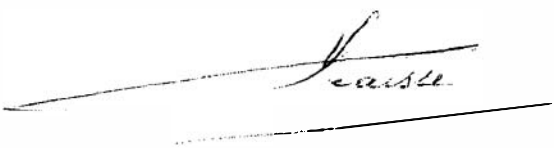

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PERCEPTION AND ESTIMATION OF TIME

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INTRODUCTION

The opportunity to prepare a prefatory chapter has provided me with a welcome occasion to survey the field of perception and estimation of time with greater historical depth than is usual in *Annual Review* chapters. Some of the topics to

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be considered here—and even some of the data—were known to pioneer psychologists such as Wilhelm Wundt, Pierre Janet, and William James. My own research in this area began more than 30 years ago. But although this field has deep roots in psychological research, it has flourished especially in the last two decades as the cognitive approach encouraged the reexamination of many aspects of human experience, including that of time. This has led to an outpouring of research, to new and revised theoretical formulations, and to important clarifications of concepts and methods. Although no revolution has appeared in this field, the knowledge obtained and the conceptual insights that have been achieved recently appear to set the stage for important new advances.

There is no single way to approach this extremely intricate subject. Time is a highly complex notion; the clearest way to begin is by an analysis of the notion of time commonly held by the adult. The adult lives in an ever-changing world. Even before becoming conscious of his own evolution over time he is witness to constant changes where he himself is the point of reference. The concept of time is first of all associated with world time; however, I can also conceive of changes in my thoughts and have a notion of personal time which is not fundamentally different from world time.

The term *notion* is used in connection with time because it is a more general and complex term than *concept;* despite this difference, the two are often erroneously substituted for each other. The term *concept* applies to a defined class of objects or experiences having a set of common characteristics which distinguishes them from all others. The notion of time applies to two different concepts which may be clearly recognized from our personal experience of change: (*a*) the concept of succession, which corresponds to the fact that two or more events can be perceived as different and organized sequentially; it is based on our experience of the continuous changing through which the present becomes the past; (*b*) the concept of duration, which applies to the interval between two successive events. Duration has no existence in and of itself but is the intrinsic characteristic of that which endures. As Gibson (1975) so aptly put it, "Events are perceivable but time is not."

These two concepts are related to specific characteristics of change and should be defined precisely, yet the scientific and philosophical literature is replete with examples of the indiscriminate use of "idea," "notion," and "concept" when referring either to succession or duration. There is, of course, no duration without succession. It is quite possible that personal experience can provide the basis for abstract representations having a wide application. The concepts we possess are thus dependent upon changes conceived or perceived by each of us.

These concepts may be extrapolated from the changes that occur beyond the range of our own experience. A slightly anthropomorphic view lets us speak of animals' perception of time: classical conditioning reveals that animals are equipped with a form of perception of succession, and operant conditioning, or more simply choosing between two durations, shows that they adapt to duration as well.

Our notion of time involves two concepts that apply to perceptible physical changes and allow us to measure time by referring to a regular sequence of succession. It also characterizes our own personal time. However, it bears no relationship to macrophysical time, as is apparent in the relativity of time and space.

The concepts of succession and duration which specify our notion of time are quite naturally empirical in their origins. This does not necessarily imply that their development is empirical. Research in this field shows that perception of both duration and succession are present very early in life, but that their joint functioning is not acquired until age 7 or 8, when the child first becomes capable of logical thinking. An abstract notion of time is gradually elaborated from that age forward (Friedman 1982). The objective sought in presenting these generalities has been to provide a framework for the present review of contemporary research in the field of the psychology of time, rather than to end the philosophical debate on the notion of time, outlined in the introduction to the *Psychology of Time* (Fraisse 1963), which in any case will never find a satisfactory conclusion.

The present article will be limited to what the human being is able to know about time as manifested through perception and estimation of duration. The distinction will be made between perception and estimation on the basis of phenomenological and experimental data. Animal research has been voluntarily excluded from this study because it provides little insight into our own knowledge of time. Also excluded is research on conditioning that focuses on the role of the time factor as one of the elements influencing our environment but in other ways than succession and duration. Finally, no mention will be made of the large body of research on temporal perspectives to be described elsewhere (Fraisse 1983).

In a review of this type, any attempt at summarizing is difficult given the rapid increase in the amount of literature on the subject. The deliberately restricted inventory of Eisler et al (1980) shows that the number of studies reported annually since 1970 has attained 150, whereas between 1900 and 1960 the annual average was about 15. One explanation lies in the growing number of research psychologists, but the underlying reason is the change in orientation in the sixties from behaviorist to cognitive approaches. Behavioral research was hard put to include time as a variable, in that it is closely linked to the phenomenal aspects of our experience of time and is not a physiological factor. Cognitive approaches were, however, not limited by this restriction. The "new look" in the field of perception was thus also extended to studies on time.

To what extent does the perception of time depend on the conditions under which the perception itself takes place and on the expectations of the knowledgeable subject? At first glance, research on perception and estimation appears to replicate experiments conducted prior to the advent of behaviorism, but in fact new emphasis has been placed on context, motivations, and the subject's own resources. In the area of time research, the role of the subject is even more obvious than in physiological studies, because stimuli which are durations have no specific sensory impact, but are relativized by the perceiving subject. On this point, current confirmations of past research findings will be identified distinctly from new discoveries in contemporary research.

A recent bibliography on time, comprising 1652 entries from 1839 to 1979, may be found in Eisler et al (1980); additional references may be found in Fraisse (1967), Doob (1971), and Zelkind & Spring (1974). The latter work alone provides 1172 references.

THRESHOLDS OF SUCCESSION AND DURATION

When does the perception of time, that is to say the perception of succession and duration, begin? These two aspects of the question will be treated in that order, thus respecting the necessity to handle each one on its own ground. Succession may be distinguished from simultaneous occurence, and duration distinguished from instantaneous. The concern here is with phenomenal particularities of our perceptions, and in no way may they be considered as physical data in which a continuum separates the end of one stimulation and the beginning of the next, each stimulation having its own duration as well. Since the advent of experimental psychology, it has been established that perceived simultaneity does not conform to physical simultaneity. The steadily increasing quantity of research on this point is aimed at providing more accurate means for measuring these phenomena as well as attempting to explain and interpret them. Contemporary technology has rendered possible more accurate definitions of the stimuli as well as the comparison of physical data to those of psychophysics. From this contemporary standpoint, the threshold figures that we established in 1963, while within the same general range, were slightly higher. Over the past few years, as a matter of fact, scientific research in this field has been less concerned with sharpening the accuracy of threshold figures than with the construction of models capable of explaining their duration and scatter.

From Simultaneousness to Succession

The distinction between succession and simultaneity may appear elementary at first sight; however, operational evidence for it may be obtained in many different ways, none of which are either neutral or equivalent from the perceptive point of view. To begin with, succession must be distinguished from discontinuity, which is most evident perceptually when two or more stimuli excite the same peripheral sense organs. For auditory sensations, a crackling sound is identified at a separation of about 1 ms between very brief stimuli, while a discontinuity requires 10 ms.

In the tactile area, the same holds true for the sensation of vibration. As for vision, the comparable phenomenon is flicker. In addition, when two retinal receptors, A and B, are excited by two stimuli, a so-called apparent movement of A toward B is perceived before the succession. The Gestaltists consider the optimum interval for this movement to be about 60 ms. However, recent findings by Westheimer & McKie (1977) show that this movement can be perceived for an interval as short as 3 ms provided the stimuli both strike the fovea.

However, the transition from simultaneity to succession properly speaking may be studied by presenting two pulses of more or less variable duration of intensity (cf Oostenbrug et al 1978, Mills & Rollman 1980), or through focusing on the onset of two durable stimuli (cf Allan 1975), or again, by focusing on the offset of two durable stimuli (cf Allan & Kristofferson 1974), or yet again, through the relationship between the offset of one stimulus and the onset of another (Efron 1970a, Allan 1976). Other authors have compared two pairs of stimuli, the S being asked to determine in which pair simultaneity or succession had occurred. Stimuli may be visual, and presented in monocular, binocular, or dichoptic vision (Rutschmann 1973); auditory stimuli may be presented in monoaural, binaural, or dichotic contexts; tactile of motor stimuli may be used as well. Here again, these experiments concern stimulations of one sensory system and introduce variations in distance or intensity. However, many other studies have focused conjointly on more than one system (visual-auditory, visual-motor, auditory-motor, etc). The stimulations may be simple or complex, and more than two may be presented (Carmon & Nachshon 1971). They may consist of shapes (Lichtenstein 1961), syllables (Fraisse 1978), or strings of letters (Hylan 1903). Furthermore, methods in psychophysics differ from one study to another: the constant method, the method of limits, and signal detection are among several commonly used. Finally, the criteria that the Ss are required to apply may not always be identical. Asking the subject to respond to a discontinuity, a succession, or to an order of events while measuring his degree of confidence in his answers does not set out equivalent tests for the subject. Consecutive to conclusions drawn from observations of Ss performances, authors have in general given up trying to establish averages and now present individual scores, which they almost unanimously recognize as being extremely divergent, sometimes to the extent of representing opposing tendencies. Allan (1976) for example found that out of three subjects tested, only two were homogeneous. Efron (1974) trained six subjects but retained only two for the final experiment. It is difficult to compare naive subjects to trained or overtrained ones, as was the case in Hirsh & Sherrig (1961). This list of experimental situations, while incomplete, provides a sufficient explanation for the fact that in the area of the psychology of time, where no specialized sensory receptor is available, final judgments are subject to all sorts of stimulation bias as well as to the type of task. This would not be an important point had the authors of explanatory models not formulated their theories on the basis of one single situation while disregarding all others.

One event in particular has been responsible for initiating numerous studies over the last 15 years. Hirsh & Sherrig (1961) showed that regardless of sensory modality, the succession order threshold was constant: approximately 20 ms. Their results were obtained after long training sessions. The stimulus pair was presented as often as the S requested before giving his response, which was always a forced choice, since the interval range was very limited. These results were the object of wide controversy. Hirsh & Fraisse (1964) showed, furthermore, that the thresholds for naive subjects were much higher when measured between an acoustical click and a brief flash of light, requiring either a judgment on simultaneity vs nonsimultaneity, or a judgment requiring a forced choice on the order of the two stimuli. The thresholds were the same in all three tasks (simultaneity, succession, and order). It was approximately 60 ms when the sound preceded the light, and from 90 to 120 ms when light preceded sound. This dyssymmetry has not always been taken into account in previous research. Allan (1975) identified this dyssymmetry but focused primarily on the fact that judgments of succession and order are given at the same stimulus values. However, this dyssymmetry emphasizes the importance of latencies in auditory and visual stimulation. Differences in latencies have often been used to explain discrepancies between successions of stimuli and successions of perceptions. It certainly plays a role, for example between louder and softer sound, brighter and dimmer light, and a lateral vs a central visual stimulation (Oostenbrug et al 1978).

It has been shown that reaction time to an auditory stimulation is approximately 40 ms less than for a visual stimulation, which gives a general idea of the size of respective latencies, although the values obtained in a reaction time task are not directly related to the succession threshold (Gibbon & Rutschmann 1969). To confirm the role of latencies, Fraisse's (1980) experiment may be mentioned. Synchronization, i.e. in this case simultaneity between hand tapping and the sound of a simple repetitive auditory rhythm, has been found easy to achieve. Data show that on the average, hand tapping (as a tactile measure) anticipates the sound by about 30 ms. This anticipation is approximately 20 ms longer when made by the foot. It is difficult not to attribute these anticipations to the fact that the tactile stimulus must precede the sound in order to be perceived as simultaneous by the brain. In fact, if a subject is asked to tap simultaneously with his hand and with his foot, at his own spontaneous rhythm, the foot tap also precedes the hand tap by about 20 ms. Finally, these are median values, with very high individual differences, even to the point of reversing the direction of the results. This variability can be explained by the subject's attitude, criteria for simultaneity, etc.

If the latency problem is left aside and only the succession or order thresholds of two identical stimuli are taken into consideration, once again there must be a notable disparity between the two stimuli if there is to be perception of succession and order. This is the case, for example, in Hirsh's (1959) experiment on two acoustic stimuli, or Mills & Rollman's (1980) experiment on dichotic perception. Ignoring for the moment the asymmetry between the two ears, results show a threshold of about 32 to 35 ms by the limits method and 55 to 60 ms by the constant method. In all these studies, there is true perception of an order in the succession of two distinct stimuli, and not a more or less total fusion.

A perception threshold equal to or greater than 20 ms thus cannot simply be attributed to disparity between the arrival of two impulses on the brain. A decision mechanism having its own duration must be postulated. A very complex model that incorporates the largest amount of data and hypotheses has been proposed by Sternberg & Knoll (1973). A value of Δt possessing its own variability must be added to the possible differences in arrival of impulses from the different stimulations. This decision function can be explained by a variety of mechanisms. Kristofferson (1967) as well as Kristofferson & Allan (1973) thought that decision time was related to the attention-switching hypothesis: in other words, that the time involved was nothing more than the length of time necessary to focus attention on each of the stimuli successively. However, there would also be a time quantum involved that would impose a minimum duration for this operation. The role assigned to attention corresponds in particular to all the studies showing the influence of attention directed voluntarily to one or the other stimulus. In the case of selective attention, as was well documented by Wundt, the stimulus receiving attention is perceived more rapidly than the other, which may modify the threshhold or even the order of succession. This attention factor, or the subject's attitude, which he may not always be aware of, can doubtless be explained in terms of numerous individual or interindividual differences. This decision mechanism is also compatible with a hypothesis proposed by Stroud (1955) called the "discrete moment" hypothesis, which has had considerable impact among researchers. It postulates that the perception of time is not continuous but intermittent and discrete. Elements of information are integrated at distinct moments. Their order is distinguished only if each one is treated at a different moment from the other. Within a given moment, order is not discriminated. Allport (1968) provides another version of the same hypothesis. The perceptive moment corresponds to a "window" which is in continuous movement. The attractiveness of these hypotheses does not permit construction of predictions other than those included in the models already mentioned. Baron (1971) made an attempt but did not succeed. Furthermore, no physiological process corresponding to this time quantum has yet been identified.

Finally, it should be noted that the succession threshold, which varies considerably for simple stimuli, greatly increases when these become more complex. Indeed, Stroud (1955) estimated that the moment duration could vary between 50 and 200 ms. Hylan (1903) had already shown that six letters forming a word, when presented successively and in any order, were perceived as simultaneous, provided that the total duration did not exceed 90 ms.

If four dots corresponding to the apexes of a diamond are lighted successively, they are perceived as being simultaneous if the separation between the first and the last does not exceed 125 ms (Lichtenstein 1961). Within the range of 100–150 ms, if two identical superimposed triangles are projected, they are perceived as an hexagon (Fraisse 1966). Eriksen & Collins (1967) superimposed two cards by means of a tachistoscope, each card having a random set of dots such that when grouped together they formed a meaningless syllable. Integration was possible within a duration range of 75–100 msec.

Although the parameters which determine succession threshold (or on the other hand, determine simultaneous integration) are numerous and their relative importance difficult to assess, it appears nonetheless that localization of decision in the left temporal lobe can be clearly asserted. This assertion is based both on neurological studies of well-identified lesions in the left as well as right hemispheres and on studies using double stimulation of each hemisphere (Efron 1963). In Ss with lesions of the left hemisphere, the succession threshold can attain 300–400 ms. This result was confirmed with normal subjects as well. Mills & Rollman (1980) studied the succession threshold of two clicks when each was presented to a different ear. The results showed that the threshold of temporal order was lower when the right ear click preceded the left ear click as compared to the opposite order of presentation. The difference was slight : 5,7 ms with the limits method, and 3,2 ms using the method of constant stimuli. The authors attribute these differences in thresholds to the differences in the time necessary for transfer from one lobe to the other according to direction. The values given are averages and the differences in thresholds vary from 2 to 16 ms among Ss. It may be noted, however, that these results do not affect decision time since the average threshold is approximately 60 ms using the limits method and 35 ms with the method of constant stimuli, as stated previously.

Differences emphasizing the role of the temporal lobe have also been found in dichoptic vision (Efron 1963, Oostenbrug et al 1978) as well as in tactile stimulation (Efron 1963). When the right lobe is stimulated first, this stimulation must be transferred to the left lobe, thus accounting for the delay in the junction of the two stimuli. In this type of dichotic or dichoptic experiment, explanations based on peripheral processes prove to be insufficient.

Instantaneous and Durable Events

Considerably less research has been carried out in this area. Early experiments, which indicated that up to a certain threshold apparent duration varied with the intensity of the stimulus, will not be discussed. The problem will therefore be dealt with only in terms of apparent constant intensity. When very brief stimuli are used, perception of instantanteity can be obtained; in more concrete terms, the *on* moment cannot be distinguished from the *off* moment. This problem has been studied in recent years by Efron (1970b, 1974) through comparison of measured apparent perceived duration to measured stimulus duration. He found a minimal duration of 130 ms for apparent perceived duration, a result which Allan (1976), however, was unable to confirm. The most reliable results have been obtained by Servière, Miceli & Galifret (1977a,b). These authors established a preliminary instantaneity threshold based on several psychophysical measurement methods and obtained a value of 60 ms with a range of uncertainty from 30 to 130 ms. Here again it was found that untrained subjects produce higher thresholds. Using evoked potential recording techniques, these same authors found that beyond 140 ms, the *on* and *off* constituents were clearly differentiated. On the other hand below 125 ms, the *on* and *off* components were increasingly interactive up to the point of coincidence. However, a closer examination of the *on* and *off* response values in relation to stimulation durations indicates the presence of a zone of uncertainty more or less equivalent to that obtained by means of the psychophysical measures. Experiments on pigeons in the same papers confirmed this relationship and support the hypothesis that the perception of instantaneity corresponds to the nonseparation of the *on* and *off* components of evoked potentials.

PERCEPTION OF DURATION

The following section will be entitled "Estimation of Duration." The distinction between that section and this one refers to two specific types of procedures for the evaluation of duration. Estimation of duration takes place when memory is used either to associate a moment in the past with a moment in the present or to link two past events, whereas perception of duration involves the psychological present.

The Psychological Present

Perception of duration refers to the ability to apprehend successive events as perceptively more or less simultaneous, within the framework of the psychological present first identified by William James (1890) under the name of "specious present," reexamined by Fraisse (1963), and later examined extensively by Michon (1978). Such a present has no fixed duration. It is based on what is perceived and refers to our capacity to apprehend sets of objects. Different schools of thought have called this ability "capacity of apprehension," "short-term memory," or "very short-term memory." More concretely, it applies to the perception of a telephone number, for example, or of a sentence simple enough to be repeated, or of a rhythmic pattern identified as a rhythm provided that its elements are perceived as being linked to each other in such a way as to form a unified group.

The psychological present corresponds to the duration of a experiential process and not to a given period of duration. However, it has an upper limit which hardly exceeds 5 sec, and has an average value of 2 to 3 sec. Within these limits one can speak of the perception of duration, which thereby becomes a quantity whose beginning has not yet been stored in memory.

Through ignorance of this distinction, psychologists studying time have compared durations associated with differing psychological processes. Such was the case for those studies using stimuli ranging from a duration of under one second to that of several dozen seconds or even to several minutes. The resulting confusion led to the formulation of a large number of misconstrued issues which continue to maintain ambiguities in an already sufficiently complex area. The present author's discussion of duration perception is to be found elsewhere (Fraisse 1978) and will not be repeated here. Poppel (1978) and Allan (1979) have discussed those recent studies presenting the most interesting findings.

Methodological Problems

As in previous sections, methodological problems will receive preferential attention over other issues; this should not surprise the reader since time is not a specific sensation.

Measurement methods play an essential role and have been greatly refined since the pioneering work of Bindra & Waksberg (1956). In addition to methods of estimation, of production, and of reproduction which yield continuous measures, there is a growing trend toward methods that tend to reduce responses to binary or trinary choices. This is the case for the forced choice method used to compare differing durations, also called the *single stimuli* method, which stipulates that one single duration must be judged by a binary choice as longer or shorter than a learned criterion (or criteria). The *magnitude estimation* or *category rating* method—a simplified version of numerical classification—is less frequently used; in this the S is asked to assess a stimulus duration in terms of several classes.

This variety of methods is a positive outcome of the development of contemporary research; however, the immediate caveat is that results are neither comparable nor homogeneous across methodologies, nor are the explanations suggested by the construction of theoretical models generated from these results.

Methods of comparison (scaling or discrimination) have renewed prime interest in the *time order error,* and numerous recent studies have dealt with it. Allan (1977) presents an overview showing that no definitive results have emerged to date. Time order error is considered as either positive or negative, depending on the authors, durations, and methods. The debate is set between those like Hellstrom (1977) who claim that the time order error is essentially perceptual, based on adaptation processes and differential weighting of sensation magnitude, and those who believe along with Allan (1977) that the time order error depends on the particular mode of responding and thus on a decision process which creates a response bias in function of the task. This would explain the variety of results ranging from null to positive or negative values.

Methods of comparison drew attention to the problem of masking. It was connected with the identification of a precategorical stage of stimulus perception having a non-negligible duration of about 250 ms. Any event intervening in this process has an effect upon it. For example, studies were conducted to determine whether during a brief stimulus (in general less than 100 ms) the occurrence of another stimulus would have an effect on the perception of the original stimulus. Massaro & Idson (1976, 1978), in the field of auditory stimulation, as well as Cantor & Thomas (1976) in the field of vision, showed the effects of masking on duration. In the latter experiment, a second stimulus (the mask) followed the first or target stimulus, which had one of two possible values (50 ms and 90 ms for example), after an interval (ITI) that could vary from 0 to 250 ms. The results showed that the target stimulus had a longer apparent duration when the ITI was longer, as though the perception of the target could be prolonged. Furthermore, the perceived duration of the mask adds something to the final duration judgment. There appears to be an integration of mask duration to target duration. These findings extend to identical sounds and also to the case where the mask frequency is different from the target frequency (Massaro & Idson 1978). The conclusion is that duration, like other stimuli, is dependent on the amount of available processing time. Durations must be close to precategorical duration values if they are to be perceived with a certain amount of precision and to be clearly distinguished (Fraisse 1974).

Along the same lines, studies were carried out on the possible presence of aftereffects in duration perception. Huppert & Singer (1967) reported aftereffects in the perception of a two-second duration. This was reproduced with 18% diminution when it was preceded by another two-second duration with an optimal interval of 3 to 7 sec. This diminution did not occur when the two-second sound was presented alone. One aftereffect which lends itself to interpretation as a time order effect has been demonstrated best by Walker et al

(1981), who in a series of experiments showed the presence of an aftereffect for lights and sounds: the duration of a test stimulus (600 ms) was displaced in a direction away from the duration of a repeated inspecting stimulus (200 to 800 ms). They also showed that if a pair of unequal lights or sounds ranging from 200 to 800 ms are presented repeatedly, and are followed by a pair of equal sounds (600 ms), the duration of the first of the two stimuli is perceived as longer than that of the second. This is called the contingency effect because it involves the relationship between two stimuli and not the absolute value of one.

The time order effects, whose similarity to aftereffects and masking effects (in the case of very brief durations) must be taken into consideration, and which appear in many types of sensations, further complicate the laws of duration perception by functioning as additional variables.

The Psychophysical Law

The relationship between the intensity of a sensation and the force of the physical stimulus has been studied since Fechner. The problem was restated by Stevens (1967), who attempted to show that the relationship between input and sensation was governed by a power law. However, Stevens himself admitted that the duration exponent was equal to 1, i.e. that the perceived time was in a direct relation with physical time. Since that time, numerous studies have attempted to prove or disprove this theory by varying methods of measurement and experimental situations. As could be expected, exponents varied widely from one experiment to another. Eisler (1976) recognized that reality but thought nevertheless that the power law was valid for an average exponent of 0.9. Studies have been conducted to reduce methodologically linked differences. Eisler (1975) claims to have demonstrated the power law but only found a correlation of .14 between exponents estimated from reproduction data and from half-setting data. The present author tends to agree with Allan (1979) that a linear relationship between duration of the physical stimulus and the perceived duration is linear only for methods that do not use ratio setting temporal data (for example producing a double stimulus or half the stimulus presented). This finding was not disproved by Bobko, Thompson & Schiffman (1977), who reported exponents varying from .90 to .99 using four methods for durations ranging from 0.5 to 5 seconds. Furthermore, they conclude that the exponent is approximately 1 and that consequently there is a linear relationship between judged duration and physical duration. This finding is particularly interesting in that it was obtained with brief durations, whereas studies such as those by Eisler take durations up to 30 sec into consideration.

While accepting the notion of a psychophysical power law, Eisler has continued to perfect his own model (1981a,b) which basically postulates that when two durations are compared, the two are stocked in different sensory registers which work along with a comparator between the total recorded duration in the first sensory register and the variable duration stocked in the second sensory register. When the difference between the two durations is equal to the standard duration, the response is given. Eisler has constructed mathematical models which have become more and more complex to accomodate his experimental data along with Allan's (1977) and Kristofferson's (1977). Space does not permit a presentation of his model. However, it suffices to say that its basic principles are extremely questionable: posing the existence of two sensory registers functioning together, when it is well-known that below 200–400 ms it is difficult to switch from one perception to another, leaves little to be said for sensory registers whose durations can attain 30 ms.

The Nature of Stimulations

The nature of stimulations has always received a great deal of attention from researchers. A review of the question was provided by the present author (Fraisse 1963). New developments in recent years have been in the area of experiments on brief durations, under 100 ms.

Modern equipment capable of producing and controlling stimulations on the order of 1 ms are partially responsible for these findings. They are certainly interesting, but what has previously been said on succession and duration thresholds can still be applied here. The findings can be expressed in terms of perception of duration, but in fact what is perceived are not durations but qualitative changes in the stimulation which allows the Ss to respond in terms of longer-shorter in discrimination task paradigms or to quantify perceived differences along a set 0,1,2, scale. Time order errors or masking effects should also be taken into consideration when comparative judgments on successive brief durations are solicited.

These reserves are justified. Divenyi & Danner (1977) report that for durations of 80 ms and over, duration marker effects are no longer present, as is the case for shorter durations. Efron (1970a) shows that although the perceptual onset latency is independent of the stimulus duration, the perceptual offset latency was longer for brief duration than for stimuli that exceeded a critical duration of about 130 ms. This is true for vision as well as for audition, and Efron concludes that durations under 130 ms have a fixed duration which exceeds the stimulus duration.

EMPTY INTERVALS–FILLED INTERVALS Thomas & Brown (1974) report that filled intervals are always reproduced as longer durations than empty intervals. This finding was also reported for vision by Long & Beaton (1980), although in another framework.

STIMULUS INTENSITY More intense sounds and lights are judged longer than less intense auditory and visual durations, and this effect is greater for vision (Goldstone et al 1978).

ROLE OF EMPTY INTERVAL MARKERS Divenyi and Danner (1977) and Divenyi & Sachs (1978) varied the type of stimulus marking the beginning and the end of empty intervals. When the two sound burst markers are very similar, the perceived duration follows the regular psychophysical law, but if there is an important difference between the two markers in terms of intensity, spectrum, pitch, or duration of sounds, the results show nonmonotonic relationships which can be explained above all by the fact that 25 ms intervals are poorly distinguished when the intensity of one of the markers is very weak or when the two markers are too disparate. However, these authors are not primarily interested in duration, but rather in the nonmonotonicity that may be observed for voice onset time discrimination functions.

VISUAL AND AUDITORY TEMPORAL JUDGMENTS An auditory stimulation seems longer than a visual one. This relatively old finding has been confirmed by more recent studies and in more varied situations. Longer durations of about 1 sec, however, are involved here. Sound seems longer than light, even when the two are presented simultaneously. This is equally the case for gaps in auditory or luminous visual stimuli (Walker & Scott 1981). However, the weight of this finding should not be overemphasized. Furukawa (1979) has stressed that the stimulus conditions and the orientation of attention in this study render the results shaky.

THE KAPPA EFFECT The effect of distance on time is usually measured by comparing time intervals between two luminous stimuli placed horizontally, defining two points in space. If a sound corresponding to each point is introduced, estimation of time is greater as the space lengthens between the points. Previous results had shown the opposite effect, called the Tau effect, in which, under the same conditions, differences in duration had a direct effect on spatial estimation. The Japanese, as well as certain researchers elsewhere, remain interested in the question (see Matsuda & Matsuda 1981 for a bibliography of their own work; see also Ono 1976).

A very complete discussion of this issue is to be found in Jones & Huang (1982). The Kappa effect is highly stable, and although studies have been conducted primarily on adults, the results are even more pronounced in 7–10 year olds (Matsuda & Matsuda 1979). The explanation of this effect provided by these authors, who have also studied the effects of velocity, lies in what they call "cue selection sets," if the S can choose as an estimation cue either one of the two dimensions, that is, velocity or distance (or, time or velocity). It is important to note that the Kappa effect is not systematically found for durations under 160 ms (Collyer 1977). Collyer points out in addition that the Kappa effect is related to the S's tendency to perceive apparent movement in constant velocity. This hypothesis was further treated by Huang & Jones (1982).

Content of Stimulations

This topic was dealt with in depth by the present author in 1978. Few new developments which modify previous data have appeared since then. However, they have provided important details particularly in terms of models used.

Important developments concern the context effects, i.e. the background used during presentation of the stimulus to be evaluated. Previous research had shown that a divided interval (within certain limits) appears longer than an empty interval. However, Adams (1977) has shown that this "illusion" decreases if the auditory pulses originate from a source other than that of the duration markers, for example from the other ear, or if they appear as part of an ongoing sequence of background pulses.

If in a pulse task the S has to compare the duration of two brief increments in an ongoing sinusoid, performance is independent of the changes in context (noise alone, noise plus continuous sinusoids, or noise plus continuous sinusoids chosen to induce a pitch segregation effect). However, if the S is asked to compare the duration of two brief interruptions during a gap task in an ongoing sinusoid, the S experiences great difficulty in comparing the two gaps when the stimulus ensemble induces the pitch discrimination effect (lasting 40 ms) (Woods et al 1979).

The results of these experiments on audition may be compared to those obtained in visual presentations of brief durations (under 100 ms) where the apparent duration is in direct relation with stimulus size. (Thomas & Cantor 1975, 1976). When the frequencies of stimulus duration (short vs long) and stimulus area (small vs large) are varied, perceived size and duration are directly related to the frequency of the lower attribute value (short or small). It is assumed that perceived size and perceived duration grow together over the course of time spent sampling size information and that attribute frequency affects the rate of sampling and/or the point at which sampling stops.

Information Processing

The present author (1978, p. 234) discussed studies showing that perception duration was dependent upon the content of the stimulus to be identified for durations under 100 ms. Thomas & Cantor (1975, 1978) attempted to define more precisely the relationship between temporal (f) and nontemporal (g) information processing which was presented by Thomas & Weaver (1975).

The task consists of estimating stimulation duration of a luminous zone on a two- or four-point scale, and on a two-point scale the presence or absence of a specific target presented on the luminous zone and inserted in a letter array. Two conditions are used. In the pure duration condition, the S judged the duration of the array, and in a detection condition the S judged whether or not the array contained the target letters. The results of these two conditions were compared with two mixed conditions where the S performed both detection and duration tasks; in one case the duration task was emphasized, and in the other the detection task was emphasized. Decrements in duration accuracy were observed in going from pure to mixed conditions, but not in the detection task.

It is argued that in the pure duration condition, judgments are based partly on a timer that starts shortly after stimulus onset and stops shortly after stimulus offset, or as soon as a critical duration is reached, whichever occurs first. When the duration task is emphasized in a mixed condition, duration and detection judgments are done simultaneously but with a decrement in each. When the detection task is emphasized, priority is given to this task and the duration judgment is derived mainly from the outcome of processing in the detection task (Thomas & Cantor 1955, p. 43). This asymmetry can be explained by the fact that the two types of stimulation are treated simultaneously but that attention is spontaneously directed to information provided by the stimulus and not to its duration. There are limits in the ability to process information

Other studies have dealt with this problem by using longer durations of about 1 second. Berg (1979) used an estimation-reproduction task for durations ranging from .58 to 3 sec. The durations were accompanied by a film showing two triangles and a circle in motion. Each film showed each object moving along a randomly chosen path. The task was presented to the S in two conditions: first, to describe the movement of the objects, and second, to imagine that the figures are representing people doing different things, and to describe the social interaction portrayed. In the second situation, the S is expected to form an organizing scheme which reduces the perceived duration of the film. The results are congruent with this hypothesis but only for durations superior to 1.6 sec. Counterbalancing the two situations did not produce significantly different scores in the two situations. Fraisse (1979) studied the relationship between temporal judgment in a duration production task and that of an information processing task. It was hypothesized that the easier the processing, the more overestimated the duration would be, since the S would be more attentive to the duration itself. The production of one duration was compared in tasks of naming four different colors or reading the names of four colors. It is well established that naming is longer and in consequence more difficult than reading. As expected, the Ss, after being trained to produce responses (reading letters) at the rate of one per second, responded with average durations of 814 ms for reading and 932 ms for naming.

The model elaborated by Thomas & Weaver (1975) postulates that attention is divided between the two processes: estimation of duration and information processing. In the study of Fraisse (1979), the easier the task is, the more attention the S is able to give to the duration, which results in an overestimation of the duration and thereby the production of a shorter duration. This finding confirms the thesis of the interaction of the two processes beyond the limits of the very brief durations studied by Thomas & Weaver (1975).

Long & Beaton (1980a,b, 1981) worked on a different aspect of the question, attempting to explain several of the effects observed with brief durations (40 and 70 ms) by retinal persistence, instead of by information processing; they thus follow Efron (1970), Efron & Lee (1971), and Kristofferson (1977). The findings of these latest experimental studies are not in contradiction with those found by Avant et al (1975). An effort was made to demonstrate that it is more parsimonious to interpret the results by sensory persistence. Efron, Lee, and Kristofferson thus showed that target size, target luminosity, target contrast, and spatial frequency of the target influence the duration of the perception "in a manner predictable from the consideration of the retinal effects of such manipulations." Likewise, Mo (1971, 1975) found that the number of dots on a given surface would lengthen the perceived duration. In this case they thought that the number of dots simply increases the contrast to the surface. However, if at the same time, the surface area is increased, the effect is weaker. The effect is also diminished if these stimuli are perceived through peripheral vision. It is yet again diminished when the background lighting and the lighting of the stimulus surface are equalized.

The proofs advanced for retinal persistence as a function of the different variables are based on rather wide considerations. The fact that persistence plays a role does not invalidate the other models, and is not applicable to auditory stimuli. It is difficult indeed to reach a decision between these two approaches to the question, but the present author points out that Long and Beaton themselves admit that their hypothesis applies only to very brief stimuli where Bloch's Law comes into play. In the case of all these experiments concerning very brief durations, the present author is of the opinion that when the Ss are asked to evaluate the durations, they make use of the qualitative differences apprehended during the preliminary experiments in which they learn a binary or ternary code, but that comparable results would be obtained if they were asked to apply another criterion of judgment such as intensity. The cognitive model has a wider range of application than the model which accords a prominent place to retinal persistence; nonetheless, the latter is not to be neglected.

Individual Differences

Within the area of perceived duration, few studies have explored the role of individual differences. Ever since the research carried out in the nineteenth century (of Fraisse 1963), it has been established that expectations and attention play an important role in the perception of durations, generally by producing an overestimation of the perceived duration. The present author has already alluded to this fact above. This single variable by itself can explain differences in results since the S's attention depends not only on instructions but also on the quality of one stimulus in relation to another.

The absence of notable differences between normal Ss and the mentally ill (Banks et al 1966, Chattajea et al 1978) in the case of perception of a duration lasting about one second explains why hardly any research has been oriented toward personality variables. However, this last remark is too general. Mentally ill Ss, even those displaying trouble in temporal orientation but excluding neurological cases, obtain more variable results than normal groups. A few differences, particularly with schizophrenics, are found when more sophisticated methods of judgment are employed. Lhamon & Goldstone (1956), using their method in which Ss are asked to compare various durations to their own idea of a one-second duration, thus found that schizophrenics overestimate a one-second duration. However, Crain et al (1975) suspect that such differences might be traced to organic differences between the Ss. By the method of absolute judgments in which the S is required to associate with 3, 5, or 9 stimuli varying from 0.10 to 1.9 sec, numbers whose quantity is equal to that of the stimuli, it is possible to measure in bits the capacity of the canal, which for normal Ss reaches 2.07 bits whereas for schizophrenics only 1.62. One understands immediately that this treatment brings into play more than just perception of duration, strictly speaking. Mo & Kersey (1982) have for several years been seeking to define the role of a preparatory period on the duration of perception cards containing one or several dots. Nothing clear has come out of several studies. The present author adopts the following conclusion: "weakness and instability of time expectancy as characteristics of schizophrenia were demonstrated." In other words, the foreperiod produces a lesser systematic effect in the case of schizophrenics than in that of the control groups which in the experiments of Mo and Kersey were generally composed of alcoholics.

Cerebral Localizations

This is a knotty issue. It can be studied on animals only through learning techniques which can succeed only with durations extending beyond the present. In addition, although it is suspected that the right and left hemispheres in humans have different roles, this specialization is not the same in animals. Such studies on humans have been limited to Ss suffering brain damage. However, even with these Ss, greater interest has been accorded to temporal disorientation problems than to the perception *stricto sensu* of duration. In those cases where this variable has been taken into consideration, the brain-damaged Ss provide results very inferior to normal ones (Marchman 1969), and even inferior to those of schizophrenics in their capacity to transmit information (Locke 1974, Crain et al 1975).

A few research studies have nevertheless attempted to identify the roles of the two cerebral hemispheres in perception of duration on groups of adults said to be normal. Vroon et al (1977) found asymmetrical results according to whether the stimulations first reached the right or the left hemisphere. These results varied to a lesser extent when the left hemisphere was brought directly into play. This hemisphere was also more accurate in predicting events in time. On the basis of complex research, Polzella et al (1977) came to the conclusion that following Thomas and Weaver's model, the left hemisphere "relies on a timer to estimate duration while the right hemisphere relies on a visual information processor to estimate duration," p. 1187. These results need to be confirmed.

ESTIMATION OF DURATION

The research area now considered requires the S to judge durations that cannot be perceived and in which memory intervenes in the making of a global judgment about the duration. Many authors do not draw this distinction. They merely speak of the experience of time or of the judgment of time, and in the time scales they study, they sometimes use durations inferior to one second, which requires a different process. However, this is not of very great importance since there is clearly a certain continuity in the results as between perception and estimation of time, the S being able to mobilize the processes of both at the same time. It will nonetheless be seen that in the case of durations which go beyond perception, new problems arise. It may be pointed out immediately that time order error also plays a role in estimation of duration. In order to avoid this inconvenience, many authors take recourse either in the production method or in estimation of a duration in traditional units or in category scales, or by absolute judgments. Those research works based on comparison and above all on reproduction need careful interpretation. Finally, it may be added that for practical reasons, the durations studied in such research rarely exceed one minute.

The Psychophysical Law

Researchers continue to preoccupy themselves with this law, but through greater and greater variations in the content of durations. They seek to know whether one and the same psychophysical law always applies.

The first problem consists in knowing whether the law applies to estimation of durations. The results published by Eisler (1975) showed that the average exponent was 1 following the power law, but he pointed to a slight change in the curve that could take place between the perceived durations and the estimated durations. This result has not been challenged in the most recent research works, but it may vary as a function of the method employed and the task required. Bobko et al (1977) thus wonders whether the central tendency effect of judgment, often found in psychophysics, might not also characterize durations. If a duration of 25 sec is the lowest value in a series of durations, or the central value in a series of durations, or finally the longest in a third, then using an estimation method does not yield this effect, and the power law with an exponent close to 1 applies to the three series (Schiffman, Bobko & Thompson 1977). However, when the reproduction method was used, Bobko et al (1977) found a central tendency effect with overestimation of short intervals and underestimation of long intervals, especially after numerous trials, which is quite normal.

Other variables also modify estimation of duration. Repetition of estimations diminishes their size, but this does not hold true when the S is allowed to count. In this case a truncation of the psychophysical function occurs (Hicks & Allen 1979a). These same authors (1979b), using the reproduction method, found that the psychophysical function increases with repetitions between the reproductions whether the interval lasts 5 min or even several days. However, estimation decreases from day to day when the verbal quantification method is employed.

Content of Duration

By varying the number and the familiarity of visual stimuli presented in a series of slides, Schiffman & Bobko (1977) found an effect concerning the number of stimuli but not their familiarity. The present author is of the opinion that the latter variable was inadequately operationalized (estimation of duration method).

Block & Reed (1978) and Block (1978), like the preceding authors, critically tested Ornstein's (1969) hypothesis which accords an essential role to the duration of storage size in memory. This variable, which is difficult to measure, is inferred from the number, the familiarity, and the complexity of a series of stimuli, as well as from their treatment. Block's experiments can hardly help advance the inquiry since he undoubtably employed inadequately different stimuli. We tend to accept his conclusion. To explain his results, he proposes a contextual change hypothesis that, incidentally, he finds similar to the present author's (Fraisse 1963) hypothesis, namely that the duration depends on the number of perceived changes. According to the present author, Ornstein has adopted the same hypothesis, but has better spelled out the nature of the changes. In fact, it may be that the S in certain cases takes into account the objective number of changes in the situation, for example, the number of slides projected, but that in other cases it would be the number of changes memorized in an individualized manner that he takes into account. Thus are explained, in particular, the results obtained in prolonged research work in which the S lives at his personal rhythm outside of any cosmic or social influence. In a 6-month longitudinal study on a subject living in a cave 70 meters deep, the present author ran several temporal experiments (Fraisse 1973). For example, the S was to estimate the duration between waking up and lunch. For 64 days, his average estimation was 4 h 40 min, but the clocked duration was 10 h 26 min.

His errors were proportionally similar for the production and reproduction of shorter durations (between 30 and 120 sec). In this case there was a repetition effect but the author thinks that such gross errors were attributable to the fact that in that life of seclusion, which reminds one somewhat of perceptual deprivation situations, few changes took place in the life of the S, and for that reason he greatly underestimated the real durations.

The nature of material and task are fundamental factors, which explains the variety of results described so well by Kowal (1981). In the same way, we can explain the same author's (1976) results in which he found no effects on estimation of duration using material endowed with greater or lesser significance: reading stories of highly cultural salience to Ss of widely varying cultural backgrounds (American and Indian students).

It is thus possible to agree with Hogan's (1978) hypothesis, when he expresses concern with authors such as Ornstein who claim that the more a duration is filled with complex stimuli the longer it seems, whereas others find that an empty duration seems longer than one filled with complex stimulations. For him, it all depends on the degree of complexity. According to Hogan, the apparent duration diminishes from very simple to optimum complexity, whereas on the contrary the apparent duration increases from optimum to excessive complexity, since it is no longer possible to stock poorly perceived events. As one goes from an absence of complexity to an excessive complexity, the established curve would be U-shaped at optimum. Having presented the thesis (1963) that apparent duration depends on the number of perceived changes, the present author adheres to this conceptualization of the problem, since when stimulus complexity is too great, individualized changes are not perceived. Unfortunately, the present author has knowledge of no experimental results confirming Hogan's hypothesis, undoubtedly because it is difficult to experiment with a range of situations going from zero complexity to a degree of complexity where events are poorly identified and can no longer be stocked.

This difficulty is not present in research where the duration to be estimated is filled in with a specific activity by the S, and where the information treated by the S is no longer a hypothetical variable introduced by the experimenter through a difference in material. The subjects of Hicks et al (1976) had to classify 104 playing cards into a single stack (0 bit), into 2 stacks, namely the 2 colors (1 bit), and into 4 stacks by suit (2 bits). They were stopped at the end of 42 sec and requested to evaluate the duration of their activity in seconds. However, one group had been advised ahead of time about this question (prospective judgment) while the other had not (retrospective judgment). For the prospective judgments, the estimated duration decreased very greatly in linear fashion with the uncertainty. Of course, an interpretation based on the number of cards processed could be attempted, since it varies from 75 to 34 in going from 0 to 2 bits. However, such reasoning cannot be accurate since this proportionality is not found in the retrospective judgments which vary neither with the information processed nor with the number of cards manipulated. The authors conclude, rightly it would seem, that when the task is difficult, the Ss are not able to pay attention to the duration and that in reality they are making a retrospective estimation. In another study, Miller et al (1978) found that in tasks of learning a list of words, the prospective judgments were longer than the retrospective judgments, which tends to make one think that in the case of prospective tasks, the Ss divide their attention between the task and the duration to be evaluated. Here again, the present author's position coincides with Thomas & Weaver's (1975) hypothesis on perceived durations. Mulligan & Schiffman (1979) reran the study of the relationship between memory organization and perceived duration along Ornstein's lines. The Ss were supposed to perceive ambiguous stimuli within durations around 60 sec. The organization was manipulated by employing or not employing a code which simplified the stimulus. Facilitating memory organization by presenting the code before or after the stimulus interval shortened apparent duration compared to the no-code condition.

Learning Estimation of Duration

Estimations of duration—above all verbal—can be modified by numerous parameters, but they differ in general very notably from physical duration. Is learning possible here? If so, under what conditions, and is it transferable?

By the method of production and reproduction, Fraisse (1971) evaluated the effect of immediate correction on a duration of 30 sec. To prevent the S from counting, he constantly had to produce the syllable "top" during the estimation of the duration. With correction, learning is very rapid and the effect of correction persists when it is stopped. The "tops", however, do not furnish landmarks for the S. It is as if the cadence of the productions of the "tops" corresponded to the S's personal tempo. However, counting at a learned cadence diminishes the variance in relation to the estimation of a time interval (Getty 1976). Learning the estimation of duration is also possible with 6- to 10-year-old children in the reproduction of a 30 sec duration (Fraisse & Orsini 1958). Friedman (1977) found the same type of result with preschool children for the production of a 15 sec duration, which makes him propose that there really is an inner clock.

It is also possible to create a time conditioning in humans in relation to a duration of, for example, 8 sec. If the alpha rhythm of the EEG is recorded during this interval, it is observed that the alpha arrest precedes by about 1 sec the S's response, as if the alpha stop and the S's response depended on one and the same alert process at the end of the duration (Fraisse & Voillaume 1969).

Is such learning transferable? From one direction to the other it undoubtedly is with the same durations (Warm et al 1975), but from one duration to another the results are not as clear. According to Hicks & Miller (1976) there is some transfer from long durations (40–80 sec) to short ones (5–10 sec) which are presented alternatively with error corrections. The transfer, however, takes place better from long to short durations than the reverse.

The Brain's Role

The role of the brain from a physiological angle remains to be considered in the estimation of duration. The respective roles of the two cerebral hemispheres have been studied less concerning estimations than for perceived durations. Vroon et al (1977) found that durations from 20 to 60 sec were equally well estimated by visual and auditory stimuli terminating on either of the two hemispheres (reproduction method that makes a negative time order error appear). The found a difference only when they calculated the variances of each S in each situation. The differences are greater when the stimuli first terminate on the right hemisphere than on the left hemisphere, which would therefore imply a predominance, but they are less marked than in the perception of durations. Hicks & Brundige (1974) attempted to demonstrate the respective roles of the two hemispheres by carrying out a recognition experiment with lists of 300 items of which 50 were present twice. The items consisted either of abstract nouns or of photographs of faces. This difference in roles of the two hemispheres was to be tested by using right-handed and left-handed Ss. The results were negative, but also the hypotheses were weak. Does a recognition task not always involve the dominant hemisphere?

By considering large groups of Ss having brain lesions in widely differing areas, and by subjecting them to a test battery (involving manipulation of temporal concepts estimating time periods, sequence of events, judging and producing short and long intervals singly and in pairs), Bruyer & Bontemps-Devogel (1979) found that by comparison with a control group, the Ss with lesions showed a lower level of performance. The group with frontal lesions showed a marked disability. A final point to indicate, and it is merely a confirmation, is that there is no relationship between the alpha rhythm and temporal estimations (Adam et al 1971). However, Coffin & Ganz (1977) found in the estimation of a 5 sec task a high correlation between the estimations and the weighted mean frequency of the EEG close to the alpha frequency.

Expectation and Attention

The study of these variables is not a recent phenomenon. Expectation raises the apparent duration (cf Fraisse 1963). "A watched pot never boils," goes the familiar saying. Lordahl & Berkowitz (1975) attempted to show that there was no expectancy effect, properly speaking, but merely the effect of a comparison of this type of experience with that of intervals occupied by varying events.

Cahoon & Edmonds (1980) state that this expectancy effect is transfered to the estimation of another duration. Block et al (1980) carried out an important research on this topic using a situation close to the reality expressed in the quoted aphorism. One group of Ss is to watch for the moment when a vessel of water starts to boil and they know ahead of time (prospective situation) that they will have to evaluate the duration between turning on the heat and the boiling point. Another group is simply asked to watch over the water in a similar beaker to the other group's, and at the end they are then asked to estimate the past duration (retrospective situation). However, the heat is regulated in such a manner that in one case the water starts boiling after about 240 sec, which is shorter than the anticipated duration (270 sec), or else it does not boil at all.

The subjects make a double estimation, reproducing the duration and verbally estimating it. In the condition where the water does not boil, and in a prospective attitude, the reproduced duration is longer (278 vs 209 sec). When estimating verbally, the result takes the same direction but is less pronounced. On the other hand, in the condition where the water boils, reproduction results are reversed (240 vs 260 sec) and the same goes for verbal estimation; with retrospection there is practically no difference.

This result has been verified in several experiments using different variables. The present author underlines the fact that an expectation seems long when it is nothing more than expectation, but once the expectation has reached its goal, the overestimation of the duration of the expectation disappears rapidly. Also the fact that the verbal estimation is always followed by the reproduction renders the results less reliable. What is being estimated? Is it the duration of the expectation or that of the reproduction? If it concerns the expectation, then there is a 4 min interval between the observation of the water and the response.

Again in the area of expectations, Edmonds et al (1981) persuaded their Ss that their expectation would be followed by a pleasant, unpleasant, or subjective neutral experience. Results indicate that the positive expectancy group overestimate the actual interval time (time passed relatively slowly) whereas there is an underestimation in the other groups. Evidently the expectation itself of an agreeable event leads to paying more attention to the passing of time.

It is possible to make attention vary in different ways. In general, it has been found that the duration seems shorter when the estimation concerns the duration of a task than when the S is simply asked to pay attention to the passing of time (Curton & Lordahl 1974).

Listening for a minute to a selection of more or less interesting prose passages has shown that the interesting passages are judged shorter than the others (Hawkins & Tedford 1976). A more original experiment was carried out by Thayer & Schiff (1975), who used a face-to-face eye contact situation between two Ss of the same or opposite sex. This eye contact is established with contemporaries who are either smiling-friendly or scowling-angry. The time is overestimated in eye contact with unpleasant faces in relationship to the case of pleasing faces.

Results reported by Underwood (1975) are more surprising. The Ss encoded nonsense syllables, unrelated words, or related words for 50 sec and then recalled for 50 sec. The Ss judged that they had taken more time on retrieval than on encoding, and this difference increased as the meaningfulness of the material decreased. Should it then be concluded that retrieval requires more attention than encoding and that greater attention then corresponds to a longer time? But is not 50 sec too long a duration for retrieval, carrying as a consequence the possibility to pay more attention to time, given that in any case the Ss have only a limited number of elements to recall?

Individual Differences

Given the wide variability of duration estimations, one might well suppose that it would be difficult to demonstrate interindividual differences that are not pathological. However, taking into account what has been said above about the roles of expectation and attention, it is not very surprising that very anxious Ss such as those detected by the Test Anxiety Scale, for example, give a longer estimation of waiting, and even of an intellectual task, than the less anxious (Sarason & Stoops 1978). Along the dimension of field dependence and independence, i.e. cognitive style, the results are not very enlightening. In several situations, Davidson & House (1978) found that cognitive style had very little importance on the estimation of the durations. Using another situation, Phillips (1977) came to the same conclusion.

As for the variable *Introversion-Extroversion* such as can be estimated by Eysenck's tests, Wudel (1979) found, after Ss spent 100 sec in relaxation or in arithmetical operations, the extroverts gave shorter estimations and had greater confidence in their responses. However, Gray et al (1975), working with a larger group but limited to extreme populations on the introversion-extroversion axis, did not find any difference between the groups when estimating 3 min readings of dull or interesting texts. Both groups estimated the intervals to be shorter when the reading was interesting.

Still on results concerning normal Ss, if the S is asked to use mental images as cues in estimating a given interval, it is observed that, as a function of individual differences in the vividness of visual images, children in the strong image group were more accurate than those in the weak group. In adults, there was no difference between groups (Orihara 1980).

Populations that are more readily identifiable by an easily recognizable trait can also be studied. Estimation of time by the *overweight* has particularly attracted attention since the 1960s. It would seem that it was Witkin (1965) who first spoke of the overweight as being more field dependent. The study of the effect of the content of the duration on the estimation of the latter by overweight subjects began across the field dependency dimension. Hughs & Reuder (1968) tested this hypothesis concerning the duration of reading either sensitive or neutral word lists. Absolute errors indicating a variability were greater for the overweight than for the control group, and more pronounced with the sensitive list than with the neutral list.

The same hypothesis has been employed in many various forms, all of which suppose that the overweight are more sensitive to external than to internal stimulations. Stutz et al (1974), using a reproduction method, found that overweight Ss made larger errors than those in a control group. This result was confirmed by Rodin (1975) on a population of men but rejected by Nail et al (1981), who found no such effect with men but did find such an effect in women. These latter authors wisely conclude, "In general, results offer little support for the existence of a generalized insensitivity to interval cues on the part of the overweight" (p. 139).

Schizophrenia has also captured the attention of numerous researchers. The most significant results seem to be as follows: schizophrenics overstimate brief durations, whether in estimation at various moments of an interview-testing session or in operational estimation. In this method the S was required to indicate when a specified number of seconds had passed (Wahl & Sieg 1980). This overestimation of brief durations must have been brought out by the well-known characteristic of chronic schizophrenics. For them, "time stood still," and when they are age-disoriented they underestimate past durations (birth date, length of stay at the hospital, and current year) (Crow & Stevens 1978). However, with schizophrenics disorientation is not as pronounced as with brain-damaged patients (Josly & Hutzell 1979).

Doob (1971) reviewed research as to estimations of duration by Ss under *hypnosis,* and showed that these estimations are above all dependent on suggestions. Two groups of volunteer Ss were given the Stanford Hypnotic Susceptibility Scale, Form C, either with a hypnosis condition or without that induction. Prior to the termination of the scale, Ss were asked to recall the activities they had performed and the time that had elapsed since they began the scale. The 10 hypnotized Ss were significantly less sequential in their recall of activities and less accurate in their estimation of the passage of time than were the 10 nonhypnotized Ss (Schwartz 1978).

The author concludes that the hypnotized Ss were less sensitive to the context that the world provided for their activities than the nonhypnotized Ss. Bowers (1979) comes to the same conclusion. Although the Ss in these groups, for the most part, underestimated the duration during which they had been hypnotized, there were also some who overestimated it. Those who underestimated it were those who were the most hypnotizable.

Estimation of Duration in Retrospect

Having studied up to now the estimation of time between the present moment and the beginning of an event that has just terminated, i.e. according to some, the estimation of time in passing, it is time to study the estimation of a duration which ran over a period of past time, i.e. between two past events. The role of long-term memory is going to be vital here whereas the durations studied previously often called upon the intervention of short-term memory.

All sorts of transitions are certainly possible between the two situations. It is thus possible to compare the reproduction of a duration right at the end of the interval or after a period of 20 sec (Guay & Bourgeois 1981). Whether during this period the S is simply at rest or occupied with an activity (counting backwards by threes) it simply has the effect of raising the variability of the reproduction responses for intervals 4, 8, 16, and 32 sec.

The dominant hypothesis on the role of memory in these estimations is obviously Ornstein's (1969), which has already been mentioned. The estimated duration at a given moment is proportional to the storage size. It constitutes a hypothetical variable which would depend on the number of events stored and retrieved as well as on the complexity of the coding of the events. Block (1974) tried to test this hypothesis with three durations to be compared: the first is a piece of music for 240 sec, the second a duration of 180 sec occupied with the audition of either 30 words at 6 sec intervals or 60 words at 3 sec intervals; this duration is followed by another interval of music lasting 120 sec. The Ss are not advised ahead of time about what will be asked of them, but they do know that they will be questioned. At the end of the presentation they are required to evaluate the last two durations by lengths proportional to a line 50 cm long representing the duration of the first musical interval. Finally they are asked to write all the words they have retained and to evaluate the number of words presented. The duration occupied with 60 words is judged relatively longer than that with 30 words, but nonetheless the number of words recalled is approximately the same in each of the two situations. What really changes is the evaluation of the number of words presented. In another experiment of the same type, Block varied the organization of the stimuli rather than their number (80 words presented in groups of 4, either belonging to the same semantic category or in disorder). The group that perceived the stimuli by semantic groupings recalled more of them and judged the duration of the presentation to be longer, whereas both groups of Ss gave identical estimates of the number of words presented.

These experiments have been described at some length because by their contrast they illustrate the two possible interpretations of Ornstein's hypothesis. In certain cases, it is not the events taken individually, but rather their numerical quality that is stocked in memory. In other cases, the criterion retained is the number of stimuli stocked in memory; this explains the different roles assigned to codes in Ornstein's experiments according to whether they increase the number of stimuli identified (which is the case in Block's second experiment) or whether they diminish the number of stimuli by integrating the complex elements into smaller sets. This double face in the role of storage size was a development of the present author's hypothesis published in 1963, namely that the estimated duration was proportional to the perceived changes. It must be pointed out that for the present author, what is involved here is either the number of events that take place in the outside world and that are perceived, or else the number of events that are identified at the perceptive level and then memorized.

A special modality for the estimation of a duration distant in time consists of classifying in order or of dating one or several events. Squire et al (1975) had Ss classify highly familiar television broadcast programs two by two. In the case of programs dating from 2 to 4 years the Ss were able to distinguish them from programs older than 5 years. However, beyond that (from 5 to 17 years) the discrimination was very weak. Linton (1975) every day for 20 months noted a personal event on file cards with the date on the back. She used a method for discrimination of order and of dating. The discrimination depends both on the time interval between two events, for example, and on how long ago they took place. Thus in the case of an interval of 17 to 32 days, there was no error on events up to 2 months past, and 20% error after 8 months. As concerns dating, the error rate was null for events of 2 to 8 days past, but the estimated error attained 10–12 days in the case of events occuring 4 to 18 months previously. Lieury et al (1979, 1980) attempted to determine more precisely not only the size of the error, but its sign as well. By requesting Ss to date numerous public events having occurred 4 to 17 years previously, and of which the Ss were well aware, he found an underestimation of the durations the farthest in the past and an overestimation concerning the most recent events. He also attempted to demonstrate the processes involved in dating; he found three; either an event which serves as a reference point, or the use of a personal calendar consisting of a series of well-dated events, or finally direct contact with the specific time period. The preceding emphasizes rather well that we do not remember long durations situated in the distant past. We can only situate past events on the basis of remembrances that are not temporal: for example, recalling the date of an event (Today is my 20th wedding anniversary); or, *knowledge about* a duration (That trip lasted a month); etc . . .

Thus, in cases of the estimation of a period of time in the distant past, subjective time is spoken of rather than estimation of a duration. Subjective time, i.e. the relative estimation of a period of time, decreases, for example, as the S advances in age. Paul Janet (1877) had maintained that this fact was due to the relationship between the subjective duration of a year and the S's chronological age. The S would establish a proportion between a given duration and his remaining life expectancy. One year at the age of 10 amounts to 10% of one's lifetime, whereas at the age of 60 it only amounts to 1.6%; life expectancy constantly grows shorter, and thus life passes more rapidly. Paul Janet used the term illusion in discussing this. More recent authors have sought to quantify this acceleration of time as a function of age. The operationalization involved is intricate. Lemlich (1975) asked Ss to evaluate at their present age the duration of a year by comparing it to the middle or to a quarter of a lifetime. The subjective relationship was evaluated as 2 for a quarter and as 1.6 for half of a lifetime. The author suggested that subjective duration varies inversely with the square root of chronological age, which equally represents subjective time at the moment of the response. Walker (1977) handled the same problem by asking that the present year be evaluated as 10, and then that the duration of a year at the middle point of lifetime and at a quarter of lifetime be evaluated in relationship to the established value given to the present year. He did not find exactly the same values as did Lemlich, nor his arithmetical formulation, but nonetheless his values were not all that different: 1.4 times longer at the half-way point, 1.6 times longer at the quarter point of life span. The present author points out that in both of these studies, there was a high variability between Ss as well and that not all of the responses were in the same direction. Thus, in Walker's research, 74% agreed that time passes faster as one grows older, but on the contrary, 18% judged the opposite, so it is difficult to formulate an abstract estimation of the passing of time. The present author, however, relates this subjective phenomenon to the fact that with advancing age, there are less novel events in life that are worthy of being stored in memory.

CONCLUSION

Having reached the end of this chapter, the evidence obliges one to concede that no revolution has taken place over the past few years in the field of perception and estimation of durations. Psychologists, however, are becoming more and more interested in the problem of time. This issue corresponds to a phenomenological order of knowledge that is placed in relationship to physical time. Such knowledge is no longer proscribed by the behaviorists' taboo. From that point of view, one is led to identify three orders of duration on the physical continuum, orders which do not hold the same status, epistemologically speaking. These orders are the following: (*a*) less than 100 ms, at which the perception is of instantaneity; (*b*) 100 ms-5 sec, perception of duration in the perceived present; and (*c*) above 5 sec, estimation of duration involving memory.

Durations shorter than about 100 ms are not perceived as such. The perception of a succession appears beyond the level of 20 ms. In fact, successions are the raw material of the physical world. This latter is nothing but successions, or if one prefers, changes that can engrave their date on physical objects. It is thus possible to date prehistoric fragments by means of carbon 14. A tree's age is recorded by means of the concentric circles produced as the trunk develops. However, duration is a construct of the human mind. Human eyes perceive succession at first, but duration is linked to the identification of on and off effects, to use the language of physiology. Nevertheless, much recent research has been devoted to brief durations; differences, qualitative in the present author's opinion, allow the comparison of two durations by a relative criterion: longer-shorter, for example.

The perception of duration, *stricto sensu,* is situated at a level above 100 ms and within the limits of the psychological present as described by W. James (1890). It includes a unity among perceptive events as is revealed, for example, by the perception of rhythmic patterns. On the other hand, the perception of rhythm disintegrates if the stimuli are spaced too far apart; there then are nothing more than more or less regular successions. The duration of the presentifiable can hardly extend beyond 5 sec. The choice of methods for its apprehension is therefore fundamental. Although estimation and production theoretically correlate negatively, each one of the methods for reproduction, for comparison, and for absolute evaluation on a small scale produces differing results. In the absence of systematic research on the comparison of methods and their interaction with the content of durations and expectations, it is difficult to separate differences arising from the method from those attributable to individual and/or interindividual variability. Within the limits of the perception of durations, the effects of time order and error, and, for the shortest durations, those of masking, are of utmost importance.

Beyond the limits of the perceived present, duration can only be estimated by the S's construct which brings to bear short- and long-term memory. The problem of methods remains even though the choice of pertinent ones has been reduced. What could possibly be learned from experiments in which one is required to produce or reproduce empty durations of 60 sec without the use of instruments of measure? In all those cases where measures are employed, a new process intervenes. A comparison between two types of contemporaneous successions can be made, whether by the differences in the movements of two runners using a clock, or by the creation of an internal clock, as for example by counting. This necessity has led numerous authors to imagine, in those cases where voluntary measurement is impossible to employ, the existence of a physiological clock and of a time counter even though that audacious hypothesis has never been confirmed directly.

In estimating durations, variability becomes a more and more difficult obstacle to overcome on the path toward accurate laws. Thus the *sources* of variability have been accorded greater and greater importance on account of attitudes, according to whether the estimation is prospective or retrospective with a very high interval effect between the experienced duration and the moment when it is estimated.

However, the most characteristic aspect of recent research has been the importance accorded to the content of the experienced duration under a passive aspect (complexity) or an active aspect (duration of an activity) within the three duration registers that have been identified. With the growing importance accorded generally to information processing, authors have sought to analyze the underlying processes of perception and of time estimation. Several models have been proposed, but it is the present author's opinion that they would be difficult to generalize in application to results obtained with other methods. One can limit oneself to general models (Fraisse 1981). Among the other models, the most potential seems to lie in the generalization of Thomas & Weaver's (1975). Within a given task, there is a compromise between temporal and nontemporal information. Temporal information is all the more taken into consideration when it is emphasized in the task (prospective judgments) and/or the nontemporal task leaves the S greater liberty to pay attention to the temporal aspect of his activity. The more one pays attention to time, the longer it seems, with the extreme being expectancy which is nothing but expectancy of a desired or feared event. Reciprocally, duration seems short when the task is difficult and/or interesting.

These are strategies proper to adults. Space has not allowed the inclusion here of research on the development of the notion of time in children. A child perceives rhythms from the age of two months (Demany et al 1977), adapts gradually to durations, and learns to speak of them (through adverbs of time and verb tenses). This omission in this chapter is happily compensated for by the recent publication (Friedman 1982) of a work in which many authors, including the present one (Fraisse 1982), presented their themes. The stages in the development of the notion of time permit a better understanding of the treatment of temporal information by adults.

In tomorrow's psychology, progress will probably be conditional on not subrepticiously mixing together sizes of durations studied and above all on clarifying the results that can be obtained by using the different methods. In other words, choose among tasks those which appear to be most revealing, and apply them over the entire choice of methods. At a time when the variation of the content of durations is being carried out, our knowledge about the construction of duration cannot progress unless the methodological mortgage is paid off, which will shed light on the way we treat temporal information as well.

Literature Cited

Adam, N., Rosner, B. S., Hosick, E. C., Clark, D. L. 1971. Effect of anesthetic drugs on time production and alpha rhythm. *Percept. Psychophys.* 10:133–36

Adams, R. D. 1977. Intervening stimulus effects on category judgments of duration. *Percept. Psychophys.* 21:523–34

Allan, L. G. 1975. Temporal order psychometric functions based on confidence rating data. *Percept. Psychophys.* 18:369–72

Allan, L. G. 1976. Is there a constant minimum under light and dark adaptation? *Q. J. Exp. Psychol.* 28:71–76

Allan, L. G. 1977. The time order error in judgments of duration. *Can. J. Psychol.* 31:24–31

Allan, L. G. 1979. The perception of time. *Percept. Psychophys.* 26:340–54

Allan, L. G., Kristofferson, A. G. 1974. Successiveness discrimination: two models. *Percept. Psychophys.* 15:37–46

Allport, D. A. 1968. Phenomenal simultaneity and the perceptual moment. *Br. J. Psychol.* 59:395–406

Avant, L. L., Lyman, P. J., Antes, J. R. 1975. Effects of stimulus familiarity on judged visual duration. *Percept. Psychophys.* 17:253–62

Banks, R., Cappon, D., Hagen, R. 1966. Time estimation by psychiatric patients. *Percept. Mot. Skills* 23:1294

Baron, J. V. 1971. The threshold for successiveness. *Percept. Psychophys.* 10:201–7

Berg, M. 1979. Temporal duration as a function of information processing. *Percept. Mot. Skills* 49:988–90

Bindra, D., Waksberg, H. 1956. Methods and terminology in studies of time estimation. *Psychol. Bull.* 53:55–59

Block, R. A. 1974. Memory and the experience of duration in retrospect. *Mem. Cognit.* 2:153–60

Block, R. A. 1978. Remembered duration: Effects of event and sequence complexity. *Mem. Cognit.* 6:320–26

Block, R. A., George, E. J., Reed, M. A. 1980. A watched pot sometimes boils. A study of duration experience. *Acta Psychol.* 46:81–94

Block, R. A., Reed, M. A. 1978. Remembered duration: Evidence for a contextual change hypothesis. *J. Exp. Psychol: Hum. Learn. Mem.* 4:656–65

Bobko, D. J., Schiffman, H. R., Casteno, R. J., Chiapetta, W. 1977. Contextual effects in duration experience. *Am. J. Psychol.* 90:577–86

Bobko, D. J., Thompson, J. G., Schiffman, H. R. 1977. The perception of brief temporal intervals: Power functions for auditory and visual stimulus intervals. *Perception* 6: 703–9

Bowers, K. S. 1979. Time distortion and hypnotizability: Understanding the duration of hypnosis. *J. Abnorm. Psychol.* 88:435–39

Bruyer, R., Bontemps-Devogel, N. 1979. Lésions du cortex cérébral et perception de la durée: approche neuro-physiologique de la "chronognosie". *J. Psychol. Norm. Pathol.* 79:279–97

Cahoon, D., Edmonds, E. M. 1980. The watched pot still won't boil: Expectancy as a variable in estimating the passage of time. *Bull. Psychon. Soc.* 16:115–16

Cantor, N. E., Thomas, E. A. 1976. Visual masking effects on duration, size and form discrimination. *Percept. Psychophys.* 19: 321–27

Carmon, A., Nachshon, I. 1971. Effect of unilateral brain damage on perception of temporal order. *Cortex* 7:410–18

Chattajea, R. G., Chatterjee, P. K., Bhattacharyya, A. K. 1978. Time estimation in psychotics and neurotics. An experimental study. *Psychologia* 21:237–40

Coffin, S., Ganz, L. 1977. Perceptual correlates of variability in the duration of the cortical excitability cycle. *Neuropsychologia* 15:231–41

Collyer, C. E. 1977. Discrimination of spatial and temporal intervals defined by three light flashes: Effects of spacing on temporal judgments and on timing on spatial judgments. *Percept. Psychophys.* 21:357–64

Crain, P., Goldstone, S., Lhamon, W. I. 1975. Temporal information processing and psychopathology. *Percept. Mot. Skills* 41: 219–24

Crow, T. J., Stevens, M. 1978. Age disorientation in chronic schizophrenia. The nature of the cognitive deficit. *Br. J. Psychol.* 133:137–42

Curton, E. D., Lordahl, D. S. 1974. Effects of attentional focus and arousal on time expectation. *J. Exp. Psychol.* 103:861–67

Davidson, W. B., House, W. J. 1978. Influence of reflection impulsivity and cognitive style on time estimation under different ambient conditions. *Percept. Mot. Skills* 46:1083–91

Demany, L., McKenzie, B., Vurpillot, E. 1977. Rhythm perception in early infancy. *Nature* 266:719–19

Divenyi, P. L., Danner, W. F. 1977. Discrimination of time intervals marked by brief acoustical pulses of various intensities and spectra. *Percept. Psychophys.* 21:125–42

Divenyi, P. L., Sachs, R. M. 1978. Discrimination of tone intervals bounded by tone bursts. *Percept. Psychophys.* 24:429–36

Doob, L. W. 1971. *Patterning of Time.* New Haven: Yale Univ. Press. 472 pp.

Edmonds, E. M., Cahoon, D., Bridges, B. A. 1981. The estimation of time as a function of positive, neutral or negative expectancies. *Bull. Psychon. Soc.* 17:259–60

Efron, R. 1963. Temporal perception aphasia and déjà vu. *Brain* 86:403–24

Efron, R. 1970a. The effect of stimulus duration on perceptual onset and offset latencies. *Percept. Psychophys.* 8:231–34

Efron, R. 1970b. The relationship between the duration of a stimulus and the duration of a perception. *Neuropsychologia* 18:37–55

Efron, R. 1974. An invariant characteristic of perceptual systems in the time domain. In *Attention and Performance*, ed. S. Kornblum, 4:713–36. New York: Academic

Efron, R., Lee, D. N. 1971. The visual persistence of a moving stroboscopically illuminated object. *Am. J. Psychol.* 84:365–76

Eisler, H. 1975. Subjective duration and psychophysics. *Psychol. Rev.* 82:429–50

Eisler, H. 1976. Experiments on subjective duration 1968–1975: a collection of power functions exponents. *Psychol. Bull.* 83: 1154–71

Eisler, H. 1981a. Applicability of the parallel-clock model to duration discrimination. *Percept. Psychophys.* 29:225–33

Eisler, H. 1981b. The parallel-clock model: reply and note. *Percept. Psychophys.* 29:516–20

Eisler, H., Linde, L., Troeng, G., Lazar, R., Eisler, B. M., et al. 1980. *A Complementary Bibliography of the Psychology of Time*. Am. Psychol. Assoc. J.S.A.S. Catalog Sel. Doc. Psychol. No. 2101. 151 pp.

Eriksen, C. W., Collins, J. F. 1967. Some temporal characteristics of visual pattern perception. *J. Exp. Psychol.* 74:476–84

Fraisse, P. 1963. *Psychology of Time*. New York: Harper & Row. 343 pp.

Fraisse, P. 1966. Visual perceptive simultaneity and masking of letters successively presented. *Percept. Psychophys.* 1:285–87

Fraisse, P. 1967. *Psychologie du temps*. Paris: P.U.F. 2nd ed.

Fraisse, P. 1971. L'apprentissage de l'estimation de la durée et ses repères. *Année. Psychol.* 71:371–79

Fraisse, P. 1973. Temporal isolation, activity rhythms and time isolation. In *Man in Isolation and Confinement*, ed. J. L. Rasmussen, pp. 85–98. Chicago: Aldine. 330 pp.

Fraisse, P. 1974. *La Psychologie du Rythme*. Paris: P.U.F. 244 pp.

Fraisse, P. 1978. Time and rhythm perception. In *Handbook of Perception*, ed. E. C. Carterette, M. P. Friedman, 8:203–47. New York: Academic

Fraisse, P. 1979. Influence de la durée du traitement de l'information sur l'estimation du'une durée d'une secondc. *Année Psychol.* 79:495–504

Fraisse, P. 1980. Les synchronisations sensori motrices au rythme. In *Anticipation et Comportement*, ed. J. Requin, pp. 233–57. Paris: C.N.R.S.

Fraisse, P. 1981. Cognition of time in human activity. In *Cognition in Motivation and Learning*, ed. G. d'Ydewalle, W. Lens, pp. 233–58. Hillsdale, NJ: Erlbaum

Fraisse, P. 1982. The adaptation of the child to time. See W. J. Friedman 1982, pp. 113–40

Fraisse, P. 1983. Le futur dans les perspectives temporelles. *Int. J. Psychol.* In press

Fraisse, P., Orsini, F. 1958. Etude expérimentale de conduites temporelles III. Etude génétique de l'estimation de la durée. *Annêe Psychol.* 58:1–6

Fraisse, P., Voillaume, Cl. 1969. Conditionnement temporel du rythme alpha et estimation du temps. *Année Psychol.* 69:7–15

Friedman, E. R. 1977. Judgments of time intervals by young children. *Percept. Mot. Skills* 45:715–20

Friedman, W. J., ed. 1982. *The Developmental Psychology of Time*. New York: Academic. 286 pp.

Furukawa, M. 1979. A study on the difference in visual and auditory temporal judgment II. *Tohoku Psychol. Folia* 38:18–28

Getty, D. J. 1976. Counting processes in human timing. *Percept. Psychophys.* 20:191–97

Gibbon, J., Rutschmann, R. 1969. Temporal order judgment and reaction time. *Science* 165:413–15

Gibson, J. J. 1975. Events are perceivable but time is not. In *The Study of Time*, Vol. 2, ed. J. T. Fraser, N. Lawrence. Berlin: Springer

Goldstone, S., Lhamon, W. I., Sechzer, J. 1978. Light intensity and judged duration. *Bull. Psychon. Soc.* 12:83–84

Gray, C. T., Gray, C. R., Loehlin, J. C. 1975. Time perception: effects of intraversion/extraversion and task interest. *Percept. Mot. Skills* 41:703–8

Guay, M., Bourgeois, J. 1981. Short-term retention of temporal information. *Percept. Mot. Skills* 52:719–26

Hawkins, M. F., Tedford, W. H. 1976. Effects of interest and relatedness on estimated duration of verbal material. *Bull. Psychon. Soc.* 8:301–2

Hellstrom, A. 1977. Time errors are perceptual. *Psychol. Res.* 39:345–88

Hicks, R. E., Allen, D. A. 1979a. Counting eliminates the repetition effects in judgments of temporal duration. *Acta Psychol.* 43:361–66

Hicks, R. E., Allen, D. A. 1979b. The repetition effect in judgments of temporal duration across minutes, days, and months. *Am. J. Psychol.* 92:323–33

Hicks, R. E., Brundige, R. M. 1974. Judgments of temporal duration while processing verbal and physiognomic stimuli. *Acta Psychol.* 38:447–53

Hicks, R. E., Miller, G. W. 1976. Transfers of time judgments as a function of feedback. *Am. J. Psychol.* 69:303–10

Hicks, R. E., Miller, G. W., Kinzbourne, M. 1976. Prospective and retrospective judgments of time as a function of amount of information processed. *Am. J. Psychol.* 89:719–30

Hirsh, I. J. 1959. Auditory perception of temporal order. *J. Acoust. Soc. Am.* 31:759–67

Hirsh, I. J., Fraisse, P. 1964. Simultanéité et succession de stimuli hétérogènes. *Année. Psychol.* 64:1–19

Hirsh, I. J., Sherrig, C. E. 1961. Perceived order in different sense modalities. *J. Exp. Psychol.* 62:423–32

Hogan, H. W. 1978. A theoretical reconciliation of competing views of time perception. *Am. J. Psychol.* 91:417–28

Huang, Y. L., Jones, B. 1982. On the interdependence of temporal and spatial judgments. *Percept. Psychophys.* 32:7–14

Hughes, R., Reuder, M. E. 1968. Estimates of psychological time among obese and nonobese women. *J. Psychol.* 70:213–19

Huppert, F., Singer, G. 1967. An aftereffect in judgment of auditory duration. *Percept. Psychophys.* 2:544–46

Hylan, J. P. 1903. The distribution of attention. *Psychol. Rev.* 10:373–403

James, W. 1890. *The Principles of Psychology*. New York: Holt. 2 vols.

Janet, P. 1877. Une illusion d'optique interne. *Rev. Philos.* 1:497–502

Jones, B., Huang, Y. L. 1982. Spacetime dependency in psychophysical judgment of extent and duration: Algebraic models of the tau and kappa effects. *Psychol. Bull.* 91:128–42

Josly, D., Hutzell, R. R. 1979. Temporal disorientation in schizophrenic and brain damaged patients. *Am. J. Psychiatry* 136:1220–22

Kowal, K. H. 1976. Apparent duration of long meaningful events and meaningless intervals. *Mem. Cognit.* 4:215–20

Kowal, K. H. 1981. Growth of apparent duration: effect of melodic and not melodic tonal variation. *Percept. Mot. Skills* 52:803–17

Kristofferson, A. B. 1967. Successiveness discrimination as a two state, quantal process. *Science* 158:1137–39

Kristofferson, A. B. 1977. A real-time criterion theory of duration discrimination. *Percept. Psychophys.* 21:105–17

Kristofferson, A. B., Allan, L. G. 1973. Successiveness and duration discrimination. In *Attention and Performance,* ed. S. Kornblum, 4:738–50. New York: Academic

Lemlich, R. 1975. Subjective acceleration of time with aging. *Percept. Mot. Skills* 41:235–38

Lhamon, W. I., Goldstone, S. 1956. The time sense: Estimation of one second durations by schizophrenic patients. *Arch. Neurol. Psychiatry* 76:625–29

Lichtenstein, M. 1961. Phenomenal simultaneity with irregular timing of components of the visual stimuli. *Percept. Mot. Skills* 12:47–60

Lieury, A., Aiello, B., Lepreux, D., Mellet, M. 1980. Le rôle des repères dans la récupèration et la datation des souvenirs anciens. *Année Psychol.* 80:149–67

Lieury, A., Caplain, P., Jacquet, A., Jolivet, C. 1979. La contraction du temps dans les souvenirs anciens. *Année Psychol.* 79:7–21

Linton, M. 1975. Memory for real-world events. In *Explorations in Cognition,* ed. D. A. Norman, D. E. Rumelhart. San Francisco: Freeman

Locke, S. A. 1974. Temporal discrimination of brief auditory stimuli by schizophrenics, neurologically impaired and normals. *Percept. Mot. Skills* 39:1111–20

Long, G. L., Beaton, R. J. 1980a. The effects of spatial frequency and target type on perceived duration. *Percept. Psychophys.* 28:413–21

Long, G. L., Beaton, R. J. 1980b. The contribution of visual persistence to the perceived duration of brief targets. *Percept. Psychophys.* 28:422–30

Long, G. L., Beaton, R. J. 1981. The effects of stimulus numerosity, retinal location, and rod contrast on perceived duration of brief visual stimuli. *Percept. Psychophys.* 29: 389–94

Lordahl, D. S., Berkowitz, S. 1975. The watched pot does not boil: A case of a wrong control group. *Bull. Psychon. Soc.* 5:45–46

Marchman, J. N. 1969. Discrimination of brief temporal relations. *Psychol. Rec.* 19:83–92

Massaro, D. W., Idson, W. L. 1976. Temporal course of perceived auditory duration. *Percept. Psychophys.* 20:351–52

Massaro, D. W., Idson, W. L. 1978. Target-mask similarity in backward recognition masking of perceived tone duration. *Percept. Psychophys.* 24:223–36

Matsuda, F., Matsuda, M. 1979. Effects of spatial separation as a cue of time estimation in children and adults. *Jpn. Psychol. Res.* 21:132–38

Matsuda, F., Matsuda, M. 1981. The anti-kappa effect in successively presented stimuli: a developmental study. Jpn. Psychol. Res. 23:9–17

Michon, J. A. 1978. The making of the present. In *Attention and Performance,* ed. J. Requin, 7:90–111. Hillsdale, NJ: Erlbaum. 730 pp.

Miller, G. W., Hicks, R., Willette, M. V. 1978. Effects on concurrent verbal rehearsal and temporal set upon judgments of temporal duration. *Acta Psychol.* 42:173–79

Mills, L., Rollman, G. B. 1980. Hemispheric asymmetry for auditory perception of temporal order. *Neuropsychologia* 18:41–47

Mo, S. S. 1971. Judgment of temporal duration as a function of numerosity. *Psychon. Sci.* 24:71–72

Mo, S. S. 1975. Temporal reproduction of duration as a function of numerosity. *Bull. Psychon. Soc.* 5:165–67

Mo, S. S., Kersey, R. 1982. On ego regression and prior time information effect in schizophrenia. *J. Clin. Psychol.* 38:34–38

Mulligan, R. M., Schiffman, H. R. 1979. Temporal experience as a function of organization in memory. *Bull. Psychon. Soc.* 14:417–20

Nail, P., Levy, L., Russin, R., Crandal, R. 1981. Time estimation and obesity. *Pers. Soc. Psychol. Bull.* 7:139–46

Ono, A. V. 1976. A study of the literature on the interrelations between subjective time, distance and speed. *Tohoku Psychol. Folia* 35:1–11

Oostenbrug, M. W. M., Horst, J. W., Kuiper, J. W. 1978. Discrimination of visually perceived intervals of time. *Percept. Psychophys.* 24:21–34

Orihara, S. 1980. The effects of mental image in time estimation. *J. Child Dev.* 16:13–20

Ornstein, R. E. 1969. *On the Experience of Time*. Harmondsworth, England: Penguin

Phillips, J. R. 1977. Relationship of field dependence-independence to posture and judgment of time duration. *Percept. Mot. Skills* 44:931–40

Polzella, D. F., DaPolito, F., Huisman, M. C., Dayton, C. V. 1977. Cerebral asymmetry in time perception. *Percept. Psychophys.* 21:1187–92

Poppel, E. 1978. Time perception. In *Handbook of Sensory Physiology,* ed. R. Held, H. W. Leibowitz, H. L. Teuber, 8:713–29. Berlin/Heidelberg: Springer

Rodin, J. 1975. Causes and consequences of time perception differences in overweight and normal weight. *J. Pers. Soc. Psychol.* 31:898–904

Rutschmann, R. 1973. Visual perception of temporal order. In *Attention and Performance,* ed. S. Kornblum, 4:687–711. New York: Academic

Sarason, I. G., Stoops, R. 1978. Test anxiety and the passage of time. *J. Consult. Clin. Psychol.* 46:102–9

Schiffman, H. R., Bobko, D. J. 1977. The role of number and familiarity of stimuli in the perception of brief temporal intervals. *Am. J. Psychol.* 90:85–93

Schiffman, H. R., Bobko, D. J., Thompson, J. G. 1977. The role of stimulus context on apparent duration. *Bull. Psychon. Soc.* 10:484–86

Schwartz, W. 1978. Time and context during hypnotic involvement. *Int. J. Clin. Exp. Hypn.* 26:307–16

Serviere, J., Miceli, C., Galifret, Y. 1977a. A psychophysical study of the visual perception of "instantaneous" and "durable". *Vision Res.* 17:57–63

Serviere, J., Miceli, D., Galifret, Y. 1977b. Electrophysiological correlates of the visual perception of "instantaneous" and "durable". *Vision Res.* 17:65–69

Squire, L. R., Chase, P. M., Slater, P. C. 1975. Assessment of memory for remote events. *Psychol. Rep.* 37:223–34

Sternberg, S., Knoll, R. L. 1973. The perception of temporal order: fundamental issues and a general model. In *Attention and Performance,* ed. S. Kornblum, 4:629–85. New York: Academic

Stevens, S. S. 1967. Intensity functions in sensory systems. *Int. J. Neurol.* 6:202–9

Stroud, J. M. 1955. The fine structure of psychological time. In *Information Theory in Psychology,* ed. H. Quastler, pp. 174–205. Glencoe, Ill: Free Press

Stutz, R. M., Warm, J. S., Woods, W. 1974. Temporal perception in obese and normal weight subjects. A test of the stimulus binding hypothesis. *Bull. Psychon. Soc.* 3:23–24

Thayer, S., Schiff, W. 1975. Eye contacts, facial expression, and the experience of time. *J. Soc. Psychol.* 95:117–24

Thomas, E. A., Brown, I. 1974. Time perception and the filled-duration illusion. *Percept. Psychophys.* 16:449–58

Thomas, E. A., Cantor, N. E. 1975. On the duality of simultaneous time and size perception. *Percept. Psychophys.* 18:44–48

Thomas, E. A., Cantor, N. E. 1976. Simultaneous time and size perception. *Percept. Psychophys.* 19:353–60

Thomas, E. A., Cantor, N. E. 1978. Interdependence between the processing of temporal and non-temporal information. In *Attention and Performance,* ed. J. Requin, 7:43–62. Hillsdale, NJ: Erlbaum

Thomas, E. A., Weaver, W. B. 1975. Cognitive processing and time perception. *Percept. Psychophys.* 17:363–67

Underwood, G. 1975. Attention and the perception of duration during encoding and retrieval. *Perception* 4:291–98

Vroon, P. A., Timmers, H., Tempelaars. 1977. On the hemispheric representation of time. In *Attention and Performance,* ed. S. Dornic. Hillsdale, NJ: Erlbaum

Wahl, O., Sieg, D. 1980. Time estimation among schizophrenics. *Percept. Mot. Skills* 50:535–41

Walker, J. T. 1977. Time estimation and total subjective time. *Percept. Mot. Skills* 44:527–32

Walker, J. T., Irion, A. L., Gordon, D. G. 1981. Simple and contingent after effects of

perceived duration in vision and audition. *Percept. Psychophys.* 29:475–86
Walker, J. T., Scott, K. J. 1981. Auditory-visual conflicts in the perceived duration of lights, tones and gaps. *J. Exp. Psychol: Hum. Percept. Perform.* 7:1327–39
Warm, J. S., Stutz, R. M., Vassolo, P. A. 1975. Intermodal transfer in temporal discrimination. *Percept. Psychophys.* 18:281–86
Westheimer, G., Mckee, S. P. 1977. Perception of temporal order in adjacent visual stimuli. *Vision Res.* 17:887–92
Witkin, H. V. 1965. Psychological differentiation and forms of pathology. *J. Abnorm. Psychol.* 70:317–36
Woods, D. D., Sorkin, R. D., Boggs, G. J. 1979. Stimulus context and duration discrimination. *Percept. Psychophys.* 26:127–32
Wudel, P. 1979. Time estimation and personality dimensions. *Percept. Mot. Skills* 48:1320
Zelkind, I., Spring, J. 1974. *Time Research, 1172 Studies.* Metuchen, NJ: Scarecrow Press. 248 pp.