THE ROLE OF RHYTHMIC FACTORS IN THE PERCEPTION OF TIME

A THESIS PRESENTED TO THE DEPARTMENT OF PSYCHOLOGY OF THE UNIVERSITY OF CAPE TOWN FOR THE DEGREE OF MASTER OF SCIENCE.

BY

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Summary Paper

In the past, research into the perception of time and the perception of pattern have proceeded independently. In the present study, the effect of the patterning of stimuli on the perception of time is investigated, and a theory of time perception elaborated. An experiment designed to investigate some of the factors postulated in this theory is described. It is suggested that really significant results can only be expected from a close analysis of the performance of individuals. Such an analysis of the data from this experiment provides definite evidence for the existence of some of the processes postulated in the theory.

Philosophical speculation as to the nature of time extends back several thousand years until at least the period of the earliest Greek schools of philosophy, while experimental psychologists have been examining the problems of time perception ever since Wundt's founding of the "first" psychological laboratory in 1879. Despite the impressive quantity of intellectual effort devoted to the problems of time, few undisputed facts have emerged from this activity, and the subject of time perception has been characterised by one recent reviewer as a "venerable, tired concept in psychology that interests very few active investigators any more". (Adams, 1964.)

Part, at least, of the reason for this malaise has been a widespread underlying conception of time as a "directly sensed" entity in the universe, in the perception of which the stimuli demarcating time-intervals are relatively unimportant. In fact, however, as A. N. Whitehead (1920) has convincingly shown, time perception is a judgement derived from the occurrence of the normal physical events of nature; from which it follows that in investigating the perception of time, we must direct our attention to the physical events demarcating time-intervals, rather than to the "stream of consciousness" flowing between and during such events.

In the past, psychological experimentation has been directed almost exclusively to the perception of single time-intervals without regard to the possible effects of various temporal patternings of the stimuli demarcating the interval. Investigations of rhythm and temporal-pattern perception, on the other hand, have not included a detailed study of the time-intervals between the stimuli forming the pattern. Curiosity about the effects on time-perception of various different patternings of stimuli flows naturally from the realisation that time-perception is a judgemental process derived from the occurrence of events. It has long been suggested that judgements of the duration of time-intervals made in the absence of such external aids as clocks and watches, are made in terms of some internal reference rhythm, and recent work by Wiener (1958) and Holubář (1969) strongly suggests that the alpha rhythm may provide such a standard. However, there exists the possibility that under certain circumstances the stimuli demarcating a time-interval may themselves set up an internal reference rhythm. Preliminary experimentation suggested that this was in fact a very strong possibility, and on the basis of this experimentation, the following outline theory of time-perception was developed.

A Theory of Time Perception

Hypothesis 1 — The duration of a time-interval is estimated by counting the number of cycles of a reference rhythm.

Hypothesis 2 — The alpha or other endogenous rhythm provides such a constant internal reference rhythm.

Hypothesis 3 — (a) When incoming stimuli (S_1, S_2) are separated by a time-interval, Ti,(the duration of Ti lying between certain critical maximum and minimum values), they set up a reference rhythm (R_R) with frequency $\frac{1}{Ti + \delta Ti}$ and variance

σ^2_{Ti}, which supersedes the endogenous rhythm as a standard in terms of which the durations of time-intervals between subsequent stimuli are judged. δTi may be positive, negative or equal to zero, and is a measure of the precision with which the internal rhythm mirrors the occurrence of the external events S_1 and S_2.

(b) By appropriate instructions, as given in the method of reproduction, the reference rhythm R_R may be converted into a rhythmic "tendency to response" (Ai) with frequency $\frac{1}{Ti + (\delta Ti + \theta_1)}$ and variance $\sigma^2_{Ti'}$, the difference between σ^2_{Ti} and $\sigma^2_{Ti'}$, being determined by the magnitude of θ_1. θ_1 reflects an increase in δTi as a result of the involvement of a larger neuronal network. As in the case of δTi, $\theta_1 \gtreqless 0$.

<u>Hypothesis 4</u>

(a) The greater the number of stimuli which follow each other at equal intervals, the more firmly will R_R be established and the more accurately will the duration of subsequent intervals be perceived. Occurrences of Si ($i > 2$) after S_2 with the same interval Ti between the Si "reinforce" R_R, reducing σ^2_{Ti}, (the variance in the time-intervals $Ti + \delta Ti$ of R_R), thus making R_R a more stable standard in terms of which the subsequent intervals are perceived.

(b) A time-interval $T_S = Ti$, following a series of n Si ($n > 2$), in which all Ti's are equal, will be reproduced as the time-interval $T_R = Ti + (\delta Ti + \theta_1 + \theta_2)$. The reproduction of this interval involves merely the conversion of two of the "tendencies to response" into overt motor responses, θ_2 representing the possible distortion of the perceived interval by the motor response mechanism. θ_2 may be positive or negative but almost certainly does not equal zero, and is at least partially a function of the length of Ti.

(c) The reproduction of a series of m equal intervals Ts = Ti involves the conversion of m Ai's into overt motor responses. For a given $T_S = Ti$, $|\{Ti + (\delta Ti + \theta_1 + \theta_2)\} - Ts|$ (the absolute error of reproduction) will approach a minimum as m increases up to a certain point (reflecting the reinforcement of R_R), but as m increases beyond this point $|\{Ti + (\delta Ti + \theta_1 + \theta_2)\} - T_S|$ will again increase (reflecting the effect of reactive inhibition).

<u>Hypothesis 5</u> The reproduction of an interval T_M = nTi after a series of intervals Ti has established R_R (with the time-interval between the Ai = Ti + δTi) requires the inhibition of (n - 1) of the Ai. The inhibition of the Ai will exercise a disrupting effect on the reproduced interval T_M, the extent of such disruption being a function of:

(a) n,
(b) the duration of T_M and
(c) certain physiological characteristics of the subject, related to the rate of build-up and dissipation of inhibition.

<u>Hypothesis 6</u> The perception of an interval T_I = nTi + ΔTi ($\Delta Ti < Ti$), after a series of intervals T_i has established R_R with frequency $\frac{1}{Ti + \delta Ti}$, involves the counting of n of the intervals Ti plus the estimate of ΔTi. ΔTi is probably estimated in terms of the number of cycles of the endogenous rhythm, or possibly by fractionation of Ti.
The reproduction of T_I then involves the inhibition of (n - 1) of the Ai and the displacement of the last Ai by a "correction interval", the length of the correction interval being determined by S's estimate of ΔTi.

As part of a series of experiments designed to test this theory, an experiment was carried out in which subjects were required to reproduce various series of 5 successive time-intervals. The effect of the length of the preceding intervals on the reproduced length of the 1000msec. interval was then observed.

<u>Apparatus</u>: All time-intervals were demarcated by a short (50msec) burst of a 297-cycle tone from a sine-wave oscillator delivered over Aiwa HP II stereo headphones. Subjects were required to reproduce the presented intervals by tapping on a light telegraph key. A Hewlett Packard 2114B computer controlled the presentation of all stimuli and measured the subjects' reproduction times. The computer was programmed to time accurately to the millisecond. As a check on this, a series of 7 time-intervals (100, 250, 500, 750, 1000, 1250 and 1500 milliseconds) output by the computer were measured by means of a Venner Digital Counter Type TSA 6636. Accuracy of measurement of the digital counter was quoted by the manufacturers as 1 microsecond. Measurements of the 7 test intervals were repeated on a further 2 occasions during the course of the experiments. A maximum discrepancy of 2 milliseconds was found between the readings of the computer and the digital counter. It can thus be concluded fairly safely that all reported reproduction times are accurate to $\pm$ 2 milliseconds.

<u>Method</u>: 5 series of time-intervals were selected, details of which are given in Table 1 below.

<u>Table 1</u>

Series	Durations of time-intervals in milliseconds				
A	200	200	200	200	1000
B	250	250	250	250	1000
C	300	300	300	300	1000
D	400	400	400	400	1000
E	500	500	500	500	1000

5 subjects were used in the experiment, each attending a 20 minute experimental session in a dimly-lit and sound-deadened room. Before the experimental session, each subject was given two half-hour practice sessions in the same room and using the same equipment, reproducing various different series of between 2 and 5 successive time-intervals. The subject was seated as comfortably as possible in front of a table to which was attached a telegraph key. He was informed that he would hear a series of 6 short sound-pips over the headphones, and asked to tap out the pattern he heard on the telegraph key, being urged to reproduce the time-intervals between successive pips as accurately as possible. Each series was presented 3 times.

Results: Each subject's reproductions of the 1000msec.interval in each series A to E are given in Table 2 below:-

Table 2

Series	Preceding Interval	Subject 1	2	3	4	5
A	200	927 943 969	872 880 894	849 894 915	695 723 775	755 805 882
B	250	680 691 701	959 968 975	950 965 1009	736 792 804	955 960 962
C	300	775 803 809	1006 1027 1058	1018 1085 1114	785 821 854	1024 1049 1087
D	400	928 937 965	842 873 892	901 939 957	851 909 926	904 941 943
E	500	980 1010 1032	1020 1061 1088	983 1021 1027	1005 1021 1033	1052 1058 1086

This data is represented graphically in Figs 1 to 5 below:-

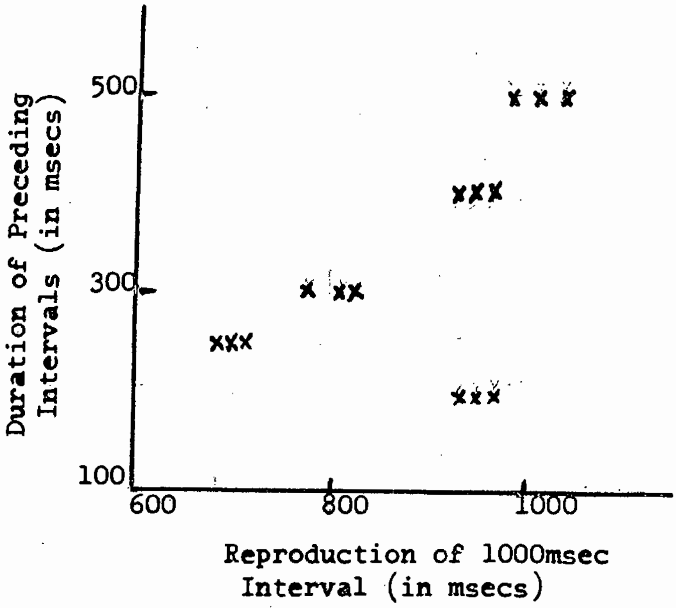

FIG. 1 (S 1)

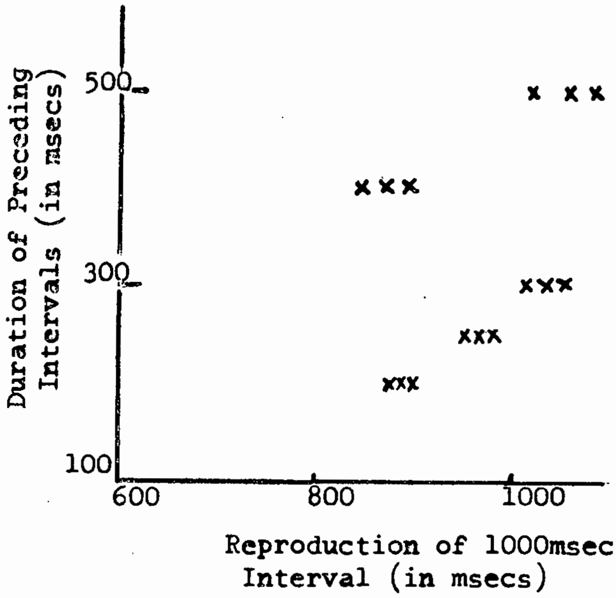

FIG. 2 (S 2)

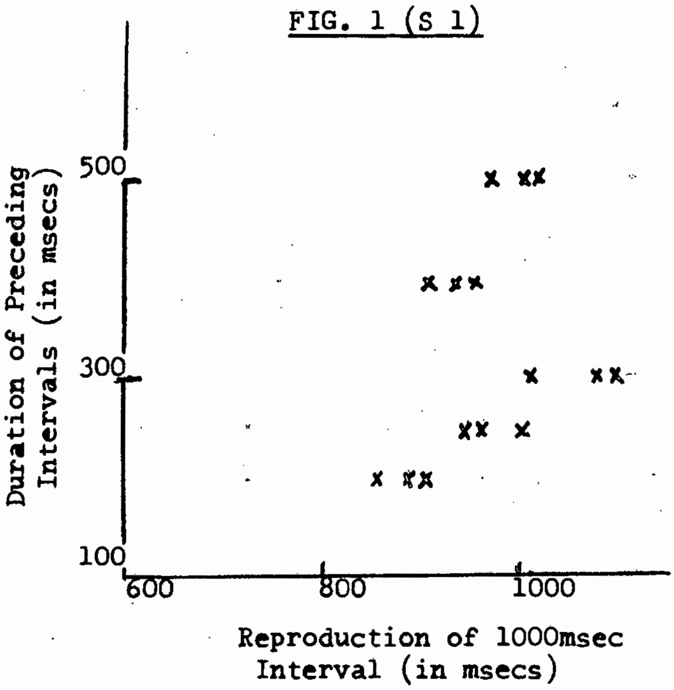

FIG. 3 (S 3)

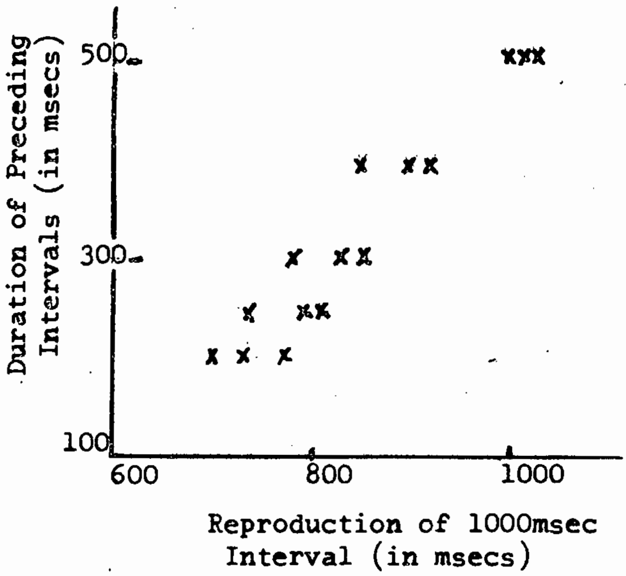

FIG. 4 (S 4)

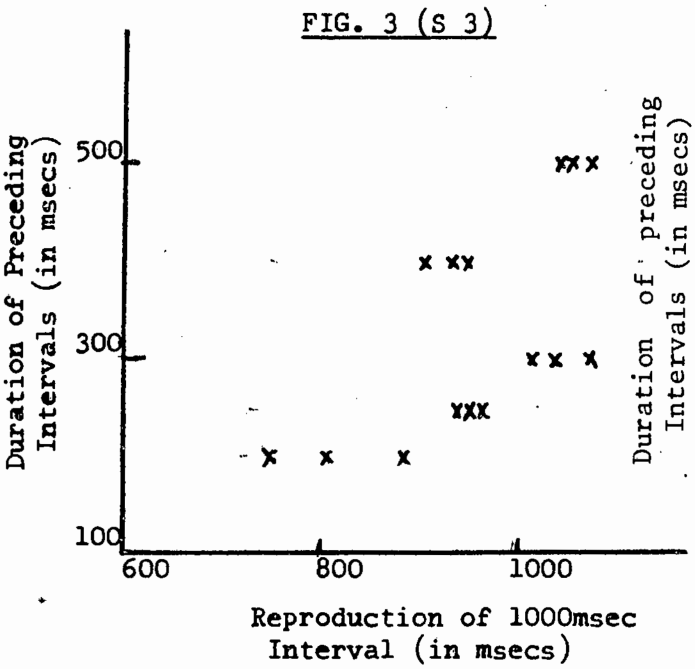

FIG. 5 (S 5)

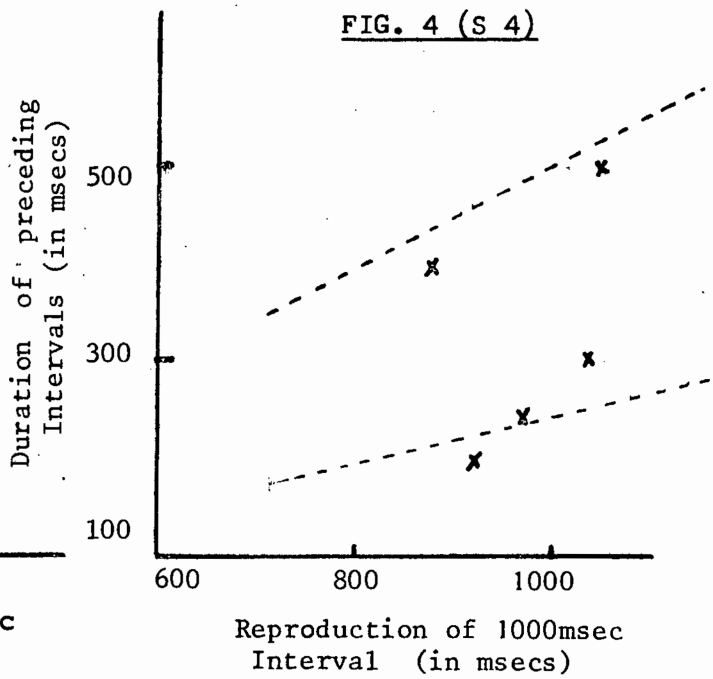

FIG. 6 (S 2)

Despite the variability in these results, so typical of results obtained by the method of reproduction, their graphical display gives a striking demonstration of the control exercised by a preceding series of time intervals over the reproduction of a 1000msec. interval. A preceding series of short intervals is followed by a shorter reproduction of the 1000msec. interval, and a preceding series of longer intervals is followed by a longer reproduction of the same interval. But that this is not a simple, generalised speeding up or slowing down of response rate is clearly shown by the way in which the graph "breaks back" (at different points for different subjects) to values of the reproduced interval which are close to simple multiples of the intervals of the preceding series (T_i). This is just the effect which would be expected when S shifts from basing his assessment of the duration of the 1000msec. interval on one multiple of the intervals T_i, to basing it on another. The difference between the reproduced interval and a simple multiple of T_i can be interpreted as indicating the effect of the hypothesised "correction factor" (hypothesis 6). In Fig. 6 the actual performance of S 2 is contrasted with the expected value of his reproductions if there were no correction factor operating.

<u>Discussion:</u>

The results of this experiment support the theory of time perception outlined earlier. They show clear evidence that a given time-interval (T_s) may be reproduced as a number of cycles of a preceding shorter interval (T_i) plus a correction factor related to the number of cycles (n) used in the estimation, and to the discrepancy between nT_i and T_s. The nature of this correction factor, which may well prove to be an important physiological constant for individuals, is a subject meriting further research.

In such further research it is essential that the method employed here of recording all a subject's reproductions and examining the data for each subject separately be employed, if significant differences between subjects are not to be lost. The variability encountered in the reproduction of time-intervals is not random variability (except perhaps within very narrow limits). It should be seen rather as occurring because the method of reproduction is a sensitive measure of complex aspects of physiological functioning which vary widely from subject to subject. To average the results from different subjects is to throw away much valuable data.

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CHAPTER 1

THE NATURE OF TIME

> .... It is impossible to meditate on time and the mystery of the creative passage of nature, without an overwhelming emotion at the limitations of human intelligence ....
>
> A.N. Whitehead. (1920)

The study of the perception of time has engaged the attention of experimental psychologists ever since the founding of the "first" psychological laboratory in 1879, Wundt himself having devoted considerable attention to investigations in this field. Initially an objective experimental approach promised to provide solutions to problems which had perplexed thinkers for centuries. An optimistic Pavlov (1897) wrote: "I am convinced that directly along this path of exact experimentation lies the solution of the problem of time, which has occupied philosophers for countless generations."

However, after almost a century of such experimentation (perhaps not all of it "exact experimentation" by Pavlov's standards) it is clear that such optimism was unjustified. A recent reviewer has written: " ... time perception is a venerable, tired concept in psychology that interests very few active investigators any more." (Adams, 1964).

This state of affairs seems hardly surprising, for confusion about the nature of time is apparent in much of the experimental work which has been carried out in this field, and clarity about the nature of the fundamental concepts involved in an experimental investigation is essential if significant results are to be obtained. As Dewey (1886) warned: "... It is quite possible that the philosophic implications embedded in the very heart of psychology are not got rid of when they are kept out of sight ... and the fact that (such are) introduced without the conscious intention of the writer may serve to confuse both the author and the reader". A rather striking illustration of such confusion is to be found in Woodrow's article in Stevens' Handbook of Experimental Psychology (1951). Entitled "Time perception" it contains the rather surprising statement that "Time is not something ... which can be perceived".

Views about the nature of time have tended to fall into one or other of two radically opposed categories. On the one had we have the assertion that time has no real existence at all. Even here there are two opposing viewpoints.

1. Spinoza (1677) argues that "Time as a definite and measurable (if not actually measured) continuance is a product of the imagination." In the modern development of this view, time is regarded as merely a human creation to simplify the understanding of nature (Lossky, 1919) - one of the "logical terms in conceptual formulae of calculations" (Whitehead, 1920). Perhaps the most extreme form of this concept has been expounded by the Cambridge philosopher J.M.E. McTaggart (1934), who insists that time is an illusion.

2. A different view of the unreality of time is embodied in the contention of the idealist philosophers (which can be traced back through Plato to Parmenides) that time does not pertain to anything "real", but only to the logically unsatisfactory world of appearance revealed to us by the senses. Understandably enough, ideas about the "unreality" of time have not been influential among psychologists examining its perception.

Of far more importance, and leading to far more unfortunate consequences, is the concept of time as an entity in the universe, which exists independently of the physical substance of that universe. This concept, and an analogous concept of space have been traced back to the writings of Pierre Gassendi (1592 - 1695). His ideas were adopted by Newton, "and thus was evoked the portrayal of space and time which became firmly established in classical physics" (Whitehead, 1920), a conception of nature in which space and time are independent entities forming a framework within which the universe is set. Events happen "in" time, which forms an "ordered succession of durationelss instants" (page 33) apprehended by us concurrently with, but independently of our knowledge of the events of nature. Such a concept has exerted considerable influence on psychological studies of the perception of time.

> "... Mach thought that a real sense of time analogous to the other five senses might exist. When we recognise the same rhythm in two different melodies, we have according to him, perceived a scheme of durations independently of their sensory supports. This is possible only if we have perceived these durations in themselves, that is if we have a sense of time. Mach obviously understood that it was not enough to speak of a sense, but that it was also necessary to define the receptors ..... (Fraisse, 1963).

A similar concept was held by Feokritoff (1912) who talks of a "conditioned reflex to pure time", and by Pavlov (1897) who writes: "I should like to remind you that time, as such, proves to be also a stimulus; we may make a Conditioned Stimulus of it, and investigate it with regard to differentiation, inhibition and disinhibition." The inadequacy of the Pavlovian conception of time has been pointed out by Skinner (1938), who asserts that time is not a stimulus but one property of a stimulus. "Time has not the proper dimensions of a stimulus. To regard it in this simplw simple and inaccurate way is to raise a strong barrier to an understanding of the part that time plays in nature and in our knowledge of nature..... Time appears as the single property of duration, comparable with intensity, wavelength and so on."

Skinner, notwithstanding the "pure-time-as-a-stimulus" concept, has remained influential. Meerloo (1948), in presenting a "physiological exploration of the time sense" discusses the "primary or biological sense of time" and Horanyi-Hechst (1948), elaborating on this, discusses the "primitive time sense which is a vegetative function bound by the hypothalamus." A similar concept of time has obviously guided Schechter, Symonds and Bernstein in their investigation of the "Development of the concept of time in children" (1955), when they state:

> ... The problem of whether the time sense can be localised in the brain is unsolved. Studies have been done which indicate that the parietal lobe and adjacent parts of the temporal lobe which are connected to the vestibular apparatus are important stations for the perception of the sequences of the experience of time. Lesions of the occipital lobe will interfere in visual terms with time and space relationships ..... To date due to the complexity of the time sense there has been no precise cerebral localisation of it .....

Explicit of implicit, such a concept is to be found in much of the experimental work on time perception.

Both these viewpoints have been strongly criticised by A.N. Whitehead (1920), the more convincingly in that he provides an explanation of how the development of such views was possible. He asserts that both these views are the result of an "illegitimate bifurcation of nature" (page 30), an unjustified division of nature by the physicist into a perceived world, an an "unreal" scientific creation of atoms, molecules and the abstractions which have hitherto proved useful in the development of scientific theories in physics. Whitehead's demonstration of the inadequacy of this theoretical position, and the full details of his alternative approach are beyond the scope of this chapter. Here attention is given to his theory only insofar as it directly concerns the concept of time, though this may make the radical nature of his proposals less evident. Criticisms such as those of Northrop (1941) and Grunbaum (1962, 1964) of various aspects of Whitehead's general theory will also not be considered here as they deal with various side-issues not germane to the present discussion, and are in any case very often examples of the "bolting up sidetracks in pursuit of misunderstandings" (Whitehead 1920) to which Whitehead was well aware readers of his difficult writings would be prone.

Whitehead states his objective thus: "I shall endeavour to show that they (time and space) are abstractions from more concrete elements of nature, namely from events. The discussion of the details of the process of abstraction will exhibit time and space as interconnected .... There can be no time apart from space, and no space apart from time; and no space and no time apart from the passage of events in nature" (page 33). This "passage of events in nature" (or as he often abbreviates it, this "passage of nature", this process of change, is fundamental in the concept of time which he propounds. (In this his views are essentially in accord with those of Bergson (1888) although they diverge in their elaboration).

Whitehead continues: "The quality of passage in durations is a particular exhibition in nature of a quality which extends beyond nature. For example, passage is a quality not only of nature, which is the thing known, but also of sense awareness, which is the procedure of knowing" (page 55). This quality of passage then has in a sense an existence independent of the natural order which manifests it. Time is an abstraction from events which are themselves only isolated parts (parts isolated by sense awareness) of the passage of nature. Thus in a sense time has a quality which extends beyond nature, but is nevertheless only to be found as an independent entity as an abstraction from that nature. "The isolation of an entity in thought, when we think of it as a bare "it", has no counterpart in any corresponding isolation in nature. Such isolation is merely part of the procedure of intellectual knowledge" (page 142).

The foregoing argument leads to the rejection of the notion of time as an independent entity to be perceived in isolation from the events of nature. This is turn necessitates the rejection of the widespread view of space and time as constituting a framework within which nature is set, (explicitly stated, for instance by Eson and Kaffka (1952) who write: "External events happen in time, and so do the internal physiological ones"). As Whitehead puts it: "We have first to make up our minds whether time is to be found in nature, or nature to be found in time. The difficulty of the latter alternative - namely of making time prior to nature - is that time then becomes a metaphysical enigma. What sort of entities are its instants of its periods? The dissociation of time from events discloses to our immediate inspection that the attempt to set up time as an independent terminus for knowledge is like the effort to find substance in a shadow. There is time because there are happenings and apart from happenings there is nothing" (pages 65-66). It is interesting to note here Bishop Berkeley's exclamation: "For my own part, whenever I attempt to frame a simple idea of time, abstracted from the succession of ideas in my own mind, which flows uniformly and is participated in by all beings, I am lost and embrangled in inextricable difficulties. I have no notion of it at all." (Berkeley, 1710).

Whitehead's argument concerning the logical-abstractive nature of time is paralled by a similar argument for space, both these concepts being derived, it is asserted, from the more fundamental perception of events (processes of change). Within nature space and time do not exist as independent entities. As Minkowski (1923) wrote, commenting on the impact of relativity theory on concepts of space and time: "From henceforth space in itself and time in itself sink to mere shadows, and only a kind of union of the two preserves an independent existence." Time and space as independent entities exist only as concepts, intellectual abstractions from nature.

Such a view that time is not a direct "given" in nature, but that temporal judgements involve intellectual abstraction from the directly sensed events of nature, is supported by two sets of observations from psychological researches, the one from developmental, the other from experimental psychology.

The work of Piaget (1946), Ames (1946), Lovell and Slater (1960) and many other investigators has shown that judgement of the length of durations is a laboriously acquired ability, which develops long after the child's ability to perceive and manipulate the events of his environment. Temporal judgements are distorted by the nature of the events occupying the interval under consideration. Piaget observes that only older children can dissociate "the work effected from the activity itself, and judge the duration according to the introspective characteristics of the latter." (Piaget 1946). In summarising this work, Fraisse (1963) concludes that for the child a time interval "seems at first to consist of nothing but the number of changes which take place in it, but as the child develops, the intuition is transformed into a representation, an abstract ground, the scene of changes but independent of them .... The young child's apprehension of duration relates to its content; it is proportional to the work accomplished or to the changes perceived during it."

It would seem therefore that the perception of events in terms of spatial and temporal components is a somewhat artificial process and one which has to be laboriously learned. There are experimental results which raise some doubt as to whether this process is ever complete even in the adult. Helson and King (1931) have demonstrated the effect of a temporal component on judgements of distances (the "tau-effect"). If three points (P_1, P_2, P_3) are marked on the subject's skin, and the interval of time between stimulating P_2 and P_3 is greater than that between the stimulation of P_1 and P_2, the subject judges the distance between P_2 and P_3 to be greater than that between P_1 and P_2, though in fact it may be equal to or even less than the former.

The reverse phenomenon, namely that judgements of the duration of events may be systematically affected by a spatial component, was observed by Abbe (1936) who found that "when the distance between two flickering lights was increased, equivalent time intervals were judged as longer." Cohen, Hansel and Sylvester (1954, 1955) termed this the "kappa effect". In their further investigations of this phenomenon, they carried out an experiment in which the subject faces a continuous cycle of three flashes of light. He can control the timing of the middle flash and has to make the interval of time between the first and second flashes equal to that between the second and third. Under these conditions he allots a shorter time to the larger of the two distances, and the bigger the ratio of the two distances, the shorter relatively, is the time he allots to the flashes spaced further apart. Where the ratio of the distances was 1:10 the magnitude of this effect was found to be 12%. A similar effect for tactual stimuli was found by Suto (1955). In reviewing his work Cohen writes: "... We may conclude that the spatial and temporal components of space-time events are experienced as interdependent."

In summary then, we may conclude that time has not independent existence as a physical entity in nature, and the ability to deal independently with the temporal dimension depends on a learned abstractive process. The search for a physiological receptor for time (Schecter et al. , 1955) must therefore inevitably be the search for a chimera, and any theory of time perception must take note of the fact that in the process it attempts to explain, the perception of events is fundamental, the judgement of duration derivative.

CHAPTER 2

THE MECHANISMS OF TIME PERCEPTION

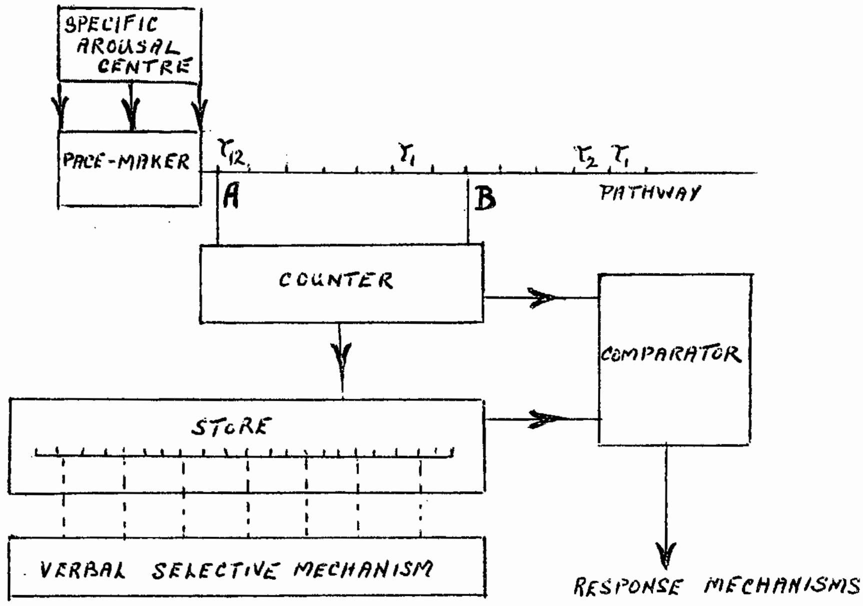
> .... The measurement of time is essentially a process of counting ....
>
> Clemence (1920)

Although the concept of a "biological clock" is one that recurs frequently in the literature, there have been few attempts to elaborate in any detail a model to represent processes involving judgements of the duration of time-intervals. Our estimation of relatively long time-intervals is in terms of the rotation of the earth about the sun. Rather shorter intervals are measured in terms of the number of rotations of the earth about its axis and these 1-day periods are further subdivided into hours, minutes and seconds which are generally measured in terms of the number of regular rhythmic oscillations of a pendulum or other cyclically repeating device, the second being officially defined as "9 192 631 770 cycles of the frequency associated with the transition between two energy levels of the isotope Caesium 133". Mechanical aids to time measurement then generally involve counting a number of rhythmically repeating events, and it has been proposed that estimates of duration made without such mechanical aids employ the same general principle of counting the number of cycles of a reference rhythm, but that in these cases the reference rhythm is an internal one. If this is so, the memory of a time interval is stored as a number, the number of cycles of the reference rhythm, and time intervals are compared by comparing the number of cycles of the reference rhythm that have passed during the one interval with the number that have passed during the other. A remarkable foreshadowing of this "biological clock" principle is to be found in the writings of St. Augustine in the 4th century. In the 11th book (Chapter 27) of The Confessions (355) we find: " ..... A sound which is not yet over cannot be measured. But when it is over it will no longer be. Then how will it be possible to measure it? Yet we do measure time ..... Thus it seems that we measure neither time past nor time present, nor time passing; and yet we measure time. What is it that I measure? .... something which remains engraved in my memory. It is in you, O my mind, that I measure time .... it is the impress that I measure when I measure time. Thus either that is what time is or I am not measuring time at all."

The most thorough-going attempt to develop this "biological clock" model has been made by Michel Treisman (1968), and although its detailed elaboration involves a number of wholly arbitrary assumptions, its general features provide a useful conceptualisation of the processes involved in estimating duration.

The components of the model are:

1. a pacemaker which can be acted on by a specific arousal centre;
2. a counter;
3. a comparator;
4. a store; and
5. a verbal selective mechanism.



The pacemaker produces a regular sequence of pulses which travel along a pathway at a constant rate. The basic interpulse interval is t_0 seconds, with variance σ_t^2. Facilitation of the pacemaker by the specific arousal centre affects the rate at which pulses are produced. A given level of specific arousal will determine a mean interpulse interval t', given by $t' = q t_0$, where $q > 1$ when specific arousal is low, and $q < 1$ when it is high. Specific arousal may be affected by features of procedure, and various aspects of the experimental situation.

The counter records the number of pulses emitted in a given interval. If an interval $Ts=nt_o$ is demarcated by initial and terminal stimulus-events S_1 and S_2, the counter will start to count the number of pulses beginning with the occurrence of S_1 and ending with the occurrence of S_2. If q=1 (i.e. $t' = t$) the number recorded should be n. The counter reads numbers either directly into the comparator or into the store, whence they may be retrieved by the comparator.

The store can be considered as a functionally unidimensional array of locations or adresses, one of which is the "zero point". Each location corresponds to a measure, the correlate of the measure being the distance of that location from the zero point. Locations can vary in their degree of activation; by activation being meant a feature of the state of a location on which the probability that it will be selected for retrieval may depend. The effect of "reading a measure into the store" is to increase the activation of the corresponding location. Some activation of neighbouring locations will also be produced, giving a distribution of activation about a modal point. Activation from different sources will sum. It will also tend to fade so that the store is essentially short-term.

The verbal selective mechanism provides a long-term memory store which can be operated by symbolic perceptual cues. It is a repository of "verbal labels" such as 1 second, 2 minutes, etc., each of which is linked to a particular location in the store. When a verbal label is specified by an instruction to the subject it will produce a distribution of activation in the store, centred at its point of attachment. This will sum with residual activation from other sources, the mode of the combined distribution determining the locus of retrieval.

Whilst Treisman stresses that his model involves no assumptions as to the neural identity of its components, it is significant to note here Thompson's report (1970) of his discovery of "counting cells" in the association cortex of the cat. The number of animals used in this study is not quoted, but he notes the identification of

> ....five counting cells in the adult cat, which code the numbers 2, 5, 6 (two cells), and 7. With such a small sample, it is not possible to make a precise estimate of the proportion of cells in nonspecific association response areas of the cortex that "count". However, crude guesses based on the proportion of such cells that we have observed suggest that in the cat about 1 percent of the cells in the association areas that respond to stimuli are counting cells (that is 5 in a sample of about 500) ....

The fact that the response of these "counting cells" has been shown in this study to be independent of stimulus modality, intensity and rate of presentation, at least over a limited range of values of these parameters, has important consequences for any theory implicating counting mechanisms in time perception.

There have been many suggestions over the past 50 years or so that various physiological processes might act as a fundamental reference rhythm in the perception of time (the pacemaker of Treisman's model). One early proposal was that the heart-beat served in this way. The hypothesis was based on the observation that the most frequently reported value (0.7 secs) of the Indifference Interval (the most accurately estimated interval) corresponds fairly closely to the average interval between successive heart-beats, but the hypothesis has been discredited by a number of studies (most recently, and most convincingly by that of Ochberg and Treister, 1970) which have revealed no significant influence of variations in heart-rate on judgements of duration. A particularly comprehensive early investigation by Gilliland (1938) reported no significant correlations between time estimations and "pulse rate, breathing rate, heart work, lung work and blood pressure changes."

The idea of a neural pacemaker was first advanced by Hoagland (1935) who hypothesised "a specific chemical clock located in the nervous system and furnishing its possessor with a subjective time scale. Various changes in the immediate environment of this chemical clock may modify its velocity." One such environmental change whose effects have been particularly studied is that of bodily temperature. Conflicting results have been obtained from experiments over the past 40 years, and the conclusion reached in one of the most recent and careful of such studies (Fox, R.H., Bradbury, P.H., Hampton, I.F.G. and Legg, C.F., 1967) is that the marked individual variability typically found in these studies "does not favour Hoagland's more specific suggestion that time judgement could depend on one particular metabolic reaction in the brain".

A more promising possibility is that brain rhythms may provide the fundamental reference. Such a possibility appears to have been first adumbrated by Craik (1943) and further examined by Pitts and McCulloch (1947) and Grey Walter (1950), and most precisely developed by Norbert Wiener (1958). Wiener observes that a careful analysis of alpha rhythm records has revealed that around a particular central frequency close to 10 cycles per second, there is a rather empty range with a short peak of great intensity and small width in frequency (less than 0, 1 cycles) in the centre. Wiener maintains that this narrow band of frequencies indicates a clock in the brain with a precision of roughly 2 parts in a thousand or about 3 minutes per day.

This hypothesis has been put to the test by Holubar (1969). Using a group of 15 subjects he examined the effect on the intervals of a previously established temporal galvanic skin reflex, of driving the alpha rhythm with flicker. He found, (in those subjects in whom the reflex did not disappear entirely in the presence of flicker!) that an imposed frequency of 7 cycles per second almost halved the intervals of the temporal reflex (reducing them on average from 29 to 14 seconds). Holubar summarises his results:

.... 1. Frequencies of flicker that do not coincide with the alpha rhythm but are themselves harmonically related, that is, 7 and 14 to 15 per second, are maximally effective.

2. Both of these frequencies, of which one is lower and the other higher than the alpha rhythm, result in a significant, and on the average almost identical, decrease of the intervals between the conditioned reflexes to time.

3. Flicker coinciding with the frequency of the alpha rhythm is without effect.

4. Flicker of frequency of half (5) and double (20) the alpha rhythm has a negligible effect ....

and concludes that "rhythmic activity of the brain or a part of it could represent a fundamental reference rhythm which serves the organism in the measurement of time."

The present study constitutes an extension of this investigation of the role of rhythmic factors in the perception of time intervals, to the investigation of the possibility that the stimuli demarcating the initial intervals in a pattern of several successive time intervals may set up a rhythmic "tendency to response" (analagous to a temporal reflex) which will temporarily supplant the alpha or other endogenous rhythm as a standard of reference in terms of which the durations of later intervals in the series are judged.

CHAPTER 3

METHODOLOGY

> .... The data that have been accumulated in the illusive field of time perception show two outstanding characteristics. One is the conflicting nature of the findings of the different experimenters, the other is the mentalistic nature of the data ....
>
> Herbert Woodrow. The Perception of Time (1951).

The problem of time has exercised a fascination for psychologists working in a wide variety of fields. The variety of these fields is well reflected in the host of time - related concepts which appear in the literature on time perception. A glance at some of those which have appeared over the past 20 years shows that there has been little change in the position as regards the predominantly "mentalistic nature of the data", upon which Woodrow commented in his 1951 review. Studies have dealt with "time consciousness", the "subjective duration of time", "psychological time", "apparent time", the "subjective extension of temporal zones", "temporal experience", "time appreciation", "time conceptualisation", "temporal organisation", "temporal integration", "temporal orientation", "temporal disorientation", "time perspective", "time distortion" and "time salience".

This rich store of imprecisely defined or totally undefined concepts has been combined with a bewildering variety of "personality variables" to form a psychological wonderland in which there are few restraints on imaginative invention. Melikian (1969) reports on: "Acculturation, time perspective and feeling tone. A cross-cultural study of the days". Thompson, Spivack and Levine (1960) have investigated: "The experience of time as a determinant of self-control". Meade (1960) has examined: "Time estimates as affected by need-tension and rate of progress", Knapp and Green (1959): "Time judgement, aesthetic preference and need for achievement", Ellis (1955): "Time orientation and social class", Levine and Spivack (1959): "Time conception and self-control in a group of emotionally disturbed adolescents", and Teahan (1958): "Future time-perspective optimism and academic achievement", while Zern (1970) has carried out a "cross-cultural and longitudinal investigation of time salience .... to test the psychoanalytically-based hypothesis that indulgent childrearing patterns lead to the development of a relatively undifferentiated sense of time and a relative indifference to structuring the time dimension at all."

One noticeable feature of this profusion of time-related concepts is a tendency to confuse time perception with consciousness. Time perception is based on the perception of events, the events themselves, their perception, and the perceiving organism being events in nature, events in which are embedded the space-time reality from which space and time are intellectually abstracted. Consciousness of time is no more (and no less) mysterious than consciousness of shape of colour or texture, and no more relevant to the study of the temporal aspects of the behaviour of the perceiving organism. To drag consciousness into an attempt to understand the mechanisms of time perception, is to add confusion to complexity, to create the problem of a disorder of mixed categories which is incapable of logical solution as long as the relationship between the categories remains undefined. A fine example of such confusion-worse-confounded is to be found in a recent article by Van Wulfften Palthe (1968) in which, in "elucidating" the mechanisms involved in time estimation, he states that: "Time sense is a function of upper brainstem paraconsciousness. Its estimation of time-span is given intuitively without reasoning, and moved by inner certainty."

By contrast, behaviouristically-inclined psychologists have limited their investigations of time perception to methods which make possible the precise measurement of unambiguous verbal or motor behaviour. The methods used may be classified as those of comparison, reproduction, verbal estimation and production. (Bindra and Waksberg, 1956). In all these methods stimuli may be presented visually, auditorily or tactually.

In the method of comparison, two time intervals (T_S and T_C) are presented for comparison, separated usually by a short pause. The subject is required to report one of the intervals as seeming shorter or longer than, or the same as, the other.

In the method of reproduction, two brief stimuli (or the turning on and off of a continuous stimulus) mark the beginning and end of the time-intervals (Ts) and the subject is required to respond in some way (e.g. by tapping a key) to demarcate a time-interval (T_R) of the same duration.

In the method of verbal estimation the subject is required to estimate the duration of an interval (T_C) in terms of verbally-identified standard units (seconds, minutes or hours.)

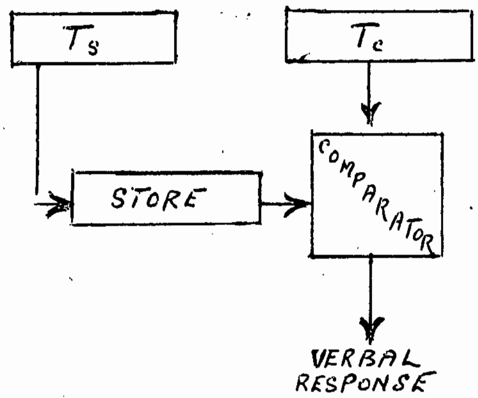
In the method of production (sometimes known as the method of operative estimation) the subject is required to demarcate a time interval (T_P) specified by the experimenter in terms of verbally-identified standard units.

Several studies have discussed the inter-relationships of the various methods in a rather inconclusive manner. Thus Clausen (1950) writes: "It seems evident that the task of reproduction involves a different underlying function than do Verbal and Operative Estimation". Gilliland and Humphreys (1943) state that: "Reproduction is perhaps easier than Verbal and Operative Estimation but these all seem to be closely related mental processes."; Bindra and Waksberg (1956): "Thus we see that a difference between standard and judgement may signify quite different underlying events in the different methods"; Kruup (1961): "The rather low intercorrelations (of the Method of Reproduction) with the other methods (Production and Verbal Estimation) seem to occur partly because the results in the method of Reproduction are not influenced by S's notion of the length of the physical time units";

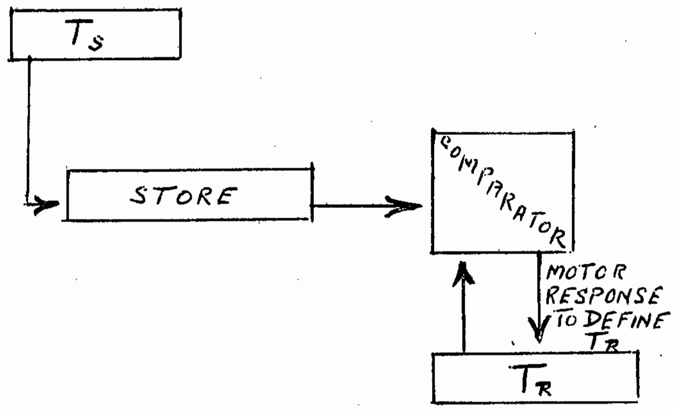
Siegman (1962): "It is suggested that these methods measure other variables in addition to subjective time units"; Fraisse (1963): "This méthod of estimation by a translation into units of time is the one used most readily, for it gives information that can be compared with that provided by our watch. It is also the method most often used in experimental studies because it is the most practical"; and Grant (1967): "The methods are not necessarily equivalent or freely interchangeable and judgements obtained by different methods cannot be expected to correlate significantly."

In general, research on the perception of time has tended to use (one or more) of the four methods described above rather indiscriminately. All the methods have in common the comparison of two time-intervals, but an important distinction should be made between those methods which involve only short-term memory (the methods of comparison and reproduction) and those in which long-term learning is involved (the methods of Verbal estimation and production). In the method of verbal estimation, the subject is required to compare the duration of an interval with his memory of some previously-learned standard (e.g. 1 second). In terms of Treisman's model, a retrieved measure from the verbal selective mechanism is compared with the current output from the counter. The method of production involves the same essential processes, but the subject is required to terminate the ongoing interval. In each case the unit of measurement is a previously-learned standard time-interval (in Treisman's model, code as a number). The important point is that this standard time-interval, and its attached verbal label have to be learned, and in the methods of verbal estimation and production the behaviour of individuals who have experienced widely differing training schedules in the acquisition of this standard is being sampled. Moreover few individuals ever experience any systematic training in the acquisition of such standards, most such learning being incidental to the use of a watch for timing purposes. The basic processes involved in these methods of verbal estimation and production are almost identical with those involved in the methods of comparison and reproduction. The only difference is that in the methods of comparison and reproduction an ongoing interval is compared with the duration of an immediately preceding interval, while in the methods of verbal estimation and production the ongoing interval is compared with an average of many preceding intervals (a learned standard). Schematically represented we have:

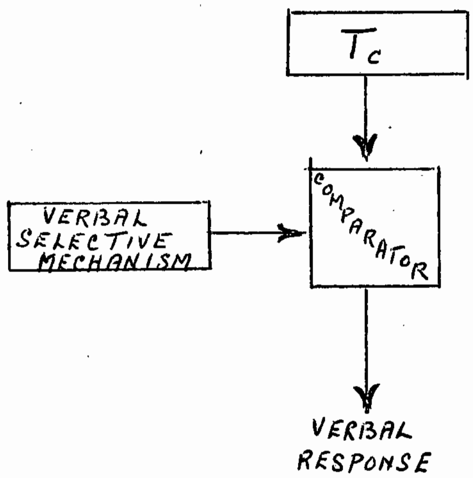
1. Method of Comparison



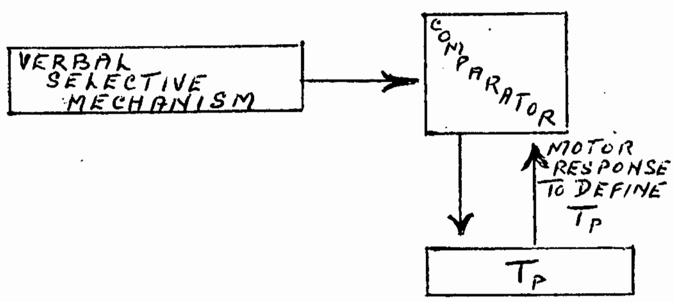
2. Method of Reproduction



3. Method of Verbal Estimation



4. Method of Production



The observed negative correlation (Clausen 1950, Kruup 1961) between the methods of verbal estimation and production is entirely predictable. If, for example, the 1 second standard retrieved from the verbal selective mechanism is less than 1 second, S will report time-intervals as being longer than they really are (containing more of his shorter units), but will produce intervals correspondingly shorter than the required value. The low correlations reported between the methods of reproduction and those of verbal estimation and production are similarly to be expected, because of the confounding effects of differential prior learning of the standard in the last two methods.

In the present study the method of reproduction was used as it is the only method which provides simple quantitative data about a subject's perception of a series of successive time intervals. This method, while resembling that of comparison in that neither involve a previously-learned standard, differs from it in terms of the form of response required from the subject. In the method of comparison the subject is required to remain passive during the presentation of the two time intervals, and then to make a verbal report. In the method of reproduction the subject is required to remain passive during the first interval and to make some form of motor response to begin and to terminate the second interval. Obviously characteristics of the motor response mechanism will be reflected in measurements of time perception by the method, as Triplett (1931) and Belyaeva-Eksemplyarskaya (1962) have pointed out. Although it is difficult to isolate the contribution of motor response factors, evidence presented in the next chapter suggests that they are of limited importance.

CHAPTER 4

THE REPRODUCTION OF TIME-INTERVALS IN SERIES

> .... The best helps to the more certain discovery of the true time may be gathered .... from the number and duration of the quickest notes in any one bar ....
>
> Carl Czerny (1840)

The present study developed from the observation that certain rhythmic patterns in musical phrases appear to be much more difficult to grasp, and much more prone to error in their reproduction, than others. The ability to tap out the rhythm of a musical phrase is a skill required of candidates at all but the most advanced levels by all the major musical examining bodies, but no information beyond the subjective impressions of teachers and examiners is available as to the degree of difficulty which various rhythms present.

In tapping out such rhythms, the subject is in fact reproducing a series of successive time intervals. Traditionally, studies of the reproduction of time-intervals have used the individual presentation of a number of single intervals (Woodrow, 1930, 1933; Kowalski, 1943; Fox, 1952), while the large number of early studies of rhythm (Bolton, 1893; Squire, 1901; Miner, 1903; Dunlap, 1912; Swindle, 1913) were not concerned with the intervals between the rhythmic stimuli, and frequently yielded merely a proliferation of such specious generalisations as Seashore's : "All rhythm is primarily a projection of personality. The rhythm is what I am. For him who is not endowed with this talent the objective workings of rhythm in nature and art are largely wasted." (Seashore, 1919).

Until quite recently, most of the very few studies involving a series of time intervals have used the method of comparison, requiring the subject to compare the rates of two different series of uniform time-intervals (Gault and Goodfellow, 1938; Cantor and Girardeau, 1959), or to spot a variation in the duration of a single interval in a very simple and otherwise repeating pattern, as in the Seashore "Sense of Rhythm" test (Seashore, 1938).

The method of comparison does not lend itself to greater sophistication than this, the method of verbally reporting a comparison being impossibly unwieldy where the variation in several different time-intervals in involved. Moreover the difficulties encountered in attempting to control with a high degree of accuracy the varying durations of a number of successive time-intervals, have in the past been very great indeed. The advent of computer control systems in the psychological laboratory has overcome this problem and vastly increased the possibilities for accurate experimentation in this field. However, the emphasis in recent studies using these techniques is on pattern perception. Attention has been directed to the importance of the effect of pitch variation (Royer and Garner, 1970), cross-modal transfer (Rubinstein and Gruenberg, 1971), and learning (Garner and Gottwald, 1968; Handel and Lewis, 1970) on pattern perception, but the effect of this patterning on the perception of the time-intervals defined by the pattern still remains unexplored.

The present study was designed to investigate this field, and to examine the possibility that the patterning of time intervals not only affects the perception of those intervals, but that in fact the intervals are perceived in terms of the pattern. It was hypothesised that on presentation of a series of time-intervals, the stimuli demarcating the initial intervals in the pattern set up their own reference rhythm in terms of which the durations of the later intervals in the series are judged. This is not to deny the importance of some fundamental physiological periodicity such as the alpha rhythm, in providing an ultimate reference for the estimation of time-intervals, but a system which can adjust to estimate in terms of a slower reference rhythm where such is provided by the environmental stimulation would appear to be much more efficient than one in which all durations, no matter how long, are judged in terms of a single high-frequency rhythm.

Eccles (1957) has point out that: "Individual nerve cells and simple spinal cord reactions show a fundamental tendency to repeat actions which have once occurred. This facilitation of response is common to all nervous tissue and constitutes the simplest form of memory." Such a characteristic of neural networks could account for the hypothesised setting-up of a reference rhythm by the two changes in environmental stimulation marking off a time-interval.

One study which, while not designed to test such a hypothesis, nevertheless provides suggestive evidence in its favour, is that by Denner, Wapner, McFarland and Werner (1963) who found that when subjects were required to tap continuously during both the presentation and the reproduction of a 70 second interval, changing the tapping rate between presentation and reproduction induced errors of up to 35% in the reproduction. Furthermore, Mayo (1950) has suggested that the "sequence of actual physical events presented by the external world to the observer, or else brought about by his actions" is used in assessing the durations of relatively long periods of time.

There are thus some grounds for the preliminary outline theory of time perception sketched below:

<u>Hypothesis 1</u>: The duration of a time-interval is estimated by counting the number of cycles of a reference rhythm.

<u>Hypothesis 2</u>: The alpha or other endogenous rhythm provides such a constant internal reference rhythm.

<u>Hypothesis 3</u>: (a) When incoming stimuli (S_1, S_2) are separated by a time-interval, T_i (the duration of T_i lying between certain critical maximum and minimum values), they set up a reference rhythm (R_r) with frequency $\frac{1}{T_i + \delta T_i}$ and variance $\sigma^2_{T_i}$, which supersedes the endogenous rhythm as a standard in terms of which the durations of time-intervals between subsequent stimuli are judged. δT_i may be positive, negative or equal to zero, and is a measure of the precision with which the internal rhythm mirrors the occurence of the external events S_1 and S_2.

(b) By appropriate instructions, as given in the method of reproduction, the reference rhythm R_r may be converted into a rhythmic "tendency to response" (A_i) with frequency $\frac{1}{T_i + (\delta T_i + \theta_1)}$ and variance $\sigma^2_{T_i'}$, the difference between $\sigma^2_{T_i}$ and $\sigma^2_{T_i'}$ being determined by the magnitude of θ_1. θ_1 reflects an increase in δT_i as a result of the involvement of a larger neuronal network. (As in the case of δT_i, $\theta_1 \gtreqless 0$).

Hypothesis 4: (a) The greater the number of stimuli which follow each other at equal intervals, the more firmly will R_r be established and the more accurately will the duration of subsequent intervals be perceived. Occurences of S_i ($i > 2$) after S_2 with the same interval T_i between the S_i "reinforce" R_r, reducing σ^2_{Ti} (the variance in the time intervals $T_i + \delta T_i$ of R_r) thus making R_r a more stable standard in terms of which the subsequent intervals are perceived.

(b) A time-interval $T_S = T_i$, following a series of n S_i $(n > 2)$ in which all T_i's are equal, will be reproduced as the time-interval $T_R = T_i + (\delta T_i + \theta_1 + \theta_2)$. The reproduction of this interval involves merely the conversion of two of the "tendencies to responce", A_i, into overt motor responses, θ_2 representing the possible distortion of the perceived interval by the motor response mechanism. θ_2 may be positive or negative but almost certainly does not equal O, and is at least partially a function at the length of T_i.

(c) The reproduction of a series of m equal intervals $T_S = T_i$ involves the conversion of $(m+1)$ A_i's into overt motor responses. For a given $T_S = T_i$, $|\{T_i + (\delta T_i + \theta_1 + \theta_2)\} - T_S|$ (the absolute error of reproduction) will approach a minimum as m increases up to a certain point (reflecting the reinforcement of R_R), but as m increases beyond this point $|\{T_i + (\delta T_i + \theta_1 + \theta_2)\} - T_S|$ will again increase (reflecting the effect of reactive inhibition).

Hypothesis 5: The reproduction of an interval $T_M = nT_i$ after a series of intervals T_i has established R_r (with the time-interval between the $A_i = T_i + \delta T_i$) requires the inhibition of (n - 1) of the A_i. The inhibition of the A_i will exercise a disrupting effect on the reproduced interval T_m, the extent of such disruption being a function of

(a) n,

(b) the duration of T_m and

(c) certain physiological characteristics of the subject, related to the rate of build-up and dissipation of inhibition.

<u>Hypothesis 6</u>: The perception of an interval $T_I = n T_i + \Delta T_i \quad (\Delta T_i < T_i)$ after a series of intervals T_i has established R_r with frequency $\frac{1}{T_i + \delta T_i}$, involves the counting of n of the intervals T_i plus the estimate of ΔT_i. ΔT_i is probably estimated in terms of the number of cycles of the endogenous rhythm, or possibly by fractionation of T_i. The reproduction of T_I then involves the inhibition of (n - 1) of the A_i and the displacement of the last A_i by a "correction interval", the length of the correction interval being determined by S's estimate of ΔT_i

EXPERIMENT 1

As a preliminary exploration of this theory, an experiment was designed to investigate the effect on the accuracy of reproduction of a 1 second interval of embedding the interval in various rhythmic patterns. The eight different patterns selected are detailed below. (In all the experiments, durations are given in milliseconds, and also, where appropriate, in the convenient shorthand of musical notation expressing 1000 as

the values of these symbols have in a moderately quick musical performance at a metronome speed of 𝅗𝅥 = 120).

A	𝅝	1000
B	𝅝 𝅝	1000 1000
C	𝅝 𝅝 𝅝	1000 1000 1000
D	𝅝 𝅝 𝅝 𝅝	1000 1000 1000 1000
E	𝅝 𝅝 𝅝 𝅝 𝅝	1000 1000 1000 1000 1000
F	𝅗𝅥 𝅗𝅥 𝅗𝅥	500 500 1000
G	𝅗𝅥 𝅝 𝅗𝅥	500 1000 500
H	𝅝 𝅗𝅥 𝅗𝅥	1000 500 500

The reproductions of series A to E provide information about changes in the accuracy of reproduction of equal intervals with increasing series length, those of series F, G and H provide information about changes in accuracy where the 1000 ms interval occupies different positions in a pattern of long and short time-intervals (in the ratio of 2:1) of equal total duration. Patterns F, G and H were submitted to three music examiners who were unanimous in arranging the three patterns in ascending order of difficulty as: F, H, G.

Apparatus:

All time-intervals were demarcated by a short (50 ms) burst of a 297-cycle tone from a sine-wave oscillator delivered over AIWA HP II stereo headphones. Subjects were required to reproduce the presented intervals by tapping on a light telegraph key. A Hewlett Packard 2114B computer controlled the presentation of all stimuli and measured the subject's reproduction times. The computer was programmed to time accurately to the millisecond. As a check on this, a series of 7 time-intervals (100, 250, 500, 750, 1000, 1250 and 1500 millisecs) output by the computer were measured by means of a Venner Digital Counter Type TSA 6636. Accuracy of measurement of the digital counter was quoted by the manufacturers as 1 microsecond. Measurements of the 7 test intervals were repeated on a further 2 occasions during the course of the experiments. A maximum discrepancy of 2 milliseconds was found between the readings of the computer and the digital counter. It can thus be concluded with reasonable confidence that all reported reproduction times are accurate to $\pm$ 2 milliseconds.

Subjects

Subjects were 11 males and 9 females drawn from various occupations and ranging in age from 16 to 48 years (Mean 25. 4 years, Median age 24 years).

Method

Each subject attended a 30 minute session in a dimly-lit and sound-deadened room, being informed that this was an experiment to test the accuracy with which he could reproduce various rhythmic patterns. S was seated as comforably as possible in front of a table to which the telegraph key was attached, and given approximately one minute to practise freely on the telegraph key.

S was then told that he would be given a number of practice trials and presented with the following series of intervals. (Each series was presented 3 times, and at the end of each of the 3 presentations, S tapped out his attempted reproduction of the pattern, being told before each presentation how many sound-pips to expect).

(all durations in milliseconds)

333 666

824

300 300 300

625 625 625 1250

400 600 400

The experimental series then commenced, S being informed of the fact and urged to respond as accurately as he was able. He was also requested to inform E immediately he felt any signs of fatigue, irritation or boredom, and also if he felt he had been distracted in any way during either the presentation or reproduction of any series. Where S did report such distraction (desire to yawn, incipient cough) his results for that reproduction were discarded and a further presentation of the series given. As in the warm-up trials, S was told before the presentation of each series how many sound-pips to expect.

Because of the reported occurrence of a gradual lengthening of reproductions during the course of a session (Treisman, 1963; Ross, 1969; Carlson and Feinberg, 1970) and the strong possibility of carry-over effects from one series to the next, each S was presented with a different randomised order of the 8 series. Each series was presented 3 times and the means of the 3 reproductions recorded for further analysis.

Results

The mean reproduction of each interval in each series A to E was recorded (Appendix I, Table 1) and from this the percentage absolute error (magnitude of error without regard to sign) of each interval in each series determined. From these figures the mean value of the percentage absolute error for each of the series as a whole was calculated (Appendix I, Table 2). Inspection of the averages of these values for all subjects for each series shows a steadily decreasing error as the length of the series increases, which is paralleled by an almost consistent decrease in the variability among the subjects.

TABLE 1.

SERIES	MEAN PERCENTAGE ABSOLUTE ERROR OF SERIES MEANS FOR ALL SUBJECTS	S.D.
A	9.89	7.95
B	8.60	4.35
C	6.52	2.41
D	5.78	2.53
E	3.50	1.49

Analysis of variance of the data revealed that the decrease in mean percentage absolute error was highly significant ($p < .01$). Further application of the Scheffé procedure revealed that only the difference between series A and E, and that between B and E were significant at the 1% level, while that between series A and D was significant at the 5% level. (Appendix I, Table 3).

Unfortunately these results are difficult to interpret, and while suggestive, do not provide unambiguous evidence in favour of hypothesis 4 (that reinforcement of a hypothesised reference rhythm leads to increased accuracy of reproduction). When making his reproduction of series E, S had in fact received in the period immediately preceding his reproduction, five times as many presentations of the standard 1000 ms interval as he had in the period immediately preceding his reproduction of series A. (In the course of the whole experimental session all subjects received the same total number of presentations of the 1000 ms interval). From the present data there is no means of determining how much of the increase in accuracy of reproduction from series A to series E is to be attributed simply to the greater number of presentations of the 1000 msec interval received by S immediately before making his reproduction of series E, and how much to the specific effect of rhythmical presentation of the standard. Additional experimentation is required to clarify this point.

However, the experiment does yield interesting data on the possible contribution of purely motor factors. Examination of the values of the percentage absolute error of the first and last intervals in each series (Appendix I, Table 4) reveals that they show the same trend as the mean percentage absolute error of each series as a whole.

TABLE 2.

SERIES	POSITION OF INTERVAL IN SERIES	MEAN PERCENTAGE ABSOLUTE ERROR OF INTERVAL
A	First and last	9.89
B	First	8.94
	Last	8.26
C	First	6.47
	Last	7.79
D	First	6.12
	Last	5.71
E	First	2.81
	Last	2.93

Analysis of variance on the data (Appendix I, Table 5) shows that the decrease in error between the first intervals of Series A and E, and that between the first intervals of series B and E is significant at the 1% level. On the other hand, the decrease in error between the last intervals in series A and E is significant at the 1% level, while that between the last intervals of series B and E is significant at the 5% level. Comparison of the percentage absolute error in the first and last intervals of each series reveals no significant differences, even at the 5% level. In other words, there is virtually no evidence of deterioration or improvement in performance over a series of up to 5 successive reproductions of equal intervals, as would be expected if fatigue or rhythmical motor response habits (Treisman, 1963) were contributing significantly to the errors in (or accuracy of) reproduction in series of this length.

The mean values over three reproductions of each interval in the series F, G and H are recorded in Table 6 (Appendix I). Again the average reproduction times for each interval were converted into percentage absolute errors (Appendix I, Table 7).

The averages of these values are given below (durations in milliseconds):

TABLE 3.

SERIES	INTERVAL IN SERIES	AVERAGE PERCENTAGE ABSOLUTE ERROR OF REPRODUCTION FOR ALL SUBJECTS
F	1st (500)	10.5
	2nd (500)	9.97
	3rd (1000)	10.15
G	1st (500)	8.34
	2nd (1000)	11.57
	3rd (500)	9.00
H	1st (1000)	10.97
	2nd (500)	12.12
	3rd (500)	13.59

Analysis of variance indicated no significant differences in this data at the 5% level. (Appendix I, Table 8).

Inspection of the mean percentage absolute error of all the intervals in each series as a whole confirms the impression that errors in series H were higher than in series F and G. These mean percentage absolute errors for the whole of series F, G and H were compared with those for the whole of series B (total durations of series B, F, G and H being equal) and those for the whole of series C (series C, F, G and H all containing the same number of intervals). (Appendix I, Table 9). The averages and standard deviations of these values for all subjects are given below.

TABLE 4

SERIES	MEAN PERCENTAGE ABSOLUTE ERROR OF ALL INTERVALS IN SERIES	
	Averages for all subjects	S.d.
B	8.6	4.35
C	6.52	2.41
F	10.2	7.15
G	9.63	5.29
H	12.73	7.45

Analysis of variance on this data showed significant differences at the 1% level. Further application of the Scheffé procedure revealed that the only significant differenct (at the 5% level) was that between the errors in series C and H which were significant at the 1% level. Differences between series F, G and H were not significant, nor was that between the average of series F, G and H (10.85) and series C (Appendix 1, Table 10).

In all the series C, F and G, the durations of subsequent time-intervals in the series are either equal to, or double that of the first. In terms of the mechanism postulated in hypotheses 4 and 5, the first interval sets up a reference rhythm and the subsequent intervals are perceived as being equal to one or two cycles of that reference rhythm. In terms of these hypotheses, of the four series C, F, G and H:

(1) C should be the most accurately reproduced (two reinforcements of R_R and no inhibition of A_i).

(2) F should be the next most accurately reproduced (one reinforcement of R_R and inhibition of one A_i).

(3) G should be less accurately reproduced (no reinforcement of R_R, and inhibition of one A_i)

(4) H should be least accurately reproduced of all, because estimation of the second and third intervals in the series, if made in terms of the cycles of a reference rhythm set up by the first interval, would require fractionation of that standard, presumably a more complex and possibly disrupting process than a simple counting of a number of cycles (but one which may well occur -- Gregg, 1951).

This predicted increasing error in the reproductions of the series C, F, G and H is in fairly close agreement with the observed results, although only the difference between the errors in series C and H are significant.

In view of the hypothesised functional relationship between the effects of inhibition of A_i and physiological characteristics of the subject (hypothesis 5) it is significant to note the considerable increase in variability among subjects in the three series F, G and H (requiring the hypothesised inhibition of A_i). The closer examination of the relationship between the disrupting effects of unequal intervals in a series of time-intervals and other inhibitory phenomena, promises to be a fruitful field of investigation, the results of which, it is hoped, will contribute considerably to the more detailed elaboration of the theory of time-perception outlined in this chapter.

Although, in the absence of statistically significant differences between the errors in series F, G and H, little importance can be attached to the comparison, it is thought-provoking to compare the ranking of the order of difficulty of the patterns F, G and H as determined by the percentage errors in reproduction with that unanimously given by the music examiners previously referred to. In ascending order of difficulty they are:

Music Examiners	Experiment 1
F	G
H	F
G	H

yielding a (non-significant) Spearman correlation coefficient of -0.5!

The general trend of the results of experiment 1 provided encouraging evidence in favour of the present theory, and seemd to justify an extension of the investigation to slightly longer series, in which it was hoped the trends manifested in experiment 1 would show up more clearly.

EXPERIMENT 2

For this experiment, two sets of six series (each consisting of five successive time intervals) were selected. The first five series of the first set (series I to M) consisted of all possible combinations of four 250 ms.intervals and one 500 ms. interval. The first five series of the second set (series O to S) consisted of all possible combinations of four 250 ms.intervals and one 1000 ms. interval. The last series of the first set (series N) consisted of a 500 ms. interval preceded by four time-intervals whose lengths were in the complex ratios of 3 : 5, 7 : 5, 6 : 5, and 4 : 5 to that of the 500 ms. interval. The durations of the four preceding intervals were chosen so that the mean of the first and second intervals, and of the third and fourth were equal to 500 ms. The last series of the second set (series T) consisted of a 1000 ms. interval preceded by the same four intervals as were used at the beginning of series N. These constitute the twelve patterns used in this experiment and listed below (durations again expressed in musical notation and in milliseconds).

TABLE 5

I	𝅗𝅥	♩	♩	♩	♩	500	250	250	250	250
J	♩	𝅗𝅥	♩	♩	♩	250	500	250	250	250
K	♩	♩	𝅗𝅥	♩	♩	250	250	500	250	250
L	♩	♩	♩	𝅗𝅥	♩	250	250	250	500	250
M	♩	♩	♩	♩	𝅗𝅥	250	250	250	250	500
O	𝅝	♩	♩	♩	♩	1000	250	250	250	250
P	♩	𝅝	♩	♩	♩	250	1000	250	250	250
Q	♩	♩	𝅝	♩	♩	250	250	1000	250	250
R	♩	♩	♩	𝅝	♩	250	250	250	1000	250
S	♩	♩	♩	♩	𝅝	250	250	250	250	1000

These patterns were submitted to the three music examiners who had previously rated the patterns F, G and H of experiment one. They submitted the following (less unanimous) rankings in ascending order of difficulty.

TABLE 6

Examiner 1	Examiner 2	Examiner 3
M	M	M
I	I	I
K	S	K
L	O	S
J	K	Q
S	Q	L
Q	J	J
R	L	R
P	R	P
O	P	O
N	N	N
T	T	T

Considering these more extended patterns carefully, it became obvious that the six hypotheses elaborated were inadequate to mediate any predictions as to the relative magnitude of the errors of reproduction which could be expected in series I to M and O to S. In order to make such predictions, hypotheses about the interaction of the disrupting effects of inhibition of A_i and level of reinforcement of R_R, and about the effects of interruptions of the reinforcement of R_R after a varying number of reinforcements, are required. It was hoped that clues as to the nature of these relationships might be provided by the performance of subjects reproducing these patterns. The only clear-cut prediction which was possible was that the error of reproduction of the 500 msec interval in series N (in which there are no reinforcements of the hypothesised reference rhythm set up by the first two stimuli) would be greater than that in series M (where there are two reinforcements of the 'reference rhythm') and similarly that the error of reproduction of the 1000 ms. interval in series T should be greater than that in series S.

METHOD

The same apparatus, subjects and method were used as in experiment 1, the subjects attending a second 30 minute session approximately one week after the first. As in experiment 1, subjects were given a minute of unguided practice in tapping the telegraph key. They were then told that they would be given a series of 5 practical trials and presented with the following series of intervals. (Each series was presented 3 times, and at the end of each of the 3 presentations, S tapped out his attempted reproduction of the pattern, being told that in each series during this session he would hear 6 sound pips.)

TABLE 7

(all durations in milliseconds)

200	200	200	200	200
350	350	350	350	700
880	440	440	440	440
225	225	225	225	225
600	600	600	1200	600

The experimental series then commenced, S being informed of the fact and urged to respond as accurately as possible. As before he was asked to report any distractions during either the presentation or the reproduction of any series, and finally reminded that each series would contain 6 sound pips. As in experiment 1, each subject was presented with a different randomised order of the 12 series, and presented with each series 3 times, the mean reproduction of each interval being recorded for further analysis.

RESULTS

The mean reproduction of each interval in each series I to N was recorded (Appendix II, Table I) and also that of each interval in each series O to T (Appendix II, Table 2). From these results the percentage absolute error of each interval in each series was determined, and from this the mean values of the percentage absolute error of all reproduced intervals in each of the series I to M and O to T (Appendix II Table 3). The averages and standard deviations of these values for all subjects for each series I to M and O to S are given below.

TABLE 8

Series	Mean percentage absolute error	S.D.
I	17.04	13.04
J	14.60	8.41
K	9.11	5.92
L	12.83	10.35
M	11.06	5.90
O	8.58	4.06
P	11.09	6.04
Q	6.49	3.78
R	13.71	9.51
S	11.22	8.24

On the basis of these results the series were ranked in ascending order of difficulty.

TABLE 9

Series	Pattern									
Q	♩	♩	𝅝	♩	♩	250	250	1000	250	250
O	𝅝	♩	♩	♩	♩	1000	250	250	250	250
K	♩	♩	𝅗𝅥	♩	♩	250	250	500	250	250
M	♩	♩	♩	♩	𝅗𝅥	250	250	250	250	500
P	♩	𝅝	♩	♩	♩	250	1000	250	250	250
S	♩	♩	♩	♩	𝅝	250	250	250	250	1000
L	♩	♩	♩	𝅗𝅥	♩	250	250	250	500	250
R	♩	♩	♩	𝅝	♩	250	250	250	1000	250
J	♩	𝅗𝅥	♩	♩	♩	250	500	250	250	250
I	𝅗𝅥	♩	♩	♩	♩	500	250	250	250	250

A further interesting sidelight on the fallibility of music examiners was provided by correlating this ranking with those of the three music examiners. This yielded (non-significant) Spearman correlation ratios of -0.297 with the ranking of the first examiner, 0.111 with that of the second, and -0.079 with that of the third.

Specific predictions about the relative accuracy of reproduction of these various series had not been made, but it was hoped that some trend would become clear in the data when collected. This hope was not to be realised. The series M, L, J, I show increasing error with decreasing number of 250 msec. intervals before the 500 msec. interval. But the 1000 msec. patterns neither exhibit nor reverse this trend, nor apparently manifest any other.

Analysis of variance on this data however indicated a significant difference (and that only at the 5% level) between the average errors of reproduction of only two of the series, I and Q. (Appendix 2, Table 4). But closer examination revealed that the variability between subjects was very high indeed, and created a situation where no significant difference showed up even in cases (series I and O) where the average error in one series was more than twice that in the other. Further discussion of this point is deferred until the end of the chapter.

In the absence of any significant differences except that between the series I and Q, it is not profitable to speculate on the possible implications of this difference.

The apparent absence of any trend in the data from the reproductions of series I to M and O to S is further confirmed by examination of the percentage errors in reproduction of just the 500 ms and 1000 ms intervals in these patterns (Appendix II, Table 7).

TABLE 10

INTERVAL in	SERIES	Average percentage absolute error for all subjects	S.D.
500 ms	I	43.73	47.04
	J	35.87	26.80
	K	20.15	24.52
	L	28.05	29.13
	M	27.02	23.00
1000 ms	O	13.67	11.92
	P	19.07	11.34
	Q	13.57	9.25
	R	24.38	11.45
	S	16.29	13.35

Analysis of variance on the data (Appendix II, Table 8) showed a significantly greater percentage absolute error (at the 5% level) in the reproduction of the 500 ms when placed first in the series (series I) than in the reproduction of the 1000 ms interval in the same position (Series O). The similarly significant difference between the 1000 ms interval in series Q and the 500 ms interval in series I is even more difficult to interpret in the absence of any other statistically significant differences.

Comparison of the accuracy of reproduction of series M (in which the 500 ms was preceded by four 250 ms intervals) with that of series N (in which the 500 ms interval was preceded by four different intervals) and that of series S with that of series T (in both of which the 1000 msec interval is similarly preceded), revealed highly significant differences ($p < \cdot 01$, Appendix II, Tables 5 and 6).

TABLE 11

SERIES	Average of mean percent absolute error
M	11.06
N	24.38
S	11.22
T	28.85

Scheffé comparisons of these means indicate significant differences between series M and N and between S and T at beyond the 1% level, and no significant differences between series M and S, and N and T at the 5% level. The accuracy of reproduction of the 500 ms and 1000 ms intervals themselves reflects the same trend, although only in the case of the 1000 ms interval (series S and T) is this difference statistically significant at the 5% level. (Appendix II, Tables 9 and 10).

TABLE 12

INTERVAL : SERIES		Percentage absolute error of reproduction
500 ms	M	27.02
	N	31.26
1000 ms	S	16.29
	T	35.38

We can therefore conclude with reasonable confidence that the prediction that the 1000 ms interval would be more accurately reproduced in series S than in series T has been borne out by the results obtained, but that these results do not provide acceptable evidence for the greater accuracy of reproduction of the 500 ms interval in series M than in series N.

CONCLUSIONS

The massive variability encountered in the results of this experiment was initially a considerable disappointment. Closer examination of the results however suggested that perhaps the use of the present method of averaging the results of a large number of subjects (the method generally used in studying the reproduction of time-intervals) may result in the loss of a great deal of valuable information, and that only a more refined analysis of the reproductions of individual subjects can hope to provide information of any significance. For instance in Table 3 (Appendix 2) the very high standard deviations associated with the larger average percentage errors suggest an exaggerated reaction on the part of certain subjects which may obscure the presence of completely different patterns of behaviour (for instance the strikingly different performance of subjects 2 and 11 - Table 3, Appendix 2).

Examination of the raw data in Table 1 (Appendix II) reveals the striking fact that no fewer than 4 subjects (1, 6, 7 and 14) over-reproduced the first (500 ms) interval in series I by more than 100%. In all the other 500 ms series put together an error of this magnitude only occurred once (S3, series L).

The fact that such an error, the occurrence of which is clearly relevant to hypotheses about the counting of cycles (hypothesis 1) and the inhibition of A_i (hypothesis 5), should occur with such relatively great frequency when the interval concerned was in first place in the series (before a reference rhythm was established) is a highly significant fact that merits closer investigation, but one that is totally obscured in the average of 20 subjects' reproductions. In view of this fact it was decided to use only 5 subjects in an experiment designed specifically to test hypothesis 6 and to examine their individual results in detail.

CHAPTER 5

THE CORRECTION FACTOR

> ... The same sound produces absolutely different effects on the ear, according as it is heard in connection with one or another series of sounds......
>
> Charles Darwin (1872)

Hypothesis 6 of the theory outlined in the last chapter postulates that a given time-interval will be differently estimated depending on the pattern of stimulation which precedes that interval. For instance, on this hypothesis a 1000 msec. interval preceded by a number of 500 msec. intervals will be perceived as being twice the length of the first 500 msec. interval, and reproduced as two cycles of the reference rhythm set up by it. A 1000 msec. interval preceded by a number of 300 msec. intervals will however be perceived as being equal to three 300 msec. intervals plus a correction interval, and reproduced as 3 cycles of the reference rhythm (R_R) set up by the 300 msec. intervals plus a correction interval.

An experiment was carried out to seek evidence for these processes by systematically varying the durations in a series of uniform time-intervals preceding a 1000 msec. interval. Errors in reproduction of the 1000 msec. interval in such series may be due to either:

(1) a miscounting of the number of cycles of R_R,

or (2) the disrupting effects of inhibition of the A_i,

or (3) errors in estimating the correction interval.

Experiment 3

5 different series were used in this experiment. The durations of each interval in each series are given in Table 13 below.

TABLE 13

Series	Durations in milliseconds				
U	200	200	200	200	1000
W	250	250	250	250	1000
X	300	300	300	300	1000
Y	400	400	400	400	1000
Z	500	500	500	500	1000

Method

5 of the subjects who had taken part in Experiments 1 and 2 each attended a further 20 minute experimental session. Experimental conditions were exactly as for experiment 2, with the same equipment, initial practice trials and instructions. As in the previous experiments a different randomised order of the series was given to each subject, and as before each series was presented 3 times. The last two subjects to be tested (S9 and S20) attended for a 50 minute session each, in which a number of additional series, following the same general pattern as series U to Z were given. (Appendix III, Table 2).

Results

The results obtained for the series U to Z are listed in Table 1 (Appendix III) and plotted graphically in Figs. 1 to 5 below.

This data is represented graphically in Figs 1 to 5 below:-

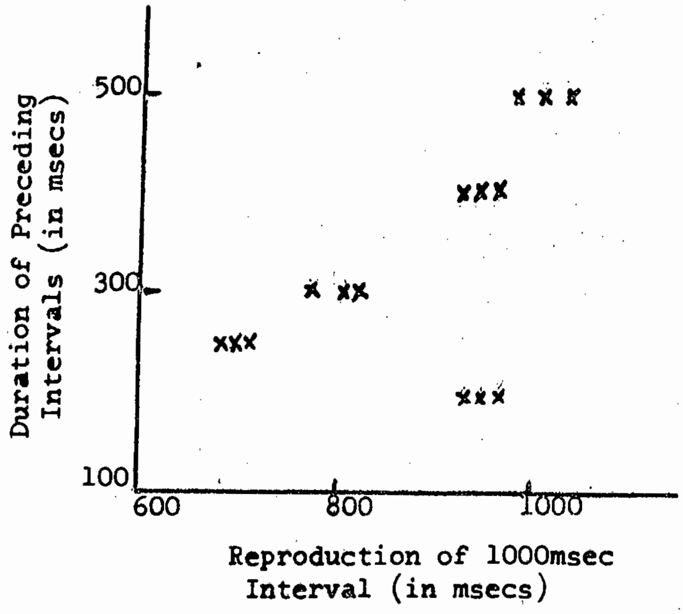


FIG. 1 (S 2)

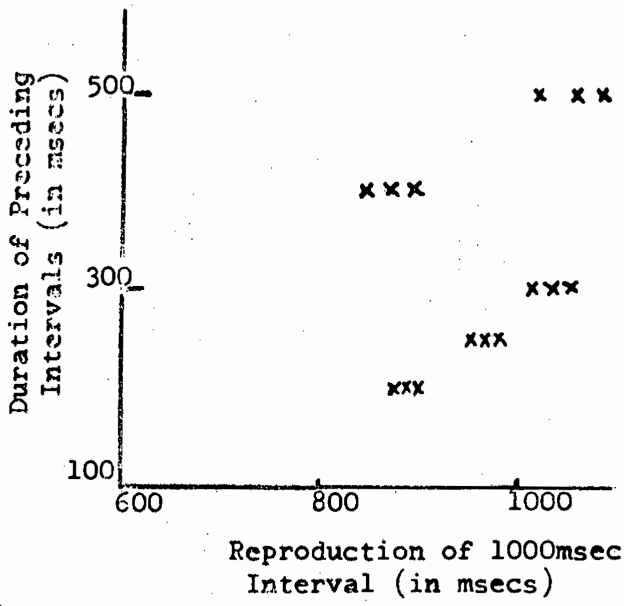


FIG. 2 (S 8)

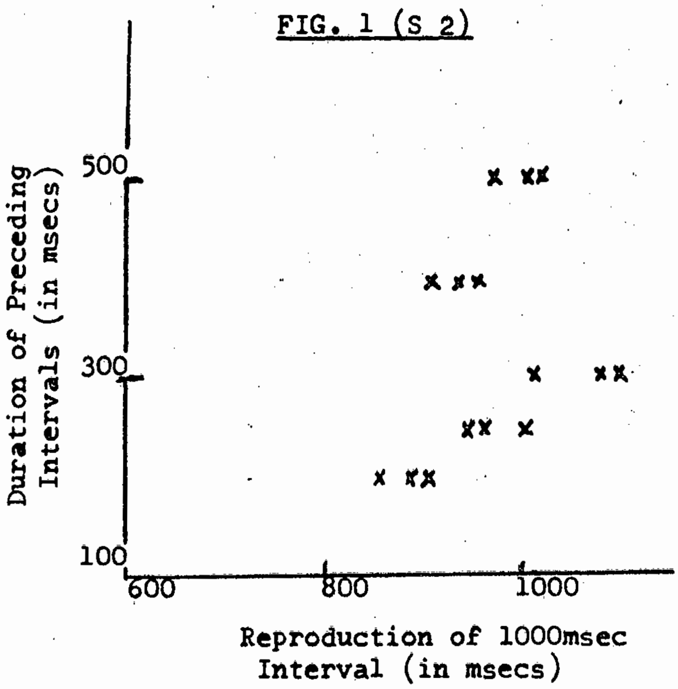


FIG. 3 (S 9)

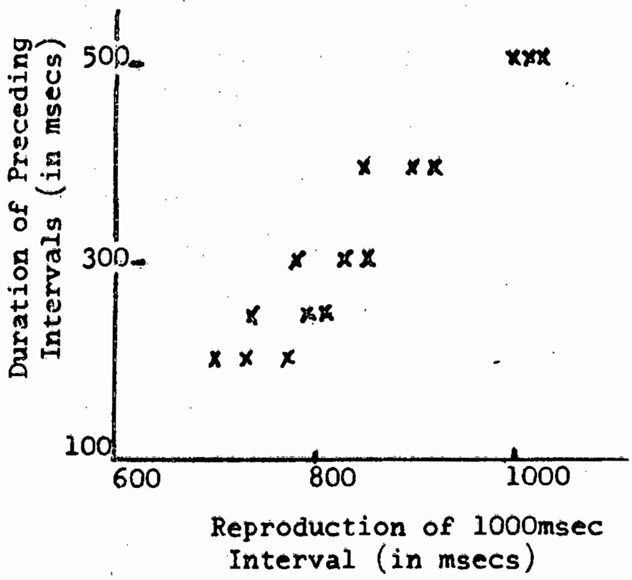


FIG. 4 (S 10)

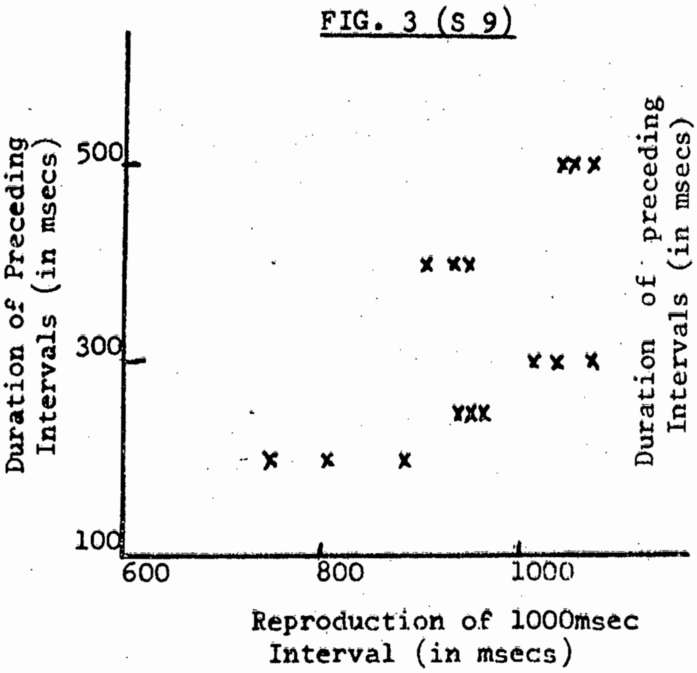


FIG. 5 (S 20)

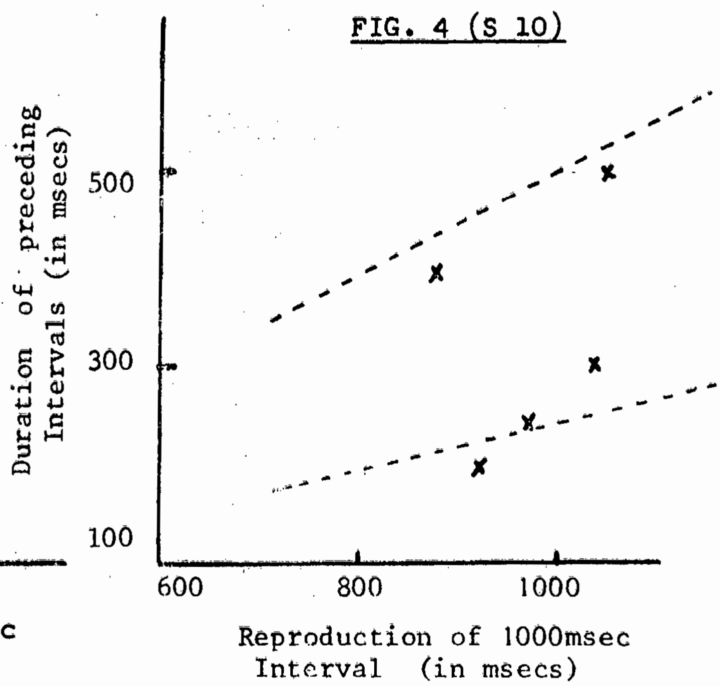


FIG. 6 (S 8)

Despite the variability in these results, their graphical display gives a striking demonstration of the control exercised by a preceding series of time intervals on the reproduction of a subsequent 1000 msec. interval. A preceding series of short intervals is followed by a shorter reproduction ~~of the 1000 msec. intervals is followed by a shorter reproduction~~ of the 1000 msec. interval, and a preceding series of longer intervals is followed by a longer reproduction of the same interval. But that this is not a simple generalised speeding up or slowing down of the response rate is clearly shown by the way in which the graph "breaks back" (at different points for different subjects) to values of the reproduced interval which are close to simple multiples of the intervals of the preceding series (T_i). This is just the effect which would be expected when *S* shifts from basing his assessment of the duration of the 1000 msec. interval on one multiple of the interval T_i, to basing it on another. The difference between the reproduced interval and a simple multiple of T_i can be interpreted as indicating the effect of the hypothesised "correction factor" (hypothesis 6). In Fig. 6 the actual performance of *S* 8 is contrasted with the expected values of his reproductions if there were no correction factor operating.

In an attempt to examine this correction effect further, subjects 9 and 20 were presented with an additional twelve series for reproduction. These were all of the same general pattern as series U to Z (4 equal intervals followed by a 1000 msec. interval), the durations of the 4 equal initial intervals being varied in 50 msec. steps from 200 to 1000 msecs. These additional series were presented in a different order, alternate long and short preceding intervals, to the two subjects. The results are recorded in Table 2, Appendix III, and displayed graphically below.

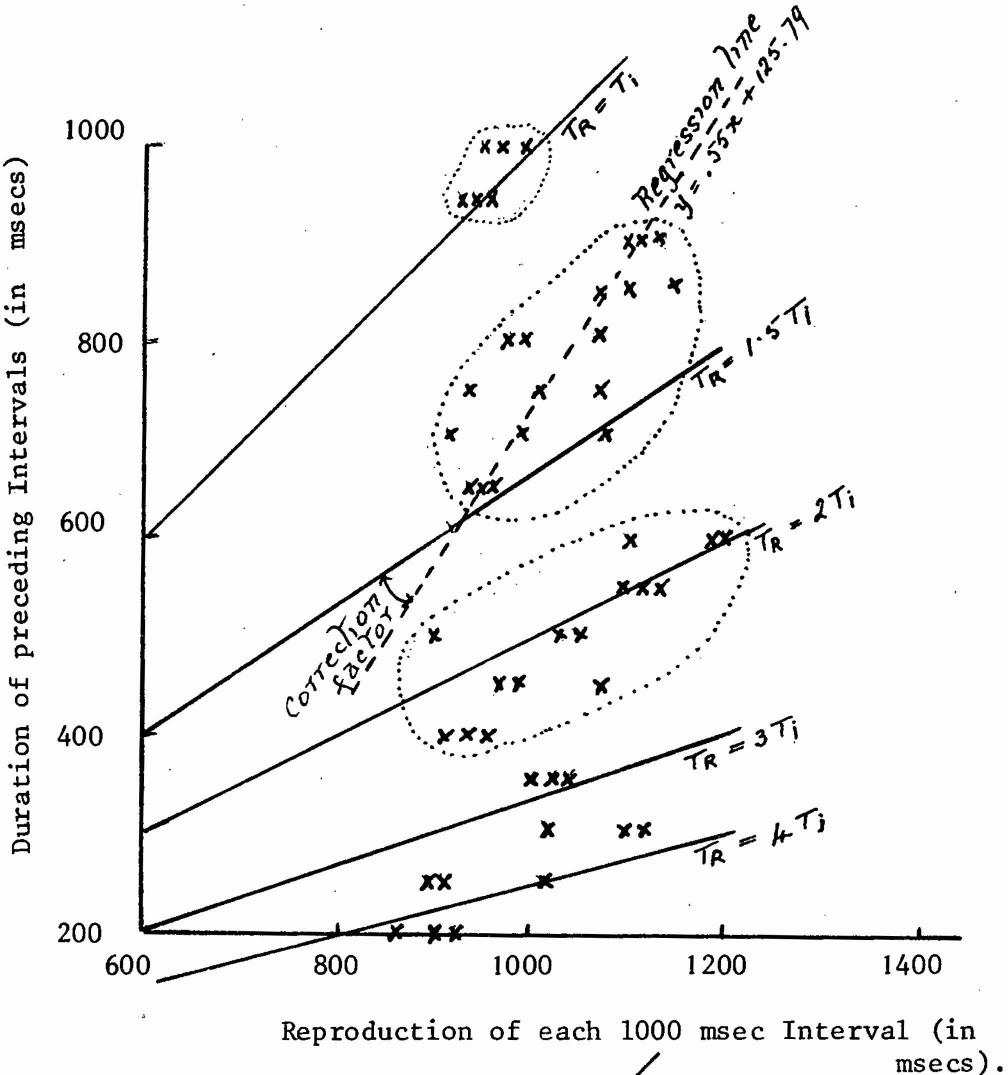


Fig. 7

(S 9)

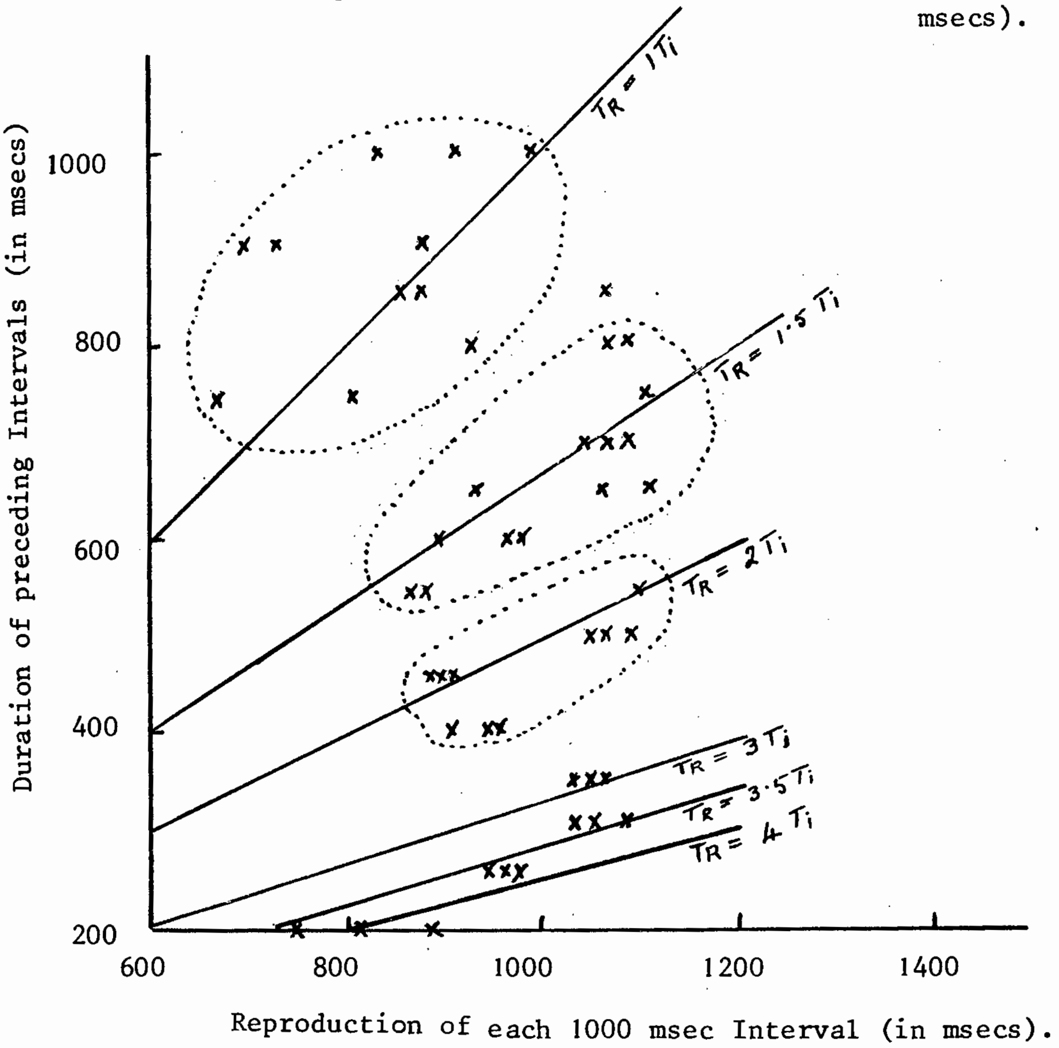


Fig. 8

(S 20)

The tendency for reproduced values of the 1000 msec. interval to cluster around the values of simple multiples of the preceding intervals, T_i (indicated by the solid lines in the graph) is even more impressive. The clear tendency in S 20's results (and slightly less obvious tendency in those of S 9) for a cluster around reproduced values $1\frac{1}{2}$ and $3\frac{1}{2}$ times the preceding intervals was very surprising and would appear to provide evidence for the occurrence of fractionation of the standard (Chapter 4, page 42).

CONCLUSIONS

If the trends manifest in the present data from this experiment are confirmed by further experimentation with more subjects and more reproductions of each series, there are stimulating prospects for further development of the present outline theory of time perception.

One such possibility is that the correction factor apparently operating here may prove to be an important physiological constant, the investigation of whose relationship with other physiological constants may prove of importance both inside and outside the field of time perception. As a preliminary step in this direction (a very tentative one because of the very few reproductions involved,) an attempt was made to quantify this correction factor by calculating linear regression lines for reproductions apparently made in terms of the same number of T_i (indicated by the dotted line envelopes in Figs. 7 and 8) and determining the angle between the slope of the regression line and the simple multiple of initial interval line. (Appendix III, Table 3).

Although at least one regression equation ($Y = -.14x - 475.3$, for subject 9) is almost certainly a spurious artifact of the small number of reproductions (3) on which this line is based, (and the fact they are all drawn from reproductions of the same series), and hence the "correction factor" associated with this line (marked * in Table 14 below) must be disregarded, the other values obtained for the correction factor suggest exciting possibilities.

TABLE 14

Correction Factor (in degrees and minutes)

SUBJECT	No. of T_i in T_2					
	1	$1\frac{1}{2}$	2	3	$3\frac{1}{2}$	4
9	$0^{\circ}35'$	$0^{\circ}44'$	$11^{\circ}23'$	$*26^{\circ}14'$	-	$9^{\circ}14'$
20	$12^{\circ}51'$	$24^{\circ}21'$	$34^{\circ}39'$	$49^{\circ}56'$	$57^{\circ}52'$	$57^{\circ}24'$

CHAPTER 6

WINDING UP THE BIOLOGICAL CLOCK

> Alice signed wearily. "I think you might do something better with the Time", she said, "than wasting it in asking riddles that have no answers."
>
> Lewis Carroll, (1865)

It is believed that the research reported in these chapters is the first to attach due importance to the patterning of the stimuli demarcating the time intervals, and to relate this factor to the mechanisms involved in time perception in general. In carrying out this research, some of the reasons for the lack of success of so many past studies dealing with this "venerable, tired concept in psychology that interests very few active investigators any more" (Adams, 1964) have become clear. Three factors stand out as being of particular importance.

(1) Attention must be directed to the stimuli defining the time interval rather than to the duration so defined. To become involved with the "qualities of consciousness" during "time experience" is to waste time "in asking riddles that have no answers." There are better things to do in the investigation of time perception.

(2) Traditional methods of analysing data obtained from the reproduction of short time intervals, of taking the average of several reproductions and dealing with the average of the average of several subjects' responses, are inadequate. The variability found in performance is not a random variability, except perhaps within very narrow limits. It seems rather that the variability in the averaged performance of many subjects occurs because the reproductions are in fact

highly sensitive measures of certain aspects of physiological functioning which vary widely from subject to subject. Only detailed analysis of all responses of each subject individually can hope to reveal data of any significance.

(3) The response traditionally used in studies of time perception, the tapping of a telegraph key, is not satisfactory. Throughout these experiments, the delay period between end of presentation and beginning of reproduction was recorded. Some interesting trends appeared discernible in the data from some subjects, but variability was so great that closer analysis would have been pointless. The "method of linear arm movement" (Danziger and Du Preez, 1963) offers a considerable improvement for relatively long time-intervals (more than 1 second) but is not usable with the shorter intervals under investigation here. The main difficulty with the traditional method of key tapping is that the subject either has to raise his hand before tapping, or keep it poised against the pull of gravity during presentation of the standard for reproduction. The uncontrolled contribution of inhibitory and "wrist-stiffness" factors, detracts considerably from the sensitivity of the method in reflecting perceived durations. In further testing of the theory of time perception elaborated here, it is proposed to arrange to have the subject's arm hanging freely by his side (eliminating anti-gravity muscular responses) with fingertips resting against a pressure-sensitive recorder. It is confidently expected that such apparatus will provide a far more sensitive measure of "tendencies to response" than that used in the present experiments.

In the course of this research many new approaches to old problems have suggested themselves. The "correction factor", if firmly established as a set of behavioural constants for a given individual, should prove of considerable importance in such a new approach. The interrelationships of this constant with EEG activity (particularly alpha rhythm characteristics), and parameters of conditioned reflex acquisition and extinction (with particular reference to the temporal reflex) are among the promising subjects for further research whose investigation may throw light on many aspects of physiological functioning at present imperfectly understood.

It is to be hoped that the development of the theory of time perception sketched in these chapters will help to bring some order and sense of direction into further research in this area, but it is also hoped that a recognition of the importance of rhythmic factors in the perception of time will stimulate research whose importance will extend far beyond this limited field.

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APPENDIX I

Series of time-intervals used in experiment 1.

	In musical notation	In milliseconds
A	𝅝	1000
B	𝅝 𝅝	1000 1000
C	𝅝 𝅝 𝅝	1000 1000 1000
D	𝅝 𝅝 𝅝 𝅝	1000 1000 1000 1000
E	𝅝 𝅝 𝅝 𝅝 𝅝	1000 1000 1000 1000 1000
F	𝅗𝅥 𝅗𝅥 𝅝	500 500 1000
G	𝅗𝅥 𝅝 𝅗𝅥	500 1000 500
H	𝅝 𝅗𝅥 𝅗𝅥	1000 500 500

APPENDIX I

TABLE I

Durations (average of 3 trials) of each subject's reproduction of each 1000 millisecond interval in each of the standard series A to E. All durations are recorded in milliseconds.

SUBJECT No.	SERIES														
	A	B		C			D				E				
	Position of reproduced interval in series														
	1	1	2	1	2	3	1	2	3	4	1	2	3	4	5
1	1351	1119	1181	959	978	956	917	889	908	918	937	908	962	940	962
2	1075	937	952	929	989	1080	919	921	987	935	976	975	1022	952	972
3	1171	1069	1105	1043	1106	1039	1015	1013	960	1017	943	946	969	964	994
4	945	995	995	1025	968	925	930	1002	980	963	988	1044	955	997	950
5	1086	918	1061	939	952	972	972	980	953	963	986	1003	992	1003	1034
6	1202	1221	1175	1103	1029	1083	1053	1052	990	1050	1037	1046	1071	1037	975
7	1043	1176	945	1024	1102	1060	971	882	1043	952	975	958	902	979	960
8	964	892	879	866	937	845	870	975	942	885	967	988	969	895	993
9	1093	1049	1092	971	1038	1043	1006	1043	1009	988	1009	1061	1001	1008	1022
10	1059	865	893	925	949	894	992	955	966	1076	935	957	939	952	940
11	879	871	937	918	898	938	918	866	937	900	904	932	929	972	975
12	1086	860	881	922	1014	949	970	874	976	975	986	900	998	1027	946
13	1009	955	919	972	953	1032	933	914	883	965	978	955	965	990	1007
14	1055	949	1044	977	990	1105	924	952	1040	1034	989	952	980	996	995
15	959	1032	1047	1110	1113	1109	1045	1095	1104	1080	980	971	990	1062	1031
16	818	936	901	953	902	933	910	953	950	943	990	951	955	987	984
17	1059	941	975	923	901	905	928	895	958	925	950	892	932	1027	956
18	962	900	967	930	969	899	882	880	924	892	980	974	948	951	953
19	830	920	906	949	984	905	1026	971	984	1022	987	978	984	1003	983
20	854	940	904	919	909	913	895	910	922	930	1017	987	961	1023	1019

APPENDIX I

TABLE 2

Mean values of the percentage absolute error of all reproduced intervals in each of the series A to E.

	SERIES				
Subject	A	B	C	D	E
1	35.1	15.0	3.6	9.2	5.8
2	7.5	5.6	5.4	5.9	2.9
3	17.1	8.7	6.3	2.1	3.7
4	5.5	0.5	4.4	3.2	3.1
5	8.6	7.1	4.6	3.2	1.2
6	20.2	19.8	7.2	4.1	4.3
7	4.3	11.5	6.2	5.9	4.5
8	3.6	11.4	12.1	8.2	3.7
9	9.3	7.1	3.7	1.8	2.0
10	5.9	12.1	7.7	4.6	5.5
11	12.1	9.6	8.2	7.0	5.8
12	8.6	12.9	4.8	5.1	4.0
13	0.9	6.3	3.6	7.6	2.4
14	5.5	4.7	4.6	5.0	1.8
15	4.1	4.0	11.1	8.1	3.0
16	18.2	8.2	7.1	6.1	2.7
17	5.9	4.2	9.0	7.3	6.0
18	3.8	6.7	6.7	10.6	3.9
19	7.0	8.7	5.4	2.3	1.4
20	14.6	7.8	8.6	8.6	2.2
Mean	9.89	8.60	6.52	5.78	3.50
S.D.	7.95	4.35	2.41	2.53	1.49

APPENDIX I

TABLE 3

Summary table of analysis of variance of the mean values of the percentage absolute error of all reproduced intervals in each of the series A to E.

Source of Variation	d.f.	Sum of Squares	Mean sum of squares
Length of	4	495.358	123.84
Residual	76	1255.1	16.51

$F = 7.5,\ P < .01$

Scheffé Comparisons

Means	d.f.	F	Probability
9.89, 8.6	4/76	.25	$>$ .05
9.89, 6.52	4/76	1.72	$>$ .05
9.89, 5.78	4/76	2.56	$<$ .05
9.89, 3.5	4/76	6.18	$<$ .01
8.6 , 6.52	4/76	.65	$>$ .05
8.6 , 5.78	4/76	1.20	$>$ .05
8.6 , 3.5	4/76	3.94	$<$ .01
6.52, 5.78	4/76	0.083	$>$ .05
6.52, 3.5	4/76	1.38	$>$ .05
5.78, 3.5	4/76	0.79	$>$ .05

APPENDIX I

TABLE 4

Percentage absolute error of reproduction of the first and last intervals in each standard A to E.

SUBJECT No.	SERIES								
	A	B		C		D		E	
	Position of reproduced intervals in series								
	First and Last	First	Last	First	Last	First	Last	First	Last
1	35.1	11.9	18.1	8.1	8.4	8.3	8.2	6.3	3.8
2	7.5	6.3	4.8	7.1	8.0	8.1	6.5	2.4	2.8
3	17.1	6.9	10.5	4.3	3.9	1.5	1.7	1.7	2.2
4	5.5	0.5	0.5	2.5	7.5	6.0	3.7	1.2	5.0
5	8.6	8.2	6.1	6.1	2.8	2.8	3.3	1.4	3.4
6	20.2	22.1	17.5	10.3	8.3	5.3	5.0	3.7	2.5
7	4.3	17.6	5.5	2.4	6.0	2.9	4.8	1.6	4.2
8	3.6	10.8	12.1	13.4	15.5	13.0	11.5	3.3	0.7
9	9.3	4.9	9.2	2.9	4.3	0.6	1.2	0.9	2.2
10	5.9	13.5	10.7	7.5	10.6	2.8	7.6	6.5	6.0
11	12.1	12.9	6.3	8.2	6.2	8.2	10.0	9.6	2.5
12	8.6	14.0	11.9	7.8	5.1	3.0	2.5	1.4	5.4
13	0.9	4.5	8.1	2.8	3.2	6.7	3.5	2.2	0.7
14	5.5	5.1	4.4	2.3	10.5	7.6	3.4	1.1	0.5
15	4.1	3.2	4.7	11.0	10.9	4.5	8.0	2.0	3.1
16	18.2	6.4	9.9	4.7	6.7	9.0	5.7	1.0	1.6
17	5.9	5.9	2.5	7.7	9.5	7.2	7.5	5.0	4.4
18	3.8	10.0	3.3	7.0	10.1	11.8	10.8	2.0	4.7
19	7.0	8.0	9.4	5.1	9.5	2.6	2.2	1.1	1.0
20	14.6	6.0	9.6	8.1	8.7	10.5	7.0	1.7	1.9
Mean	9.89	8.94	8.26	6.47	7.79	6.12	5.71	2.81	2.93
S.D.	7.95	5.21	4.60	3.10	3.12	3.51	3.07	2.33	1.65

APPENDIX I

TABLE 5

Summary table of analysis of variance of percentage absolute error of reproduction of first and last intervals in series A to E.

Source of Variation	d.f.	Sum of Squares	Mean Squares
Series and position in series	8	986.226	123.28
Residual	152	2172.78	14.29

$F = 8.62,\ P < .01$

Scheffé Comparisons

Means		d.f.	F	Probability
8.94,	8.26	8/152	.0404	> .05
6.47,	7.79	8/152	.1524	> .05
6.12,	5.71	8/152	.0147	> .05
2.81,	2.93	8/152	.0126	> .05
9.89,	2.81	8/152	4.38	< .01
9.89,	6.12	8/152	1.24	> .05
8.94,	2.81	8/152	3.29	< .01
8.94,	6.12	8/152	.70	> .05
6.47,	2.81	8/152	1.17	> .05
9.89,	2.93	8/152	4.24	< .01
8.26,	2.93	8/152	2.48	< .05
9.89,	5.71	8/152	1.53	> .05

APPENDIX I

TABLE 6

Durations (average of 3 trials) of each subject's reproduction of each interval in each of the standard series F, G and H. All durations are recorded in milliseconds.

SUBJECT	SERIES								
	F			G			H		
	Position of reproduced interval in series								
	1	2	3	1	2	3	1	2	3
No. 1	514	503	1037	540	1120	526	1224	581	710
2	442	528	1059	491	1142	480	899	664	439
3	587	571	1090	535	1156	425	1235	442	521
4	461	424	725	393	1179	417	1042	402	372
5	429	423	689	403	832	413	889	572	341
6	598	635	1078	598	1109	592	1453	542	575
7	591	608	1200	505	1133	539	963	575	671
8	343	346	818	405	1225	397	818	331	344
9	483	503	1047	433	1035	521	989	492	474
10	483	485	880	501	988	524	898	468	468
11	543	512	971	477	850	476	1047	484	492
12	428	438	884	459	1131	445	950	583	552
13	572	518	1032	485	1038	506	521	1130	896
14	525	531	1003	452	860	434	1251	521	519
15	488	518	1018	481	1156	502	1129	529	524
16	420	474	784	475	821	495	951	463	496
17	495	578	1128	536	1102	568	961	397	443
18	495	472	909	522	966	480	1079	525	531
19	495	467	983	470	1023	460	865	466	447
20	460	490	993	476	1103	467	820	455	471

APPENDIX I

TABLE 7

Percentage absolute error of each reproduced interval in each of the series F, G and H.

SUBJECT	SERIES								
	F			G			H		
	Position of reproduced interval in series								
No.	1	2	3	1	2	3	1	2	3
1	2.8	0.6	3.7	8.0	12.0	5.2	22.4	16.2	42.0
2	11.6	5.6	5.9	1.8	14.2	4.0	10.1	32.8	12.2
3	17.4	14.2	9.0	7.0	15.6	15.0	23.5	11.6	4.2
4	7.8	15.2	27.5	21.4	17.9	16.6	4.2	19.6	25.6
5	14.2	15.4	31.1	19.4	16.8	17.4	11.1	14.4	31.8
6	19.6	27.0	7.8	19.6	10.9	18.4	15.0	8.4	15.0
7	18.2	21.6	20.0	1.0	13.3	7.8	3.7	15.0	34.2
8	31.4	30.8	18.2	19.0	22.5	20.6	18.2	33.8	31.2
9	7.8	6.0	1.7	13.4	3.5	4.2	1.1	1.6	5.2
10	3.4	3.0	12.0	0.2	1.2	4.8	10.2	6.4	6.4
11	8.6	2.4	2.9	4.6	15.0	4.8	4.7	3.2	1.6
12	14.4	12.4	11.6	8.2	13.1	11.0	5.0	16.6	10.4
13	14.4	3.6	3.2	3.0	3.8	1.2	7.2	1.6	9.8
14	5.0	6.2	0.3	9.6	14.0	13.2	25.1	4.2	3.8
15	2.4	3.6	1.8	3.8	15.6	0.4	12.9	5.8	4.8
16	16.0	5.2	21.6	5.0	17.9	1.0	4.9	7.4	0.8
17	1.0	15.6	12.8	7.2	10.2	13.6	3.9	20.6	11.4
18	1.0	5.6	9.1	4.4	3.4	4.0	7.9	5.0	6.2
19	5.0	3.4	2.0	5.3	0.2	10.1	10.4	9.1	9.3
20	8.0	2.0	0.7	4.8	10.3	6.6	18.0	9.0	5.8
Mean	10.5	9.97	10.15	8.34	11.57	9.0	10.97	12.12	13.59
S.D.	7.76	8.72	9.20	6.64	6.17	6.32	7.23	9.23	12.30

APPENDIX I

TABLE 8

Summary table of analysis of variance of percentage absolute error of reproduction of each interval in each of the series F, G and H.

Source of Variation	d.f.	Sum of Squares	Mean Square
Rhythmic pattern	8	410.69	51.34
Residual	152	6,700.66	44.08

$F = 1.16, \quad P > .05$

APPENDIX I

TABLE 9

Mean values of the percentage absolute error of all reproduced intervals in each of the series B, C, F, G and H.

Subject No.	SERIES				
	B	C	F	G	H
1	15.0	3.6	2.4	8.4	26.9
2	5.6	5.4	7.7	6.7	18.4
3	8.7	6.3	13.5	12.5	13.1
4	0.5	4.4	16.8	18.6	16.5
5	7.1	4.6	20.2	17.9	19.1
6	19.8	7.2	18.1	16.3	22.9
7	11.5	6.2	19.9	7.4	17.6
8	11.4	12.1	26.8	20.7	27.7
9	7.1	3.7	5.2	7.0	2.6
10	12.1	7.7	6.1	2.1	7.7
11	9.6	8.2	4.6	8.1	3.2
12	12.9	4.8	12.8	10.8	10.7
13	6.3	3.6	7.1	2.7	6.2
14	4.7	4.6	3.8	12.3	11.1
15	4.0	11.1	2.6	6.6	7.8
16	8.2	7.1	14.3	7.9	4.4
17	4.2	9.0	9.8	10.3	11.9
18	6.7	6.7	5.2	3.9	6.4
19	8.7	5.4	3.5	5.2	9.6
20	7.8	8.6	3.6	7.2	10.9
Mean	8.60	6.52	10.20	9.63	12.73
S.D.	4.35	2.41	7.15	5.29	7.45
Mean of means				10.85	

APPENDIX I

TABLE 10

Summary table of analysis of variance of mean percentage absolute error of all the intervals in each of the series B, C, F, G and H.

Source of Variation	d.f.	Sum of Squares	Mean Square
Rhythmic pattern	4	413.281	103.32
Residual	76	1581.66	20.81

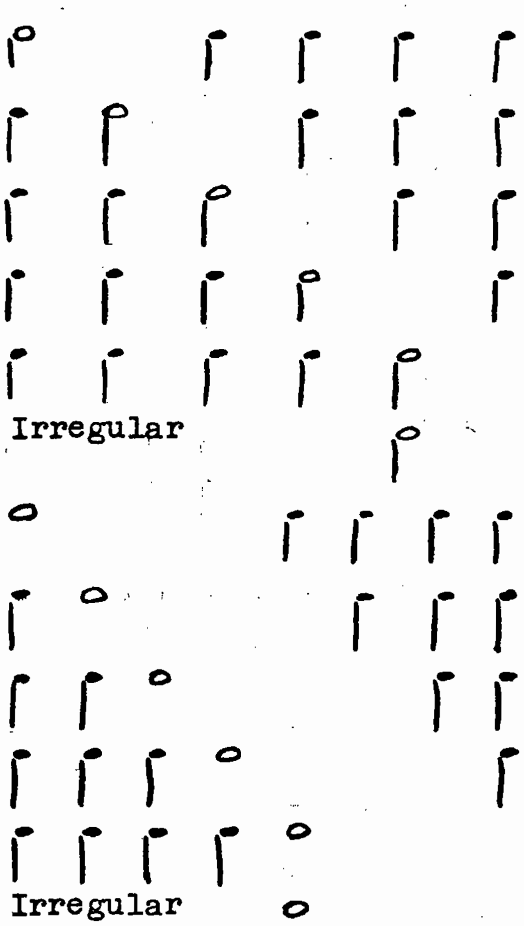
$F = 4.96,\ P < .01$

Scheffé Comparisons

Means	d.f.	F	Probability
9.63, 12.73	4/76	1.15	> .05
8.60, 12.73	4/76	1.78	> .05
6.52, 9.63	4/76	1.21	> .05
6.52, 10.20	4/76	1.64	> .05
6.52, 12.73	4/76	4.65	< .01
6.52, 10.85	4/76	2.25	> .05

APPENDIX II

Series of time intervals used in Experiment 2



	In musical notation	In milliseconds				
I		500	250	250	250	250
J		250	500	250	250	250
K		250	250	500	250	250
L		250	250	250	500	250
M		250	250	250	250	500
N	Irregular	300	700	600	400	500
O		1000	250	250	250	250
P		250	1000	250	250	250
Q		250	250	1000	250	250
R		250	250	250	1000	250
S		250	250	250	250	1000
T	Irregular	300	700	600	400	1000

APPENDIX II

TABLE I

Durations (average of 3 trials) of each subject's reproduction of each interval in each of the standard series I to N. All durations are recorded in milliseconds.

Sub-ject No.	SERIES I					SERIES J					SERIES K				
	POSITION OF REPRODUCED INTERVAL IN SERIES														
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	1025	272	242	279	301	423	772	219	221	247	255	237	601	239	237
2	625	241	257	260	637	262	683	217	237	279	219	240	542	249	273
3	915	255	249	253	274	241	773	320	337	354	269	268	946	258	245
4	671	279	296	267	296	240	981	234	242	247	253	261	806	242	222
5	514	308	224	260	255	271	703	264	297	257	242	253	535	244	261
6	1262	283	303	313	353	255	683	223	230	237	264	294	678	277	312
7	1049	257	293	259	281	250	793	258	286	258	215	268	576	236	272
8	595	246	235	253	273	223	519	248	238	253	226	268	548	240	260
9	603	263	263	241	258	265	575	266	265	264	263	251	587	257	263
10	525	254	251	253	235	233	453	259	226	264	238	269	497	253	279
11	589	264	244	249	273	316	605	273	252	269	283	281	626	284	254
12	599	264	252	273	2407	278	759	281	251	255	242	257	556	256	241
13	508	275	249	256	244	250	590	241	226	235	255	249	478	270	254
14	1165	275	242	247	276	249	465	250	215	233	254	233	502	265	241
15	617	259	273	259	260	274	546	283	219	261	264	256	264	276	261
16	532	248	263	260	271	360	635	244	245	249	245	268	547	279	308
17	617	280	272	261	279	259	714	260	243	251	250	254	600	254	273
18	867	235	230	257	236	260	779	236	260	228	222	242	525	226	209
19	519	273	237	248	236	245	584	234	224	255	229	245	516	244	230
20	606	224	230	229	248	256	617	233	237	242	255	263	517	244	250

APPENDIX II

TABLE I (continued)

Durations (average of 3 trials) of each subject's reproduction of each interval in each of the standard series I to N. All durations are recorded in milliseconds.

SERIES L (♩ ♩ ♩ 𝅗𝅥 ♩) SERIES M (♩ ♩ ♩ ♩ 𝅗𝅥) SERIES N (Irregular 𝅗𝅥)

Sub-ject No.	POSITION OF REPRODUCED INTERVAL IN SERIES														
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	243	241	266	557	229	271	282	289	334	718	269	713	1096	246	625
2	248	252	284	637	289	225	239	244	279	716	307	689	736	575	333
3	341	345	348	1119	280	267	266	272	269	921	312	1152	429	431	696
4	238	229	238	559	217	236	261	277	293	679	325	819	884	335	367
5	267	315	285	691	286	235	253	260	261	351	263	882	746	346	322
6	251	233	276	518	273	265	271	272	276	624	391	847	817	365	819
7	275	275	272	821	293	238	258	265	265	739	283	731	1033	300	335
8	235	239	270	488	249	214	238	233	271	522	250	475	876	382	526
9	254	241	270	489	275	231	227	226	262	580	357	655	658	316	305
10	254	250	222	538	226	248	238	231	264	554	253	308	618	290	603
11	283	253	277	627	316	268	257	246	262	552	312	597	727	300	734
12	273	279	282	761	259	255	255	237	259	568	293	638	803	368	761
13	256	209	275	621	253	246	260	219	283	454	352	971	531	726	507
14	270	255	279	829	294	272	260	267	283	666	313	796	805	298	721
15	260	245	246	579	278	277	247	265	253	604	325	531	124	305	549
16	239	243	269	630	298	253	248	233	263	501	303	669	722	665	412
17	239	243	222	618	244	252	227	248	248	572	291	714	768	303	753
18	255	266	263	624	286	208	222	222	237	608	420	818	932	376	287
19	243	230	245	574	235	250	239	226	286	879	279	770	766	287	584
20	230	226	247	559	249	237	226	218	246	536	310	915	308	308	609

APPENDIX II

TABLE 2

Durations (average of 3 trials) of each subject's reproduction of each interval in each of the standard series O to T. All durations are recorded in milliseconds.

SERIES O (𝅝 ♩ ♩ ♩ ♩) SERIES P (♩ 𝅝 ♩ ♩ ♩) SERIES Q (♩ ♩ 𝅝 ♩ ♩)

Subject No.	POSITION OF REPRODUCED INTERVAL IN SERIES														
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	1366	275	264	284	279	221	954	258	254	266	236	251	995	234	244
2	943	232	233	257	329	266	779	270	268	270	234	244	904	251	243
3	1144	241	239	235	278	277	1413	279	272	294	255	281	1161	257	268
4	980	274	258	257	276	256	1222	275	261	280	219	236	1123	229	247
5	882	286	300	303	272	267	1041	297	275	263	263	262	217	230	265
6	1107	252	266	265	306	356	1270	279	297	398	241	264	1148	228	266
7	900	264	247	252	254	293	890	275	295	277	252	259	840	256	289
8	855	271	243	251	283	244	638	252	236	255	234	244	731	240	269
9	993	254	241	245	258	270	845	252	253	245	247	251	1038	236	251
10	603	250	246	255	272	248	585	257	242	258	237	268	755	266	262
11	889	260	255	239	269	291	715	279	259	265	258	267	839	259	264
12	993	276	252	236	271	276	793	277	293	271	255	263	875	253	257
13	914	280	279	267	229	297	812	309	285	250	261	261	978	272	210
14	1280	261	247	244	295	266	1120	254	246	275	253	242	840	262	258
15	1076	281	233	239	274	239	911	272	242	245	239	271	1099	269	258
16	1057	290	271	285	299	311	887	284	270	276	249	270	618	268	284
17	1164	266	267	267	297	211	903	251	243	279	248	235	988	247	242
18	1357	268	268	270	1915	227	758	240	258	223	244	264	913	241	244
19	951	260	214	219	271	271	877	248	244	254	234	264	1067	242	248
20	915	254	238	224	264	280	906	258	242	283	241	258	1155	253	257

APPENDIX II

TABLE 2 (continued)

Durations (average of 3 trials) of each subject's reproduction of each interval in each of the standard series O to T. All durations are recorded in milliseconds.

Subject No.	SERIES R					SERIES S					SERIES T (Irregular)				
	POSITION OF REPRODUCED INTERVAL IN SERIES														
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	295	307	317	1243	262	295	270	281	275	1049	285	817	1373	257	1101
2	261	279	280	828	743	217	241	245	273	705	296	731	661	836	322
3	253	258	274	1227	254	287	261	264	273	912	300	1136	378	795	328
4	280	276	279	1306	265	257	288	283	300	988	306	903	660	333	856
5	238	261	250	655	270	278	279	297	283	729	325	784	855	883	312
6	283	264	349	766	340	269	313	313	325	792	435	971	424	338	752
7	289	306	289	764	294	453	317	339	357	932	328	890	983	355	631
8	253	265	264	614	270	290	304	287	311	682	285	514	1030	304	727
9	254	249	275	713	258	246	249	275	289	1033	335	984	320	358	358
10	240	239	272	649	275	269	246	263	252	544	299	605	711	301	622
11	269	247	270	635	294	263	240	237	264	908	318	634	669	327	642
12	262	244	274	826	286	255	240	252	251	617	293	941	940	337	929
13	268	279	262	1016	254	257	263	245	273	1075	300	647	681	257	610
14	290	274	294	942	299	275	265	255	268	1026	314	717	614	293	683
15	266	244	255	886	261	265	255	269	300	885	282	645	724	303	753
16	241	247	268	553	300	263	239	243	290	714	288	319	739	339	875
17	239	231	248	855	262	286	244	261	250	843	283	867	1016	300	912
18	247	235	249	787	311	228	256	241	266	768	233	680	772	255	691
19	260	243	250	625	265	254	237	263	258	941	265	690	866	280	538
20	262	230	255	819	259	256	219	217	250	1001	396	991	399	511	484

APPENDIX II

TABLE 3

Mean values of the percentage absolute error of all reproduced intervals in each of the series I to M and O to T.

Subject No.	SERIES									
	I	J	K	L	M	O	P	Q	R	S
1	29.8	29.8	7.4	6.5	22.8	15.5	5.5	3.1	19.3	10.6
2	38.0	14.3	6.9	11.6	14.3	10.8	10.3	4.3	48.5	11.5
3	19.2	32.5	21.8	50.3	22.7	7.9	18.0	8.1	7.7	8.6
4	17.9	22.2	16.2	8.6	14.7	5.8	10.2	8.0	14.1	4.6
5	8.5	15.0	3.6	19.9	9.1	15.2	9.0	16.7	10.3	16.4
6	50.6	12.5	18.9	6.1	11.7	9.3	31.8	7.8	23.6	21.8
7	29.2	15.9	10.2	22.0	13.6	3.8	13.2	7.7	18.9	38.6
8	7.4	4.3	6.9	4.2	7.8	7.9	9.4	0.5	11.9	21.7
9	7.6	7.8	6.2	5.1	9.4	2.2	5.5	2.3	8.8	6.2
10	2.8	7.0	5.2	6.0	5.9	10.4	10.3	9.6	12.9	12.2
11	7.0	13.0	13.2	15.4	5.4	5.8	13.2	7.1	14.2	5.8
12	19.7	15.6	4.6	13.9	5.3	5.2	13.5	4.7	9.7	9.1
13	3.3	7.4	3.3	10.8	8.0	9.6	15.0	7.2	5.4	5.3
14	31.6	5.6	3.7	21.0	13.2	10.8	6.3	5.7	13.7	5.6
15	8.8	9.8	7.1	6.9	8.0	8.2	5.5	6.7	5.3	9.4
16	5.0	15.2	10.7	12.0	2.8	12.7	13.5	13.5	15.3	11.4
17	11.2	31.4	20.0	13.5	8.4	11.0	8.0	2.5	6.4	7.4
18	28.0	15.6	9.1	10.6	13.2	14.5	10.3	4.5	10.7	8.9
19	4.9	7.5	4.8	6.7	20.8	8.8	5.1	4.5	10.1	3.6
20	10.2	9.5	2.3	5.5	4.0	6.2	8.2	5.3	7.3	5.6
Mean	17.04	14.60	9.11	12.83	11.06	8.58	11.09	6.49	13.71	11.22
S.D.	13.40	8.41	5.92	10.35	5.90	4.06	6.04	3.78	9.51	8.24

APPENDIX II

TABLE 4

Summary Table of analysis of variance of the mean values of the percentage absolute error of all reproduced intervals in each of the series I to M and O to T.

Source of Variation	D.F.	Sum of Squares	Mean Squares
Rhythmic Pattern	9	1732.17	192.46
Residual	171	9042.81	52.88

$F = 3.64, \quad P < .01$

Scheffé Comparisons

Means		D.F.	F	Probability
6.49,	17.04	9/171	2.34	$<$ .05
6.49,	14.6	9/171	1.38	$>$ .05
6.49,	13.71	9/171	1.09	$>$ .05
6.49	11.22	9/171	0.47	$>$ .05
9.11	17.04	9/171	1.32	$>$ .05
8.58,	17.04	9/171	1.50	$>$ .05
10.22,	12.93	9/171	0.15	$>$ .05

APPENDIX II

TABLE 5

Mean values of the percentage absolute error of all reproduced intervals in each of the series M, N, S and T.

SUBJECT	SERIES			
	M	N	S	T
1	22.8	31.7	10.6	39.3
2	14.3	20.7	11.5	38.5
3	22.7	28.8	8.6	53.0
4	14.7	23.1	4.6	14.4
5	9.1	22.3	16.4	50.5
6	11.7	32.0	21.8	30.7
7	13.6	28.1	38.6	29.7
8	7.8	20.9	21.7	30.9
9	9.4	19.0	6.2	34.7
10	5.9	24.6	12.2	18.9
11	5.4	22.3	5.8	16.2
12	5.3	21.0	9.1	23.2
13	8.0	30.1	5.3	19.2
14	13.2	24.6	5.6	13.6
15	8.0	21.7	9.4	16.7
16	2.8	20.8	11.4	21.9
17	8.4	21.6	7.4	26.5
18	13.2	32.2	8.9	24.2
19	20.8	17.9	3.6	26.7
20	4.0	24.2	5.6	48.1
Mean	11.06	24.38	11.22	28.85
S.D.	5.90	4.50	8.24	11.97

APPENDIX II

TABLE 6

Summary table of analysis of variations of the mean values of the percentage absolute error of all reproduced intervals in each of the series M, N, S and T.

Source of Variation	d.f.	Sum of squares	Mean squares
Rhythmic pattern	3	4990.7	1663.57
Residual	57	3177.11	55.74

$F = 29.85$, $P < .01$

Scheffé Comparisons

Means	d.f.	F	Probability
11.06, 24.38	3/57	10.61	< .01
11.22, 28.85	3/57	18.59	< .01
11.06, 11.22	3/57	.015	> .05
24.38, 28.85	3/57	1.19	> .03
11.06, 28.85	3/57	18.93	< .01
11.22, 24.38	3/57	10.36	< .01

APPENDIX II

TABLE 7

Percentage absolute error of each reproduction of each 500 ms interval in each of the series I to M and of each 1000 ms interval in each of the series O to S.

SUBJECT No.	500 ms					1000 ms				
	SERIES									
	I	J	K	L	M	O	P	Q	R	S
1	105.0	54.4	20.2	11.4	43.6	36.6	4.6	0.5	24.3	4.9
2	25.0	36.6	8.4	27.4	43.2	5.7	22.1	9.6	17.2	29.5
3	82.8	54.6	89.2	123.8	84.2	14.4	41.3	16.1	22.7	8.8
4	34.2	96.2	61.2	11.8	35.8	2.0	22.2	12.3	30.6	4.6
5	2.8	40.6	7.0	38.2	29.8	11.8	4.1	19.9	34.5	27.1
6	152.4	36.6	35.6	3.6	24.8	10.7	27.0	14.8	23.4	20.8
7	109.8	58.6	15.2	64.2	47.8	10.0	11.0	16.0	23.6	6.8
8	19.0	3.8	9.6	2.4	4.4	14.5	36.2	26.9	38.6	31.8
9	20.6	15.0	17.4	2.2	16.0	0.7	15.5	3.8	28.7	3.3
10	5.0	9.4	0.6	7.6	10.8	39.7	41.5	24.5	35.1	45.6
11	17.8	21.0	25.2	25.4	10.4	11.1	28.5	16.1	36.5	9.2
12	19.8	51.8	11.2	28.2	13.6	0.7	20.7	12.5	17.4	38.3
13	1.6	18.0	4.4	24.2	9.2	8.6	18.8	2.2	1.6	7.5
14	133.0	7.0	0.4	65.8	33.2	28.0	12.0	16.0	5.8	2.6
15	23.4	9.2	12.8	15.8	20.8	7.6	8.9	9.9	11.4	11.5
16	6.4	27.0	9.4	26.0	0.2	5.7	11.3	38.2	44.7	28.6
17	42.6	90.4	66.0	41.6	14.6	16.4	9.7	1.2	14.5	15.7
18	60.0	55.8	5.0	24.8	21.6	35.7	24.2	8.7	21.3	23.2
19	3.8	16.8	3.2	14.8	75.8	4.9	12.3	6.7	37.5	5.9
20	9.6	14.6	1.0	1.8	0.6	8.5	9.4	15.5	18.1	0.1
Mean	43.73	35.87	20.15	28.05	27.02	13.67	19.07	13.57	24.38	16.29
S.D.	47.04	26.80	24.52	29.13	23.00	11.92	11.34	9.25	11.45	13.35
Mean of Means	30.96					17.40				

APPENDIX II

TABLE 8

Summary table of analysis of variance of percentage absolute error of reproduction of each 500 ms interval in each of the series I to M and of each 1000 ms interval in each of the series O to S.

Source of Variation	d/f	Sum of Squares	Mean Squares
Rhythmic Pattern	9	17,394.6	1932.74
Residual	171	83,977.9	491.10

$F = 3.93,\ P < .01$

Scheffé Comparisons

Means	d/f	F	Probability
13.67, 43.73	9/171	2.04	$< .05$
19.07, 35.87	9/171	0.64	$> .05$
13.57, 20.15	9/171	0.10	$> .05$
24.38, 28.05	9/171	0.05	$> .05$
16.29, 27.02	9/171	0.26	$> .05$
17.40, 30.96	9/171	0.42	$> .05$
13.57, 43.73	9/171	2.06	$< .05$
13.57, 35.87	9/171	1.13	$> .05$
13.57, 28.05	9/171	0.47	$> .05$
20.15, 43.73	9/171	1.26	$> .05$
13.57, 24.38	9/171	0.26	$> .05$

APPENDIX II

TABLE 9

Percentage absolute error of each reproduction of the 500 ms intervals in each of the series M and N and of the 1000 ms in each of the series S and T.

SUBJECT	SERIES			
	M	N	S	T
No.				
1	43.6	25.0	4.9	10.1
2	43.2	33.4	29.5	67.8
3	84.2	39.2	8.8	67.2
4	35.8	26.6	4.6	14.4
5	29.8	35.6	27.1	68.8
6	24.8	63.8	20.8	24.8
7	47.8	33.0	6.8	36.9
8	4.4	5.2	31.8	27.3
9	16.0	39.0	3.3	64.2
10	10.8	20.6	45.6	37.8
11	10.4	46.8	9.2	35.8
12	13.6	52.2	38.3	7.1
13	9.2	1.4	7.5	39.0
14	33.2	44.2	2.6	31.7
15	20.8	9.8	11.5	24.7
16	0.2	17.6	28.6	12.5
17	14.6	50.6	15.7	8.8
18	21.6	42.6	23.2	30.9
19	75.8	16.7	5.9	46.2
20	0.6	21.9	0.1	51.6
Mean	27.02	31.26	16.29	35.38
S.D.	23.00	16.62	13.35	20.32

APPENDIX II

TABLE 10

Summary table of analysis of variance of percentage absolute error of reproduction of the 500 ms intervals in each of the series M and N and of the 1000 ms intervals in each of the series S and T.

Source of Variation	d.f.	Sum of Squares	Mean Square
Rhythmic pattern	3	4042.44	1347.48
Residual	57	19235.8	337.47

$F = 3.99, \quad P < .05$

Scheffé Comparisons

Means	d.f.	F	Probability
16.29, 35.38	3/57	3.60	$<$ .05
16.29, 31.26	3/57	2.21	$>$ .05
16.29, 27.02	3/57	1.14	$>$ .05
27.02, 31.26	3/57	0.18	$>$ .05
31.26, 35.38	3/57	0.17	$>$ .05
27.02, 35.38	3/57	0.69	$>$ .05

APPENDIX III

Series used in Experiment 3.
(All durations in milliseconds)

Series	Durations of time-intervals in milliseconds				
U	200	200	200	200	1000
W	250	250	250	250	1000
X	300	300	300	300	1000
Y	400	400	400	400	1000
Z	500	500	500	500	1000

APPENDIX III

Table 1

Durations of each of the three reproductions by each subject of the 1000msec interval in each series U to Z.

All durations are in milliseconds.

Series	Preceding Interval	Subject 2	Subject 8	Subject 9	Subject 17	Subject 20
U	200	927	872	849	695	755
		943	880	894	723	805
		969	894	915	775	882
W	250	680	959	950	736	955
		691	968	965	792	960
		701	975	1009	804	962
X	300	775	1006	1018	785	1024
		803	1027	1085	821	1049
		809	1058	1114	854	1087
Y	400	928	842	901	851	904
		937	873	939	909	941
		965	892	957	926	943
Z	500	980	1020	983	1005	1052
		1010	1061	1021	1021	1058
		1032	1088	1027	1033	1086

APPENDIX III

Table 2

Additional results from subjects 9 and 20.

Durations of each of the three reproductions by each subject of the 1000msec interval in 12 additional series. All durations are in milliseconds.

4 Preceding Intervals	Subject 9			Subject 20		
350	995	1022	1032	1035	1041	1058
450	972	974	1066	910	913	925
550	1085	1105	1111	866	868	1100
600	1098	1193	1198	895	974	976
650	935	941	944	937	1063	1116
700	913	981	1078	1042	1064	1084
750	936	1001	1076	671	810	1102
800	953	982	1064	935	1062	1083
850	1071	1090	1142	857	873	1072
900	1091	1106	1132	695	730	875
950	926	937	945	-	-	-
1000	946	955	984	834	917	996

APPENDIX III

Table 3

Linear regression equations for reproductions of the 1000msec interval associated with various multiples of the initial series intervals.

Subject	No. of Ti in T_R	Regression Equation	Correction Factor
9	1	y = .62x + 347.89	$12^{\circ}51'$
9	1.5	y = .55x + 125.79	$24^{\circ}21'$
9	2	y = .55x + 84.92	$34^{\circ}39'$
9	3	y = .4x - 65.35	$49^{\circ}56'$
9	3.5	y = .29x - 8.07	$57^{\circ}52'$
9	4	y = .26x - 7.98	$57^{\circ}24'$
20	1	y = .98x + 42.56	$0^{\circ}35'$
20	1.5	y = .77x - 15.53	$0^{\circ}44'$
20	2	y = .78x - 313.84	$11^{\circ}23'$
20	3	y = -.14x - 475.5*	$26^{\circ}14'$
20	4	y = .43x - 173.35	$9^{\circ}14'$

* probably artifactual