PIGEONS' MEMORY FOR EVENT DURATION

by

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ABSTRACT

Pigeon's working memory for event duration was investi-
gated using variations of the delayed matching to sample
procedure. When a retention interval of variable length was
interposed between the sample and comparison stimuli, pigeons
responded as though a long-duration sample had been short
after retention intervals of 10 sec or greater. This "choose
short" effect occurred reliably in each subject, regardless
of whether the subject was naive or experienced, whether the
sample durations were represented by food-access or light,
or whether a two- or three-choice procedure was used.

In order to account for these findings, a "subjective
shortening" model of memory for event duration was proposed.
According to the model, the choose short effect is produced
by a discrepancy between a relatively static reference
memory of the sample durations and a dynamic working memory
of the sample durations that "shortens" over the retention
interval. This discrepancy produces the tendency to respond
as though the long sample was short.

A number of predictions, derived from the subjective
shortening model, were confirmed in subsequent experiments.
First, after a long retention interval, the point of subjec-
tive equality between the short and long samples shifted to

a longer duration. Second, stepwise increases in the reten-
tion interval produced a temporary choose short effect,
whereas stepwise decreases in the retention interval produced
a temporary choose long effect. Third, with extended
training at a given retention interval, the choose short
and choose long effects diminished and overall accuracy
improved. These results provided strong support for the
subjective shortening model, whereas they could not be
interpreted readily within the context of other conceptuali-
zations of working memory processes.

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INTRODUCTION

The concept of animal memory

It is difficult to imagine how an animal without a capacity to remember past events could easily return to a source of food or water, find its way to a nest or through a burrow system, avoid cues previously associated with dangerous or noxious events, or in fact show any changes in behaviour as a result of its past experience. Until recently, however, the study of animal memory has been systematically ignored by most behavioural scientists.

Early views. Two major factors may have contributed to the reluctance of early psychologists to study animal memory processes. First, the possibility that animals possess higher-order processing capacities, such as memory, had been viewed with skepticism since the time of Aristotle (cf. Ruggiero & Flagg, 1976). Early investigators therefore were reluctant to attribute any apparent retention abilities in animals to memory processes. For example, Hunter (1913) studied the retentive abilities of rats, dogs, racoons, and children, using a delayed response procedure. Each subject was exposed to a set of three spatial locations, one of which was illuminated briefly. Following a delay period, the subject was permitted to choose one of the locations and was rewarded with food for choosing the location that previously had been illuminated.

Hunter found that rats responded correctly after a maximum delay of 10 sec, dogs after 5 min, racoons after 25 sec, and children after 50 sec or 25 min, depending upon their age. Hunter, however, was by no means ready to attribute these abilities to memory processes. He attributed the performance of the rats and dogs to their use of physical orientation towards the correct location during the delay interval. Although overt orientation was not used by racoons, Hunter still did not attribute their performance to memory, but instead to "sensory thought." In all likelihood, "sensory thought" would not be viewed today as a more parsimonious explanation of retention abilities than "memory." Nevertheless, Hunter viewed "sensory thought" as a process intermediate to the high-level cognitive and memorial capacities of humans, and the low-level orienting capacities of dogs and rats.

Following Hunter's lead, most researchers in the 1920s and 30s viewed the delayed response paradigm mainly as a procedure for comparing species; only a few investigators during this period used the delayed response procedure to investigate animal memory processes (e.g., Tinklepaugh, 1928). Accordingly, considerable research was directed toward categorizing species in terms of whether or not they could bridge a delay without the use of bodily orientation, and toward ordering species in terms of the maximum delay at which they could perform correctly. Both areas of research proved to be unproductive. First,

the results of several studies (e.g., Maier & Schneirla, 1935; Ladieu, 1944) did not support Hunter's conclusion that "lower animals" depend upon bodily orientation to bridge a retention interval; even rats were found to delay responding success- fully when orientation to the goal during the delay was elimi- nated. Second, attempts to order species in terms of their retention capacities yielded inconclusive results; it soon became clear that procedural variables were far more important in determining the limits of retention than was the type of species studied (cf. Roberts & Grant, 1976).

A second factor that served to impede the study of animal memory processes during the first half of the 20th century was that most of the major behavioural theorists (e.g., Guthrie, Hull, Pavlov, Skinner, Spence, Tolman) showed little interest in memory processes. None of these figures conducted any research on memory, and none included the construct of memory as a major part of their theories. Although Tolman's (1932) cognitive theory of behaviour included the construct of "expectancy" -- a construct that may imply a form of represen- tational memory (cf. Ruggiero & Flagg, 1976) -- Tolman himself did not include the construct of memory in his theory of behaviour.

Most learning theorists (e.g., Guthrie, Hull, Pavlov, Spence) were interested primarily in the acquisition of learned responses. Basically, they hypothesized that the

acquisition of a response was due to the development of associations, either between conditioned and unconditioned stimuli (e.g., Pavlov, 1927), or between stimuli and responses (e.g., Hull, 1943). Performance of a learned response was thought to be determined by the strength of these associations and by the degree to which the stimulus conditions of original training had been reinstated. Furthermore, learning was often thought to be permanent unless interfered with by new learning (e.g., Guthrie, 1935). Memory therefore was viewed as an unnecessary hypothetical construct because the principles of learning could be used to account for performance after a retention interval (cf. Bolles, 1976).

The results of experiments that were designed to test these learning theories did not offer a serious challenge to the view that memory was an unnecessary construct. In fact, the design of most learning experiments tended to obscure memory phenomena. For example, the interstimulus and inter-trial intervals used in these experiments were generally short enough that "forgetting" rarely occurred. In the rare instances in which the design of the experiment permitted the effects of forgetting to occur (i.e., when there was a substantial interval between training and testing) the fact that some retention occurred was emphasized; the fact that substantial forgetting occurred was ignored (cf. Bolles, 1976).

Although animal memory was viewed by many early learning

theorists as an unimportant contruct, this view could not be shared by those researchers interested in the physiological basis of memory (e.g., Lashley, 1950). The nature of research on the physiological basis of memory demanded the use of animals as subjects, and thus the tacit assumption that animals had significant memory capacities was a necessary part of the rationale for this research. However, apart from making this assumption, psychologists interested in the biological basis of memory made little attempt to formalize global theories of animal memory processes (cf. Spear, 1978).

Challenges to the early views. Although learning theorists believed that learned associations persisted over time, they maintained that any substantial delay between the events to be associated would prevent learning (e.g., Hull, 1943; Spence, 1947). Because learning sometimes did occur when the events to be associated were separated by a short delay, some of the early theorists (e.g., Hull, 1943; Pavlov, 1927) postulated a minimal, memory-like process. Both Hull and Pavlov conceptualized this process as a trace or after-effect of the physical stimulus that persisted for a few seconds after the offset of the stimulus. Spence (1947) attributed any learning that occurred when there was a delay between a stimulus and a response to immediate secondary reinforcement. None of these learning theorists believed that associative learning involved any substantial memory mechanism.

Over the years, however, data gradually began to accumulate that could not be interpreted easily in the absence of a more substantial associative memory mechanism. For example, Petrinovich and Bolles (1957) found that rats could learn to alternate their responding for reward between two different spatial locations with intertrial intervals of up to 4 hours. They concluded that the rats were able to remember where they had gone on the previous trial and then choose the opposite side.

Capaldi (1967) also postulated an associative memory mechanism to account for the results of his reward alternation studies (e.g., Capaldi & Cogan, 1963). In these studies rats that alternately received reward and nonreward in a runway developed appropriate alternations in running speeds: they ran faster on rewarded trials than on nonrewarded trials even with intertrial intervals of up to 24 hours (Capaldi & Spivey, 1964). Capaldi concluded that a memory of reward or nonreward on the preceding trial could act as a stimulus to control responding on the following trial. Although Capaldi did not have a theory of memory processes per se, he was one of the first theorists to have the construct of animal memory as an essential component of a theory of learning.

A significant impetus for the postulation of an associative memory mechanism in animals developed out of the work of Garcia and his associates (e.g., Garcia, Ervin, & Koelling,

1966). They found that rats exposed to a novel taste and sub-
sequently made sick by an injection of a toxic substance, later
showed an aversion to the novel taste. This "conditioned food
aversion" was surprising in view of the fact that it could
occur with delays of up to 24 hours between taste and sickness
(Etscorn & Stephens, 1973). The traditional belief that
learning required close temporal contiguity between the events
to be associated was seriously challenged by these results.
The most parsimonious explanation was that the rats must be
able to remember novel tastes for long periods of time in order
to associate them with subsequent illness (cf. Bolles, 1976).
This interpretation was elaborated into a theory of associative
memory by Revusky (1971).

Another convincing example of long-delay associative
learning was provided by Lett (1973; 1975). Lett trained rats
to go to one arm of a T-maze, but did not reward them for a
correct choice in the goal box. Instead, she removed the
animals from the apparatus for intervals up to 1 hour, and
then placed them back in the start box where they received
reward. The fact that rats were able to learn this task
implied an associative memory mechanism capable of bridging a
long delay between the response and reward.

Parallel with research into long-delay associative con-
ditioning was a growing interest in the study of long-term
retention of learned responses in animals (e.g., Gleitman &

Holmes, 1967; Gleitman & Jung, 1963; Kamin, 1957; Gabriel, 1967). Some of this work was directed at assessing the empirical basis for the widespread assumption of the durability of learning in animals, and with the interference theory of forgetting in animals (cf. Gleitman, 1971). In addition, other work in this area was concerned with apparent nonmonotonic retention functions (e.g., the "Kamin" and "incubation" effects; cf. Spear, 1978), and with the factors that produced these functions. This line of research further served to promote interest in animal memory processes (see Spear, 1978, for a detailed review of this work).

Resistance to the study of animal memory abated further during the early 1970s as the popularity of traditional learning theories declined (Seligman, 1970) and interest in cognitive approaches to the study of animal behaviour increased (e.g., Bolles, 1975; Jarrard, 1971; Premack, 1971). These trends provided a more supportive climate for the systematic study of memory processes in animals. Consequently, research on animal memory has accelerated dramatically during the past decade, and is today a major field of study in animal behaviour.

Current trends in animal memory research

During the past decade, research on animal memory has followed three general lines. One line of research has been directed toward the study of long-term retention of acquired

responses. This retention of learned responses has been referred to alternately as long-term retention (Spear, 1978), long-term memory (cf. Spear, 1978), retentive memory (Revusky, 1971), or reference memory (Honig, 1978). Other research has been concerned with long-delay learning; i.e., where there is a delay between the events to be associated. The memory process thought to be involved in this type of learning has been called associative memory (Honig, 1978; Revusky, 1971). A third line of research has been concerned with the retention of specific events over a short delay when associative learning already is complete. This kind of retention has been called short-term retention (Riley, Cook, & Lamb, in press), short-term memory (Roberts & Grant, 1976), or working memory (Honig, 1978).

In this thesis, the terminology of Honig (1978) will be used: the three types of memory described above will be referred to as reference memory, associative memory, and working memory. The remainder of this thesis will be concerned primarily with the study of working memory.

The concept of working memory

Honig (1978) has described working memory in terms of a group of procedures that involve delayed conditional discriminations. Working memory is thought to be required whenever an animal's discriminative responding is based upon a conditional

stimulus that terminates before the response can be executed, and that varies from trial to trial. Consequently, in order to respond correctly, the animal must remember which conditional stimulus had been present at the beginning of the trial, and avoid "confusion" with the memory of stimuli present on previous trials (Honig, 1978).

The relationship between working memory and reference memory. According to Honig (1978), reference memory refers to the long-term maintenance of learned associations. Because most working memory tasks involve the acquisition and maintenance of conditional discriminations in reference memory, a stable reference memory is necessary for stable performance on these tasks. Thus, as Honig (1978) has pointed out, it is important to be aware of the possibility that changes in performance on a working memory task sometimes may reflect changes in reference memory, as well as changes in working memory.

Procedures used to study working memory. There are a number of procedures that can be used to study working memory in animals, including the delayed response task (Hunter, 1913), reward substitution tasks (Tinklepaugh, 1928), delayed alternation tasks (Capaldi, 1967), radial arm maze tasks (Olton, 1978), advance key procedures (Honig, 1978), and the delayed paired comparisons task (Shimp & Moffitt, 1977). Recently, the delayed matching to sample task and its variations have found wide use among researchers interested in working memory.

These delayed matching procedures have advantages over some of the earlier procedures (e.g., Hunter, 1913) in that they facilitate precise control over experimental stimuli, and easily eliminate the possibility of simple orientation towards the location of the correct stimulus during the delay.

In the delayed matching to sample (DMTS) task (e.g., Blough, 1959) trials consist of three components: presentation of a sample stimulus; a delay (i.e., retention) interval; and presentation of two or more comparison stimuli, one of which physically matches the sample. Choice of the comparison that matches the sample results in reinforcement. The stimuli used as the samples are alternated randomly over trials. Consequently, in order to choose the correct comparison stimulus, the animal must remember which sample stimulus had been presented at the beginning of the trial. Delayed oddity from sample tasks (e.g., Lydersen, Perkins, & Chairez, 1977) are identical to DMTS tasks except that the subject is rewarded for choosing the comparison that does not match the sample. Another variation of the DMTS task is called delayed symbolic matching to sample (DSMTS; e.g., Wilkie, 1978). This task differs from the DMTS and the delayed oddity tasks in that none of the comparison stimuli is identical to the sample stimuli; the relationship between the sample and the correct comparison is arbitrary. Finally, in successive matching to sample tasks (e.g., Nelson & Wasserman, 1978), presentation of the sample is followed after a delay by

a single test stimulus that either does or does not match the sample. Reinforcement is available only when the test stimulus matches the previously presented sample. These tasks hereafter will be referred to collectively as delayed matching tasks.

Current views of working memory in animals

There are a number of questions that might be asked about the process of working memory in animals. For example, how is information stored? How much information can be stored? What is the form or content of the memory? How is it organized? Is information maintained actively or passively over a delay? If it is maintained passively, how is it retrieved? What are the sources of forgetting?

In recent years, a number of views or hypotheses have been proposed that address some of these issues. Before describing each of these views, it is important to note that these views do not always address all of the possible questions that could be asked about working memory. Because these views often focus upon different aspects of working memory, they cannot always be contrasted easily.

Trace decay theory. Roberts and Grant (Roberts, 1972; Roberts & Grant, 1976) have developed a theory of working memory based on the concept of a stimulus trace. These investigators hypothesized that presentation of a sample stimulus

generates an internal trace of the sample that is strengthened gradually during the exposure to the sample, and that decays gradually in its absence. Thus, the storage of sample information is a simple function of exposure time: longer exposure times increase the strength of the memory trace. What is stored (i.e., the "content" of the memory) is a representation that is isomorphic with the sample. Loss of the stored representation is thought to correspond either to a passive decay of the initial trace, or to interference from competing traces (Roberts & Grant, 1976). This trace decay theory subsequently has been modified to include an active rehearsal process that serves to maintain the sample trace during the delay (Grant & Roberts, 1976). According to this revised trace theory, loss of stored information could be produced by interference with this active rehearsal process, as well as by simple decay of the trace, or interference from competing traces.

Temporal discrimination hypothesis. D'Amato (1973) and D'Amato and Worsham (1974) have developed an hypothesis of working memory that is based on a temporal discrimination process, rather than on a storage process. Using the DMTS task as an illustration, D'Amato conceptualized the problem for the subject as involving a decision about which of the comparison stimuli has most recently served as the sample. In this conceptualization, the "storage" and "content" of the memory are reduced to a process of temporal discrimination, and

"forgetting" is attributed to discrimination failure rather than to a loss of stored information. For example, the deleterious effects of long delays (i.e., retention intervals) on matching accuracy are thought to occur because a discrimination of which of the comparison stimuli was last seen as the sample is more difficult.

Although D'Amato's basic view is that the "storage" of memories can be reduced to a process of discrimination, he does invoke an "internal representation" process in order to account for delayed symbolic matching. The addition of this latter process was necessary because the comparison stimuli in symbolic matching are never seen as samples, and thus it would be impossible to solve this task on the basis of their relative recency. Therefore, the critical discrimination in symbolic matching tasks is between the relative recency of "internal representations" of the sample set (D'Amato, 1973).

Information processing theory. Wagner (Wagner, 1978; Wagner, Rudy, & Whitlow, 1973) has proposed a model of animal memory that is based in part upon Atkinson and Shiffrin's (1968) two-process theory of human memory. Basically, Wagner's model assumes that there is a short-term storage buffer in which a limited amount of information can be maintained through "active rehearsal." According to this model, working memory is limited by a number of factors, including the size of the short-term storage buffer, and the capacity of the rehearsal

mechanism. As new items enter the short-term store, they may displace old ones from the store, and rehearsal of one item may decrease the ability to rehearse another item. The "content" of memory is conceptualized as an activated representation of the stimulus in the short-term store; "forgetting" is an inactivation of the stored representation due to either a passive decay process, failure of rehearsal, or displacement by a new item entering the short-term store.

Coding views of working memory. Recently, a number of "coding" processes have been invoked to account for working memory phenomena (Carter & Werner, 1978; Farthing, Wagner, Gilmour, & Waxman, 1977; Honig & Wasserman, 1981; Riley et al., in press; Roitblat, 1980). "Codes" have been conceptualized variously as a stimulus trace (Farthing et al., 1977; Riley et al., in press), an abstract representation of the sample stimulus (Farthing et al., 1977), a representation of the test stimulus (Roitblat, 1980), a covert or overt mediating response (Carter & Werner, 1978), a response decision, or instruction (Honig, 1978; Honig & Wasserman, 1981; Riley et al., in press), a representation of anticipated reinforcement (Spetch, Wilkie, & Skelton, 1981), or, in fact, as any "transformation of the sample stimulus that allows the organism to function appropriately at the time of the test" (Riley et al., in press, p. 7). As can be seen, the coding hypotheses as a group do not make up an internally consistent "theory" of working memory.

Individually, however, different coding hypotheses represent distinct conceptualizations of the content or form of memory.

Variables thought to affect working memory

There are a number of factors that affect performance on delayed matching tasks. In general, most of these factors have been assumed to affect working memory (Roberts & Grant, 1976; Farthing et al., 1977; Roitblat, 1980; Cook, 1980; but see Wilkie & Spetch, 1978; in press). These factors and their effects on matching accuracy will be briefly described in the following sections, along with a brief account of how these effects have been interpreted within the context of current theories of working memory.

Delay between sample and comparison stimuli. One widely studied variable in delayed matching tasks is the duration of the delay, or retention interval, between the sample and comparison stimuli. Generally, matching accuracy has been found to decrease systematically with increases in the delay, and to approach chance level within a few seconds (e.g., Blough, 1959; Roberts & Grant, 1976), although some instances of above-chance matching accuracy with delays of 25 sec (Wilkie, 1978), or even 60 sec (Grant, 1976) have been reported.

According to the trace decay model of working memory (Roberts & Grant, 1976), the decline in matching accuracy over the delay is due to a simple decay process, which is thought

to occur as a negatively accelerated function of time since the sample offset. Wagner's (1978) information processing model also postulates a trace decay mechanism which can account for the effect of delays.

An alternative interpretation of the effect of delay is provided by the temporal discrimination hypothesis (D'Amato, 1973). According to this view, performance after a delay depends upon the animals' ability to make a temporal discrimination between the relative recency of the samples. As the delay interval increases, the ratio describing the relative recency of the samples decreases, which leads to poorer temporal discrimination.

A similar discrimination-like process has been proposed within the context of certain versions of the coding view to account for decreased matching accuracy at longer delays. Roitblat (1980), for example, suggested that pigeons maintain a coded representation of the correct choice stimulus during the delay, and that as the delay increases, this representation increasingly becomes "confused" with other choice stimuli.

Exposure to the sample. Delayed matching by pigeons improves with increases in presentation time of the sample (e.g., Nelson & Wasserman, 1978; Roberts & Grant, 1974; 1976) and with increases in the number of responses required to terminate the sample (e.g., Roberts & Grant, 1976; Wilkie & Spetch, 1978).

According to the trace decay theory, increases in the duration of exposure to the sample are thought to strengthen the memory trace and thereby improve matching accuracy (e.g., Roberts & Grant, 1976). The effect of sample duration can also be interpreted in terms of coding processes. For example, a number of investigators (e.g., Farthing et al., 1977; Roitblait, 1980) have suggested that a coded representation of the sample is formed gradually during exposures to the sample. Increases in the sample duration improve the likelihood that this coded representation will be developed fully, thereby increasing the probability of an accurate choice.

Intertrial interval. Delayed matching accuracy improves with increases in the intertrial interval (Jarrard & Moise, 1971; Herman, 1975; Maki, Moe, & Bierley, 1977; Nelson & Wasserman, 1978).

Lengthening the intertrial interval improves performance, according to the trace decay theory, because it allows more time for the decay of competing stimulus traces from the previous trials (Roberts & Grant, 1976). The facilitative effect of increases in the intertrial interval is also consistent with the temporal discrimination hypothesis (D'Amato, 1973). Temporal discrimination is facilitated with longer intertrial intervals because the relative recency ratio of the samples is increased.

Interfering stimuli. Delayed matching performance is

adversely affected by the presentation of certain extraneous "interfering" stimuli (e.g., ambient illumination) during the delay interval (e.g., Cook, 1980; Roberts & Grant, 1976; Wilkie, Summers, & Spetch, 1981). Cook (1980) has demonstrated that the degree of interference produced by extraneous delay interval stimuli is related directly to the degree of stimulus change, and Wilkie et al. (1981) have shown that the degree to which stimuli disrupt delayed matching accuracy is correlated positively with the degree to which these stimuli disrupt simple operant responding.

Most views of working memory can account for the deleterious effects of some extraneous delay interval stimuli. For example, views that postulate active rehearsal mechanism (e.g., Grant & Roberts, 1976; Farthing et al., 1977; Roitblat, 1980; Wagner, 1978) can account for the interfering effects of extraneous delay interval stimuli by assuming that these stimuli disrupt the rehearsal process. Alternatively, the simple trace decay theory (Roberts & Grant, 1976) dealt with interference effects by assuming that the delay interval stimuli generate a memory trace that competes or interferes with the trace of the sample. D'Amato (1973) interpreted the deleterious effect of delay interval illumination on delayed matching performance in terms of his temporal discrimination hypothesis by assuming that "visual events will appear more recent after an interval spent in darkness than after a like period filled with

a myriad of visual perceptions." (D'Amato, 1973, p. 263).

"Forget" cues. Several recent studies (Grant, 1981; Maki
& Hegvik, 1980; Rilling, Kendrick, & Stonebraker, in press)
have examined the effect on matching performance of "forget"
and "remember" cues presented during the delay interval. In
these studies, birds were trained under a delayed matching
task in which the presentation of a "remember" cue during the
delay signalled that the regular retention test (i.e., presen-
tation of the comparison stimuli) would occur at the end of
the delay, and the presentation of a "forget" cue indicated
that the retention test would be cancelled on that trial. To
test for the effect of the forget cues, "surprise" retention
tests were conducted on some forget-cue trials; matching accur-
acy on these trials has been found consistently to be lower
than on remember-cue or no-cue trials. The location of the
forget cue within the delay interval also is important; the for-
get cue has a greater detrimental effect upon matching accuracy
if it occurs early in the delay than if it occurs later in
the delay interval (Grant, 1981; Rilling et al., in press).

The deleterious effects of forget cues on matching
accuracy are inconsistent with a simple trace decay process
(Roberts & Grant, 1976), in which information is lost through
a passive decay of the trace, or an interference from competing
traces. There is no obvious reason to assume that forget cues
should affect the decay process, and because the stimuli serving

as forget and remember cues generally are counterbalanced, the trace of the forget cues should not compete with a trace of the sample stimulus to any greater extent than would the trace of the remember cue.

Grant (1981) has interpreted the effect of forget cues in terms of active rehearsal processes. He suggested that the forget cue decreases matching accuracy because it results in a cessation of rehearsal of the sample memory. In contrast, Rilling et al. (in press) have interpreted the effects of forget cues in terms of a "behavioral-context hypothesis." According to this hypothesis, the animal's behaviour during the delay interval produces stimuli that are necessary for retrieval of sample representations during the choice period. They suggested that forget cues disrupt delay interval behaviour and thereby eliminate part of the stimulus context needed to retrieve the sample representation.

Stimulus serving as the sample. The stimulus used as the sample also can affect performance on working memory tasks. For example, Farthing et al. (1977) found differences between pigeons' memory for colored samples and line-tilt samples: the "forgetting curves" for the line-tilts were steeper and were less affected by sample duration than were the curves for colored samples. In the same vein, Wallace, Steinert, Scobie, and Spear (1980) found that rats remembered an auditory sample better than a visual sample after delay intervals of 2 and 4

sec, even though their delayed matching performance with these two types of samples was equivalent at the 0-sec delay.

These sorts of findings have significant implications for current views of working memory processes. For example, in order for the simple trace decay theory to encompass differences in the "forgetting" functions with different types of stimuli it would be necessary to make an additional assumption that traces for different stimuli decay at different rates (cf. Farthing et al., 1977). Similarly, in order for coding views to encompass these effects, it must be assumed that "encoding is more efficient for some types of stimuli than for others" (Farthing et al., 1977, p. 528), or that the rehearsal of some codes is more effective than the rehearsal of others.

The differential retention of different sample stimuli is also problematic for D'Amato's temporal discrimination hypothesis. If memory of a sample is based simply upon a discrimination of its relative recency, then there is no reason to expect that one type of sample stimulus would be remembered better than another.

Wagner's information processing model includes an assumption that some stimuli command rehearsal more than others. Evidence consistent with this notion is provided by demonstrations that "surprising" stimuli are remembered better than "expected" stimuli (Terry & Wagner, 1975; Maki, 1979; but see

Colwill & Dickinson, 1980). An extention of this view could be that other properties of stimuli may have a similar effect upon rehearsal, and this could account for the differences in retention found between different samples.

Rationale and purpose of the present investigations

Clearly, the stimulus or stimulus dimension used in working memory tasks may have a significant effect on animals' performance, a finding that has important implications for current views of working memory processes. In the human psychophysical literature, a distinction has been made between quantitative, or "prothetic" stimulus dimensions, and qualitative, or "metathetic" dimensions (Coren, Porac, & Ward, 1979). For prothetic dimensions, changes in the physical stimulus (e.g., weight) are perceived as a change in the apparent quantity of the stimulus (e.g., heaviness), whereas for metathetic dimensions, changes in the physical stimulus (e.g., wavelength) are perceived as a change in the apparent quality of the stimulus (e.g., color). Certain psychophysical laws seem to hold for one of these types of stimulus dimension but not for the other (Scharf, 1975).

It is possible that the distinction between dimensions that have been classified as metathetic and those that have been classified as prothetic on the basis of human psychophysical studies also may have significance for the study of working

memory in animals. Almost all studies of working memory in animals have used stimuli that vary along dimensions that are classified by humans as metathetic: e.g., different colors (Wilkie & Spetch, 1978), line tilts (Farthing et al., 1977), shapes (Cohen, Calisto, & Lentz, 1981), responses (Maki, Moe, & Bierley, 1977), spatial locations (Wilkie & Summers, in press), food or no food (Wilkie, 1978), and flickering or steady light (Blough, 1959). Little is known about animals' working memory for stimuli that are varied along dimensions that are classified as prothetic, such as duration.

Although numerous studies have been concerned with animals' discrimination of event duration (e.g., Church, Getty, & Lerner, 1976; Elsmore, 1972; Kinchla, 1970; Perikel, Richelle, & Maurissen, 1974; Reynolds & Catania, 1962; Spetch & Wilkie, 1981; Stubbs, 1968), at the time the present research was initiated there were no published studies of working memory for event duration in animals. In view of the fact that animals' performance on working memory tasks may depend upon the stimulus used as the sample (Farthing et al., 1977), and that working memory for stimuli that vary along "prothetic" dimensions had not been studied, a systematic investigation of pigeons' memory for event duration was warranted.

PART I: A DEMONSTRATION OF THE "CHOOSE SHORT" PHENOMENON

Experiment 1

This experiment was designed to investigate pigeons'
working memory for short and long duration samples over various
delay intervals. The procedure used in this experiment was one
in which pigeons were trained to peck a red comparison stimulus
following short (2-sec) samples, and a green comparison stimu-
lus following long (10-sec) samples. On half the trials in
each session, the sample consisted of timed access to food,
whereas on the remaining trials the sample was light presenta-
tion. The delay between the sample and comparison stimuli
was varied within the range of 0 to 20 sec during each session.

The use of both food-access and light samples was in-
cluded in the present study for two reasons. First, it pro-
vided a means of assessing the generality of working memory for
event duration across these two types of samples. Second, it
would extend previous research (Spetch & Wilkie, 1981) which
had shown that pigeons are more accurate in discriminating
the duration of food access than the duration of light at a
0-sec delay. Because most variables that affect delayed match-
ing performance at a 0-sec delay show a similar effect at longer
delays (cf. Roberts & Grant, 1976; Wilkie & Spetch, 1978), it
was expected that this superior performance with food access as

the sample would be maintained at the longer delay intervals.

Method

Subjects

Three adult Silver King pigeons (Birds 1, 2, and 3) served
as the subjects. Each was experienced at discriminating stimulus
durations, but none had been exposed previously to delay
interval manipulations. Each bird was deprived of food until
they were approximately 80% of their free-feeding weight and
maintained at this weight by mixed grain obtained during and
after daily experimental sessions. The birds were housed in
large individual home cages in which water and health grit were
continuously available.

Apparatus

A BRS-Foringer Model #PS-004 pigeon chamber was used.
One wall contained a horizontal row of three plastic pecking
keys; each required a force of .2 N to operate. An Industrial
Electronics Engineers' Series 10 stimulus projector was mounted
behind each key; these illuminated the keys with a uniform
field of colored light. A Gerbrands Model #G5610 solenoid-
operated feeder that permitted timed access to mixed grain was
centered below the keys. Grain presentations were illuminated
by a 2.8 W lamp located within the feeder. The houselight
consisted of two 2.8 W lamps mounted behind a transparent
plastic reflector above the pecking keys; these lamps provided

a diffuse illumination of the chamber.

Control of experimental conditions and collection of data in this and all subsequent experiments were performed by a Data General Nova 3 computer.

Procedure

Baseline Procedure. A variation of the delayed symbolic matching to sample (DSMTS) paradigm was used. Trials began with the presentation of a sample stimulus for either a short (2 sec) or a long (10 sec) duration. Food access (presentation of the raised illuminated grain-filled feeder) served as the sample stimulus on half of the trials; on the remaining trials the sample consisted of illumination of the houselight. Sample offset was followed by illumination of the side pecking keys with a green and a red comparison stimulus; the position of red and green was varied randomly across trials. Correct choices (a peck at the red comparison key after short samples, or at the green key after long samples) produced a 5-sec grain reinforcer, followed by a 30-sec intertrial interval (ITI). Incorrect choices (red after long samples or green after short samples) terminated both comparison stimuli and initiated the ITI.

Each subject was trained under this procedure with a 0-second delay between the sample and comparison stimuli until matching accuracy appeared stable and asymptotic. The acquisition data from this phase of the experiment are reported in a

previous study (Spetch & Wilkie, 1981). For the last ten days of this phase, matching accuracy was well above chance on both types of trials but was higher on food-sample trials than on light-sample trials for all birds.

Delay Manipulations. Variations in the length of the delay between sample offset and comparison stimuli onset (i.e., the retention interval) were conducted within sessions. Three series of delays were arranged. The first series consisted of delays of 0, 1, 2, 3, 4, and 5 sec; the second series consisted of delays of 0, 5, and 10 sec, and the third series consisted of delays of 0, 5, and 20 seconds, During each series, the 0-sec delay occurred on half of the trials of each session; the longer delays occurred on the remaining trials with equal probabilities. Each bird was tested for 60 sessions under Series 1 and for 40 sessions under each of Series 2 and 3.

Results

Figure 1 shows the birds' overall matching accuracy with food-access and light samples at each delay. Data points for the 0- and 5-sec delays were averaged over the three series of delays. Consistent with the results of previous studies (Spetch & Wilkie, 1981), overall matching accuracy with food access samples was better than with light samples at the 0-sec delay. However, it is clear from Figure 1 that the

superior matching accuracy with food as the sample was not maintained over any of the longer delay intervals. These results were confirmed by a priori orthogonal comparisons between average matching accuracy on food and light trials at each of the eight delay intervals [0 sec: $t(2)=15.67$, $p<.05$; 1 sec: $t(2)=1.34$, $p>.05$; 2 sec: $t(2)=.97$, $p>.05$; 3 sec: $t(2)=.45$, $p>.05$; 4 sec: $t(2)=1.75$, $p>.05$; 5 sec: $t(2)=.95$, $p>.05$; 10 sec: $t(2)=1.21$, $p>.05$; 20 sec: $t(2)=.75$, $p>.05$].

Figure 2 shows each bird's matching accuracy after short and long samples. At the short delays, the percentage of correct choices was approximately equal after both short and long samples. However at the longer delays accuracy after short samples was greater than accuracy after long samples.

These effects were assessed by a four-way repeated measures analysis of variance on choice accuracy, with the factors being delay, sample type, sample duration, and subjects. This analysis revealed that there was a significant main effect of delay [$F(7,14)=12.4$, $p<.05$], sample duration [$F(1,2)=34.64$, $p<.05$], and subjects [$F(2,14)=70.24$, $p<.05$]. In addition, there were significant two-way interactions between delay and sample duration [$F(7,14)=4.29$, $p<.05$], delay and subjects [$F(14,14)=3.48$, $p<.05$], and sample type and subjects [$F(2,14)=6.11$, $p<.05$]. Finally, there were significant three-way interactions between delay, sample type, and subjects [$F(14,14)=2.51$, $p<.05$], and between sample type, sample duration, and subjects

Figure 1.   Overall matching accuracy
(percent correct) on food-access
and light trials at each of the
eight delays.
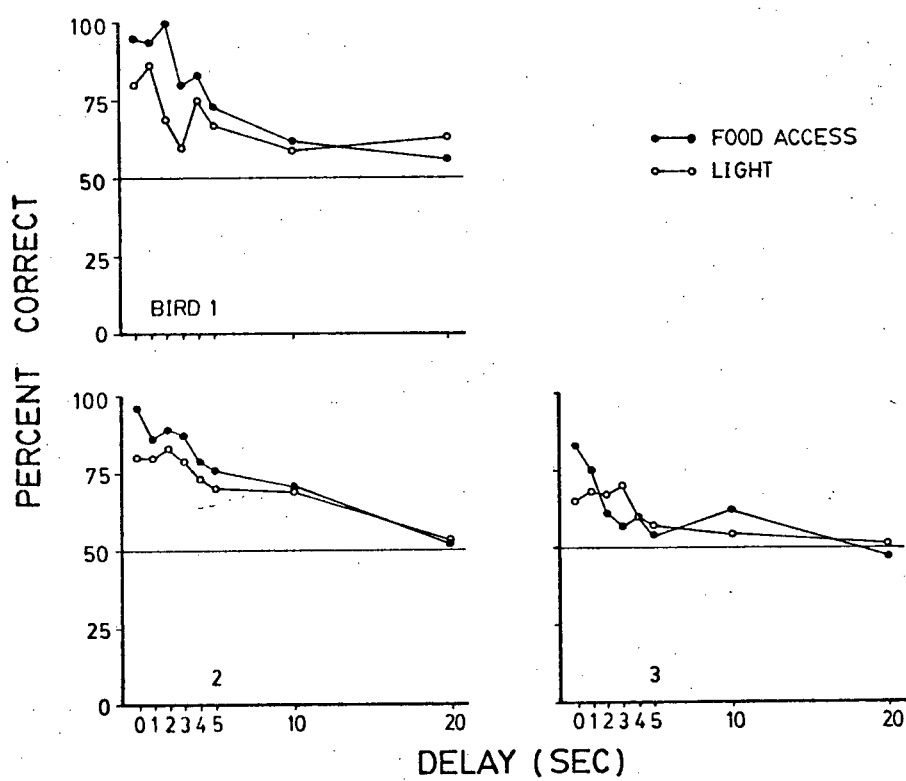
Figure 2.   Percent correct after short
     and long samples at each of the
     eight delays, with food access as
     the samples (left panels) and light
     as the samples (right panels).
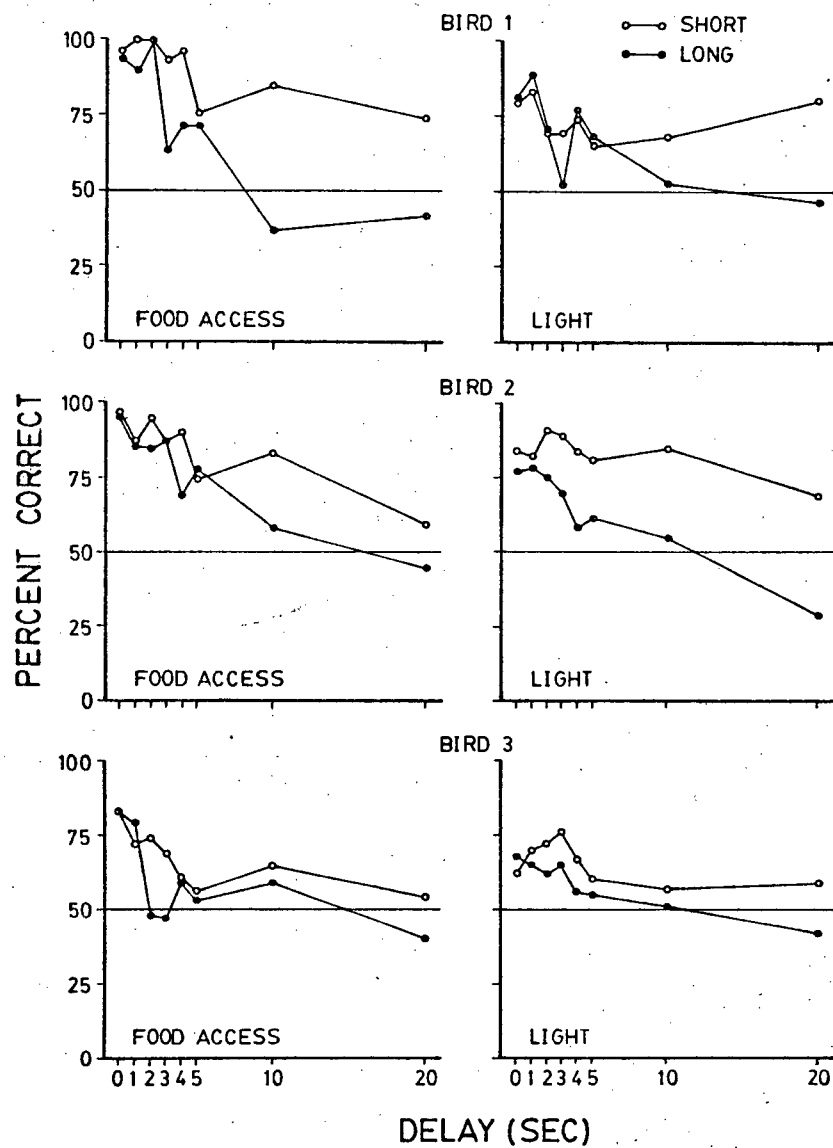
[F(2 ,14)=10.3, p<.05]. No other effects were significant.

The effects of delay and sample duration were analyzed further by a posteriori comparisons (Newman-Keuls, p= .05). These comparisons revealed that accuracy after short samples was significantly greater than after long samples at the 10- and 20-sec delays, but not at shorter delays. In addition, overall matching accuracy was significantly greater at 0-sec, 1-sec, and 2-sec delays than at either 5-sec, 10-sec, or 20-sec delays, and accuracy after 5- and 10-sec delays was significantly greater than accuracy after the 20-sec delay.

Thus, changes in the delay interval had three effects on the birds' performance. First, with delays greater than 0 sec, the significant difference between matching accuracy with food and light samples disappeared. Second, increases in the delay led to a decrease in overall matching accuracy. Third, with long delays, the birds showed a strong tendency to choose the comparison stimulus associated with the short samples, as indicated by the significantly greater accuracy after short than after long samples. This increased tendency to choose the comparison associated with the short sample hereafter will be called the "choose short" effect.

Discussion

Consistent with the results of previous studies of delayed

matching (e.g., Roberts & Grant, 1976), there was a systematic decrease in overall matching accuracy as a function of the delay for both food- and light-duration samples. However, the expectation that food durations would be remembered over longer delays than light durations was not confirmed. Performance with food samples was not better than performance with light samples at any of the delays except 0-sec. This is surprising in view of the fact that most variables that improve matching at a 0-sec delay also improve performance at longer delays (e.g., Roberts & Grant, 1976; Wilkie & Spetch, 1978). One interpretation of this result is that food durations are not more memorable for pigeons than light durations in spite of the fact that they are more discriminable. Alternatively, food durations might in fact be more memorable than light durations, but the increased tendency for birds to choose the comparison associated with the short sample at long delays (i.e., the "choose short" effect) may have decreased accuracy for both, thereby masking the differences in memorability.

The choose short effect found in Experiment 1 was interesting particularly in view of the fact that no comparable results have been reported in other delayed matching studies that have used "metathetic" stimulus dimensions such as line tilts and colors. These results suggest that duration might be processed and retained differently than other stimulus dimensions.

The choose short effect does not appear to be interpreted easily within the context of most current views of working memory. For example, according to both the trace decay theory and certain coding views of working memory, accuracy after long samples should be better than accuracy after short samples. Accuracy should be better after long samples, according to certain coding views, because longer duration stimuli are more completely coded than shorter duration stimuli (e.g., Roitblat, 1980). Better accuracy after long samples also would be predicted on the basis of the trace decay theory because longer sample stimuli should generate a stronger trace than shorter duration stimuli (Roberts & Grant, 1976). Clearly, neither of these views can accomodate easily the observation that accuracy after short samples was better than accuracy after long samples at long delays.

An alternative interpretation of the "choose short" effect, which will be elaborated upon in Part II, is that animals base their responses on a subjective representation of the sample duration in working memory that shortens as a function of the delay interval. At a 0-sec delay, the animals' subjective representation of the sample duration still would be close to the actual sample durations, leading to equally accurate performance after short and long samples. However, at long delays, the animals' representation of the duration of the long sample would have shortened, and thus would be more

similar to the actual duration of the short sample. This would lead to more incorrect choices of the comparison associated with the short sample. Although the subjective duration of the short sample would also become shorter after a long delay, it would be <u>less</u> similar to the actual duration of the long sample, and thus incorrect choices to the comparison associated with the long sample should not be as prevalent as incorrect choices to the comparison associated with the short sample.

In view of the potential importance of the choose short effect for current formulations of animal memory processes, and the paucity of research on animals' working memory for event durations, further systematic investigation of the choose short effect was warranted.

Experiment 2

This experiment was designed to establish the generality of the choose short effect using naive subjects. In this experiment, pigeons were trained under a procedure similar to that used in Experiment 1, except that each bird received only one type of sample stimulus (light for two birds, food access for one bird), and the comparison stimuli associated with the short and long samples differed for the three birds. Accuracy after short and long samples then was compared at delays of 0, 5, and 20 sec.

Method

Subjects

The subjects were three naive Silver King pigeons (Birds 4, 5, and 6). Deprivation and housing conditions were the same as described in Experiment 1.

Apparatus

The apparatus was the same as that described in Experiment 1 except that for Birds 4 and 5, the side pecking keys were illuminated with yellow and blue light as the comparison stimuli.

Procedure

During preliminary sessions, the birds were trained to eat from the raised illuminated grain feeder, and then trained

to peck the side pecking keys when illuminated with blue or yellow light (Birds 4 and 5), or with red or green light (Bird 6). Next, the birds were trained for several sessions under the baseline (0-sec delay) DSMTS procedure. All aspects of this procedure were the same as described in Experiment 1 except that houselight durations served as the sample stimuli on all trials for Birds 4 and 5, and feeder durations served as the sample stimuli on all trials for Bird 6. In addition, blue and yellow lights served as the comparison stimuli for Birds 4 and 5, and their designation as correct after short and long samples was counterbalanced over these two birds. Red and green lights served as the comparison stimuli for Bird 6.

Following baseline training, the birds received several sessions in which a variable delay procedure was in effect, with 0-sec delays occurring on a random half of the trials, and 5- and 20-sec delays occurring equally often on the remaining trials.

Results

Acquisition

Figure 3 shows the birds' matching accuracy after short and long samples during baseline training. Bird 4 was more accurate after short samples, whereas Bird 5 was slightly more accurate after long samples. For Bird 6, accuracy after short

Figure 3.   Percent correct after short
    and long duration samples during
    blocks of consecutive sessions of
    baseline training.

PERCENT CORRECT

bird 4

short
long

5

6

BLOCKS OF 10 SESSIONS

BLOCKS OF 5 SESSIONS
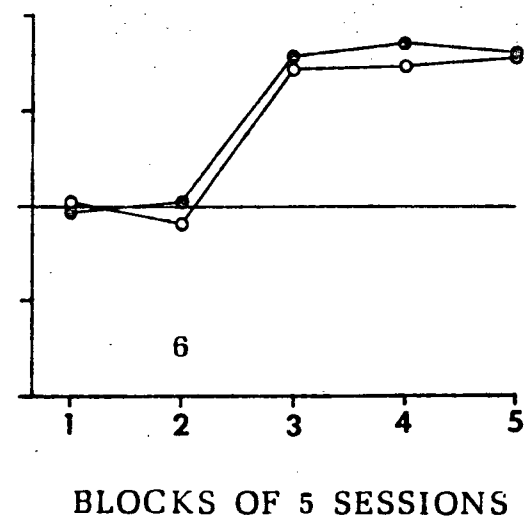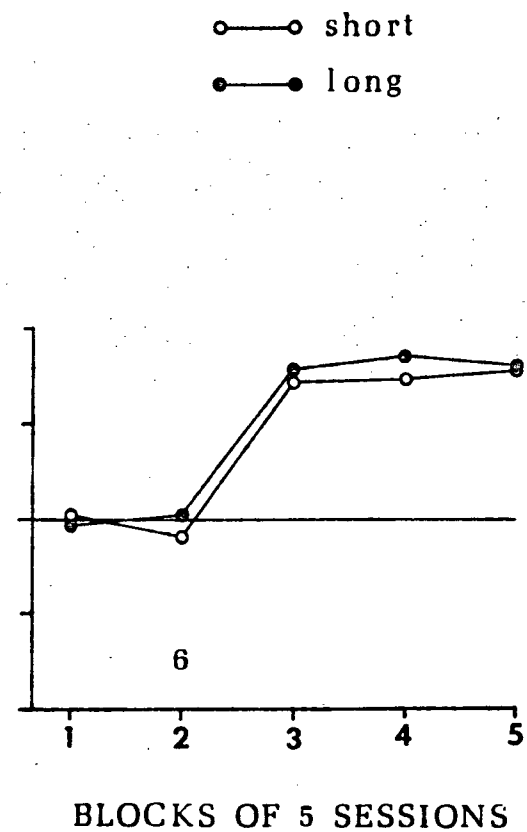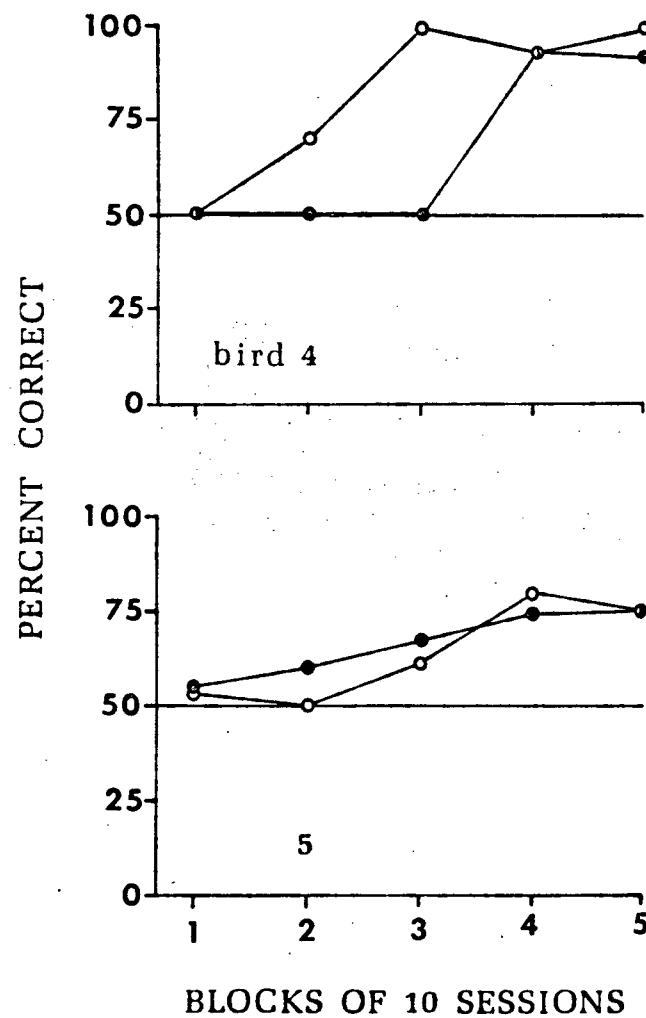
and long samples was very similar. Thus there was no systematic tendency for the birds to choose either one of the comparison stimuli during acquisition.

Delay manipulations

Figure 4 shows matching accuracy after short and long samples at the three delays. These data are displayed as two replications, which correspond to the first and the second half of the total number of sessions in which the variable delay procedure was in effect. During both replications the birds showed a strong tendency to choose the comparison associated with short samples at the 20-sec delay. This choose short effect was not as pronounced at the 5-sec delay, and was not apparent at the 0-sec delay. Finally, overall accuracy decreased as the delay interval was increased.

These effects were assessed using a four-way repeated measures analysis of variance on choice accuracy, the factors being delay, sample duration, replications, and subjects. This analysis yielded significant main effects of delay [$F(2,4)=$ 15.99, $p<.05$], sample duration [$F(1,2)=90.11$, $p<.05$], and subjects [$F(2,4)=15.49$, $p<.05$]. In addition, there was a significant two-way interaction between delay and sample duration [$F(2,4)=18.18$, $p<.05$], and between delay and subjects [$F(4,4)=$ 16.85, $p<.05$], as well as a significant three-way interaction between delay, sample duration, and subjects [$F(4,4)=7.58$, $p<.05$]. No other effects were significant.

Figure 4. Percent correct after short
     and long duration samples at the
     three delays during the first half
     (solid lines) and the second half
     (dashed lines) of the delay manipula-
     tion phase.

PERCENT CORRECT

DELAY (SEC)

bird 4

o short
● long
— rep 1
--- rep 2
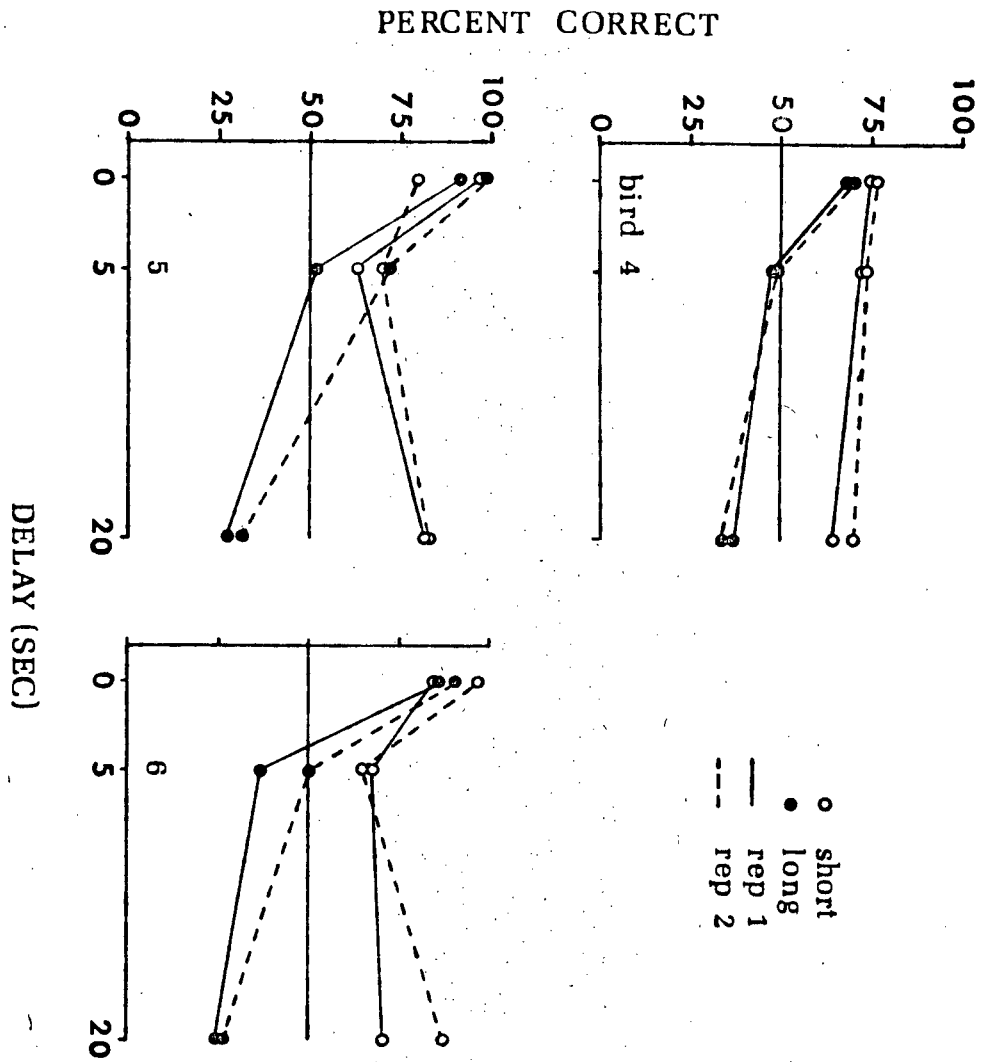
The effects of delay and sample duration were analyzed
further by a posteriori pairwise comparisons (Newman-Keuls,
p=.05). These analyses showed that accuracy was greater after
short samples than after long samples at the 20-sec delay,
but not at the 0-sec or 5-sec delay. Moreover, this effect
was significant for each bird, and during both replications.
Finally, overall accuracy was significantly higher at the
0-sec delay than at either the 5-sec or 20-sec delay. Thus,
each bird showed a choose short effect at the 20-sec delay,
and the effect remained stable across test sessions.

Discussion

These results replicate and extend those of Experiment
1 in four ways. First, they demonstrate that the choose
short effect is a reliable phenomenon, and that it also occurs
in naive subjects. Second, in this experiment, each subject
was exposed to only one type of sample stimulus (either food
or light durations). Thus, the choose short effect is not
specific to the more complex task of Experiment 1, which in-
volved both kinds of sample stimuli within the same session.
Third, the present results suggested that the choose short
effect cannot be attributed easily to either a color preference,
or to a bias present during acquisition. There was no apparent
relationship between the birds' tendency to choose short or

long during acquisition and the choose short effect they dis-
played during the delay manipulation phase. Finally, this
experiment demonstrated that the choose short effect does not
diminish with extended testing with the variable delay pro-
cedure.

Experiment 3

This experiment was designed to extend the previous findings by demonstrating the choose short effect with a procedure that involved more than two sample durations. Two pigeons were trained under a three-choice DSMTS procedure in which three different light durations served as "short," "medium," and "long" samples, and three different key stimuli served as the comparisons. The birds were trained to match each of the three sample stimuli to the appropriate comparison. The effect of the delay interval on choice of the three comparisons after each sample duration ("short," "medium," and "long") then was examined. Under this procedure, a choose short effect would be reflected by a selective increase in incorrect choices to the "short" comparison, and a decrease in correct choices to both the "medium" and the "long" comparisons.

Method

Subjects and apparatus

Birds 1 and 2 from Experiment 1 served as the subjects. The apparatus was the same as that used in Experiment 1 except that three different stimuli (red, yellow, and green light for Bird 1; red light, green light, and a white rectangle on a black background for Bird 2) were presented on the three

pecking keys as comparisons.

Procedure

Baseline procedure. Each trial began with the presentation of a houselight sample for one of three durations: 2 sec (short), 6 sec (medium), or 14 sec (long). Immediately following termination of the sample (0-sec delay), the three pecking keys were illuminated with the three comparison stimuli. For Bird 1, choices of red after short, yellow after medium and green after long were designated correct; for Bird 2 the correct choices were green after short, the rectangle after medium, and red after long. Correct choices were reinforced with 4-sec access to grain followed by a 30-sec ITI; incorrect choices terminated the trial and initiated the ITI. The order of presentation for three samples and the six possible key arrangements of the comparison stimuli was determined randomly. Bird 1 received 50 sessions and Bird 2 received 30 sessions of baseline training.

Delay manipulations. The variable delay procedure was initiated following baseline training. On a randomly-determined half of the trials in each session the delay was 0-sec; on the remaining trials a delay of 5-sec or 10-sec occurred, each with an equal probability. All other aspects of the procedure were unchanged. Both birds were tested for 20 sessions.

Results

Baseline performance

Figure 5 shows the percentage of trials on which the birds chose the "short," "medium," or "long" comparison keys after each sample duration during the last 10 sessions of baseline training. Each bird was well above chance level (33.3%) in choosing the correct comparison after each sample duration. Moreover, after short and long samples, more errors occurred to the "medium" comparison, whereas after medium samples the errors were equally likely to be a choice of the "short" or "long" comparisons. Thus, both birds' choice of the comparison stimuli clearly was controlled by the sample duration.

Delay manipulations

Choices of the three comparison stimuli after each sample duration at the three delays are shown in Figure 6. Data from all 20 sessions are included. Several features of these data should be noted. First, after both the medium and long samples, choice of the correct comparison decreased over the delays, whereas after the short samples, choice of the correct comparison did not change greatly over the delay. Second, after medium samples, choice of the "short" comparison increased at the 10-sec delay, whereas choice of the "long" comparison did not change substantially at any of the delays.

Figure 5. Percentage of trials on which
     the birds chose the "short" (S),
     "medium" (M), or "long" (L) compari-
     son stimulus after each of the three
     sample durations during the last 10
     sessions of baseline training.
     Slashed bars represent correct choices;
     the dashed line indicates chance level
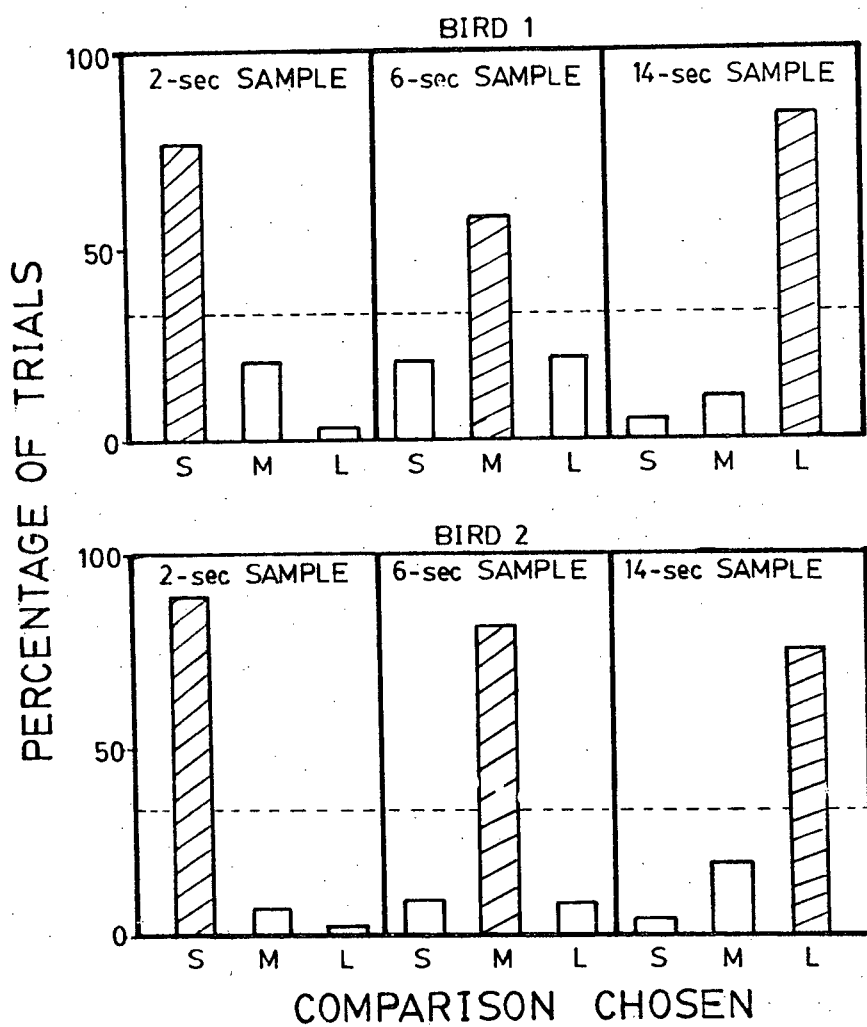   (33%) for a three-choice procedure.

Figure 6. Percentage of trials on which
the birds chose the "short" (S),
"medium" (M), and "long" (L) compari-
son after each of the three sample
durations at the 0-, 5-, and 10-sec
delays. Slashed bars represent
correct choices. The dashed line
indicates chance level (33%) for a
three-choice procedure.
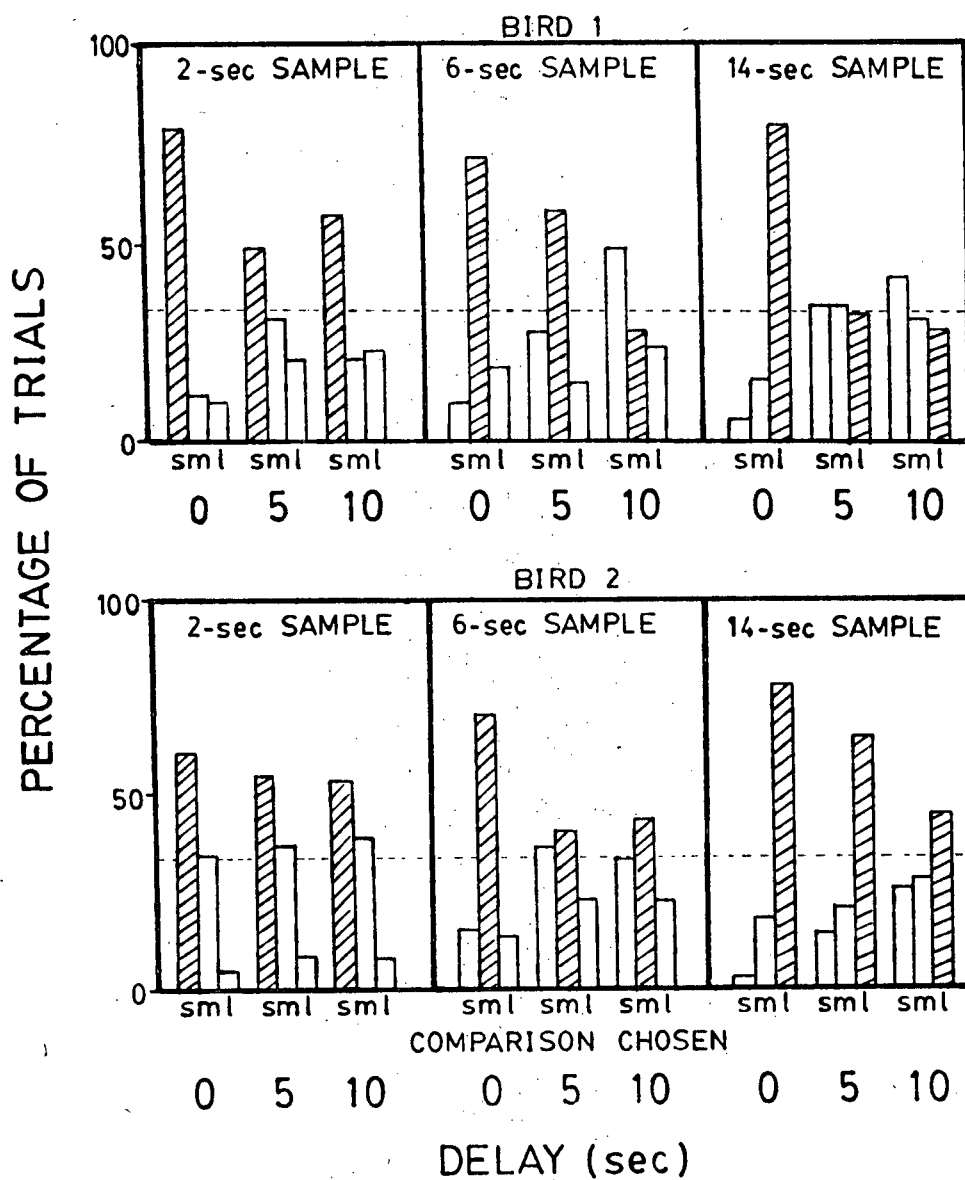
Third, after long samples, choice of the "short" comparison increased at the 10-sec delay.

These results were confirmed by three, three-way repeated measures analyses of variance of choices of the "short," "medium," and "long" comparisons, with the factors being delay, sample duration, and subjects. The analysis of choices of the "short" comparison revealed a significant main effect of sample duration $[F(2,2)=46.08, p<.05]$. No other effects were significant. The analysis of choices of the "medium" comparison showed a significant sample duration by delay interaction $[F(4,4)=14.02, p<.05]$, but no other significant effects. Similarly, the analysis of choices of the "long" comparisons showed a significant sample duration by delay interaction $[F(4,4)=7.65, p<.05]$, and no other significant effects.

Subsequent a posteriori comparisons (Newman-Keuls, p= .05) showed that incorrect choices of the "short" comparison after both medium and long samples occurred more often at the 10-sec delay than at the 0-sec delay, whereas incorrect choices of the "medium" comparison after either short or long samples, and of the "long" comparison after either short or medium samples, did not change significantly over the three delays. Furthermore, correct choices of both the "medium" and the "long" comparisons decreased significantly at both of the longer delays; whereas, correct choices to the "short"

comparison did not change significantly as a function of the delay. Thus, under the three-key procedure, increases in the delay produced an increased tendency to choose the comparison associated with the shortest sample.

Discussion

These results extend the previous findings by showing that the choose short effect also occurs in a three-choice procedure. In addition, the three-choice procedure permitted a more refined analysis of the response tendencies that are the basis of the choose short effect. The choose short effect demonstrated in the previous experiments could have been due to either an increased tendency to choose the "short" comparison, or to an increased tendency to avoid choosing the "long" comparison. Although the two-choice procedure did not provide any means of distinguishing between these two alterna-tives, the three-choice procedure was useful in this regard. If the choose short effect was due to an avoidance of choosing the "long" comparison rather than a tendency to choose the "short" comparison, then correct choices of the "medium" comparison would not be expected to decrease over the delay, and incorrect choices of the "short" comparison should not increase selectively; the fact that both of these results were obtained supports the assumption that the choose short effect does reflect an increased tendency to "choose short."

PART II: TESTS OF THE SUBJECTIVE SHORTENING MODEL

The results of the first three experiments demonstrated the reliability and generality of the choose short effect. Experiment 1 demonstrated the choose short effect with both food-access and light durations as samples.   Experiment 2 extended the generality of this effect to naive subjects, and ruled out the possibility that simple color preferences were the basis of the choose short effect.   Finally, Experiment 3 extended the generality of the choose short effect to a more complex procedure that involved three sample durations and three choice stimuli.

As mentioned in Experiment 1, one interpretation of the choose short effect is that the duration of events in pigeons' working memory shortens over time.   A model, based on this idea of subjective shortening, will now be described in detail. This model hereafter will be referred to as the "subjective shortening" model.

The subjective shortening model has two principal components: a working memory and a reference memory.   According to this model, pigeons base their choice of the comparison stimuli upon a working memory of the sample duration that shortens as a function of time.   Consequently, the representation of the sample in working memory is shorter after an extended delay than it is after a brief delay.   These changes

in the subjective duration of the sample as a function of the delay are the basis of the choose short effect. The manifestation of this choose short effect, however, also depends upon the second, reference memory, component of the model. During initial training with a 0-sec delay, the pigeons form an association between the sample representations and the correct comparisons; this association is maintained in reference memory. This reference memory, which is based upon the 0-sec delay trials, is maintained during the delay phase provided that a considerable portion of the trials consist of 0-sec delays. The choose short effect on long delay trials occurs because of a discrepancy between the working memory representation of the sample and the reference memory representation of the sample. As the delay increases, the working memory of the long sample shortens, becoming less similar to the reference memory of the long sample, and more similar to the reference memory of the short sample. Simple stimulus generalization then would lead to an increased tendency to choose the short comparison. Because the working memory of the short sample also is shortened after a long delay, it becomes less similar to the reference memory of the long sample. Therefore, stimulus generalization would not be expected to produce an increased tendency to choose the long comparison. Thus, the two components of the model, working memory and reference memory, combine to produce the choose short effect.

At the time this research was initiated, no other investigations of the effects of delay manipulations on duration discrimination in animals had been reported. However, two studies of memory for event duration in animals have since appeared. Church (1980) used a right-left, lever-choice procedure to test rats' memory for short (2-sec) and long (8-sec) signals over retention intervals of 0, .5, 2, 8, and 32 sec. He found that with delay increases of up to 8 sec, accuracy decreased approximately equally for short and long signals. However, with a 32-sec delay, accuracy was much lower after long signals than after short signals; the rats chose the "short" lever on approximately 65% of the trials. Church also found that when the signal was omitted, the rats chose the "short" lever with a probability of .79.

In a second experiment, Church compared performance after a .5-sec, a 2-sec, and an 8-sec retention interval to performance after a 0-sec retention interval, using a psychophysical procedure. In this study he found no evidence of any changes in rats' subjective representation of duration as a function of the retention interval.

For the most part, Church's results are not inconsistent with those of the present research. First, Church did demonstrate that after a long retention interval (32 sec), rats showed a choose short effect. Second, although there was no evidence of a choose short effect in his second experiment, this could have been due to a failure to use a sufficiently long

retention interval (e.g., the 32-sec interval used in his previous experiment).

Church, however, interpreted the choose short effect demonstrated in his first experiment in terms of "biased guessing" rather than subjective shortening. He favored this interpretation because the rats also showed a choose short tendency when the signal was omitted. On the basis of the similarity between the rats' performance after a 32-sec delay and after a 0-sec signal, Church argued that a similar process was the basis of responding in both cases. Specifically, he suggested that the tendency to choose short reflected biased guesses that occur "if the trace of the sample had faded" (i.e., after a 32-sec delay), or "if the signal was not presented" (i.e., on the 0-sec signal tests).

Nevertheless, the subjective shortening model also can account for the similarity between responding in the absence of a signal and responding after long delays. First, a tendency to choose short after long delays should occur because of the subjective shortening of the signal duration. Second, a similar choose short tendency should occur after no signal because of stimulus generalization; the absence of a signal may be more similar to a brief signal than to a longer signal. Thus, rats should respond after no signal and after long delays in much the same way: they should choose short. The guessing interpretation of responding after no signals and after a long

delay, on the other hand, does not offer any explanation for why guessing should be biased in the short direction.

The second study investigating animals' memory for event duration was conducted by Cohen et al. (1981). They tested pigeons' working memory for a .5-sec (short) and a 4-sec (long) sample in a DSMTS procedure. They varied the delay from 0 sec to 16 sec in a stepwise fashion in which each delay was in effect for several consecutive sessions. They found no consistent differences between accuracy after short and long samples at any of the delays.

Although Cohen et al. failed to demonstrate a significant choose short effect, the experimental procedure they used and their method of data collection may have obscured this effect. They used a stepwise rather than a variable delay procedure, and they only reported and analyzed the mean accuracy scores of the last five sessions at each delay. Although the present experiments demonstrated that the choose short effect is relatively stable over test session when a variable delay procedure is used, it is possible that the choose short effect may decrease after extended training at a single, constant delay. In fact, this can be predicted directly from the subjective shortening model (see Experiment 5).

The purpose of the following two experiments was to provide empirical tests of the subjective shortening model in the light of the recent studies by Church (1980) and Cohen et al. (1981).

Experiment 4

One method of testing the subjective shortening model is to use a psychophysical procedure to compare the point of subjective equality (PSE) across different delay intervals (cf. Church, 1980). The PSE is thought to represent the sample duration that produces an internal representation that is halfway between the "long" and "short" training durations. In order to determine the PSE, subjects are exposed to a number of sample durations in addition to the training values, and the probability of choosing "long" is plotted as a function of sample duration. Then the method of least squares can be used to calculate a linear regression equation relating the probability of choosing long to sample duration. This equation then can be used to derive the sample duration that corresponds to a probability of .5 of choosing long, which defines the PSE.

If the sample durations subjectively become shorter over the delay, then a longer sample duration would be required in order to maintain a probability of .5 of choosing long. Thus, according to the subjective shortening model, the PSE should shift towards longer durations as the delay interval is increased.

Although Church (1980) failed to find any shifts in the PSE as a function of the delay interval, he did not use any

delays of longer than 8 sec. The present experiment therefore was designed to compare the PSE at 0-, 5-, and 20-sec delays. Pigeons were trained under a DSMTS procedure with 2- and 10-sec samples, then were tested with various sample durations after delays of 0, 5, and 20 sec. Functions relating the probability of choosing long to sample duration then were determined, and the PSE was calculated for each delay interval. A significant increase in the value of the PSE as a function of increases in the delay clearly would support the subjective shortening model.

Method

Subjects and apparatus

These were the same as those used in Experiment 1.

Procedure

Baseline sessions. In the present experiment, the birds first were exposed to a few baseline sessions which involved the same basic procedure as described in Experiment 1, except that only one type of stimulus (light) served as the 2- and 10-sec samples, and correct choices were reinforced with a probability of .75.

Generalization testing: Series 1. The procedure used in this condition was similar to that used in the baseline sessions, except that within each session, generalization test

trials occurred with a probability of .25. On these test trials, the light sample was presented for one of three test durations: 4 sec, 6 sec, or 8 sec, each occurring with an equal probability. Following the delay, the usual comparison stimuli were presented. A peck to either of the comparison keys terminated the trial and was recorded but never reinforced. On the remaining 75 percent of the trials, one of the usual 2- and 10-sec samples was presented, each with an equal probability, and correct choices were reinforced with a probability of .75. Both birds were tested under this condition for 30 sessions.

Generalization testing: Series 2. The procedure used in this condition was identical to that used for Series 1, except that the test durations of the samples in this series were 6 sec, 12 sec, and 18 sec. Both birds were tested for 30 sessions under this condition.

Treatment of the data. For each series, the point of subjective equality (PSE) was estimated for each of the three delays in the following manner. First, a linear regression equation relating the probability of a "long" response to sample duration was calculated by the method of least squares for each delay. Second, these equations (of the form $y = mx + b$) were used to find the sample duration at each delay that corresponded to a probability of .5 of a "long" response, which represents the estimated PSE (cf. Church & Deluty, 1978).

In addition, the proportion of trials on which the birds chose the "long" comparison was plotted as a function of the sample duration for each of the three delays, and the PSE was plotted as a function of delay. For these graphic presentations the data were collapsed over the two series.

Results

Figure 7 shows the probability of responses to the "long" comparison as a function of sample duration for the three delay intervals. The delay interval clearly had a marked effect upon these functions. The sample duration at which the birds began to choose "long" on over half of the trials was much longer after a 20-sec delay interval than after a 0-sec or a 5-sec delay.

A comparison of the estimated PSE at the three delay intervals corroborated these observations: the PSE was longer at the 20-sec delay than at either the 0-sec or 5-sec delay (see Figure 8). At the 0-, 5-, and 20-sec delays, respectively, the estimated PSE for Bird 1 was 4.8 sec, 5.8 sec, and 17.6 sec during Series 1, and 5.4 sec, 3.9 sec, and 20.6 sec during Series 2. For Bird 2 the estimated PSE with the 0-, 5-, and 20-sec delays, respectively, was 4.4 sec, 5.1 sec, and 20.6 sec during Series 1, and 4.5 sec, 7.6 sec, and 10.8 sec during Series 2.

Figure 7. Probability of a response to
     the "long" comparison as a function
     of sample duration for the 0-sec,
     5-sec, and 20-sec retention intervals.
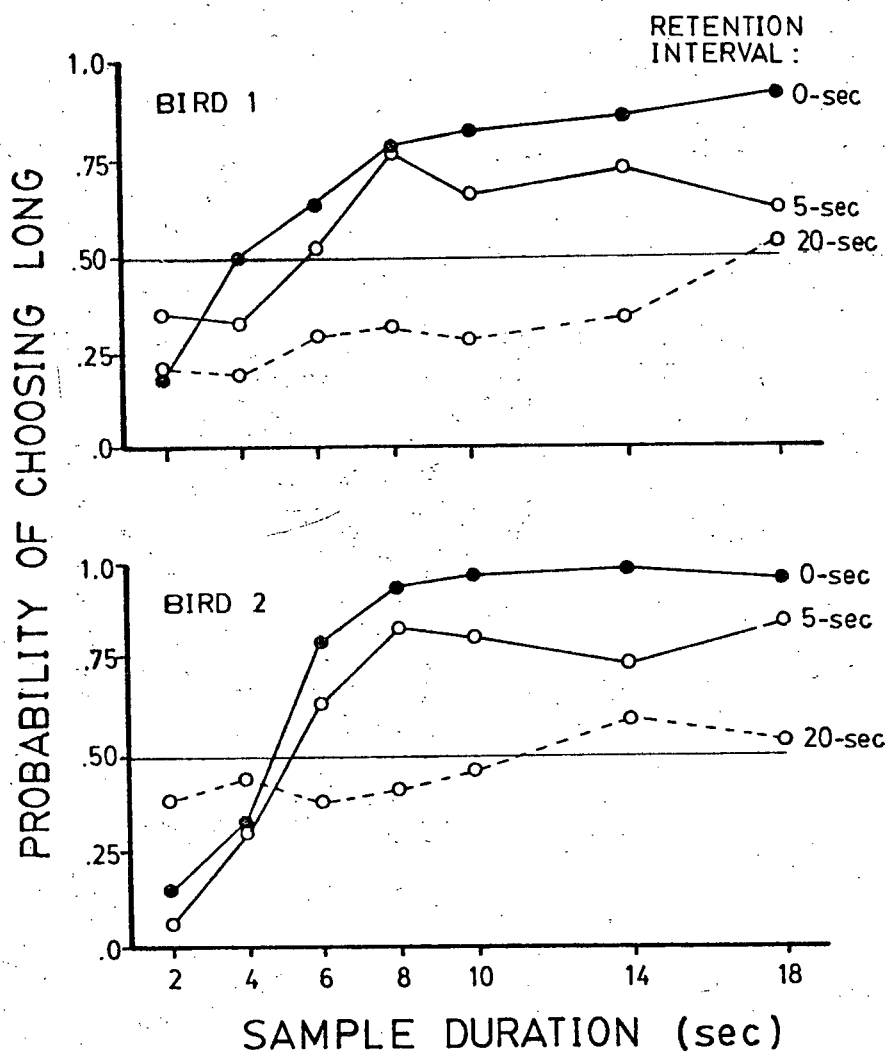
Figure 8. Point of subjective equality
at the three delays.
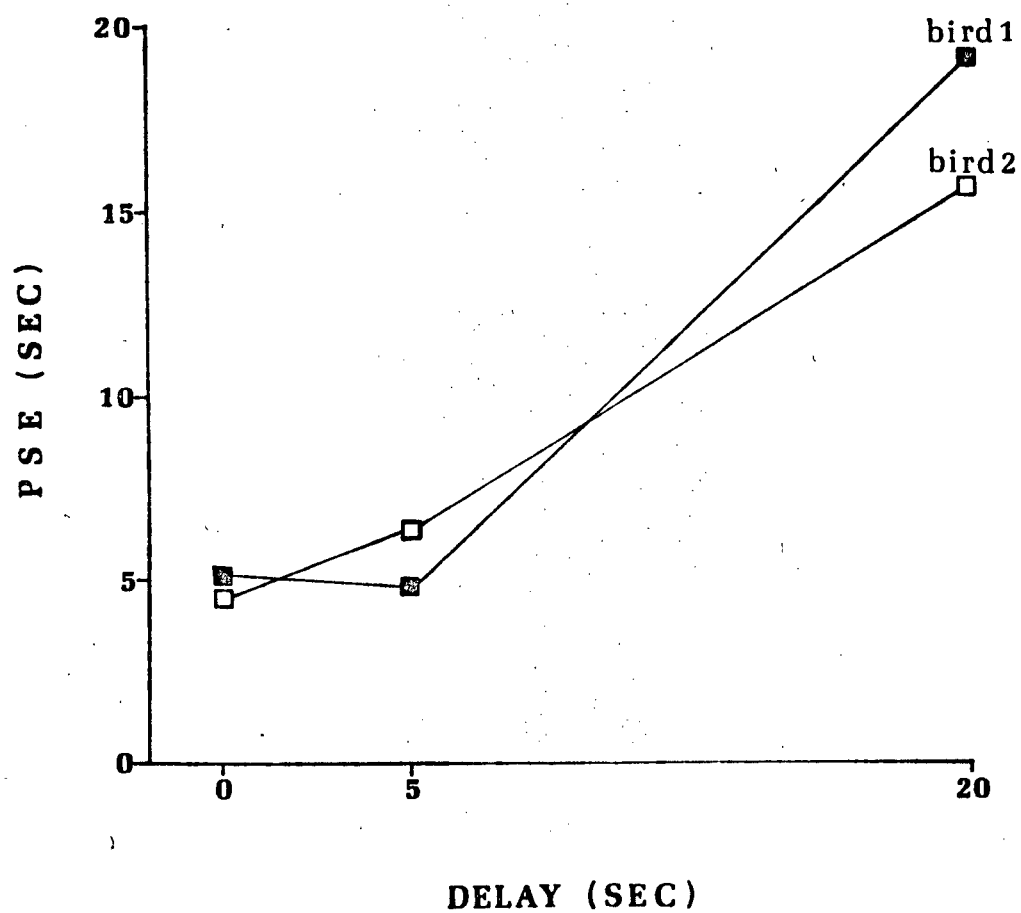
A two-way repeated measures analysis of variance per-
formed on the PSE data revealed a significant main effect of
delay [$F(2,2)=33.8$, $p<.05$], but not of series [$F(1,1)=.64$, $p>$
$.05$] or subjects [$F(1,2)=.76$, $p>.05$]. None of the interactions
were significant. Subsequent a posteriori comparisons (Newman-
Keuls, $p=.05$) confirmed that the PSE was longer at the 20-sec
delay than at either the 0-sec or the 5-sec delay.

Discussion

The finding that the PSE had shifted towards a much
longer duration at the 20-sec delay confirms the prediction
that was derived from the subjective shortening model. These
results challenge Church's (1980) argument that the subjective
duration of a signal does not decrease over delays. The
failure to find any changes in the PSE as a function of delay
may be restricted to the shorter delays used in his study.

Experiment 5

Experiment 5 was designed to provide further support for the subjective shortening model. As in the previous experiments, pigeons were trained first on a 0-sec DSMTS procedure with two durations of light as the samples. In this experiment, however, the delay between the sample and the comparison stimuli then was manipulated in a stepwise rather than a variable fashion. The delay was increased first from 0 sec to 5, 10, then 20 sec, and then was decreased to 5 and 0 sec, with each delay being in effect for several consecutive sessions.

According to the subjective shortening model, the step-wise delay procedure should produce different results from those produced by the variable delay procedure. In order to illustrate how these different outcomes are derived from the model, it may be useful to consider the memory requirements under each procedure. In both procedures, during initial training with a 0-sec delay, it is assumed that a reference memory is formed which contains an association between the representations of the samples at a 0-sec delay and the correct comparison stimuli. When the delay then is manipulated using the variable delay procedure, a random half of the trials in each session still are composed of 0-sec delays. These 0-sec delay trials should serve to maintain the reference memory established during initial training. On the remaining trials, in which a longer delay is presented, responding should con-

tinue to be guided by the previously established association in reference memory. Thus, the animals' responses are based not only upon their working memory of the sample, but also upon the relationship between this working memory and their reference memory. A choose short tendency occurs after long delays because of the discrepancy between their working memory of a long sample (which has become shorter) and the representation of a long sample in their reference memory (which is based upon the 0-sec delay). In the variable delay procedure, this choose short effect is stable over time because of the relative stability of the reference memory.

When the delay is manipulated using a stepwise procedure, on the other hand, the reference memory should not remain stable over the delay manipulation phase because 0-sec delays are not interspersed with the longer delays. Extended training with a single delay at a time should result in a change in the reference memory as a new association between the sample representations at that delay and the correct comparisons in learned. Because the stepwise procedure results in a changing reference memory, this procedure was expected to yield a number of unique outcomes.

First, with each increase in the delay between the sample and the comparisons, the pigeons should show a temporary choose short effect. The reasons for this temporary choose short effect are as follows. During the 0-sec delay, the pigeon

would have learned to associate the two comparisons with the long and short sample representations, and this association would become part of their reference memory. However, when the delay between the samples and comparisons is lengthened, the pigeon initially should base its responses on the prevously established reference memory. If the subjective representation of the samples in working memory had shortened as a function of the delay, then the working memory duration of the long sample would be shifted towards the reference memory duration of the short sample, leading to an increased tendency to choose short.

Second, with extended training at a given delay, this choose short effect should diminish and overall accuracy should improve as a new association between the subjective durations of the samples and the comparisons is formed and maintained in reference memory.

Third, following extensive training at a given delay, a subsequent decrease in the delay should result in a temporary tendency to choose the comparison associated with the long sample (a "choose long" effect). The reason for this temporary choose long effect can be illustrated with the following example. Given that the working memory durations of the samples would have shortened more after a 20-sec delay than after a 5-sec delay, the subjective representations of the samples after a 5-sec delay would be longer relative to those after a 20-sec delay. If the animal had formed a reference

memory containing an association of the comparison stimuli
with the subjective sample durations present at a 20-sec
delay, a decrease in the delay from 20 sec to 5 sec should
result initially in a disruption of the discriminability of
the short sample, and hence more incorrect choices of the
"long" comparison.

In summary, on the basis of the subjective shortening
model, it was predicted that with a stepwise delay procedure:
1) increases in the delay between the samples and comparisons
would lead to an initial choose short effect, 2) decreases in
this delay would produce an initial choose long effect, and
3) with extended training at a given delay, these choose short
and choose long effects would diminish and overall matching
accuracy would improve; furthermore, there should be a positive
correlation between these two changes. Empirical confirmation
of these predictions would provide strong support for the
subjective shortening model. Experiment 5 also was designed
to assess pigeons' choice behaviour when the sample was
omitted (i.e., 0-sec sample tests). It was expected that
pigeons would be more likely to treat a 0-sec sample as "short"
than as "long" because of the process of stimulus generalization.

Method

Subjects

Five naive adult Silver King pigeons (Birds 7, 8, 9, 10,

and 11) served as the subjects. Deprivation and housing conditions were the same as those described for subjects in Experiment 1.

Apparatus

The test chamber for Birds 7, 8, and 9 was identical to that described in Experiment 1. For Birds 10 and 11, a BRS/LVE #132-02 light-proof, sound-attenuating test chamber was used. One wall of this chamber contained a horizontal array of three pecking keys, each equipped with a microswitch to sense pecks of .2N or greater. An Industrial Electronics Engineers' Series 10 stimulus projector was mounted behind each key; these illuminated the center key with a uniform field of yellow light, or with a white square on a dark background, and the side keys with a uniform field of either red or green light. A BRS/LVE #114-10 grain feeder containing a 2.8W lamp was mounted below the center key.

Procedure

Preliminary training. During a few preliminary sessions, each bird was trained to eat from the raised illuminated grain feeder, and then trained to peck the center key when illuminated with yellow light, and the side keys when illuminated with either red or green light.

Baseline condition (0-sec DSMTS). A variation of the DSMTS procedure, similar to that described in Experiment 1, was used. In this experiment, trials began with the presenta-

tion of a yellow light on the center pecking key; the first

peck to this key terminated the yellow light and produced

the sample stimulus, which lasted for either a short (2-sec)

or long (10-sec) duration. For Birds 10 and 11, the sample

stimulus was the presence on the center key of a white square

on a dark background, whereas for Birds 7, 8, and 9 the sample

stimulus was illumination of the houselight. Immediately

(0-sec) following the offset of the sample, the side keys

were illuminated with red and green light, which served as the

comparison stimuli. For Birds 10 and 11 the red comparison

was designated as correct after short samples and the green

comparison after long samples; for Birds 7, 8, and 9, green

was designated correct after short, and red after long samples.

A peck to the correct comparison terminated both comparisons

and produced 3-sec access to grain followed by a 30-sec ITI;

pecks to the incorrect comparison terminated the trial and

initiated the ITI. The presentation of the short and long

samples, and the arrangement of the red and green comparisons

on the side keys occurred in a mixed and counterbalanced order

over trials in each session.

Each bird was trained under this condition until matching

accuracy was well above chance and appeared to be stable.

Accordingly, Birds 7, 8, 9, 10, and 11 were exposed to this

condition for 24, 18, 18, 36, and 24 sessions, respectively.

Delay manipulations. During this condition, all aspects of the procedure were the same as during baseline except that the delay between the sample and comparison stimuli was manipulated over blocks of several sessions. For each bird, the delay manipulations were conducted in three consecutive phases:

Phase 1: Increases in the delay.

During this phase, the delay was increased for several sessions to 5 sec, then to 10 sec and/or to 20 sec. Birds 7, 8, and 10 were tested at all three of these delays, whereas Bird 9 was tested only at the 5- and 20-sec delays and Bird 11 was tested only at the 5- and 10-sec delays. Birds 7, 8, 9, 10, and 11 were tested at the 5-sec delay for 21, 21, 21, 24, and 27 sessions, respectively. Birds 7, 8, 10, and 11 were tested at the 10-sec delay for 15, 12, 12, and 33 sessions, and Birds 7, 8, 9, and 10 were tested at the 20-sec delay for 18, 21, 12, and 18 sessions, respectively.

Phase 2: Decreases in the delay.

During this phase, the delay first was decreased from 10 sec (Bird 11) or from 20 sec (Birds 7, 8, 9, and 10) to 5 sec for several sessions. Subsequently, the delay was decreased to 0 sec for several sessions. Birds 7, 8, 9, 10, and 11 were tested at the 5-sec delay for 6, 6, 9, 9, and 12 sessions, and at the 0-sec delay for 6, 6, 6, 6, and 9 sessions, respectively.

Phase 3: Replication of the increases in the delay.

Following exposure to the 0-sec delay in Phase 2, the delay was increased again to 5 sec for six sessions (Bird 8) or three sessions (Birds 7, 9, 10, and 11). For Bird 8, the delay subsequently was increased once again to 20 sec for three additional sessions.

0-sec sample tests. Following the delay manipulation phase, each of the birds was administered three 0-sec sample test sessions in which the sample stimuli were not presented; the comparison stimuli simply were presented at the beginning of each trial without being preceded by a sample. Each of the three 0-sec sample test sessions were separated by a baseline (0-sec delay) session. On the 0-sec sample tests, the birds' choice of the comparisons, which had been designated as correct for short and long samples throughout the experiment, was recorded. These test sessions were conducted to determine whether the birds would show a tendency to choose short after a 0-sec sample.

Results

The results of this experiment confirmed each of the predictions derived from the subjective shortening model. During the first session following an increase in the delay to 5 sec, 10 sec, or 20 sec, the birds showed a consistent

choose short effect, whereas during the first session following a decrease in the delay to 5 sec, the birds showed a choose long effect. In addition, with extended training at each delay the choose short and choose long effects diminished and overall accuracy improved. Finally, on 0-sec sample tests, the birds tended to choose the short comparison. These results will be discussed in detail in the following sections.

A. Choose short and choose long effects

The percentage of correct choices after short and long samples is shown in Figures 9a and 9b for each bird in blocks of three consecutive sessions, except for the first three sessions after each delay change which are shown individually to facilitate detection of the initial choose short and choose long effects. Each increase in the delay resulted in an initial choose short effect, whereas a decrease in the delay led to an initial choose long effect. Figure 10 shows the mean percentages of all the birds' correct choices after short and long samples during the first session after each delay change in the three phases. Clearly, during Phases 1 and 3 (increases in the delay), accuracy was higher after short samples than after long samples, whereas during Phase 2 (decreases in the delay), accuracy was higher after long than after short samples.

A priori one-tailed dependent t-tests, comparing accuracy after short and long samples, were conducted on the data shown in Figure 10. These analyses revealed that accuracy after

Figure 9a. Percent correct after short
    and long duration samples during
    blocks of three consecutive sessions
    of the experiment, and during the
    first three individual sessions
    after each change in the delay
    (indicated by the solid vertical
    lines) for Birds 7 and 8.

DELAY (SEC)

Figure 9b: Percent correct after short
     and long duration samples during
     blocks of three consecutive sessions
     of the experiment, and during the
     first three individual sessions
     after each change in the delay
     (indicated by the solid vertical
     lines) for Birds 9, 10, and 11.

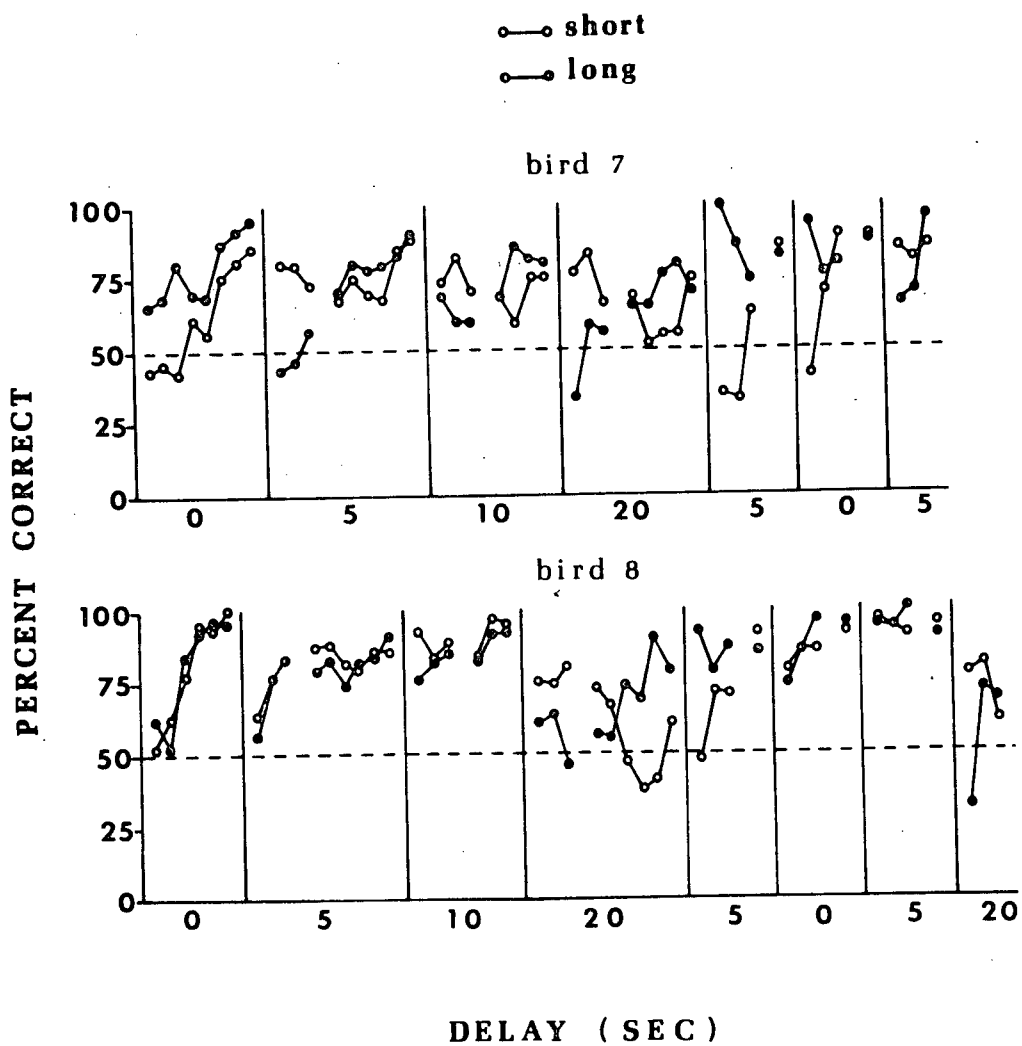bird 9

bird 10

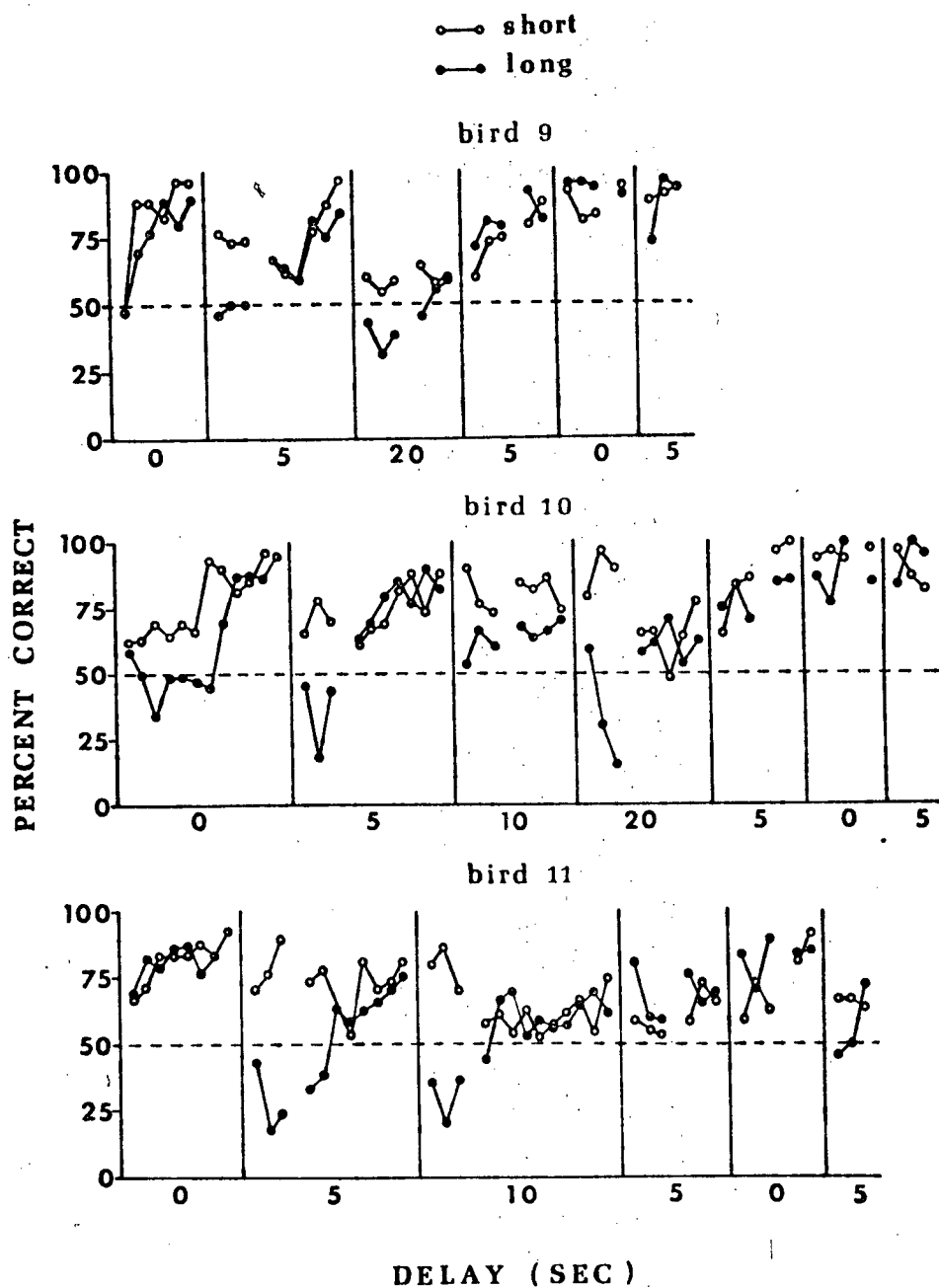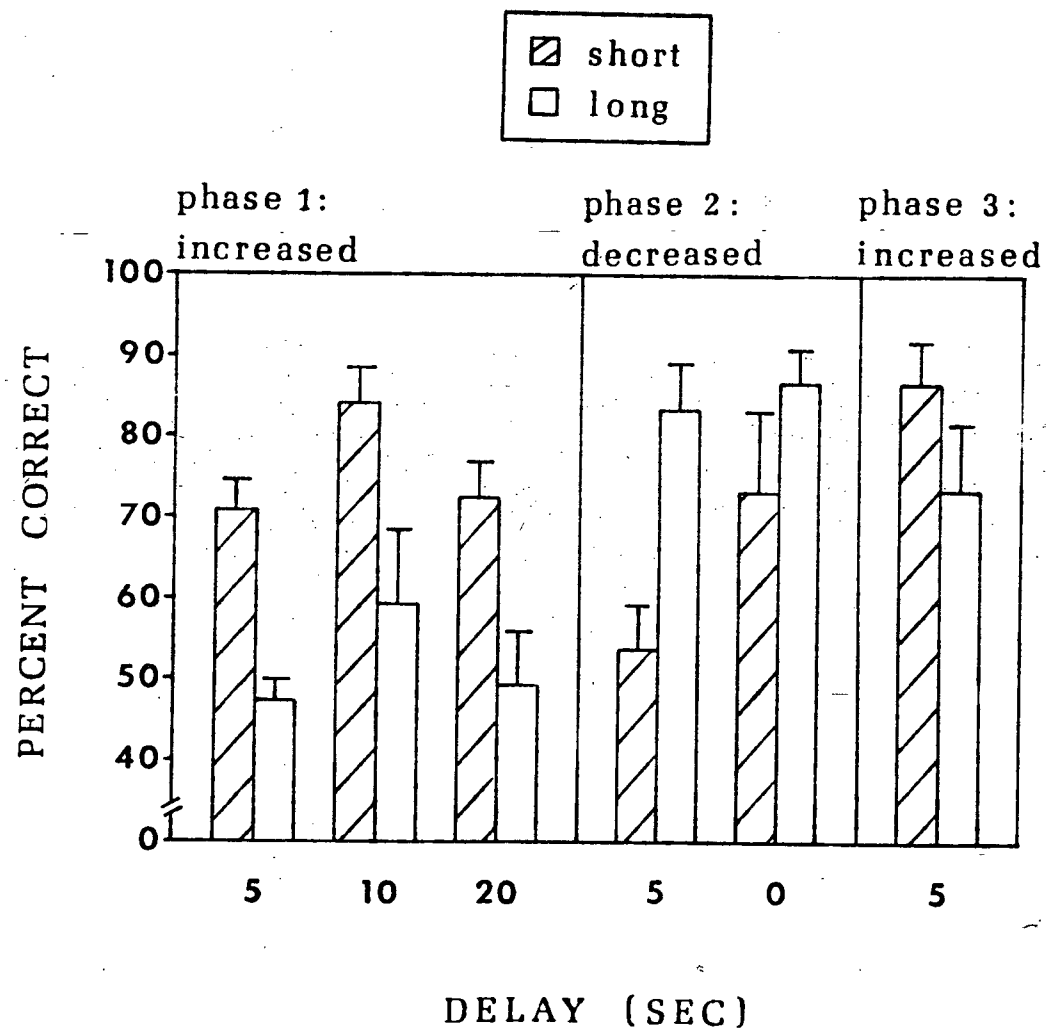bird 11

PERCENT CORRECT

DELAY (SEC)

Figure 10. Mean percentage (± SEM) of
      correct choices after short (slashed
      bars) and long (open bars) sample
      durations during the first session
      after each delay change.

short samples was significantly greater than accuracy after
long samples during the session following each delay increase
in Phase 1 [5-sec delay: t(4)=4.41, p<.01; 10-sec delay: t(3)=
2.68, p<.05; 20-sec delay: t(3)=3.4, p<.05], and following
the second delay increase to 5 sec in Phase 3 [t(4)=3.67, p<
.05]. In contrast, accuracy after short samples was signifi-
cantly lower than accuracy after long samples during the first
session following a decrease in the delay to 5 sec in Phase 2
[t(4)=2.67, p<.05]. The lower accuracy after short samples
at the 0-sec delay in Phase 2 was not significant [t(4)=1.19].

B. Effect of extended training at a given delay

   1. Decreases in the choose short and choose long effects.
The choose short and choose long effects that were present
after the delay changes tended to diminish with extended
exposure to each of the delays (Figures 9a and 9b). To test
the significance of this change with extended training,
"choice ratios" were calculated using the data from the first
and last blocks of three sessions at each delay in Phase 1 and
Phase 2. These ratios were calculated by dividing the per-
centage of correct choices after short samples by the sum of
the percentage of correct choices after both short and long
samples. Thus, ratios of greater than .5 indicate higher
accuracy after short samples (i.e., a choose short effect),
and ratios of less than .5 indicate higher accuracy after long
samples (i.e., a choose long effect). A decrease in the choose

short effect over training therefore would be reflected in a decrease in the choice ratio, whereas a decrease in the choose long effect over training would result in an increase in the choice ratio.

For all except the 10-sec delay in Phase 1, the prediction that the choose short and choose long effects would diminish with extended training was confirmed by one-tailed dependent measures t-tests comparing the choice ratios for the first and last block of three sessions. During Phase 1 (delay increases), the choice ratio decreased significantly from the first to the last block of sessions at the 5-sec delay [M (first)=.626, M (last)=.510; t(4)=3.45, p<.05] and at the 20-sec delay [M (first)=.625, M (last)=.502; t(3)=6.28, p<.01], but not at the 10-sec delay [M (first)=.589, M (last)= .515; t(3)=2.21, p>.05]. In contrast, during Phase 2 (delay decreases), the choice ratio increased significantly from the first to the last block of sessions at both the 5-sec delay [M (first)=.440, M (last)=.515; t(4)=4.17, p<.01] and the 0-sec delay [M (first)=.476, M (last)=.511; t(4)=2.61, p<.05].

2. <u>Increases in overall accuracy</u>. Figure 11 shows each bird's overall matching accuracy for blocks of three consecutive sessions. As predicted on the basis of the subjective shortening model, overall matching accuracy improved with extended training at each delay during Phase 1 and Phase 2. One-tailed dependent measures t-tests comparing overall

Figure 11. Each bird's overall match-
ing accuracy during blocks of
three consecutive sessions of the
experiment.

DELAY (sec)
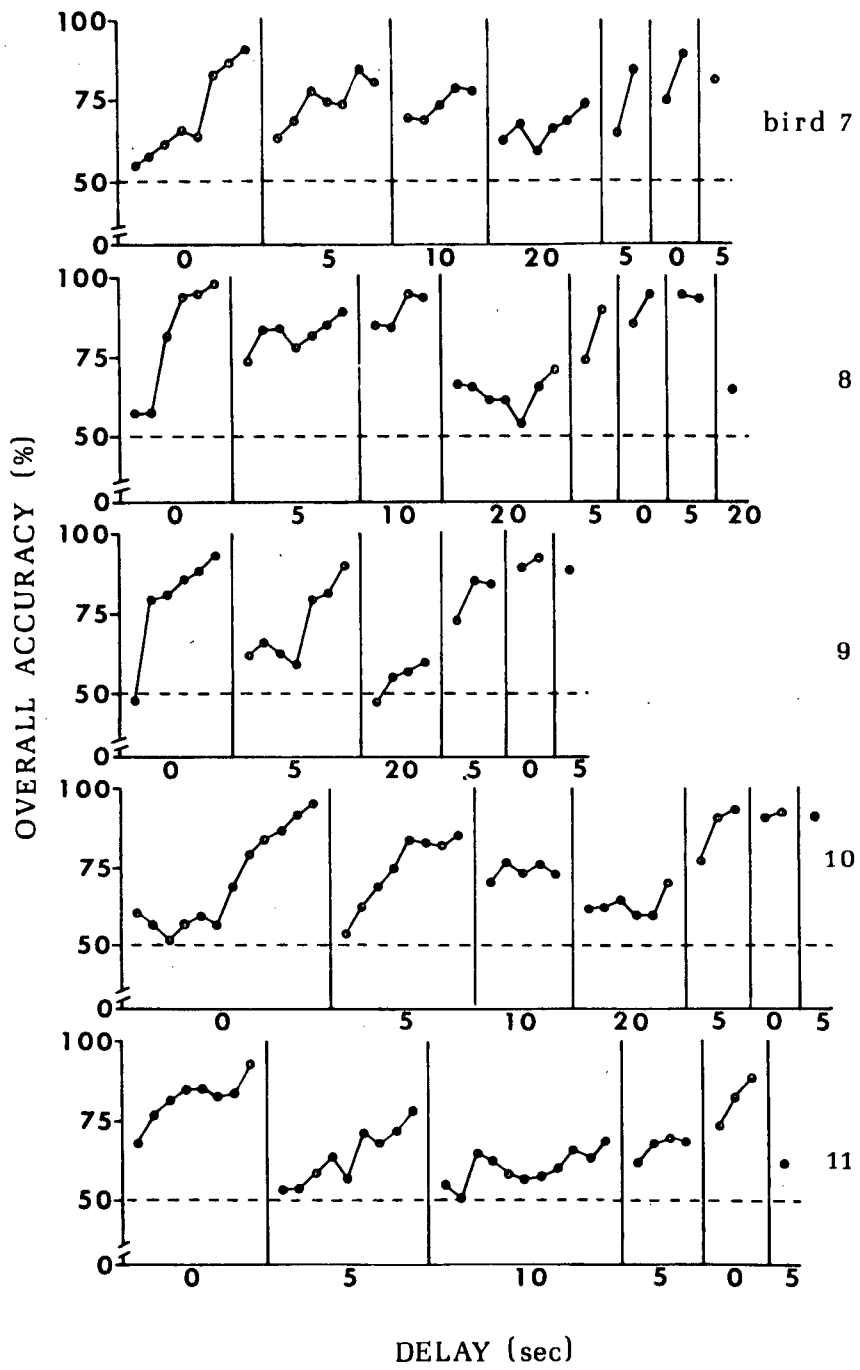
accuracy on the first and last block of three sessions con-
firmed that overall accuracy increased significantly from the
first to the last block of sessions at the 5-sec delay [t(4)=
7.51, p<.01], at the 10-sec delay [t(3)=3.57, p<.05] and at
the 20-sec delay [t(3)=5.15, p<.01] during Phase 1, as well
as at the 5-sec delay [t(4)=6.18, p<.01] and the 0-sec delay
[t(4)=2.65, p<.05] during Phase 2.

3. Relationship between the increases in accuracy and
the decreases in the choose short and choose long effects.
In addition to predicting that extended training at a given
delay would lead to an increase in overall accuracy and a
decrease in the choose short and choose long effects, it was
also predicted that these two effects would be correlated:
both changes should begin to occur when the animal begins to
acquire a new association between the comparisons and the sub-
jective sample durations present at the particular delay.

This prediction was tested by determining the correla-
tion between the choice ratio and overall accuracy at each
delay during Phase 1 and Phase 2, using the data from the first
two blocks of sessions for each bird. The prediction of a
direct relationship between increases in accuracy and decreases
in the choose short effect during Phase 1 was confirmed by a
significant negative correlation (one-tailed, p<.05) between
the choice ratio and overall accuracy at the 5-sec delay
(r=-.788), and the 10-sec delay (r=-.649). At the 20-sec

delay the correlation was negative, but failed to reach significance (r=-.294). Similarly, the prediction that there should be a direct relationship between increases in accuracy and decreases in the choose long effect during Phase 2 was confirmed by a significant positive correlation between the choice ratio and overall accuracy at the 5-sec delay (r=.771), and at the 0-sec delay (r=.788).

0-sec Sample Tests

Figure 12 shows the percentage of trials on which the birds chose the "short" comparison during the three 0-sec sample tests. All birds showed a consistent tendency to choose the "short" comparison in the absence of the sample.

The results of a dependent t-test (two-tailed) of the mean percentage of "short" and "long" choices confirmed that the birds chose short significantly more often than they chose long on these 0-sec sample tests [t(4)=5.17, p<.05].

Discussion

Each of the predictions derived from the subjective shortening model was confirmed. First, each stepwise increase in the delay led to an initial choose short effect. Second, a decrease in the delay to 5 sec led to an initial choose long effect. Third, these choose short and choose long effects diminished, and overall accuracy improved as a function of

Figure 12.   Percentage of trials on
    which the birds chose "short"
    during the three 0-sec sample
    tests.
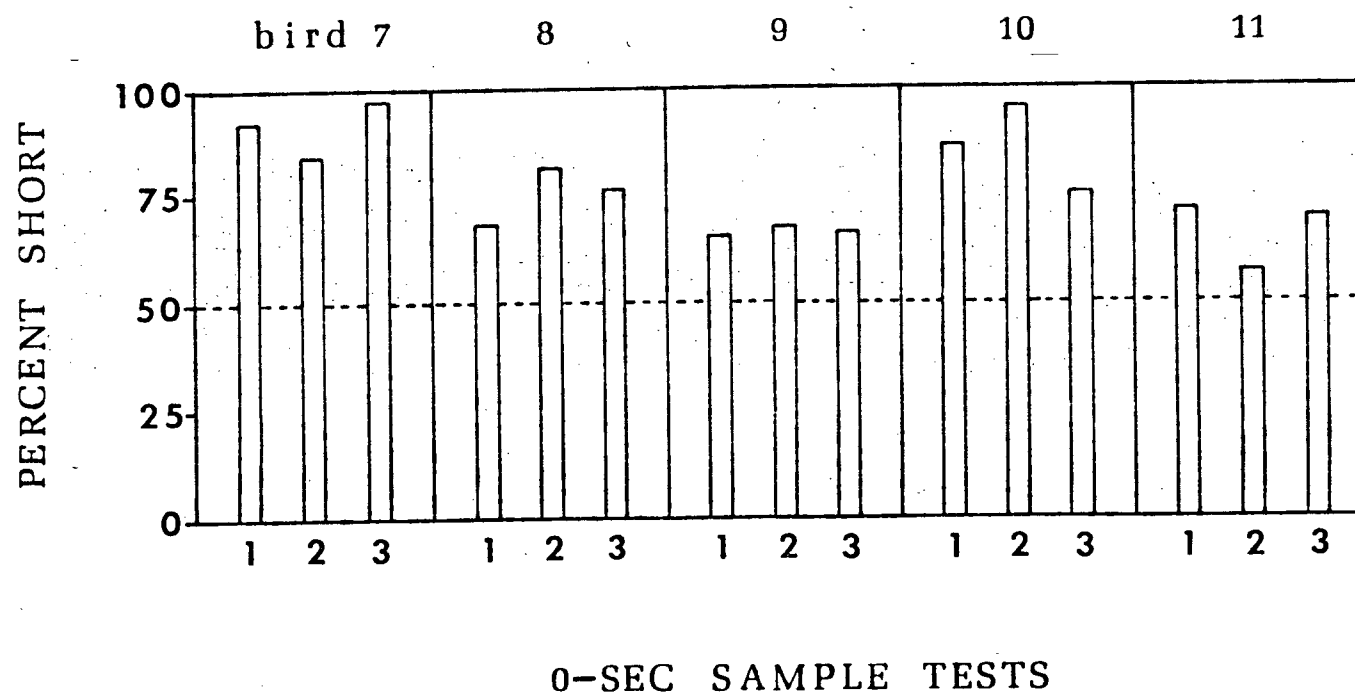
training at each delay. Furthermore, these two effects were significantly correlated. The empirical confirmation of these predictions provides strong support for the subjective shortening model.

The present results also illustrate the importance of precedural variables in the study of working memory. Clearly, the stepwise delay procedure used in this experiment produced very different outcomes from those produced by the variable delay procedure used in the previous experiments. Furthermore, the present results showed that, with a stepwise procedure, performance at a given delay is very different during initial sessions than during later sessions at the same delay: the choose short and choose long effects are pronounced during the first few sessions at a new delay, but disappear after extended training at that delay. In view of the present results, it seems likely that the failure of Cohen et al. (1981) to demonstrate a choose short effect was due, at least in part, to their failure to report and analyze the data from the first few sessions at each delay.

Finally, the results of the 0-sec sample tests confirmed the expectation that the absence of a sample would be treated more like a short sample than a long sample. Although Church (1980) has interpreted similar findings in terms of "biased guessing," he does not offer any explanation of why guesses should be biased consistently toward "short." In contrast,

the process of stimulus generalization readily can account for the fact that 0-sec samples are treated more like short samples than long samples.

GENERAL DISCUSSION

The first section of the general discussion is comprised
of a summary and discussion of the results of the present
investigations, and their implications for the experimental
study of working memory in animals. The second section con-
sists of a discussion of the implications of the present
research for theories and models of working memory processes.

I Summary of the results and their
methodological implications

The general purpose of the experiments in Part I was to
investigate pigeons' working memory for event duration. In
these experiments, variations of the DSMTS procedure were used
in which event durations served as the sample stimuli. The
first experiment revealed that when a variable delay was
interposed between the sample and the comparison stimuli,
pigeons showed a strong tendency to choose the comparison
stimulus associated with the short sample at 10- or 20-sec
delays, but not at shorter delays. This choose short effect
was found to occur with both food and light durations as the
sample stimuli (Experiments 1 and 2), with both naive and
experienced subjects (Experiments 1 and 2), and with both a
two-choice (Experiments 1 and 2) and a three-choice procedure
(Experiment 3). Furthermore, in addition to being statisti-

cally reliable, the choose short effect occurred in every subject in each experiment.

Experiments 4 and 5 extended the results of the first three experiments by showing that the choose short effect was reflected in a shift in the point of subjective equality after a 20-sec delay (Experiment 4), and that the choose short effect also occurred after stepwise increases in the delay (Experiment 5). In addition, the fifth experiment demonstrated that a choose long effect occurred after a stepwise decrease in the delay. Both the choose short effect and the choose long effect diminished with extended exposure to a given delay. Finally, Experiment 5 also demonstrated that after a 0-sec sample the birds tended to choose the "short" comparison.

The present experiments constitute the first systematic investigation of pigeons' working memory for event duration. Although previous research has shown that the type of stimulus used as the sample may have a significant effect on performance on working memory tasks (e.g., Farthing et al., 1977), no phenomena similar to the choose short and choose long effects have been reported to occur when more commonly-used stimuli, such as colors or line tilts, serve as the sample. Thus, memory for event duration may differ in important ways from memory for other types of stimulus dimensions (cf. Church, 1980).

The results of the present investigations have a number

of methodological implications for the study of working memory.
First, the present results suggest that the routine practice
of analyzing and reporting overall accuracy as opposed to
accuracy after each sample in delayed matching tasks may some-
times obscure important phenomena (cf. Sidman, 1980). Had the
present data been analyzed in terms of overall accuracy alone,
the choose short and choose long effects would not have been
detected. Second, the results of Experiment 1 suggest that
chance level overall accuracy is not necessarily indicative
of random choice behaviour. In a two-choice procedure, overall
accuracy may fluctuate around chance level either because the
subjects are choosing randomly or because they are choosing
one sample more often than the other (e.g., the choose short
effect). Third, and most importantly, the present results
illustrate that the procedure used to manipulate the delay
may have a profound effect upon the outcome of studies of
working memory. In the present experiments, the variable
delay procedure clearly yielded different results from those
obtained with the stepwise delay procedure. Under the variable
delay procedure, the choose short effect was stable over test
sessions, whereas under the stepwise delay procedure the
choose short effect occurred only during the first few sessions
following a delay increase. In addition, stepwise decreases
in the delay produced a temporary choose long effect, which

had never been observed under the variable delay procedure.
These results suggest that the use of only one type of delay
manipulation procedure or the practice of reporting only data
from the last few sessions (e.g., Cohen et al., 1981; Wilkie
& Spetch, 1978) may sometimes lead to inconsistent or erroneous
conclusions about the processes of working memory in animals.

II The subjective shortening model and its implications for theories of working memory in animals

In order to account for the choose short effect observed
in the first experiment, a model of memory for event duration
was proposed. This "subjective shortening model" consists of
two essential components: working memory and reference
memory. According to the model, a reference memory of the
sample durations and their association with the comparison
stimuli is established during initial training. This reference
memory, once established, remains relatively stable within and
between trials provided that a substantial proportion of the
trials consist of the delay interval at which the animal was
originally trained. On the other hand, the working memory of
the sample undergoes a systematic change within the trial
when there is a delay between the sample and comparison stimuli:
the remembered duration of the sample shortens over the delay.
It is the discrepancy between the reference memory of the sample

and the working memory of the sample that produces the choose short effect. As the working memory of the long sample shortens, it becomes more similar to the reference memory of the short sample, thereby producing a tendency to respond as though a long sample was short. In a variable delay procedure that includes a substantial proportion of trials containing the delay used in original training (e.g., 0-sec), reference memory should be relatively stable. Consequently, the discrepancy between the reference memory of the sample and the working memory of the sample after a long delay should be maintained over test sessions. The results of the first three experiments were completely consistent with this subjective shortening model.

A number of predictions derived from the subjective shortening model were tested in Experiments 4 and 5. Experiment 4 tested the prediction that the point of subjective equality would shift to a longer sample duration as the delay between the sample and comparisons was increased. This outcome was predicted on the basis of the model in the following way. If the subjective duration of the sample in working memory shortens over the delay, then after a long delay the sample duration that would be treated as the subjective midpoint between the short and long samples in reference memory would be longer. This prediction was confirmed by the results of Experiment 4, which showed that the point of subjective

equality was shifted to a significantly longer duration after a 20-sec delay. Thus, Experiment 4 provided further support for the subjective shortening model.

It was Experiment 5, however, that provided the most stringent test of the subjective shortening model. This Experiment tested a number of predictions derived from the model concerning the outcome of stepwise manipulations of the delay. The pivotal aspect of the model from which the predictions were derived was the interplay between working memory and reference memory. According to the model, the stability of a previously established reference memory depends upon the proportion of trials that consist of the delay used during the initial training. When the delay is changed to a value that remains constant on all trials for several sessions, as in a stepwise procedure, the reference memory of original training should not be maintained. Instead, a new reference memory that is based upon the working memory of the samples at that constant delay gradually should develop. As a result, the discrepancy between the working memory and the reference memory of the samples gradually should diminish. Moreover, once a reference memory has been established at a long delay, a subsequent decrease in the delay should produce a temporary discrepancy between working memory and reference memory that is in the opposite direction to that produced by an increase in the delay.

Thus, it was predicted that stepwise increases in the delay would produce a temporary choose short effect and that after extended training at a given delay the choose short effect would diminish and overall accuracy would improve. Furthermore, stepwise decreases in the delay would produce a temporary choose long effect, which also would diminish after extended training at a given delay. Each of these predictions was confirmed by the results of Experiment 5. Because none of these effects could have been predicted simply on the basis of the results of the previous experiments, which had revealed only a stable choose short effect, this experiment represented the most rigorous test of the predictive power of the subjective shortening model.

The present results do not appear to be easily interpretable within the context of other current views of working memory processes. D'Amato's (1973) temporal discrimination hypothesis assumes that performance on delayed matching tasks is based upon a discrimination of the relative recency of the samples. This view does not provide any basis for predicting that one stimulus would be chosen more often than the other, given that both samples occur equally often in the session. Thus, a temporal discrimination hypothesis of working memory cannot readily accommodate any of the present results.

It is also difficult to imagine how coding views of

working memory can deal with the present findings. According to some coding views (e.g., Farthing et al., 1977), the encoding process occurs gradually during exposure to the sample. Long duration samples are assumed to be remembered better than short duration samples because long samples are encoded better than short samples. Thus, this coding view would lead to the prediction that accuracy after long samples would be higher than accuracy after short samples. Clearly, the choose short effect is not consistent with this coding view of working memory. Furthermore, there is no reason to assume that a coded representation of one stimulus duration should change systematically into a coded representation of another stimulus duration over a delay interval. Thus, without such an ad hoc assumption, the present results could not be predicted easily on the basis of coding views of working memory.

Wagner's information processing model does contain an assumption that some stimuli are maintained in short-term memory longer than other stimuli because they "command" rehearsal to a greater degree. Although it would be possible to assume that short stimuli are rehearsed more effectively than long stimuli, several features of the present data suggest that differential rehearsal is not the basis of the choose short effect. First, the choose short effect often was characterized by below chance level accuracy after long samples. Because failure to rehearse the sample should at worst produce

chance level accuracy, these results suggest that the long samples were not forgotten, but instead were remembered as being short. The second feature of the present data that argues against a differential rehearsal interpretation of the present findings was the occurrence of a choose long effect in Experiment 5. Explaining why short samples should be rehearsed better after delay increases but long samples after delay decreases, would constitute a serious challenge for a differential rehearsal interpretation of the present results.

Roberts and Grant's (1976) trace decay theory also cannot easily accommodate the present results. According to their theory, longer duration samples should produce a stronger trace and therefore be remembered better than short duration samples. Accordingly, accuracy after long samples should be better than accuracy after short samples (cf. Cohen et al., 1981). The choose short effect clearly is inconsistent with this expectation. Although the choose short effect might be explained by a modified trace decay theory, in which the process of subjective shortening is conceptualized as a decay of the sample trace along the duration dimension, trace decay theory still could not accommodate the results of Experiment 5 unless it also included a reference memory component similar to that of the subjective shortening model.

The results of Experiment 5 are also problematic for a

"biased guessing" interpretation of the choose short effect, such as that proposed by Church (1980). It is not immediately obvious why guesses should be biased towards short after the delay is increased, become progressively less biased during extended exposure to a given delay, and then be biased towards long after the delay is decreased.

In short, the subjective shortening model provides the best fit to the present results. None of the other conceptualizations of working memory processes, as they are currently formulated, can accommodate the present findings.

There are a number of possible reasons why the results of the present investigations cannot be interpreted easily within the context of other current views of working memory. One possibility is that other current views do not represent accurate descriptions of the processes involved in working memory. However, it seems unlikely that all of these views are completely inaccurate, given that each of them seems to account well for some working memory phenomena. A second possibility is that the processes involved in working memory for event duration may be different from those involved in memory for the more commonly studied stimulus dimensions such as wavelength or line orientation. Thus, the present results may represent a limitation on the generality of other models of working memory, rather than a challenge to their internal

validity. In fact, it may be necessary to develop different models to account for the processes of working memory for different types of stimulus dimensions or different types of memory tasks (cf. Honig, in press; Riley et al., in press).

In the human psychophysical literature, certain stimulus dimensions have been classified as metathetic because subjects perceive a change in the physical stimulus as a change in its quality, whereas other stimulus dimensions have been classified as prothetic because subjects perceive a change in the physical stimulus as a change in its quantity. Although it may never be possible to determine whether an animal subject perceives a qualitative or a quantitative change in a physical stimulus, the distinction between dimensions that have been classified as metathetic and those that have been classified as prothetic on the basis of human reports may have some utility for the development of models of animal memory processes. For example, it is possible that certain models of animal memory may best describe the processes involved in memory for "metathetic" stimuli, and that other models may be needed to describe memory for "prothetic" stimuli.

The subjective shortening model appears to describe the processes involved in pigeons' memory for event duration, a dimension that has been classified as prothetic. Although it seems unlikely that a process of subjective shortening is

involved in working memory for stimuli that are varied along

a metathetic continuum, such as color, it is possible that

subjective shortening may be involved in memory for stimuli

that are varied along other prothetic dimensions, such as

size, or length. Whether or not the subjective shortening

model will provide an adequate description of memory for any

stimulus dimensions other than duration remains to be deter-

mined.

The concept of subjective shortening in memory is not

entirely new (cf. Frankenhaeuser, 1959; Ornstein, 1969).

For example, Frankenhaeuser (1959) believed that memory of

a time interval depended upon retention of the stimulus events

that filled the interval; if any of these stimuli were for-

gotten, the interval itself would be remembered as being

shorter. In support of this view, Frankenhaeuser reported

that human subjects' estimates of past time were consistently

smaller than the present time estimates on which they were

based. Furthermore, she reported that "a close correspondence

was found between amount of time retained and number of

stimuli retained." (Frankenhaeuser, 1959, p. 121).

The idea that memory of time undergoes systematic change

or distortion has also been discussed in relation to a phenome-

non reported in the human psychophysical literature called the

"time-order-error" (cf. Allan, 1979). When two stimuli are

presented successively to a subject whose task is to compare them along a particular prothetic dimension (e.g., weight, duration, loudness), it is often found that the order of presentation of the stimuli affects subjects' judgements of equality. For example, when two stimuli longer than 1 sec and of equal duration are presented successively, subjects often judge the first stimulus as shorter than the second (e.g., Hellstrom, 1977; Woodrow, 1935). Kohler (1923) has suggested that this type of error occurs because the second stimulus is being compared to a "faded" trace of the first stimulus, leading to an underestimation of the first stimulus. In support of his fading trace theory, Köhler (1923) found that the degree to which the first stimulus was underestimated increased as a function of the length of the interstimulus interval.

The idea that remembered durations may shorten over time also has been mentioned in the animal memory literature (Church, 1980; Honig, in press). Church (1980) discussed this idea in terms of an "internal clock" mechanism, which he assumes is the basis of rats' ability to time event durations. He suggested that shortening of subjective durations could occur if the internal clock was reset gradually toward zero during a retention interval: after a long retention interval the rats would respond on the basis of a "shortened" (i.e.,

partially reset) clock setting. Church, however, dismissed the idea that the internal clock is reset gradually and concluded that the subjective duration of events in rats' memory does not shorten over time. Honig (in press) also mentioned the possibility that the remembered duration of prior stimuli might be "foreshortened." He suggested that this process of foreshortening might not have been observed in Church's study because the rats may have solved the task by remembering a coded response decision rather than the duration of the stimulus.

It is important to note that the subjective shortening model proposed in the present investigations is an attempt to describe the processes involved in memory for event duration rather than an attempt to explain the specific mechanisms responsible for subjective shortening. There are several possible mechanisms that could produce subjective shortening, such as the gradual resetting of an internal clock (cf. Church, 1980), decay of a stimulus trace along the time dimension (cf. Roberts & Grant, 1976), or forgetting of events that fill the interval (cf. Frankenhaeuser, 1959; Ornstein, 1969). The subjective shortening model, as it is presently formulated, does not specify which, if any, of these possible mechanisms may underly the subjective shortening process.

Finally, the two-process framework of the subjective shortening model, which emphasizes the relationship between

working memory and reference memory, may have general utility
for the development of models of working memory in animals.
The two-process framework is derived from the idea that per-
formance on a working memory task is determined not only by
the processes of working memory but also by the content of
reference memory (cf. Honig, 1978; in press). Changes in
reference memory may affect performance on a working memory
task, and changes in working memory may gradually alter the
content of reference memory. This interactive, two-process
framework was an essential aspect of the subjective shortening
model; without it, many of the results of Experiment 5 could
not have been predicted. Furthermore, the emphasis on this
interactive relationship between working memory and reference
memory differentiates the subjective shortening model from
most other models of working memory. The fact that single-
process models of working memory, such as trace decay, cannot
easily accommodate the present data does not necessarily mean
that they are incorrect, but rather that they may be incom-
plete. For example, trace decay theory might easily accommo-
date the present data by adopting a two-process interactive
framework. The shortening of time in working memory could be
conceived of as a process of decay along the time dimension;
then, by assuming that the subject responds on the basis of
the similarity between a working memory trace of the sample

and a representation of the sample in reference memory, the results of the present experiments could be predicted. Thus, an awareness of the ways in which reference memory and working memory may interact might facilitate the development of more viable models of working memory in animals.

REFERENCES

Allan, L. G. The perception of time. Perception and Psychophysics, 1979, 26, 340-354.

Atkinson, R. C., & Shiffrin, R. M. Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (eds.), The psychology of learning and motivation. Vol. 2. New York: Academic Press, 1968.

Blough, D. S. Delayed matching in the pigeon. Journal of the Experimental Analysis of Behavior, 1959, 2, 151-160.

Bolles, R. C. Learning, motivation and cognition. In W. K. Estes (ed.), Handbook of learning and cognitive processes. Vol. 1. Hillsdale, N.J.: Lawrence Erlbaum, 1975.

Bolles, R. C. Some relationships between learning and memory. In D. L. Medin, W. A. Roberts, & R. T. David (eds.), Processes of animal memory. Hillsdale, N.J.: Lawrence Erlbaum, 1976.

Capaldi, E. J. A sequential hypothesis of instrumental learning. In K. W. Spence & J. T. Spence (eds.), The Psychology of learning and motivation. Vol. 1. New York: Academic Press, 1967.

Capaldi, E. J., & Cogan, D. Magnitude of reward and differential stimulus consequences. Psychological Reports, 1963, 13, 85-86.

Capaldi, E. J., & Spivey, J. E. Intertrial reinforcement and after effects at 24-hour intervals. Psychonomic Science, 1964, 1, 181-182.

Carter, D. E., & Werner, T. J. Complex learning and information processing by pigeons: A critical analysis. Journal of the Experimental Analysis of Behavior, 1978, 29, 565-601.

Church, R. M. Short-term memory for time intervals. Learning and Motivation, 1980, 11, 208-219.

Church, R. M., Getty, D. J., & Lerner, N. D. Duration discrimination by rats. Journal of Experimental Psychology: Animal Behavior Processes, 1976, 2, 303-312.

Cohen, S. L. , Calisto, G., & Lentz, B. E. Comparisons of sample stimuli in delayed symbolic matching-to-sample: Some results and implications. The Psychological Record, 1981, 31, 77-93.

Colwill, R. M. & Dickinson, A. Short-term retention of "surprising" events by pigeons. Quarterly Journal of Experimental Psychology, 1980, 32, 539-556.

Cook, R. G. Retroactive interference in pigeon short-term memory by a reduction of ambient illumination. Journal of Experimental Psychology: Animal Behavior Processes, 1980, 6, 326-338.

Coren, S., Porac, C., & Ward, L. M. Sensation and perception. New York: Academic Press, 1979.

D'Amato, M. R. Delayed matching and short-term memory in monkeys. In G. H. Bower (ed.), The psychology of learning and motivation: Advances in research and theory. Vol. 7. New York: Academic Press, 1973.

D'Amato, M. R., & Worsham, R. W. Retrieval cues and short-term memory in capuchin monkeys. Journal of Comparative and Physiological Psychology, 1974, 86, 274-282.

Elsmore, T. F. Duration discrimination: Effects of probability of stimulus presentation. Journal of the Experimental Analysis of Behavior, 1972, 18, 465-469.

Etscorn, F., & Stephens, R. Establishment of conditioned taste aversions with a 24-hour CS-US interval. Physiological Psychology, 1973, 1, 251-253.

Farthing, G. W., Wagner, J. M., Gilmour, S., & Waxman, H. M. Short-term memory and information processing in pigeons. Learning and Motivation, 1977, 8, 520-532.

Frankenhaeuser, M. Estimation of time. Stockholm: Almquist & Wiksel, 1959.

Gabriel, M. Intersession delay in avoidance extinction to training and generalization stimuli. Psychonomic Science, 1967, 9, 243-244.

Garcia, J., Ervin, F. R., & Koelling, R. A. Learning with prolonged delay of reinforcement. Psychonomic Science 1966, 5, 121-122.

Gleitman, H. Forgetting of long-term memories in animals. In W. K. Honig & P. H. R. James (eds.), Animal memory. New York: Academic Press, 1971.

Gleitman, H., & Holmes, P. Retention of incompletely learned CER in rats. Psychonomic Science, 1967, 7, 19-20.

Gleitman, H., & Jung, L. Retention in rats: The effect of proactive interference. Science, 1963, 142, 1683-1684.

Grant, D. S. Effect of sample presentation time on long-delay matching in the pigeon. Learning and Motivation, 1976, 7, 580-590.

Grant, D. S. Stimulus control of information processing in pigeon short-term memory. Learning and Motivation, 1981, 12, 19-39.

Grant, D. S., & Roberts, W. A. Sources of retroactive inhibition in pigeon short-term memory. Journal of Experimental Psychology: Animal Behavior Processes, 1976, 2, 1-16.

Guthrie, E. R. The psychology of learning. New York: Harper, 1935.

Hellstrom, A. Time-errors are perceptual. Psychological Research, 1977, 39, 345-388.

Herman, L. M. Interference and auditory short-term memory in the bottle-nosed dolphin. Animal Learning & Behavior, 1975, 3, 43-48.

Honig, W. K. Studies of working memory in the pigeon. In S. H. Hulse, H. Fowler, & W. K. Honig (eds.), Cognitive processes in animal behavior. Hillsdale, N.J.: Erlbaum, 1978.

Honig, W. K. Working memory and the temporal map. In N. E. Spear & R. R. Miller (eds.), Information processing in animals: Memory mechanisms. Hillsdale, N.J.: Lawrence Erlbaum, in press.

Honig, W. K., & Wasserman, E. A. Performance of pigeons on delayed simple and conditional discriminations under equivalent training procedures. Learning and Motivation, 1981, 12, 149-170.

Hull, C. L. Principles of behavior. New York: Appleton-Century-Crofts, 1943.

Hunter, W. S. The delayed reaction in animals and children. Behavior Monographs, 1913, 2, 1-86.

Jarrard, L. E. (ed.) Cognitive processes of nonhuman primates. New York: Academic Press, 1971.

Jarrard, L. E., & Moise, S. L. Short-term memory in the monkey. In L. E. Jarrard (ed.), Cognitive processes of nonhuman primates. New York: Academic Press, 1971.

Kamin, L. J. The retention of an incompletely learned avoidance response. Journal of Comparative and Physiological Psychology, 1957, 50, 457-460.

Kinchla, J. Discrimination of two auditory durations by pigeons. Perception and Psychophysics, 1970, 8, 299-307.

Köhler, W. Zur Theorie des Suksessiuvergleichs und der Zeitfehler. Psychologie Forschung, 1923, 4, 115-175.

Ladieu, G. The effect of length of the delay interval upon delayed alternation in the albino rat. Journal of Comparative Psychology, 1944, 37, 273-286.

Lashley, K. S. In search of the engram. Symposia of the Society for Experimental Biology, 1950, 4, 454-582.

Lett, B. T. Delayed reward learning: Disproof of the traditional theory. Learning and Motivation, 1973, 4, 237-246.

Lett, B. T. Long delay learning in the T-maze, Learning and Motivation, 1975, 6, 80-90.

Lydersen, T., Perkins, D., & Chairez, H. Effects of fixed-ratio sample and choice response requirements upon oddity matching. Journal of the Experimental Analysis of Behavior, 1977, 25 , 97-101.

Maier, N. R. F., & Schneirla, T. C. Principles of animal psychology. New York: McGraw-Hill, 1935.

Maki, W. S., Jr. Sustained attention: Stimulus control determined by the schedule of cue production inter- acting with cue duration. Animal Learning & Behavior, 1975, 3, 312-316.

Maki, W. S., Jr. Pigeons' short-term memories for surprising vs. expected reinforcement and nonreinforcement. Animal Learning & Behavior, 1979, 7, 31-37.

Maki, W. S., Jr., & Hegvik, D. K. Directed forgetting in pigeons. Animal Learning & Behavior, 1980, 8, 567-574.

Maki, W. S., Jr., Moe, J. C., & Bierley, C. M. Short-term memory for stimuli, responses, and reinforcers. Journal of Experimental Psychology: Animal Behavior Processes, 1977, 3, 156-177.

Nelson, K. R., & Wasserman, E. A. Temporal factors influencing the pigeon's successive matching-to-sample performance: Sample duration, intertrial interval, and retention interval. Journal of the Experimental Analysis of Behavior, 1978, 30 , 153-162.

Olton, D. S. Characteristics of spatial memory. In S. H. Hulse, H. Fowler, & W. K. Honig (eds.), Cognitive processes in animal behavior. Hillsdale, N.J.: Erlbaum, 1978.

Ornstein, R. E. On the experience of time. London: Penguin, 1969.

Pavlov, I. P. Conditioned reflexes. (Translated by G. V. Anrep.) London: Oxford University Press, 1927.

Perikel, J. J., Richelle, M., & Maurissen, J. Control of keypecking by the duration of a visual stimulus. Journal of the Experimental Analysis of Behavior, 1974, 22, 131-134.

Petrinovich, L., & Bolles, R. C. Delayed alternation: Evidence for symbolic processes in the rat. Journal of Comparative and Physiological Psychology, 1957, 50, 363-365.

Premack, D. Language in a chimpanzie? Science, 1971, 172, 808-822.

Reynolds, G. S., & Catania, A. C. Temporal discrimination in pigeons. Science, 1962, 135, 314-315.

Revusky, S. The role of interference in association over a delay. In W. K. Honig & P. H. R. James (eds.), Animal memory. New York: Academic Press, 1971.

Riley, D. A., Cook, R. G., & Lamb, M. R. A classification and analysis of short term retention codes in pigeons. In G. H. Bower (ed.), The psychology of learning and motivation. New York: Academic Press, in press.

Rilling, M., Kendrick, D. F., & Stonebraker, T. B. Stimulus control of forgetting: A behavioral analysis. In M. L. Commons, A. R. Wagner, & R. J. Herrnstein (eds.), Quantitative studies of operant behavior: Acquisition. Ballinger Publishing Co., in press.

Roberts, W. A. Short-term memory in the pigeon: Effects of repetition and spacing. Journal of Experimental Psychology, 1972, 94, 74-83.

Roberts, W. A., & Grant, D. S. Short-term memory in the pigeon with presentation time precisely controlled. Learning and Motivation, 1974, 5, 393-408.

Roberts, W. A. & Grant, D. S. Studies of short-term memory in the pigeon using delayed matching to sample. In D. L. Medin, W. A. Roberts, & R. T. Davis (eds.), Processes of animal memory. Hillsdale, N.J.: Erlbaum, 1976.

Roitblat, H. L. Codes and coding processes in pigeon short-term memory. Animal Learning & Behavior, 1980, 8, 341-351.

Ruggiero, F. T. & Flagg, S. F. Do animals have memory? In D. L. Medin, W. A. Roberts, & R. T. David (eds.), Processes of animal memory. Hillsdale, N.J.: Erlbaum, 1976.

Scharf, B. (ed.) Experimental sensory psychology. Glenview, Ill.: Scott, Foresman and Co., 1975.

Seligman, M. E. P. On the generality of the laws of learning. Psychological Review, 1970, 77, 406-418.

Shimp, C. P. & Moffitt, M. Short-term memory in the pigeon: Delayed-pair-comparison procedure and some results. Journal of the Experimental Analysis of Behavior, 1977, 28, 13-25.

Sidman, M. A note on the measurement of conditional discrimination. Journal of the Experimental Analysis of Behavior, 1980, 33, 285-289.

Spear, N. E. The processing of memories: Forgetting and retention. Hillsdale, N.J.: Lawrence, Erlbaum, 1978.

Spence, K. W. The role of secondary reinforcement in delayed reward learning. Psychological Review, 1947, 54, 1-8.

Spetch, M. L. & Wilkie, D. M. Duration discrimination is better with food access as the signal than with light as the signal. Learning and Motivation, 1981, 12, 40-64.

Spetch, M. L., Wilkie, D. M., & Skelton, R. W. Control of pigeons' pecking topography by a schedule of alternating food and water reward. Animal Learning & Behavior, 1981, 9, 223-229.

Stubbs, A. The discrimination of stimulus duration by pigeons. Journal of the Experimental Analysis of Behavior, 1968, 11, 223-238.

Terry, W. S. & Wagner, A. R. Short-term memory for "surprising" vs. "expected" unconditioned stimuli in Pavlovian conditioning. Journal of Experimental Psychology: Animal Behavior Processes, 1975, 1, 122-133.

Tinklepaugh, O. L. An experimental study of representative factors in monkeys. Journal of Comparative Psychology, 1928, 8, 197-236.

Tolman, E. C. Purposive behavior in animals and men. New York: Appleton-Century-Crofts, 1932.

Wagner, A. R. Expectancies and the priming of STM. In S. H. Hulse, H. Fowler, & W. K. Honig (eds.), Cognitive processes in animal behavior. Hillsdale, N.J.: Erlbaum, 1978.

Wagner, A. R., Rudy, J. W., & Whitlow, J. W. Rehearsal in animal conditioning. Journal of Experimental Psychology, 1973, 97, 407-426.

Wallace, J., Steinert, P. A., Scobie, S. R., & Spear, N. E. Stimulus modality and short-term memory in rats. Animal Learning & Behavior, 1980, 8, 10-16.

Wilkie, D. M. Delayed sybolic matching to sample in the pigeon. The Psychological Record, 1978, 28, 463-469.

Wilkie, D. M. & Spetch, M. L. The effect of sample and comparison ratio schedules on delayed matching to sample in the pigeon. Animal Learning & Behavior, 1978, 6, 273-278.

Wilkie, D. M. & Spetch, M. L. Pigeons' delayed-matching-to-sample errors are not always due to forgetting. Behaviour Analysis Letters, in press.

Wilkie, D. M. & Summers, R. J. Pigeons' spatial memory: Factors affecting delayed matching of key locations. Journal of the Experimental Analysis of Behavior, in press.

Wilkie, D. M., Summers, R. J., & Spetch, M. L. The effect of delay interval stimuli on delayed symbolic matching to sample in the pigeon. Journal of the Experimental Analysis of Behavior, 1981, 35, 153-160.