
DIFFERENTIAL SENSITIVITY FOR INTERVAL SERIES

applies not only to the results of fig. 6, but also to more recent investigations.

Nevertheless it is likely that the effect found in the present experiment is due to some effect of the repetition of the stimulus intervals. No double minimum appears in those investigations which use single presentation of intervals: neither in reproduction experiments (e.g. Woodrow (13)), nor in comparison studies (e.g. Stott (10)). The present results point therefore to the operation of two relatively independent mechanisms, each with a characteristic frequency, rather than to a shifting of the point of maximum sensitivity under influence of the experimental procedure. The presence of the faster component depends on the repetition of stimulus intervals.

The problem of the nature of the mechanisms underlying these findings remains to be clarified. This in fact is the paramount problem of time psychology after one hundred years of experimentation: thus far only incidental suggestions have been made about the mechanisms of time evaluation.

Summary

The differential sensitivity for series of time intervals in the range from 67 to 2700 msec was measured with the method of comparison and revealed a curve with two maxima of sensitivity:

a) at an interval of about 110 msec, with a Weber fraction $\Delta t/t$ of about 0.01.

b) at an interval of about 600 msec, with a Weber fraction $\Delta t/t$ of about 0.02.

The results bring together data from the classical time psychology and studies on "intermittent" stimulation. In the latter type of work for some reason no attention seems to have been paid to the maximum at 600 msec, although it is found to be present in most of the studies. This fact is discussed.

References


