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Chapter · January 1978

DOI: 10.1007/978-1-4899-6771-8_49

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Chapter 23

Time Perception

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With 1 Figure

Time is not a thing that,
like an apple, may be perceived.
H. WOODROW, 1951

Contents

A. Introduction 713
B. Duration Estimation 717
C. Temporal Processing Units 719
D. Time Tags 721
E. Subjective Present 722
F. Temporal Organization 725
G. Conclusion 726
References 726

A. Introduction

The experience of time and how it might be explained has always been a persistent challenge. One of the most compelling analyses of subjective time is the one given by AUGUSTINUS (397/398 A.D.) in the 11th book of his "Confessions." His ideas about the subjective measurement of time are still impressive today; he relates time to the perception of events, an idea that recently has been discussed by GIBSON (1973, "Events are perceivable but time is not"). This chapter has been written in order to argue for such a substitution of time perception by event perception. It shall further be argued that in order to deal with human time perception one has to establish a *taxonomy* of temporal experiences. It appears that different unrelated temporal experiences are often subsumed under the term time perception and that many controversies found in the literature on subjective time stem from an absence of such a taxonomy of temporal experiences.

The exploration of human time perception and temporal organization of behavior in general had a magnificent start in the last century. In 1860, KARL ERNST VON BAER gave an important lecture in St. Petersburg on „Welche Auffassung der lebenden Natur ist die richtige?" where he introduced the concept of time quanta; this concept is in the center of modern theorizing on time perception (cf., STROUD, 1955; SHALLICE, 1964). Even as early as 1865, MACH showed that Weber's law does not hold true for time perception but that there is an interval (in his case 300 to 400 ms) for which there is maximal differential sensitivity, below and above which differential sensitivity is worse; he also pointed out how variable subjective time estimates can be and that the temporal acuity for audition is much better than for the other senses. Within the same decade, DONDERS (1868) tried to measure the "speed of mental processes" using the subtraction method in reaction time experiments, and VIERORDT (1868) published his work on the time sense where he described the "indifference interval" still persecuting the experimentalists today.

Unfortunately, the interest in problems of time perception has declined over the last decades, perhaps because of the many controversies not only over theories but also data. If one reads introductory books, chapters or articles on time perception (e.g., JAMES, 1890; NICHOLS, 1891; WEBER, 1933; WOODROW, 1951; WALLACE and RABIN, 1960; FRAISSE, 1964; COHEN, 1967; MICHON, 1967; GOODDY, 1969; HOLUBÁŘ, 1969; ORME, 1969; ORNSTEIN, 1969; DOOB, 1971; ALLAN and KRISTOFFERSON, 1974), one notices how subjective the selection and presentation of problems often is. One reason why the exploration of time perception might have led to a state of confusion might have been the misconception that time actually is a thing that, like an apple, can be perceived (cf., WOODROW, 1951). On the basis of this misconception, the psychophysical methods developed in the last century were used in the same way as in other psychophysical experiments, such as studies of brightness perception (see for instance WUNDT, 1881); subjective time was looked upon (and still is) as a prothetic continuum (STEVENS, 1957) and a stationary process (PÖPPEL, 1972). The experiments of MACH (1865), however, should have made clear from the beginning that there is something peculiar about subjective time and that discrimination of durations is not analogous to the discrimination of intensities.

What is needed appears to be a *taxonomy* of "elementary time experiences." The only purpose of this chapter is the attempt to provide such a taxonomy. The basic assumption is that time perception has to be related to the occurrence of events as they are perceived and actions taken by the subject. In order to outline the taxonomy, it might be helpful to use a simple scheme (Fig. 1) in which different elementary time experiences are related to such events or actions. The arrow from the left to the right in Figure 1 represents the continuum of time in the sense of classical physics, *past* being represented on the left and *future* on the right. The long vertical line in the middle represents the *now*, conceived of as a point in time without duration. The sequence of events (past) and actions to be taken by the subject (future) is indicated above the time line by a row of small circles. The taxonomy consists basically of five elementary time experiences; these will be briefly characterized now and in more detail in the following sections.

One elementary time experience is *duration estimation;* it refers to our ability to estimate how much time has elapsed between two specified events by using, for instance, conventional time units (like seconds, hours, or weeks). The bulk of research on time perception is actually performed on duration estimation, and for some investigators, duration estimation is the only interesting aspect

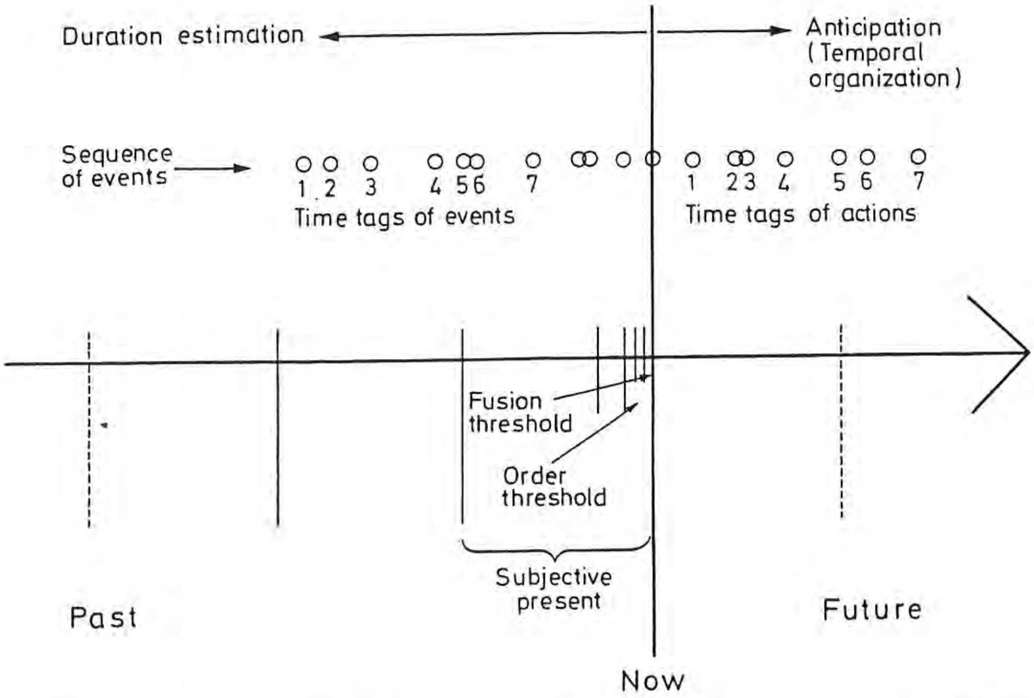

Fig. 1. Graphic representation of elementary time experiences. The arrow from the left to the right represents the continuum of time in the sense of classical physics. Above this line, the sequence of events is shown by small circles. The continuum of time is divided by a vertical line, representing the *now*, into *past* and *future*. The different elementary time experiences (duration estimation, perception of sequences of events, anticipation, or temporal organization of actions to be taken, the experiences of successiveness and of order, and the subjective present) are explained in the text

of human time experience. Duration estimation of longer intervals (minutes or hours) appears to be mainly determined by the amount of information processed (and/or stored) or by the "mental content." This view has been advocated by GUYAU (1890) and STURT (1925) and is presently supported, for instance, by ORNSTEIN (1969) and MICHON (1970). The phenomenon of boredom appears to be partly caused by a lack of information during a specific time interval, and a characterization of boredom as given by HOCHE (1923) will be reported below.

Events occurring in a rapid succession may not necessarily be experienced successively but may appear subjectively simultaneous. In order to be actually perceived as different events, they must be separated by a minimal temporal interval. This minimal interval is of different duration for the different senses ("fusion threshold"). However, even if events are perceived as different, they must be separated by at least 20 ms or so—this number seems to be the same for different modalities—if their order is to be indicated (HIRSH and SHERRICK, 1961). This last observation on the "order threshold" and many other experimental results have suggested the idea of central *temporal processing units* or subjective time quanta with a duration in the range of 20–40 ms. It may be that the experience of "instantaneousness" is related to such subjective time quanta; for very short stimuli neither a beginning nor an end is experienced, and thus no experience of duration is provided (RUBIN, 1935).

Another elementary time experience besides duration estimation and the experience of simultaneity and successiveness is characterized by our ability to record the sequence of events. Apparently, not only events as such are recorded in memory, but their time of occurrence as well. Under certain pathologic conditions, as has been suggested for patients with Korsakoff psychosis (e.g., VAN DER HORST, 1932), the *time tags* of events might be lost. Although the events themselves can still be recalled, these patients are said to be no longer able to indicate their sequence.

The experiences of duration, simultaneity/successiveness, and sequence have to be distinguished from one temporal experience which is perhaps the most basic time experience of all and which might be described as the "feeling of nowness." The experience of nowness appears to be embedded in a temporal interval which has been called the "specious" or the *subjective present.* JAMES (1890) called this interval that we experience as present "a sort of saddle-back of time with a certain length of its own, on which we sit perched, and from which we look in two directions into time." It has been suggested (FRAISSE, 1963) that the term time perception should be restricted to those short intervals (a few seconds in duration) when we have this feeling of nowness (this interval of subjective present obviously has nothing to do with the now point (Fig. 1) on the physical time scale).

Thus far, only those aspects of subjective time have been mentioned that refer to whatever lies in the past or in the present on the physical time scale. However, in order to discuss time perception appropriately, the future must also be considered. The elementary time experience that refers to the *temporal organization* of future actions can be called anticipation or planning. The problem of serial organization or preprogramming of behavior has been discussed in a very important article by LASHLEY (1951). He suggested that temporal organization of behavior might be understood by assuming rhythmic mechanisms. If indeed rhythmic mechanisms are basic for the programming of behavioral sequences in the immediate future, they might be expected to influence the experience of temporal intervals in the immediate past as well. The possibility of such a relationship between rhythmic temporal organization of actions and time perception had been suggested a long time ago by MACH (1885), and Pavlov was convinced that rhythmic phenomena might be important in the establishment of temporally conditioned reflexes (see HOLUBÁŘ, 1969).

Each of the five elementary time experiences mentioned (experience of duration, simultaneity/successiveness, sequence, present, and anticipation) is discussed in more detail in the following sections. It will be obvious that the diverse types of time perception preclude any general theory on how time might be perceived. The different elementary time experiences appear to be independent of each other and should be treated as such.

One may miss in such a report (in addition, perhaps, to other matters) a review of methods used in time perception studies. Methodologic questions have been discussed many times, and the interested reader is referred to the following works: WUNDT, 1881; CLAUSEN, 1950; GREGG, 1951; ROSS and KATCHMAR, 1951; BINDRA and WAKSBERG, 1956; FRAISSE et al., 1962; DANZIGER and DU PREEZ, 1963; CARLSON and FEINBERG, 1970; HORNSTEIN and ROTTER, 1969; DOOB, 1971; PÖPPEL, 1972; EISLER, 1976.

B. Duration Estimation

Everybody is aware of the fact that our experience of passing time is influenced by what we are doing. SWIFT and MCGEOCH (1925) pointed out that a speaker may think he is talking only for a few minutes while members of the audience are already checking their watches. These authors asked subjects to read short stories or to listen to them; they observed that doing something actively (such as reading) results in an impression that less time has passed than if one listens passively to what is being read. AXEL (1925) obtained similar results in more standardized experiments and argued that the "level of behavioral activity" determines the experience of time. If one is engaged in a higher level of behavioral activity, time appears to pass rapidly, whereas a low level of behavioral activity, when one is bored for instance, results in the impression that time is dragging.

It is important to note that these experiences of a fast or slow passage of time are present only during the activity (or nonactivity). Retrospectively, the experience of the passage of time is reversed. A period devoid of interesting events that appeared never to end is estimated as having had a very short duration if one looks back on it. On the other hand, time during a day full of new experiences may seem to fly, but the retrospective estimation of time is that of a long duration. The idea that the number of recorded events determines our estimation of time has been analyzed by STURT (1925). She thought that exogenous events as well as thoughts (endogenous events) determine duration estimates. "In estimating time we rely on the amount of mental content experienced during that time ... Time which has been filled by many thoughts appears longer whereas time occupied by few thoughts appears shorter" (STURT, 1925; p. 101).

In more recent discussions of human temporal experience (e.g., FRANKENHAEUSER, 1959; ORNSTEIN, 1969; MICHON, 1970; VROON, 1970), this notion of mental content plays an important role. Duration estimation is treated as an aspect of cognitive organization, and it is stressed that in order to understand duration estimates it may be unnecessary to assume (biologic) time units. With regard to this, the recent book by ORNSTEIN "On the Experience of Time" has greatly influenced modern thought. He shows how powerful the metaphor of *storage size* can be, if one deals with duration estimates.

> We ... relate the experience of duration of a given interval to the size of the storage space for that interval in general information-processing terms. In the storage of a given interval, either increasing the number of stored events or the complexity of those events will increase the size of the storage, and as storage size increases the experience of duration lengthens (ORNSTEIN, 1969; p. 41).

In several experiments, he tested his hypothesis directly, and the results strongly support the hypothesis that the storage size essentially determines the estimates of durations.

Some aspects of estimating duration are revealed by the experience of boredom. HOCHE (1923) pointed out that there is a lack of events (exogenous and endogenous) in relation to what one expects; during boredom, one is prevented from escaping the situation or changing it. As an example, he described how he was sitting in the first row during a lecture listening to an endless talk which he could not follow. Because of the lack of information and because one is trapped in a situation, one's attention is focused on the passage of time. When one concentrates on the passage of time, it appears to move even more slowly—as has been portrayed, for instance, in Morgenstern's poem "Die Zeit." Essentially, boredom is a consequence of a severe mismatch between two time scales, i.e., between "personal" and "government" time as GOODDY (1969) calls it. It takes some time before this mismatch is recognized; HOCHE (1923) suggested that at least a few minutes have to pass before boredom can be experienced. Psychotic patients apparently are not bored when they stay in an institution for a long time; HOCHE suggested that it is a sign of improvement when psychotic patients become bored.

In order to be able to estimate time on the basis of events that occurred during an interval, a mechanism of *temporal integration* (HEARNSHAW, 1956) has to be assumed. Such a mechanism must exist—but there is nothing known about it. The scope of the problem can be appreciated when one reads:

"Temporal integration involves essentially the formation, from temporally disparate units, of configurations, in which the present moment and immediate stimuli lose the dominance they possess at the perceptual level. The capacity to form and to scan such temporal configurations frees the organism from control by the present situation (HEARNSHAW, 1956; p. 17).

On a descriptive level, one can distinguish at least two aspects of temporal integration as being relevant for duration estimates, and these two aspects must entail two different mechanisms. If duration estimates are based on the "size of storage" as ORNSTEIN (1969) suggests, there must be some kind of *summative* temporal integration adding up exogenous and endogenous events; the result of such an integration would be the basis of duration estimates. Summative temporal integration has to be distinguished from *averaging* temporal integration, as is implied, for instance, in the adaptation level theory (HELSON, 1964). It is assumed in this theory that information processed about past events generates a personal reference system of subjective time (or brightness, weight, etc.). Duration estimates are made by comparing the storage size produced by the events within a particular interval with the subjective frame of reference developed by averaging the durations of different time intervals experienced in the past (GOLDSTONE, 1967). Each act of duration estimates would thus be dependent on both temporal integration mechanisms, the long term *averaging* temporal integration responsible for the "frame of reference," and the short term *summative* temporal integration that determines the storage size. Some specific predictions of the adaptation level theory, such as anchor effects (POSTMAN and MILLER, 1945; ADAMSON, 1967), have been verified in experiments on duration estimates. Some advocates of the theory also claim that it explains the *indifference interval* (VIERORDT, 1868). This might be true for longer time intervals in the range of minutes. It will be seen in the section on the subjective present, however, that other explanations not related to averaging temporal integration of events must be invoked in order to understand the indifference interval observed in the range of 2–3 seconds.

C. Temporal Processing Units

A century ago, EXNER (1875) observed that the temporal fusion threshold is different in the different sense modalities; two auditory stimuli must be separated by 1–2 msec in order to be heard as successive, but visual or tactile stimuli separated by such short intervals are still experienced as simultaneous. The auditory system has apparently the best and the visual system the worst "temporal acuity." Temporal fusion thresholds mainly reflect peripheral sensory mechanisms, although central mechanisms can influence them as well. LACKNER and TEUBER (1973), for instance, observed an impaired auditory fusion threshold in patients with left temporal lobe lesions, and it is a well-known fact that critical flicker fusion is affected by lesions in the occipital areas of the brain (e.g., PÖPPEL et al., 1975).

Temporal resolving power must be broken down into two measures as HIRSH and SHERRICK (1961) have pointed out. One of these two aspects of temporal resolving power has just been mentioned, i.e., the minimum time interval that can separate two events so that they are just perceived as nonsimultaneous or successive. The second aspect of temporal acuity refers to the experience of temporal order. Given that two events are perceived as successive, a judgment has to be made as to their temporal order, i.e., which of the two events comes first and which comes second. Experimental observations indicate that measurements of fusion and order thresholds give quite different results. When the temporal order of events is to be recognized, the events must be distinctive so that they can be labeled differently. HIRSH and SHERRICK (1961) observed in their experiments that different events must be separated by 20 ms in order to be reported in their correct temporal order 75% of the time. In contrast to fusion threshold, order threshold has the same numerical value in all modalities tested (vision, hearing, touch); it even has the same value for judgments across modalities. "It is reasonable to hypothesize that a single quantitative process is shared by all three modalities at some point" (HIRSH and SHERRICK, 1961; p. 430). Some kind of time-organizing system is suggested by their results on temporal order threshold that is independent of purely sensory mechanisms, and, presumably, more central.

Time-organizing systems such as these have been suggested under various headings, i.e., biologic clocks, subjective time quanta, processing units, perceptual moments, central oscillations, or excitability cycles. It has been pointed out by WIENER (1958) and SHALLICE (1964) that central clocks allow for a much more economical organization of behavior. WIENER is often quoted as one of the important advocates of biologic clocks:

"The brain has much in common with the computing or control machine, in which various incoming impulses are combined to make outgoing impulses. Such a combination of impulses may take place in at least two ways. One possibility is that the impulses are stored up in the machine or the brain until the proper combination has been recorded, and they go out at whatever time the process is complete. This is a suitable means of computing by means of impulses of a continuing nature. However, there are very considerable advantages in having the impulses of the nature of pulses of brief duration. The proper combination of these involves that they should come in at the proper tick of a clock. Such a mechanism is likely to be more economical in the use of time than control by continuing impulses, and accordingly most forms of control and computation machinery do in fact deal with pulsed impulses and contain a clock as an intrinsic part" (WIENER, 1958).

SHALLICE (1964) showed in his analyses that the detection of change can be done in the fastest and most reliable way if one assumes central oscillations, i.e., that the perceptual input is processed in discrete temporal steps. There is less of a computable load for the brain, and the empirical evidence that SHALLICE discusses suggests that the perceptual moment hypothesis is most satisfactory.

If these central processing units do, in fact, exist, one would expect that different studies show approximately the same numerical value for their duration. This, however, is not the case, although there is a strong bias that favors a duration similar to the order threshold described above (HIRSH and SHERRICK, 1961). Several years ago, attempts were made to relate the duration of these hypothetic processing units (or perceptual moments) to the period of the alpha rhythm of the EEG (e.g., HOLUBÁŘ and MACHEK, 1962; WHITE, 1963) or to the half-period of the alpha rhythm (KRISTOFFERSON, 1967). In most studies, however, a value close to 30 ms, or to be more conservative, between 20 and 40 ms, has been suggested. For instance, when using a reaction time paradigm in memory studies, STERNBERG (1975) observed that the scanning process which is exhaustive has an approximate speed of 30 ms per item. In well-trained tasks such as typing or piano playing, up to 30 bits per second are transferred; within approximately 30 ms one-bit decisions can be made (AUGENSTINE, 1962). LATOUR (1967) observed that visual thresholds oscillate with a period close to 30 ms. If two random patterns that together form a word are shown for 6 ms, each with temporal intervals of 25 ms, 50 ms, etc., the words will be recognized perfectly with a 25 ms interval, but much less often with a 50 ms interval (ERIKSEN and COLLINS, 1968). Two experiences that can be distinguished from each other are reported when the overall duration of two stimuli is 60 ms, i.e., 30 ms for each of the temporally contiguous stimulus events (EFRON, 1967). PODVIGIN (1972) has speculated that oscillations with a frequency of approximately 30 Hz might serve the neuronal identification of specific features of sensory events; his neurophysiologic observations suggest the existence of a visual memory operating in a rhythmic fashion with such a frequency.

Finally, the work on reaction time supports the notion that 30 ms is a basic temporal processing unit (e.g., HARTER and WHITE, 1968; PÖPPEL, 1968, 1970). It has been shown that histograms of choice reaction time are in most instances multimodal with a 30–40 ms temporal interval between adjacent modes. The histograms on choice reaction time can be used to decide between two different alternatives of how the biologic clocks or processing units operate. The question is, in terms of oscillation theory, whether the temporal processing units behave more like relaxation or more like pendulum oscillators (WEVER, 1965), or in psychophysiologic terms, whether they are excitability or scanning cycles (HARTER, 1967). Excitability cycles, but not scanning cycles, can be instantaneously entrained by exogenous stimuli. The multimodal histograms suggest that entrainable temporal processing units have the characteristics of relaxation oscillations or excitability cycles. "If the eye is to respond to external stimuli, it must be assumed that the internal clock is synchronized with the external event . . . If this resetting tendency is not present we shall never find periodicities in the reaction time" (LATOUR, 1967; p. 347). PÖPPEL (1970) demonstrated with the so-called "paternoster" model that scanning cycles (where the periods are not synchronized by the stimulus) cannot explain the multimodal response distributions; scansion is therefore inappropriate as a model for central intermittency. Some authors apparently refer only to scanning cycles when discussing the concept of subjective time quanta. Thus, some of the contradictions in the literature may have resulted from the fact that the important distinction between instantaneously entrainable excitability cycles and continuous scanning cycles has not been made (e.g., ALLPORT, 1968). The point made by VROON (1974) that time quanta might be artificial is hardly convincing, because the evidence is based on numerous, quite different experimental paradigms. In the specific case, however, that he is discussing, he may certainly be right that "time quanta" may be the "result" of statistical manipulations.

Changes in the duration of temporal processing units as a result of physiologic changes in the organism or of lesions in the brain have often been suggested. HOAGLAND's paper (1933) has played an influential role; its subject is a theoretical chemical clock in the organism that is temperature-dependent. His interest had been aroused by his wife who reported a change in the subjective passage of time while she had a fever. Some observations of patients with injuries of the brain indicate that the assumption of central temporal processing units might be helpful in trying to understand certain behavioral aberrations. ALBERT and BEAR (1974), for instance, described a case of word deafness in which the understanding of speech was improved when the examiner spoke very slowly. The authors point out that normal comprehension of speech depends on intact functioning of two components of the "time sense," i.e., sequencing and temporal resolution. One can interpret these observations by assuming that in their patient temporal resolution was decreased, i.e., temporal processing units were prolonged. Different speech sounds produced at regular speed might have fallen into one processing unit and could, therefore, not be decoded properly. The patient was only able to understand when speech was adapted in speed to the prolonged temporal processing units.

D. Time Tags

When we recall a telephone number, we not only remember the numbers themselves, but also their sequence. Reversing two digits would be as big a mistake as replacing one; it would not be possible to place the call. If the digits were given in a random sequence, the particular message would be destroyed. In most messages, units must occur in a specified sequence, like the words of a sentence. A melody changes its character completely if the sequence of tones is changed; the gestalt of a melody is lost if it is played backwards.

Until recently, this specific problem of *time tags* for events has been neglected in studies on time perception. Important contributions, however, have come and can certainly be expected from the psycholinguistic work (e.g., FODOR et al., 1974), since one basic aspect of speech perception and speech production is its sequential order. Trouble with sequencing has been proposed as one aspect of dyslexia (CORKIN, 1974; ZURIF and CARSON, 1970). "It is reasonable to suggest that developmental dyslexia is more parsimoniously related to trouble with the apprehension of temporal sequences within a given sense modality than to the consequent disturbances of crossmodal matching" (ZURIF and CARSON, 1970; p. 359). It has also been observed that patients with left hemispheric lesions do worse than controls in reproducing sequences of three to five visual or auditory stimuli (CARMON and NACHSHON, 1971). These observations may suggest that the time tags defining the position of events in a sequence can be selectively destroyed because of brain injuries. Apparently it is a non-trivial task for the nervous system to keep track of the sequence of events.

The existence of a dissociation of memory for events and the times at which the events happened has also been claimed on the basis of some characteristics of the Korsakoff psychosis. It has been said that in Korsakoff psychosis a selective loss of time tags for events occurs (VAN DER HORST, 1932; WILLIAMS and ZANGWILL, 1950). The basic disturbance, according to VAN DER HORST, would be a loss of time tags; the events themselves can still be remembered. This dissociation between actual events and the times at which they happened would result in confabulation and account for the disorientated impression the patients make. This view, however, has been criticized by TALLAND (1961) who maintains that the Korsakoff psychosis is a result of a more general memory disturbance. Observations on recency discrimination (MILNER, 1974) suggest a selective impairment of time tags that occur after frontal lobe lesions, specifically after left frontal lobectomy.

One problem which might be interesting to investigate is whether sequences are coded in a different way when they are a result of event perception (like in speech perception) or a result of one's own actions. For instance, is one's performance better when repeating the sequence of self-produced actions, or is it better when repeating the sequence of another person's perceived actions? In one case, the time tags are actively selected at the stage of the planning of a sequence, in the other case they have to be perceived.

E. Subjective Present

Temporal intervals up to a few seconds are experienced in a way qualitatively different from longer temporal intervals. This has already been stressed by JAMES (1890) who maintained that there are different mechanisms in time perception. Intervals of up to approximately 5 s can be experienced as a unit, whereas longer intervals are coded symbolically and can only be estimated and not perceived. Completely different mechanisms of temporal integration have to be assumed for short and long temporal intervals. EDGELL and WALLER (1903) tried to answer the question of why short and long temporal intervals are experienced in different ways. They believed that during short intervals of a few seconds, it is possible to focus one's attention on specific events, whereas this is impossible during longer intervals of time.

The short temporal interval of up to a few seconds in duration, experienced as a temporal unit, is usually referred to as the *subjective present* (STERN, 1897; WUNDT, 1911; QUASEBARTH, 1924). There are different means of estimating the duration of this subjective present. BORING (1942) has suggested that the subjective present is associated with the indifference interval (VIERORDT, 1868). If the method of reproduction is used, the indifference interval is that duration which is reproduced correctly. In general, stimuli shorter than the indifference interval are reproduced as longer, and stimuli longer than the indifference interval are reproduced as shorter. In most of the studies, however, there is mixed opinion concerning the duration of the indifference interval (WOODROW, 1934). If the subjective present is not some kind of time constant in our nervous system, then a physiologically oriented explanation like the one based on the theory of a fading trace (KÖHLER, 1923) would appear rather unlikely, and one might perhaps consider the applicability of the adaptation level theory (HELSON, 1964). However, most of the experiments in which the indifference interval was measured cannot be assessed with respect to the subjective present, because the experimental design selectively favored results that would fit the adaptation level theory.

With a different design conceptually similar to the one previously employed by WOODROW (1934), PÖPPEL (1972) tried to test the appropriateness of the adaptation level theory for interpretations of the indifference interval. On the basis of this theory, a specific prediction can be made: an indifference interval should only be established when a subject is required to make a series of reproductions of different intervals. No such indifference interval would be expected when each subject in a group reproduces only one interval, even though collectively the group reproduces intervals over a given range. If in such a situation an indifference interval would be obtained, this observation would be incompatible with the adaptation level theory, since no individual reference system could have been built up in such a test situation. Furthermore, according to the adaptation level theory, indifference intervals should be obtained in any temporal range, whereas if the indifference interval is a temporal constant (related to the subjective present), one would expect it in one temporal range only and not in another. The predictions made by the adaptation level theory were tested using two experimental groups. The range of reproduced intervals for one experimental group was 0.5–5.0 s in steps of 0.5 s; the range for the other experimental group was 10.5–15.0 s. Each subject reproduced once only one temporal interval; there were 38 subjects in the first and 28 subjects in the second experimental group. The results show a clear indifference interval for the experimental group which reproduced intervals between 0.5 and 5.0 s;

no indifference interval was seen for the other experimental group. The indifference interval was observed between 2.0 and 2.5 s. Intervals of up to 2.0 s were reproduced by longer periods, and intervals of 2.5 s and more were reproduced by shorter ones. These results show that the adaptation level theory cannot explain the existence of an indifference interval in the lower range; one has to acknowledge a specific temporal mechanism in the range of a few seconds which might perhaps be related to the subjective present, as BORING (1942) suggested. The results do not, of course, contradict the existence of indifference intervals at other temporal ranges obtained with other experimental paradigms. It is interesting to note that WOODROW (1934) also obtained an interindividual indifference interval with his experimental paradigm, in essence similar to the one used by PÖPPEL (1972), however, at approximately 600 ms. Possibly, a second interindividual indifference interval exists at a much shorter duration. Another explanation for the different outcome of the experiments might be that the number of trials and the stimulus presentation were rather different in both experiments.

There are a number of additional observations that indicate that there is something peculiar about the subjective experience of temporal intervals in the range of 2s. For instance, GETTY (1975) maintains that Weber's law describes time discriminations much better than CREELMAN'S (1962) model; however, both models cannot deal with a duration of time longer than 2 s. Another mechanism of temporal experience apparently applies for longer intervals. In another experiment, BECHINGER et al. (1969) tested "the hypothesis that the 2 s duration is the most common natural unit time (cycle time) in time judging experiments" (p. 419). They measured information transmission and observed that channel capacity is maximal with the category interval of 2 s (i.e., stimuli had a duration of 2,4,6,... s). A slightly shorter value (1.5 s) has been suggested by RICHARDS (1964) on the basis of time reproduction experiments.

These experiments suggest that time intervals of approximately 2 s are experienced differently, and perhaps the experiments give a good measure of the subjective present. There are some observations that might indicate some specific features of the temporal mechanism underlying the subjective present. In the discussion of temporal processing units, we made a distinction between excitability and scanning cycles. The same question can be asked here. Is the subjective present a "traveling" time interval (ALLPORT, 1968) that always has the same duration, or is it organized as an oscillatory process as suggested by RICHARDS (1964), BECHINGER et al. (1969), and PÖPPEL (1972)? Using the reproduction paradigm, this question was tested (PÖPPEL, 1973), and the observations strongly support an oscillatory model using the excitability or relaxation mode.

Some temporal aspects of behavior that have been found in other areas might be intimately related to the subjective present. Stimuli with a regular pattern, such as the beating of a metronome, are subjectively grouped into units; temporal grouping may override contiguity (MÜLLER and SCHUMANN, 1894). The temporal grouping of successive stimuli, however, has a temporal limit of approximately 2.5 s, as WUNDT (1911) pointed out. Finally, there is a very old observations which appears to be relevant in this context. URBANTSCHITSCH (1875) described that a very weak auditory stimulus would only be heard periodically; he maintained that central effects must be responsible for this oscillatory phenomenon with a period of a few seconds.

F. Temporal Organization

So far our discussion of human time experience has been limited to the apprehension of past or present events, yet time also relates to actions that lie in the future. To what extent is it appropriate to consider the programming of behavioral sequences as it appears, for instance, in speech production (e.g., LASHLEY, 1951) as yet another aspect of time perception?

It has been shown that articulatory sequences must be preprogrammed because there is not enough time for feedback (KENT and MOLL, 1975). Thus, not only the proper phonemes have to be selected but in addition *time tags* have to be distributed in advance in order to produce meaningful words and sentences. It has been suggested by GOLDMAN-EISLER (1967) that the planning of utterances occurs during hesitation pauses and that spontaneous speech is characterized by a rhythmic organization, i.e., alteration between hesitation pauses and fluent speech. The notion that preprogramming of speech occurs in a rhythmic fashion has been strongly suggested by LASHLEY (1951) and recently been discussed by MARTIN (1972) and ALLEN (1975). MARTIN maintains that speaking and listening are dynamically coupled rhythmic activities. Equal-interval accents in speech are a language universal. "Speech utterances are temporally patterned, and many of their elements are temporally predictable" (MARTIN, 1972; p. 489). A listener given initial cues actively enters into the speaker's tempo; such an adaptation of the listener to the speaker with respect to temporal aspects might greatly facilitate the understanding of speech.

In experiments on verbal random number generation, it was observed that subjects are not able to produce sequences of numbers in which the single numbers are independent of the preceding ones (PÖPPEL, 1972). The number sequences that were produced by the subjects, who intended to select randomly, showed marked periodicities. The duration of these periodicities was in the range of a few seconds. It was specifically tested whether the duration of the periodicities is a function of the number of alternatives that are to be brought into a random sequence or whether it is a function of time. When the production rate of the numbers was increased, i.e., the subjects "spoke" faster, the length of the periodicity within the subjective random sequence increased; however, the actual time for the periodicity produced unintentionally under the two conditions remained constant. It is tempting to argue that such periodicities are a reflection of the rhythmic temporal organization suggested, for instance, by LASHLEY (1951) in the programming of speech or all skilled acts. The duration of these periodicities of a few seconds is reminiscent of the duration of the subjective present, and one should, therefore, ask the question of whether the duration of the subjective present might not be a consequence the programming of a behavioral sequence. It could be suggested that the rhythmic organization of speech that entails programming of future events produces a temporal framework that is also the basis of the subjective present.

G. Conclusion

One assumption of this chapter has been that there is no such thing as time perception. If one deals with problems of subjective time, it is suggested that one begin with "event perception." In so doing, one is automatically led to distinguish one *elementary temporal experience* from another. Such experiences, as they relate to the occurrence of events, are graphically illustrated in Figure 1, and it was the intention of this chapter to characterize them. There may be other elementary temporal experiences, and there may be better names for the ones discussed here; however, it is believed that time perception can be explained only if the different aspects of subjective time are first identified, before asking the question of how these relate to each other. It does not appear to be a fruitful strategy (as has often been followed in the past) to seek an understanding of time perception on the basis of only one elementary temporal experience. The mechanisms underlying the different elementary temporal experiences may well be completely different in nature, and this should be acknowledged in the experimental approach. For instance, the basis of the experience of simultaneity, successiveness, or order might be studied on a neuropsychologic or even neurophysiologic level, whereas investigating duration estimation mainly requires the experimental techniques of cognitive psychology. The approach of this chapter has been obviously phenomenologic. However, it is believed that the search for mechanisms and the elaboration of neuronal models entails such a preparatory descriptive attempt.

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