Temporal Cognition

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Timing is essential to the functioning of organisms. Perhaps because the time dimension plays such an important role in human life, the psychology of time was an important topic of early psychological research and theorizing. An examination of the role that time plays in people's lives can focus on various aspects of temporal experience. For example, a researcher can study what makes people judge events to be simultaneous, or judge one event as preceding or following another event. In this article, we focus on the processes that subserve experiences of short duration (ranging from seconds to minutes). Duration timing is essential for representing the immediate external environment. For example, driving or crossing a busy street requires the continual estimation of speed and duration. As people wait in a queue while shopping or receiving a service, feelings of lengthened duration may determine whether they complete the transaction or abandon it. A person using computer software assesses the time required to complete an operation; if this duration seems excessive, the attitude regarding the software will be negative. Because many everyday situations involve duration estimation, it is important to understand the underlying processes.

Recommended Reading

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METHODOLOGY OF TIME ESTIMATION RESEARCH

When studying the psychology of time, investigators often present participants with tasks of different lengths and ask them to estimate the duration of each task. In order to study the relationships between such duration judgments and other factors, investigators manipulate the conditions under which the tasks are performed. For example, a time period may be *empty* (containing no presented stimuli or required task) or filled with a task that is not subject to time constraints. (We call such tasks *nontemporal*.) A task may be relatively easy or difficult; the difficulty of sorting playing cards, for example, depends on whether the sorting must follow a simple or a complex rule. Researchers assess the impact of different kinds of information processing on duration estimates by comparing estimates obtained under different conditions.

A duration may be estimated verbally, by reproduction, by production, or by comparison. Different ways of estimating duration require somewhat different cognitive processes (Zakay, 1993). When duration is estimated verbally, the participants experience a target duration, and after it ends they must translate their experiences to estimates in clock units, usually seconds. Verbal estimates are usually more variable than are estimates obtained by other methods. When reproducing a duration, the participants are asked to delimit a second time period corresponding to their previous experience of the target duration. In the method of production, a target duration is stated verbally, and the participants are asked to delimit an actual time period that they judge to be the length of the specified duration. The methods of verbal estimation, reproduction, and production are all absolute estimation methods in that on any trial, only one target duration is estimated. With the comparison method, a standard duration is presented, and the participants make estimates by comparing the target duration to the standard duration.

An estimate may be made either prospectively or retrospectively. In a prospective paradigm, participants are aware before a target duration starts that its length is to be estimated. In a retrospective paradigm, participants become aware of the need to estimate duration only after the target duration has ended.

DURATION ESTIMATES

When people are asked to reproduce durations, short durations tend to be reproduced relatively accurately; however, reproductions of longer durations tend to be slightly shorter than the target durations (Eisler, 1976). People also estimate equal durations differently depending on the amount of information presented or processed during the time period. People may estimate filled durations as being longer than empty durations, but sometimes the reverse is found. Duration judgments tend to be shorter if a more difficult task is performed than if an easier task is performed, but again the opposite has also been reported. People usually make longer duration estimates for complex than for simple stimuli, although some researchers have found the opposite.

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Duration experience usually lengthens if a time period contains a greater number of meaningful events. The meaningful events may be external, such as changes in room lighting, or internal, such as changes in mood, thoughts, or information processing strategies. Temporal expectations and attentional allocation also influence duration judgments. For example, judgments of the same target duration are longer if participants expect an early ending of the duration than if they expect a late ending (Boltz, 1993).

In one experiment (Zakay, 1992), young children reproduced the duration that a lamp was lit. If the children's attention had been distracted from the lamp by a jumping toy frog, they reproduced the lighting time as being shorter than if their attention had not been distracted. Similarly, when adults were asked to perform a task and to reproduce its duration, estimates were longer if time estimation was defined as the primary task than if it was defined as the secondary task (Zakay, 1989). These results indicate that if more attention is focused on processing temporal cues, reproductions lengthen. Although verbal estimates and reproductions usually decrease with greater processing demands during a time period, the reverse usually holds for time productions.

A recent review that combined the results of many studies using the technique of meta-analysis (Hedges & Olkin, 1985) revealed some interesting age and sex differences in human duration judgments (Block, Zakay, & Hancock, 1995). Children and older adults tend to give larger verbal estimates and shorter productions than do young adults, and their duration judgments are also more variable. In addition, females tend to give slightly larger verbal estimates and shorter productions than do males, and females' duration judgments also tend to be slightly more variable.

Literature on human duration judgments seems to contain many contradictory findings. In the following sections, we show that one can make sense out of this seemingly chaotic pattern by distinguishing the experimental paradigms used and considering appropriate explanatory models.

BIOLOGICAL CLOCKS VERSUS COGNITIVE TIMING

An appealing idea is to relate duration timing to biological clocks, which control cyclic behavior like circadian (approximately daily) rhythms, or to body temperature. Counting at the rate of one per subjective second may become faster as body temperature increases. This finding suggests that a temperature-sensitive biological clock influences time-related behaviors and judgments. Although duration judgments of many minutes are correlated with body temperature (Campbell & Birnbaum, 1994), the relationship between body temperature and judgments of shorter durations is somewhat inconsistent.

Because cognitive variables (e.g., the attentional demands of a task) greatly influence estimates of short durations, many theorists have proposed cognitive models of psychological time. Psychological time depends on complex interactions among the conditions under which a duration is experienced and the context in which the estimate is given (Block, 1989). One important factor is the time estimation paradigm. The differences between prospective and retrospective time estimations are now becoming clear. Under prospective conditions, participants focus their attention on time during a target duration and accumulate relevant temporal cues. Under retrospective conditions, however, participants primarily construct a duration judgment from information stored in memory representing the number of contextual changes that occurred during an interval. In short, different cognitive processes underlie prospective and retrospective judgments of duration.

AN ATTENTIONAL MODEL OF PROSPECTIVE TIMING

Many theorists have emphasized that attention to time, or temporal information processing, plays a major role in prospective duration experience. One influential model proposes that the experienced duration of a time period depends on the amount of information encoded by a temporal information processor and by a nontemporal information processor (Thomas & Weaver, 1975). Task demands determine the way in which a person divides attention between the two processors. If less nontemporal (stimulus) information processing is required, the person allocates more attention to temporal information, and vice versa. In one recent experiment (Macar, Grondin, & Casini, 1994), participants were told how to divide attention between nontemporal and temporal information (e.g., 25% to words and 75% to duration). Duration judgments varied according to the particular division of attention that participants were instructed to use. Thus, attending to time and attending to stimulus information require access to a common pool of attentional resources.

The attentional model was tested in an experiment in which participants performed a verbal task with three levels of difficulty

(Zakay, Nitzan, & Glicksohn, 1983). The easy task was reading words, the intermediate task was naming objects shown in pictures, and the difficult task was giving associations to low-frequency words. There was also an empty-time condition, in which no task was performed. Another variable, external tempo, was also manipulated: For each 14-s duration, a light bulb near the person was flickering at a frequency of either 0.5 flashes per second (slow) or 2 flashes per second (fast). Participants were told in advance that they would be asked to reproduce each duration.

Reproduced durations were longest in the empty-time condition and were progressively shorter as the difficulty of the verbal task increased. Reproductions were also shorter when the external tempo was slow than when it was fast. This latter effect may be explained in terms of arousal level if one assumes that the faster external tempo led to increased arousal. It cannot be explained by traditional attentional models of time estimation, which assume a constant pool of attentional resources. Another interesting finding was that in almost all conditions, reproductions were shorter than the target durations. This is a typical finding characterizing reproductions under prospective conditions. Traditional attentional models cannot explain this finding either. An elaborated model, which we call the attentional-gate model, is needed to remedy these shortcomings (Block & Zakay, 1996).

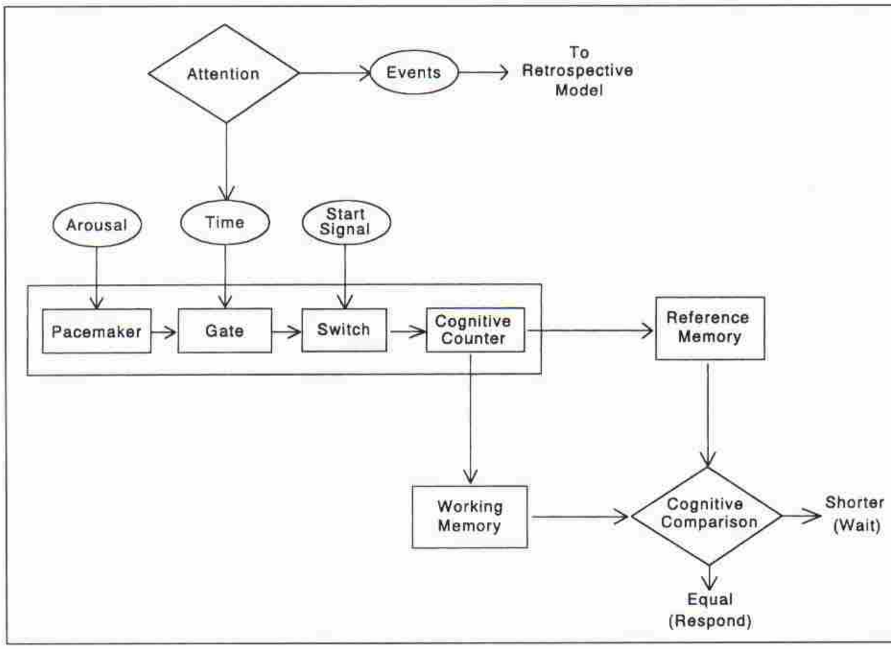

Fig. 1. The attentional-gate model of prospective time estimation.

ATTENTIONAL-GATE MODEL

The attentional-gate model (see Fig. 1) is a cognitive model in that it does not propose specific kinds of neural networks or brain structures to subserve its components (however, see Binkofski & Block, 1996, regarding some brain structures that may be involved). The first component of the model is a pacemaker that autonomously produces pulses at a rate that is influenced only by arousal. In other words, neither stimulus features nor the characteristics of an information processing task influence the pulse rate. When a person attends to time, as opposed to external stimulus events, the attentional gate opens, and the pulse stream is sent to subsequent components. At the start of a duration, a switch allows the pulse stream to be transmitted through a channel. A cognitive counter accumulates a pulse count, which is transferred to a working memory store. When an external signal indicates that the duration has ended, the switch closes and the accumulated pulse total is sent to the reference memory store. If a person must verbally estimate the duration, the accumulated pulse total from working memory is compared with correspondences between pulse totals and verbal (numerical) labels for various durations, which have been previously stored in reference memory. If a person is engaged in a production or reproduction task, there is no external stop signal; instead, the accumulation of pulses in working memory is accompanied by an ongoing cognitive comparison. If fewer than the criterion number of pulses have accumulated, this cognitive comparison results in the person judging that the duration is shorter than what is required (i.e., it is necessary to wait longer for the end of the time period). When the pulse count in working memory is approximately equal to that in reference memory, the person judges that the duration is appropriate for some response (i.e., it is now the end of the time period).

Thus, the attentional-gate model holds that a person may divide attentional resources between attending to external events and attending to time. Attending to time opens the attentional gate, thereby allowing pulses to pass through to the cognitive counter.

The attentional-gate model explains prospective duration timing. Prospective judgments depend both on arousal level and on the amount of attention allocated to time. According to the model, increasing arousal level leads the pacemaker to produce more pulses in a given time unit. Therefore, the target duration is represented in working memory by a higher pulse count if arousal is high than if it is low. This feature may explain why reproduced durations lengthen with increased external tempo. In addition, the amount of attention allocated to temporal cues is inversely related to the attentional demands of a concurrent task. When a relatively easy nontemporal task fills a duration, the amount of attentional resources left for opening the attentional gate is greater than when the task is more difficult. Therefore, the attentional gate is open more widely during an easy task, resulting in more pulses passing through and being accumulated per objective time unit. As a result, verbal estimates and reproductions are longer for an easy task than for a difficult task. What about duration productions? If workload is high, less attention is focused on time and therefore more clock time is needed in order to reach the target time than when workload is low. Thus, productions mirror verbal estimates and reproductions.

The attentional-gate model also explains why prospective reproductions are typically shorter than target durations. During a reproduction, all attentional resources are allocated to timing, and therefore the gate is opened more widely than during the target duration, when attention was divided between timing and a concurrent nontemporal task. Therefore, during the reproduction, the pulse stream transmitted through the gate is greater than it was during the target duration. A reproduction ends when a match is achieved between the current pulse count (in working memory) and the count representing the target duration (in reference memory). The wider gate during the reproduction means that this match occurs after a shorter duration than the duration during which the target count was accumulated. In the experiment combining levels of difficulty with manipulation of external tempo (Zakay et al., 1983), when the target duration was empty and no external tempo was activated, the reproduction was close to the actual duration. Under these conditions, attention is allocated mainly for timing during both the target and the reproduced durations, and therefore there is little or no difference between the lengths of the target and reproduced durations.

It may sometimes be difficult to identify which component of the model (e.g., pacemaker, attentional gate, or working memory) is influenced by a particular manipulation. Such determinations will require investigating several theoretically relevant variables, usually in a quantitative framework. However, some research with pigeons and rats has partially succeeded in this endeavor (for a review, see Church, 1989). Future research with human subjects may also isolate variables that influence the separate components of the model.

A CONTEXTUAL-CHANGE MODEL OF RETROSPECTIVE TIMING

Attention to time has little or no influence on retrospective duration judgments, so processing difficulty typically does not influence these judgments (Block & Zakay, in press). Instead, retrospective judgments depend mainly on the retrieval of contextual information that was encoded in association with event information during the time period. A contextual-change hypothesis proposes that the remembered duration of a time period lengthens as a function of the amount of contextual changes stored in memory and available to be retrieved at the time of the duration judgment (Block, 1990). These include changes in environmental context, mood, and type of processing. A person remembers a time period spent performing different kinds of processing as being longer than one spent performing a single kind of processing, presumably because changes in processing engender changes in encoded contextual elements. A person usually remembers complex stimuli or sequences as being longer than simple stimuli or sequences, perhaps because more varied kinds of processing were required. A segmented time period is remembered as being longer than an unsegmented period, perhaps because each segmenting event is a source of contextual changes (Poynter, 1983). In short, prospective and retrospective duration judgments (or experienced and remembered duration) differ primarily in that the former depend mainly on the encoding of temporal information whereas the latter depend mainly on the encoding of nontemporal information.

CONCLUSIONS

Timing of relatively short durations is an essential cognitive function that influences many aspects of humans' daily behavior. Human duration judgments often show large influences of content and context, as well as individual variability, such as age- and sex-related differences. At first glance, many findings seem contradictory. The key to navigating in the stormy sea of research findings is to realize that a complete understanding of any kind of temporal experience occurs only if one considers complex interactions among contextual factors. Whether the duration judgment is prospective or retrospective is perhaps the most important factor—not only in the laboratory but also in everyday life. When one is waiting, time draws one's attention and one becomes engaged in prospective timing. As a result, a duration spent waiting seems to pass slowly. In contradistinction, when one is interested in a book or a movie, prospective time seems to collapse. One is not attending to time, and an estimate of duration has to be made retrospectively on the basis of retrieved contextual changes. Prospective and retrospective timing involve different cognitive processes, and separate models are needed. At present, the attentional-gate and contextual-change models seem to provide good explanations for prospective and retrospective timing, respectively.

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Note

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Coaching the Coaches: Youth Sports as a Scientific and Applied Behavioral Setting

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In U.S. culture, sport touches the lives of a great many people, whether as participants or as spectators. It is also touching the lives of a growing number of psychologists who have come to appreciate the world of athletics as a fertile setting for the study of psychological phenomena, for the development and testing of psychological theories, and for the application of psychological principles. Very few psychological processes that are of interest within "mainstream" psychology do not occur within the context of sport, meaning that they can often be studied within a naturalistic setting in which participants are heavily involved and committed.

Recommended Reading

Smith, R.E., & Smoll, F.L. (1996). *Way to go, Coach!: A scientifically validated approach to coaching effectiveness.* Portola Valley, CA: Warde Publishers.

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The most heavily publicized area of sport psychology tends to be interventions for enhancing performance of elite athletes, as the re-