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TOWARDS AN UNDERSTANDING OF TEMPORAL UNCERTAINTY

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Towards an Understanding of Temporal Uncertainty," submitted by Eric Ernest Buckolz in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

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Abstract

Four experiments were conducted in order to examine selected aspects of Temporal Uncertainty. The primary purpose of Experiments 1 and 2 was to discover whether the numeric values of the coefficients of proximity and the percentage constant error (PCE) were constant for the Time Standards (0.5, 1.0, 2.0, 4.0 and 8.0 seconds) employed. Both intra-subject and inter-subject coefficients of proximity and PCEs were considered. These two experiments differed from each other in that Experiment 1 used constant Time Standards within a testing session while in Experiment 2, variable Time Standards were utilized within a session.

When intra-subject coefficients of proximity were used, a constant coefficient of proximity hypothesis was conditionally accepted in Experiment 1 but was rejected in Experiment 2 at the 0.01 level. Conclusions regarding this hypothesis were just the opposite in each experiment when inter-subject coefficients of proximity were employed. Reasons for abandoning the use of inter-subject coefficients of proximity were given.

Intra-subject PCEs differed significantly at the 0.01 level over the Time Standard conditions employed for both Experiments 1 and 2. The same results were obtained for the inter-subject PCEs.

The purpose of Experiment 3 was to determine if time

estimation was the only process operating during the foreperiod of a simple reaction time (SRT) task with constant foreperiods. On the basis of the results obtained, it appeared that S did not simply time estimate during the foreperiod.

Experiment 4 was conducted in order to determine if a priori probability functioned independently of the Previous Foreperiod Effect (PFE) within a SRT task with variable foreperiods. This possibility was confirmed.

On the basis of the results obtained from these four experiments, several general conclusions were derived.

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Chapter 1

Introduction

The environments within which man often operates, including those of sport and games, exhibit a great deal of variety in the demands they place upon him, yet within themselves each task is usually highly structured. As such, a given task requires a repertoire of highly constrained responses of an individual if he is to successfully adapt to and control his environment. The formation and modification of appropriate response patterns is, of course, the essence of skilled performance. Therefore the question is, what changes occur which permit the acquisition of motor skill? In pursuing the answers to this general question, it is necessary to consider the abilities of the performer and the characteristics of the skill to be learned.

One change which occurs when task demands permit, is a shift from a reactive to a predictive mode of control (Poulton, 1957; Trumbo, Noble, Fowler and Porterfield, 1968; Fitts and Posner, 1967). Because of transmission and information processing delays, the basic human operator makes decisions based upon information which is out of date and initiates responses which will be inappropriate at the time they have an effect upon the environment. Such delays in responding to the appropriate stimulus-event are sometimes referred to as reaction times. When errors caused by these inherent lags cannot be tolerated, reaction times must be reduced or eliminated and there is ample experimental evidence available to support the fact that S is capable of doing so. Bahrick and Noble (1966) have stated:

> Of even greater interest is the fact that the subject learns to anticipate the exact moment at which the target moves from one position to another.

Further, Schmidt (1968) commented:

> Anticipation of the time arrival of stimulus events allows the subject to get his response under way early and to respond coincidentally with the event . . .

Therefore, in order for S to compensate for his initial reactive status he must predict when the stimulus event will occur and his ability to do this will depend on his capability in reducing the temporal uncertainty associated with the task. The position taken here is that temporal uncertainty is a broad term which is a function of the length and the probability of a particular time-event as well as the possible interaction between these two factors. This definition, however, like the following statement by Schmidt (1968):

> It seems clear that the high levels of skill displayed by well-practiced subjects could not be attained without proper timing.

is merely a description. Neither of these should be interpreted as indicating the manner in which temporal uncertainty and hence, initial response intermittencies, are reduced.

The question which should more likely be considered is, how does this "proper timing" evolve? Does the human operator consciously estimate the time of stimulus arrival which he then uses as the basis for initiating his response in advance? Does S mediate his time estimates as Schmidt (1971) has suggested, in which case he really doesn't estimate time at all? Is "proper timing" achieved merely as the by-product of other response adjustments? Are time estimates under conscious or subconscious control or both? If the latter is the case, do both loci of control result in time estimations which have the same parameters? It is possible then that the "proper timing" of motor responses may be accomplished in a variety of ways, some of which do not rely upon conscious time estimation or indeed, upon time estimation of any kind.

Therefore, the question could be asked, in what manner, if any, does conscious time estimation contribute to the acquisition of motor skill in terms of modifying the time component of response structure? The experiments to follow were conducted primarily as a beginning towards answering this question. The approach taken was, of necessity, a narrow one. It was assumed that the influence of time estimation upon some task or dependent variable could be assessed by the extent to which predictions based upon conscious time-keeping parameters could be confirmed.

Time Estimation

Approximately twenty years ago, Woodrow (1951) summarized the state of knowledge regarding time perception up to that time. He wrote:

> The data that have been accumulated in the illusive field of time perception show two outstanding characteristics. One is the conflicting nature of the findings of different experimenters; the other is the mentalistic nature of the data.

Although contradictory results are still prevalent in the area of time estimation, they are being reduced, possibly because more consideration is being given to the nature of the method used to obtain the data. Several of the methods traditionally used are apparently not compatible in their demands and therefore have resulted in conflicting data (Falk and Bindra, 1954). Although progress is being made in this respect, further modifications in the method employed to acquire time-keeping data may be warranted. Although the trend has been towards more unanimous results, they are being questioned on the basis of the appropriateness of the data analysis (McConchie and Rutschmann, 1971). In addition to this problem, the difficulty of interpreting time-keeping results is compounded by limited research devoted to this topic. In this regard Schmidt (1968) commented:

> As important as they seem for skilled performance, anticipation and timing have received very little investigation.

If the relevance of conscious time estimation to the acquisition of motor skills is to be ultimately assessed, further research must be directed toward isolating time-keeping parameters.

The Nature of the Task

Tasks are usually not structured along a single dimension but often a given dimension dominates the others. The ideal task about which to make predictions based upon time-keeping parameters is one which is dominated by the temporal dimension. In addition, coexistent task demands should be minimized so that the parameters of the dependent variable are influenced as little as possible by factors other than time-keeping. The distorting effects of additional task responsibilities upon the time variable has been demonstrated by Gifford (1967). On the basis that it satisfied the above criteria a simple reaction time (SRT) task was selected.

Typically, the only uncertainty in a SRT design is <u>when</u> the reaction stimulus will occur, the stimulus and the response being predetermined. The fact that the response is fixed may permit <u>S</u> to operate at a detection level of information processing whereby the effective stimulus for response initiation is simply a change in the environment to which he is attending. Thus, if the signal-to-noise ratio, as well as the payoffs are kept constant, simple reaction time should remain relatively invariant, changing only due to moment to moment fluctuations in attentional level, receptor sensitivity, postural set, and response member differences from trial to trial. A true simple reaction time (TSRT) is independent of temporal uncertainty and therefore involves no time estimation or readiness component.

Previously, temporal uncertainty was considered to be a function of both the probability structure of the time-events and/or their lengths. In the situation where the foreperiod is constant (i.e. the time-event probability is 1.0) temporal uncertainty is solely a function of foreperiod magnitude. Under these conditions, S may abandon a true reaction time mode of operating and instead, attempt to estimate the time of arrival of the stimulus-event in order to reduce his lag in responding. Therefore, with a constant foreperiod, time-keeping becomes a factor in simple reaction time only to the extent that S chooses to adopt a time estimation strategy. Thus, if SRT is to be used as an indicator of time-keeping ability, within whatever limits, it must be assumed that S is not operating in a true simple reaction time mode.

The degree to which time-keeping parameters are successful in predicting those of SRT has not been directly tested, probably because of the scarcity of time estimation data. The tendency seems to be to use SRT as an indication of time-keeping ability (Karlin, 1959), a practice of questionable validity. The reason for the skepticism is the possible intervention of an operator variable during the foreperiod which will be referred to here as the readiness process. This readiness process is supposedly responsible for the degree of central receptivity for incoming information which, in turn, could alter SRT. Neurologically some support for the existence of a readiness process exists. Karlin (1970), in a review article, found that during the foreperiod for reaction time and signal detection tasks there evolves a negative DC shift in EEG and Posner and Keele (1972) pointed out that this follows a similar time course to that of behavioural preparation during this interval.

Unfortunately, the characteristics of such a readiness process are not well defined which makes it difficult to assess its influence upon SRT (Posner and Keele, 1972). Thus, SRT may be dependent upon other than time-keeping factors, factors which are not implicit in the task but which are inherent in the operator. It is because of such factors as a readiness process that the use of SRT as an indicator of time-keeping ability should be questioned.

Results obtained using a SRT design can be generalized to the field setting only to the extent that the tasks being considered have a similar structure and hence similar demands. For example, the sprinter in the starting blocks or the swimmer on the starting platform both awaiting the firing of the starting gun are both functioning within a SRT task framework. The importance of analyzing the task demands in light of the basic capabilities of the human operator cannot be overemphasized if confusion and misapplication of research is to be avoided. This approach has only recently been stressed in the literature (Wilberg, 1969; Posner and Keele, 1972).

When variable foreperiods are used in a SRT design, temporal uncertainty becomes a function of both time-event probability and length. In this case the response is still fixed and therefore, the backward dependency of the response upon stimulus processing still permits S to operate at a detection level of analysis. This, together with the fact that only temporal uncertainty is being manipulated, is the reason that such a design is still considered to yield simple reactions.

The inclusion of a variable foreperiod experiment in the following investigation was done so primarily in the interest of completeness, the data obtained with such designs have been quite consistent. The general trend being that SRT decreases, within limits, as the foreperiod length increases. This relationship has been called the immediate foreperiod effect (IFE) and two hypotheses have been advanced to explain it.

One suggestion incorporates the concept of a readiness process which operates in conjunction with time-event probability such that the more probable the time-event the more S prepares for the stimulus event and the shorter the SRT (i.e. Gottsdanker, 1970). Implicit in this explanation is the assumption that S employs his time-keeping ability to take advantage of transitional probabilities and therefore, this hypothesis will be called an information reduction effect (IRE). A second explanation for the IFE is based upon the assumption that the S prepares for the present stimulus-event in time based to some extent upon the length of the previous foreperiod and this has been called the previous foreperiod effect (PFE) (Karlin, 1959). Since the PFE is unidirectional, longer foreperiods preceding shorter foreperiods, such an effect would produce an IFE. Both hypotheses appear legitimate to some extent but whether one dominates the other is not known.

If an information reduction hypothesis is accepted, it should be possible to reduce the IFE gradient by increasing the a priori probability of the shorter time-events in the series. The problem arises because in such a situation, a reduction in the IFE gradient could be explained by either the PFE or the IRE. Resolving this issue would be one way in which to determine if the information to which S is attending is probability and therefore, whether it is the dominate factor controlling SRT in a variable foreperiod design. Of course, probability will be effective only to the extent that time-keeping is good enough to permit S to discriminate among the lengths of foreperiods used.

Purpose

The major purpose of this study was to serve as a beginning, a beginning towards investigating more thoroughly the manner in which temporal uncertainty reduction occurs and the way it contributes to skill acquisition.

Subpurposes

1. The major subpurpose of this study was to obtain time-keeping parameters, an aspect of temporal uncertainty which has been neglected and questionably analyzed in the past. The reference here is to conscious time estimation in which neither

knowledge of results is given nor mediation permitted.

2. How well do time-keeping parameters predict those of SRT when the foreperiod is constant? The general question being asked is, what happens during the foreperiod? Does S simply estimate time or are there other processes involved which have an appreciable effect upon SRT?

The removal of reaction lags is often important to the acquisition of motor skills, just how such delays are eliminated is not yet known but it is obvious that assuming that it is accomplished by conscious time estimation is not sufficient since other alternatives exist.

3. If S estimates time during the foreperiod (constant) in a SRT task, the reaction stimulus has the potential of supplying him with feedback as to the appropriateness of his estimate. If S uses this feedback information, his time estimates should become more accurate as practice continues and they should differ from those time estimations obtained where no knowledge of results were available. An attempt will be made to measure time estimations during the foreperiod of the SRT task. Such time estimates may be a better predictor of SRT parameters.

At least one problem may be encountered when time estimates are acquired in such a manner. It is possible that the two responses S has to make, a time estimation and a reaction, will interfere with one another because of Ss limited processing capacity in which case he may attend to one response to the detriment of the other.

4. The final subpurpose was to extend what is already known about the effects of time-event probability upon SRT when the foreperiods are variable. Specifically, does a priori probability function independently of the PFE when the a priori probability for the shorter foreperiods in the range is increased? In addition, will a combination of a priori probability and transitional probability alter expectancy in such a manner as to produce a reduction in the initial IFE gradient?

Definitions

Foreperiod (FP). The foreperiod is a length of time, the duration of which is bounded by the onset of the warning stimulus and the onset of the reaction stimulus.

Electroencephalagram (EEG). This term refers to the measurement of the electrical potential of the brain.

Simple reaction time (SRT). The time which elapses between the onset of the stimulus-event and the initiation of the response.

Delimitations of the Study

1. In a broad sense, the purpose in conducting the following experiments is to provide some direction for future research of a more intensive nature. Because this approach was taken, several experiments were undertaken which reduced the sample size used and the amount of data obtained relative to any given issue.

Summary

In view of the purpose and subpurposes the following experimental work is considered to be relevant.

Chapter 2

Review of Literature

The following review initially considered literature related to what was known about Ss time estimation ability within the limitations of the interest of the present study. Subsequent to this, attention was devoted to selected aspects of simple reaction time tasks which are primarily constrained by temporal uncertainty.

Time Estimation

Method

Undoubtedly, one of the most influential factors which has inhibited the integration of results between various studies of time estimation has been the employment of different methods. Bindra and Waksberg (1956) have commented upon this problem:

> Despite this relatively simple design of time estimation studies, they are quite confusing to read, and an attempt to make generalizations from the results of different studies gets one involved in many apparent or real contradictions.

The point is that, if , as appears to be the case, time estimation methods are incompatible in their demands, a choice must be made as to which is the most appropriate method to employ.

Traditionally, three general methods of time estimation have been used. With the verbal method of time estimation, the Time Standard is presented operatively and the subject must give a verbal response. With the production method, the Time Standard is given verbally and the subject must give an operational response. Finally, with the reproduction method both presentation and response are operative.

Research evidence, which used either inter-subject or intra-subject variance as the dependent variable, generally supported the contention that the method of reproduction produced significantly less variable time estimations than did the methods of verbal estimation and production (Kruup, 1961; Ochberg, Pollack and Meyer, 1965; Warm, Morris and Kew, 1963; Underwood, 1966 and McConchie and Rutschmann, 1971). Treisman (1963) also found that reproductions were more consistent estimates of time than were productions.

Further support for the hypothesis of the incompatibility between the methods of time estimation has been derived using correlations. Correlations between reproduction and verbal estimations have usually been low and negative (Siegman, 1962; Warm et al, 1963). Correlations between production and verbal estimates have painted a less consistent picture, being moderately high, positive and non-significant in some instances (Warm et al, 1963; Siegman, 1962) or significant and negative in others (Krupp, 1961; Clausen, 1950 and Carlson and Feinberg, 1968).

The incongruity of the results obtained using the three traditional methods of time estimation just discussed necessitated a decision as to which was the most appropriate in view of the present context. It was decided that the reproduction method was most relevant since many physical and sport activities appear to place analogous time-keeping demands upon the operator. Therefore, generalizations to these situations regarding time estimation would be most germane with this method. In addition, the reproduction method of time estimation was most consistent with the time-keeping demands in simple reaction time designs.

Actually, a slight modification of the traditional reproduction method was used in the present investigation. The task was self-paced in that the subject and not the experimenter determined when the standard time stimulus and the response (time estimate) were to begin. The impetus for this change was provided by Davis (1959, 1965). He compared the effects of a voluntary versus a non-voluntary warning signal in a simple reaction time task. He found that having a voluntary warning signal reduced simple reaction time relative to the condition where the warning signal was imposed by the experimenter. This occurred for foreperiods values up to about 450 milliseconds (msec.).

This finding was interpreted to indicate that the actual onset of the stimulus-event had a surprisal effect which lasted for approximately 0.5 seconds. It was thought that this surprisal effect might influence the perception of the Standard Time, which was indicated by the onset of a stimulus light which remained on for the desired time length.

If this did occur it would affect time estimates for the shorter Time Standards used. In fact, this factor might account for the larger relative variance found by Treisman (1963) for the shortest time length in the range.

Time-Keeping Parameters

Relative variance. Before discussing the related literature pertinent to this section some introductory comments will be considered.

Within the context of sensory discrimination, the assumption made is that when the physical energy to which the operator is attending is altered along some dimension, there occurs a change in sensation which covaries in some manner with the extent of energy disturbance. If a change in the sensitivity for energy disturbances is reflected by a change in variability, a decrease in sensitivity for a given degree of stimulation would be accompanied by an increase in the variety of responses elicited by this stimulus. According to Weber's Law, response variety as measured by the differential limen (DL) is a constant proportion of the standard energy level at which the DL was measured.

Treisman (1963), among others, has attempted to discover if Weber's Law applied to judgments of time length obtained with the method of reproduction. Unfortunately this may not be possible since the method of reproduction yields proximity data while the data referred to in Weber's

Law concerns dominance relationships. That is, Weber's Law deals with man as a difference detector, his sensitivity to differences. The method of reproduction, on the other hand, is structured such that the operator responds on the basis of proximity, that is, he attempts to produce similarities not differences. Incongruity evolves when attempts are made to assign dominance properties to proximity data as has been done by Treisman (1963). This was equivalent to scaling Ss sensitivity for similarities along a dimension which reflected sensitivity for differences.

Treisman (1963) called his dependent variable a Weber fraction which was calculated by dividing the mean standard deviation by the means of the response distribution. In order to avoid the confusion implied by this term, this same dependent variable will be referred to as the coefficient of proximity. Just what inferences can be made about dominance relationships with proximity data is open to question, one which will not be answered here.

The initial hypothesis to be considered is whether the coefficient of proximity remains constant over the various Standard Time lengths used. This question has already received limited experimental attention, however, two major factors which may be important in determining the answer to this question have not been adequately tested.

The first such factor concerns the possible differential effects of using constant as opposed to variable time-events within a series upon time estimation. Does the company a time-event keeps affect the judgments made in response to it? An affirmitive to this question is suggested by those authors who found support for the previous foreperiod effect (PFE) in simple reaction time studies (Karlin, 1959; Moss, 1969). The PFE is more thoroughly explained in a subsequent section of this review and was referred to in Chapter 1 and therefore it will not be elaborated upon here. In addition, Treisman (1963) found support for an assimilation effect using the method of constant stimuli which in this instance means that the point of subjective equality shifted towards the preceding time-event.

A second factor of considerable importance is the influence of different dependent variables upon the conclusions drawn. In particular, the appropriateness of inter-subject versus intra-subject variance as dependent variables will be considered in so far as the use of one of these warrants conclusions which contradict those arrived at using the other variable.

Almost all of the studies which have investigated relative variance in time estimations have used constant Time Standards within a session and inter-subject variance as their measurement of dispersion (Treisman, 1963; Snodgrass, Luce and Galanter, 1967 and Woodrow, 1930).

Treisman (1963) used time lengths of 0.5, 1.0, 2.0, 4.0 and 9.0 seconds. He found that the magnitude of the Weber fractions decreased as the time length increased and although these differences were large, they were not statistically significant. The Weber fractions ranged in value from 17.6% for the shortest time-event to 7.5% for the longest Time Standard used. Snodgrass, Luce and Galanter (1967) used time lengths of 0.6, 1.0, 1.9, 3.5 and 5.0 seconds and the same criterion variable as Treisman (1963). Their results also provided evidence to support a constant proximity coefficient for time estimation. They suggested an absolute of 10% for the coefficient of proximity which was somewhat smaller than that indicated by Treisman (1963).

Richards and Livingston (1966) employed Time Standards of 2.0, 8.0 and 16.0 seconds and differed from the above authors only with respect to the dependent variable they used. They calculated the percentage of the semi-interquartile range (SIR) about the Standard Time interval. Their results confirmed those of Treisman (1963) in that the percentages decreased as the standard interval increased, these differences just failing to reach statistical significance.

Woodrow (1930) also employed the Weber fraction as one of his dependent variables and obtained results which were not in agreement with those of Treisman (1963) and Snodgrass et al (1967). He found that the Weber fractions remained fairly constant up to an interval of 2.0 seconds and were of a similar magnitude as those reported by Snodgrass et al (1967). However, the Weber fraction values doubled for time intervals of 4.0 to 16.0 seconds while remaining constant again within this range. Consequently, Woodrow (1930) stated:

> On the whole, the data are rather indecisive as to whether a Weber's Law relationship holds for intervals beyond 4 seconds or not.

No readily apparent reason presents itself which would permit the reconciliation of Woodrow's (1930) results with those of Treisman (1963) and Snodgrass et al (1967).

The conclusion warranted by the research findings just presented is that the coefficient of proximity is a constant for time judgments within the limits of the time lengths studied. However, the admissibility of this conclusion remains suspect for several reasons.

One reason for skepticism centers about a very fundamental and important issue in psychological measurement theory and this is the uniqueness problem (Coombs, Davis and Tversky, 1970). Very simply uniqueness refers to the fact that there are limits to the freedom one has in assigning numbers to represent the behaviour of relational systems. It is essential that the relationships between the numbers assigned reflect the relationships as they exist in the real world and that any transformation of these numbers must also maintain the relationship being measured. One such possible transformation is grouping of data and therefore, its justification rests upon the assumption that it does not alter the relational system under study. This assumption needs to be tested in regard to time-keeping parameters.

A second reason for questioning the above conclusion concerns the phenomenon labelled 'lengthening effect' by Treisman (1963). Treisman (1963) and Warm, Morris and Kew (1963) found significant increases in time estimations over trials for all of the time-events they used. These authors used the method of reproduction. This 'lengthening effect' was also found using the method of production (Falk and Bindra, 1954; Emly, Schuster and Lucchesi, 1968; Von Sturmer, 1968 and Schectman, 1970). Perhaps the large differences between the coefficients of proximity for different time lengths would have been statistically significant had this source of unreliability been controlled. Emly et al (1968) stated that the 'lengthening effect' asymptotes between 30 to 60 trials and if this also holds for the method of reproduction, it would be possible to overcome this initial instability in proximity coefficient calculations.

A final reason for doubting the conclusion that the proximity coefficient is a constant stems from the results of McConchie and Rutschmann (1971). They used both inter-subject and intra-subject variance estimates in their calculation of the coefficient of variation (coefficient of proximity) and found that each of the dependent variables so formed resulted in different conclusions. When inter-subject variance was employed, the differences between the coefficients of variation were not significant but they were when intra-subject variance was used. These results would argue against grouping data for time estimations, however, this issue cannot be resolved on the basis of this study alone. The uncertainty stems from the fact that McConchie and Rutschmann (1971) used variable, not constant time lengths within a series. Whether the different conclusions found by McConchie and Rutschmann (1971) are applicable to those situations where the time-events have been constant within a series is yet to be determined.

Detailed analyses of the effects of variable time lengths within a series do not appear to be available and therefore, the differential effects of constant versus variable time-events can only be implied in a gross manner. As mentioned previously, McConchie and Rutschmann (1971) used variable time-events and they, like Treisman (1963) and Snodgrass et al (1967), found no significant differences between the coefficients of variation when using inter-subject variance in the calculations of their coefficients. However, McConchie and Rutschmanns' (1971) results were different from those obtained with constant time lengths in that the magnitudes of their coefficients were larger by approximately 20%. In addition, their coefficients did not show a decreasing trend as the time-events increased in length. However, these latter differences cannot be attributed with any certainty to the variable times procedure because McConchie and Rutschmann (1971) used very short time lengths with only small differences between them. The small differences between the Time Standards (100 msec.) might have been the reason for the lack of a descending trend in the coefficients with increasing Time Standards. It is also conceivable that the larger values of the coefficients might be due to the fact that McConchie and Rutschmann (1971) used such small time-events and a small number of trials when compared with Treisman (1963) and Snodgrass et al (1967).

The major reasons for the limited progress made with respect to time estimation variance data have been summarized by McConchie and Rutschmann (1971):

> Other difficulties are related to the scarcity of published data on variability, . . . as well as to the use of questionable data analyses.

Average Estimations. In addition to the accuracy information provided by average time estimations, their use in the calculation of the coefficients of proximity and the fact that they were needed to test an hypothesis regarding simple reaction time made their consideration here necessary.

The most prevalent finding reported regarding average time estimates was that shorter Time Standards were overestimated while the longer time lengths were underestimated, classically referred as the range effect (Kowalski, 1943; Wallace and Rabin, 1960; Warm et al, 1963; Treisman, 1963 and Richards and Livingston, 1966). The usefulness of this generalization is questionable. For example, Woodrow (1951) has pointed out that the indifference interval did not remain constant and therefore, what was overestimated and what was underestimated changed. He stated:

> Sometimes no indifference interval has been found; sometimes several.

Kowalski (1943) located the indifference interval between 0.92 and 1.90 seconds while Kruup (1961) found this interval be situated between 5.0 and 12.0 seconds. Both of these authors used median time estimations. Richards and Livingston (1966) also used this dependent variable and he suggested that the indifference interval was between 2.0 and 8.0 seconds.

Treisman (1963), in his first experiment, found that all of the Time Standards were overestimated while in a second experiment, with the same procedures as the former, a range effect was demonstrated. Woodrow (1934) has also reported that a considerable number of his subjects consistently overshot all of the Time Standards with their estimates.

It is unlikely in the above studies that when the range effect occurred, that it did so because of a central tendency strategy because the time-events within a session were constant. The central tendency strategy explanation of the range effect is that as the subject continues to practice he becomes more aware of the range of the Time Standards being used and that as a result, his indifference value shifts towards the central moment of the range. Since the range in the above studies was zero the central tendency hypothesis cannot be used as an explanation for the range effect when it was obtained. This contention was substantiated experimentally by Treisman (1963).

An alternative explanation of the range effect under constant time conditions is that people have such a tendency built-in, either because it is inherited or because it is established during the course of experience. On this basis it might be expected that some people are overestimators, some underestimators and some range estimators of time and therefore, it may be possible to classify people in terms of such criteria. If this were the case, it would afford one possible explanation for the fact that experiments with essentially similar procedures provide inconsistent results regarding the existence of a range effect and the value of the indifference interval.

In order to compare mean time estimates across the different Time Standards, Treisman (1963) measured the percentage constant eror and although he didn't report their absolute numeric values, he did state that the percentage constant error (PCE) was significantly larger at the shorter Time Standards. Treisman (1963) also found a tendency for mean PCE to increase with successive sessions and that these increases were proportionally larger for the shorter time-events, a finding which was statistically significant. Treisman (1963) pointed out that the lengthening effect was responsible for the increases in PCE over sessions, for the relatively larger proportional increases in PCE for the shorter time-events and for the shifts in the indifference interval. The notable feature about these experiments by Treisman (1963) was that the significance of the lengthening effect and hence, of the shifting indifference interval and

PCE with sessions, was not consistent across all subjects. For example, in experiment 2, only 2 of 4 subjects had significant lengthening effects. These results supported Woodrow (1934) in emphasizing individual differences with respect to the range effect and conform to the notion stated above which suggested that average time estimation parameters may, when the task is such as to permit, reflect inherent operator characteristics.

McConchie and Rutschmann (1971) also measured PCE but in this instance the time-events within a session were variable. For reproduction, they found a weak tendency toward a range effect, however, unlike Treisman (1963), they found that PCE did not differ significantly between Time Standards.

A central tendency hypothesis would predict that the smallest constant error should be found at the central moment of the range of times and this effect may also be demonstrated using PCE (McConchie and Rutschmann, 1971).

Summary

Inter-subject differences regarding time-keeping have received very little consideration in data analysis. It makes no sense to blindly group results in the interest of work reduction and ease of data manipulation if the price to be paid is the acquisition of a set of relationships which apply only to fantasy land. Consequently, possible distorting effects of grouping results were investigated to some extent in this study.

Specifically, does the use of inter-subject variance in the coefficient of proximity warrant a different conclusion than when intra-subject variance is employed regarding the question of whether the coefficient of proximity is a constant for time estimation? In addition, differences in the absolute numeric values of these coefficients may also occur. There is weak evidence to indicate that differences with the different dependent variables should be expected for variable time-events (McConchie and Rutschmann, 1971), however, evidence regarding constant time-event conditions was not found.

Similarly, trends across Time Standards, absolute numeric values and effects of grouping will be investigated regarding PCE. Trends in constant error and PCE appear to depend upon subject differences (Treisman, 1953; Woodrow, 1934) and upon whether the time-events are variable or constant (McConchie and Rutschmann, 1971). However, for reasons mentioned previously, the results of these latter authors must be viewed within a restrictive framework.

The lengthening effect, if found, should be accommodated to investigate its possible effects upon conclusions made regarding time-keeping parameters.

Finally, time estimations made with constant and variable time-events will be investigated since this factor may have an effect upon the time-keeping parameters obtained (McConchie and Rutschmann, 1971).

Simple Reaction Time and Temporal Uncertainty

Constant Foreperiods

Simple reaction time variance. Czudner and Marshall (1967) used constant foreperiods of 1.0, 2.0, 4.0, 7.5, 11.0 and 15.0 seconds and found that the standard deviation increased as a positive function of foreperiod length, however, the magnitudes of the standard deviations were much less than would be predicted from the time estimation evidence previously reviewed.

Attenuated variances for simple reaction times relative to those values which would be predicted on the basis of time-keeping alone might be expected on the basis of the fact that SRTs which occur before or 100 msec. after the stimulus are not generally used in calculations. The question which evolves is whether this factor alone can account for the magnitude of the variance decrease or whether an additional process (or processes) are operating during the foreperiod.[1] This additional process (or processes) would have to be one operating in conjunction with time estimation which is capable of attenuating the effects of time-keeping variance. The former contingency is necessary because the increase in SRT variance with an increase in foreperiod length suggests the involvement of time-keeping.

One possibility is the readiness process mentioned

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[1]Not tested in this study.

in the introduction. The properties of such a readiness process are not yet well defined but there is some evidence which indicated that a finite time is required to reach maximal readiness. The indications are that maximal readiness can be achieved within 200 msec. (Davis, 1959; Rosner and Keele, 1972), however, times as long as 500 msec. have been reported (Lindsley, 1964). The length of time maximal readiness can be maintained is unknown but it is felt that this maintenance requires considerable effort (Nickerson, 1968; Posner and Keele, 1972). This property is important because it may provide the basis for the relationship between the readiness process and time-keeping in the sense that S must selectively place his maximal readiness in time. His ability to do so will depend upon his time-keeping accuracy. The rise time required for maximal readiness achievement would then set the limit for SRT variance, if S does not anticipate the stimulus-event. An anticipatory response or reaction is one which is initiated centrally before the stimulus-event actually occurs.

Given the operation of a readiness process in partnership with time estimation, certain general predictions are possible. When time-keeping is accurate enough to the extent that optimal readiness occurs consistently at the time of the reaction stimulus, SRT will be relatively short and consistent. When time estimation accuracy and consistency decreases, it should be accompanied by an increase in mean SRT and an increase in SRT variance. Finally, when time-keeping is so poor that S is unwilling or unable to selectively prepare for any particular point in time, mean SRTs should be relatively longer but should improve in reliability since S would now be in true reaction time mode of operation. At this point then average SRT would be asymptoting.

It also follows that if such a readiness process operates during the foreperiod, time-keeping would only have to be good enough in order to maintain equivalent SRTs for different foreperiod lengths. Thus there limits to the extent that SRT can be used as a crude indication of time-keeping accuracy.

Average simple reaction time. When foreperiods were constant within a session but were varied between sessions, average simple reaction time increased, within limits, with the length of the foreperiod (Klemmer, 1956; Karlin, 1959; Hohle, 1965; Moss, 1969). An asymptote in average SRT was also substantiated, although the foreperiod length at which this occurred was not consistent among the studies (Karlin, 1959; Klemmer, 1956; Moss, 1969). Karlin (1959) used ofre-periods of .5, 1.0, 2.0 and 3.5 seconds and obtained the same average SRT for the latter two foreperiods. Moss (1969) used foreperiods of 1.0, 3.0 and 5.0 seconds and found a significant increase in median SRT between 1.0 and 3.0 seconds but not between 3.0 and 5.0 second foreperiods. Aiken and Lichenstein (1964) have suggested that the asymptote occurs with foreperiods which are 5.0 seconds or longer. Hohle's

(1965) results were indicative of an asymptoting affect beginning at about 3.0 seconds.

Variable Foreperiods

When variable foreperiods were employed within a session, average SRT decreased as the length of the foreperiod increased which was just the opposite trend which manifested itself when the foreperiods were constant (Karlin, 1959; Moss, 1969; Snodgrass, 1969; Gottsdanker, 1970). This inverse relationship between average SRT and foreperiod length has been labelled the immediate foreperiod effect (IFE).

Gottsdanker (1970) has stated that the IFE occurred because of the Ss differential willingness to prepare or to get ready and that the level of his willingness varies because of what he knows, not because of what he doesn't know. Implicit in this idea was the suggestion that the operator's ability to use probability changes with time, hereafter called transitional probability, depended upon his time-keeping accuracy. This was, in fact, demonstrated by Gottsdanker (1970) and Requin and Granjon (1969) by using an added condition in their designs which improved Ss opportunity to keep more accurate track of time. By doing so both authors increased the IFE gradient which would be predicted since they increased what S knew. They improved Ss ability to use transitional probabilities which had consequent effects upon average SRT.

A priori probability, as well as transitional probability, has been shown to alter Ss willingness to get ready and so his SRT. Karlin (1966) found that the minimal SRTs occurred at the mode of the foreperiod distribution, plus or minys 100 msec. He felt that readiness was a ballistic process because S did not use transitional probabilities but geared his readiness based upon a priori probability. However, the operator may not have used transitional probabilities because Karlin (1966) employed short foreperiods with the differences between adjacent times being small. In this instance, time-keeping might not have been good enough to permit S to use this transitional information.

Zahn and Rosenthal (1966) used larger foreperiods and differences between them than did Karlin (1966) and found that both a priori and transitional probability were used within a trial. If this is true, it should be possible to reduce or remove the initial gradient in the IFE curve by increasing the a priori probability for the shorter foreperiods in the range.

As was stated in Chapter 1, the previous foreperiod effect (PFE) was another hypothesis advanced to explain the IFE. The PFE hypothesis implies that Ss expectancy as to when the stimulus event will occur during the present foreperiod is influenced by the length of the previous foreperiod and therefore, the relative differences between adjacent foreperiod magnitudes is the important factor in determining average SRT. The PFE occurred only when a long foreperiod was followed by a short foreperiod and not when the reverse was true, the effect being that SRT to the shorter foreperiod was increased relative to when the adjacent foreperiods were of equal length. Thus, when the foreperiods were variable, the shorter foreperiods were more often preceded by longer foreperiods than the longer foreperiods were. This then accounted for the longer SRTs to the shorter foreperiods in the range. The PFE has received some experimental support (karlin, 1959; Moss, 1969; Gottsdanker, 1970).

If increasing the a priori probability for the shorter foreperiods in the range reduces the IFE gradient, it cannot be said that this was due to this probability change in that S used this information because such a procedure would reduce a PFE which would also predict a reduction in the IFE gradient.

Summary

The exact nature of the relationship between time-keeping and SRT parameters has received little, if any, empirical attention. Preliminary evidence has indicated that factors other than time-keeping may be operating during the foreperiod. In fact, when foreperiods are constant, time-keeping itself may cease to operate during the foreperiod as was suggested by the fact that average SRTs asymptoted as foreperiod length increased.

When foreperiods were variable, probability factors, likely mediated by time-keeping, appeared to be used by S as a basis upon which to selectively get ready for the stimulus. The result was the IFE. The PFE has also been suggested as an explanation for the IFE. Both the IRE and the PFE have received empirical support.

The general question is then, what happens during the foreperiod? The purposes with regard to SRT in this investigation have already been outlined in Chapter 1.

Chapter 3

Procedures

A total of 4 experiments were conducted each of which has been described separately.

I. Experiment 1

Purpose

Experiment 1 was performed in order to obtain estimates of time when the length of time (Time Standard) to be estimated was constant within a session.

Factors

Time Standards was the only factor considered. Five Time Standard conditions (levels) were selected; 0.5, 1.0, 2.0, 4.0 and 8.0 seconds. The 0.5 second Time Standard was used because there was some indication in the literature (Treisman, 1963) that time lengths of this value (or less) may represent a unique group with respect to time estimation. The remaining Time Standards were chosen along a log scale to the base 2 which would allow discussing the results in terms of Information Theory, although such discussion was not developed in the present study. The 8.0 second Time Standard was included because Ss span of time was approximately 5.0 to 6.0 seconds (Woodrow, 1951) and therefore, Time Standards of this length or greater may also have represented a unique group.

Dependent Variables

Time Estimations. Time estimations were those readings obtained from a one-thousanth of a second timer.

Coefficient of Proximity

The general form of the coefficient of proximity is

$$\text{coefficient of proximity} = \frac{\text{standard deviation}}{\text{mean}} \times 100 = \%.$$

Two forms of the coefficient of proximity were used. The intra-subject coefficient was calculated by using the mean time estimation for each subject for each Time Standard condition and dividing this value into the standard deviation about this mean. The resulting proportion was multiplied by 100 to obtain a percent. The inter-subject coefficient was calculated by obtaining the mean of the time estimations for each Time Standard condition for all subjects combined. This value was subsequently divided into the standard deviation about this mean and the result was multiplied by 100.

The coefficient of proximity was simply one manner in which to evaluate time estimation variance in terms of the mean of the response distribution. If this value was constant, time estimation variance could be predicted if the means of the distribution were known.

Percentage Constant Error (PCE)

The general form of the PCE is

$$\text{PCE} = \frac{\text{mean time estimate} - \text{Time Standard}}{\text{Time Standard}} \times 100 = \%$$

Two forms of the PCE were used. Intra-subject PCE employed the mean time estimate of each subject for each Time Standard. Inter-subject PCE used the mean time estimate for each Time Standard condition for the time estimations of all of the subjects combined.

PCE was an indication of mean time estimation accuracy in terms of a percentage of the Time Standard being estimated. In addition, information regarding whether the mean estimate was greater or less than the Time Standard, was also indicated. The use of the PCE variable, like that of the coefficient of proximity, was one manner in which to increase the generalizability of the results.

Experimental Design

The experimental design selected was a subjects by treatments one-way analysis of variance with each subject receiving 60 replications per condition.

Task

A time estimation Reproduction task was used (Falk and Bindra, 1954) and therefore, both the Time Standard length and the time estimation made by S were operative. More specifically, the Time Standard was presented to S by the onset of a light and a tone which remained on for the length of time which was to be estimated. Similarly, the operative response was performed by S holding a Switch closed for a time length which he considered to be equivalent to the Time Standard.

Apparatus

Two wooden handles in the shape of pistol-grips with Licon Switches (10-822) placed in a position normally occupied by the trigger of a revolver were bolted to a table (Appendix A, Illustration 1, section A). The Licon Switch (normally open) operated by Ss left hand was connected to a Hunter Decade Interval Timer[1] (Model 111-B, series D)(DIT-1; see Appendix A, Illustration 3) which in turn was connected to a light source and a tone producing system that consisted of a Bogen 'Challenger' Amplifier (CHB20A), an EICO Audio Generator (Model 377) and a Speaker (Appendix A, Illustration 3). When the Licon Switch was depressed, the light and the tone came on and remained on for a length of time controlled by the Decade Interval Timer. This circuit was used to operatively present S with the Time Standard to be estimated.

The Licon Switch (normally open) controlled by Ss right hand was wired to a Hunter Klockcounter (Model 120A, series D). The Klockcounter (CK-1) represented to the nearest millisecond the length of time the Licon Switch was closed. This was the response circuit by which S gave an operative reproduction of the length of the Time Standard provided for him by the circuit which he controlled with his left hand.

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[1]All of the Decade Interval Timers used in the following 4 experiments were the same models.

Apparatus Calibration

The Decade Interval Timer was connected to a Klockcounter (CK-1). Twenty trials were run with the Decade Interval Timer set at each of the Time Standard lengths used in the study. The Decade Interval Timer was then wired to another Klockcounter (CK-2) and the same procedure was followed. The time lengths produced were accurate to within ± 4% of the Time Standard value setting. The mean scores between the two Klockcounters for each Time Standard condition differed by approximately 2% of the Time Standard magnitude.

In order to improve the absolute accuracy of the Time Standards, the settings on the Decade Interval Timer were adjusted so that the mean scores recorded by the Klockcounters were accurate to within ± 1% of the desired Time Standard lengths. Based upon these latter scores, the range of Time Standard lengths produced for the 20 trials for any Time Standard condition was approximately .90% or less of the Time Standard magnitude.

Subjects

Nine graduate students in physical education at the University of Alberta volunteered as subjects for this experiment.

Method

Each subject was instructed to assume a comfortable sitting position with his forearms resting on the table and his hands holding the pistol-grip handles situated in front of him (Appendix A, Illustration 2). At this time, 4 main instructions were discussed with S.

(a) S was told that his task was to reproduce (or estimate) as accurately as possible the length of the Time Standard presented to him. It was explained that the length of time (Time Standard) to be estimated was the length of time that the light, situated directly in front of him, and the tone, located above him and to his right, remained on. Several demonstrations were given to S until E was satisfied that S understood the instruction.

(b) S was then told that the task was self-paced. This meant that he and not E determined when the Time Standard presentation began and that he did this by pressing the Licon Switch with index finger of his left hand. This Switch had to be depressed only for a moment because a holding circuit was wired into the Decade Interval Timer which kept the light and the tone on for the required Time Standard duration. Similarly, the time between the offset of the Time Standard and the beginning of the time estimation response was determined by S. He was at liberty to begin his response whenever he chose to do so. The time estimate response was made by depressing the Licon Switch with the index finger of his right hand for a length of time S considered to be equivalent to the Time Standard.

The self-paced task was employed because of the possible interference of a paced task with the shortest Time Standard (See Chapter 2) and to offset a possible fatigue factor. In addition, rigid pacing normally used in time estimation studies may have accounted for the 'lengthening effect' obtained (Eg. Treisman, 1963).

(c) It was emphasized to S that he was not to use any mediational techniques at any time. E explained thoroughly what mediation was, giving examples. In addition, S was told that later on in the experiment he would be asked to use mediation and these results would be compared with those presently being obtained. This was done in order to further deter S from mediating.

(d) Finally, S was told that if he was not 100% certain that a particular time estimate was the best he could do to tell E and the trial would be redone. This was done because once S made a response it could not be modified even if S felt it should have been.

Each subject attended five sessions of approximately one hour duration each. In each session, S had a short practice period and was then given 60 time estimation trials which were recorded for analysis. The Time Standard remained constant throughout a session and was changed between sessions so that all five Time Standards were estimated by S. The Time Standards were presented in ascending order as Treisman (1963) found no significant differences between ascending and descending orders.

Analysis

The time estimation distributions were tested for skewness.

Both a primary and a secondary analysis were performed. Experiment 1 was basically a one factor experiment and therefore the primary analyses were calculated with this main factor only. Five one-way analyses of variance were performed, one for each of the dependent variables described previously in this chapter. The Newman-Keuls test was used to test the differences between the condition means when the F-ratios were significant.

The primary analyses permitted comparisons to be made between intra-subject and inter-subject dependent variables since the one-way analyses of variance using the inter-subject dependent variables could not be extended to include additional factors.

The primary analyses was made more conservative (the one-way analyses of variance were stringent tests of the main factor) by using Greenhouse and Geissers'[1] (1959) conservative degrees of freedom which further increased the power of the tests. The conservative approach was taken because this study was exploratory and therefore, the directions taken as a result of this experimentation should be those which are most likely to provide useful and meaningful information. The directions most suitable for this purpose should be based

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[1]Greenhouse and Geissers' (1959) conservative degrees of freedom were not used for the inter-subject dependent variables because of the small number of replications.

upon those tests which pass the most stringent examination. Too often the area of Human Performance has been seduced by the phrase 'statistically significant' into pursuing phantom issues which have done nothing more than add chaos to the brickyard.

The secondary analyses extended the primary analyses by including Subjects and/or Repetitions as main factors. The purpose of the secondary analyses was to provide information on these additional factors and to contribute to the formation of conclusions. Again, Greenhouse and Geissers' (1959) conservative degrees of freedom were used. The secondary analyses did not include the inter-subject dependent variables.

Each subject was tested separately for the Time Standards main factor in order to discover if grouping intra-subject dependent variables had a distorting effect. All Subject by Treatment interactions were considered random.

II. Experiment 2

Purpose

Experiment 2 was a supplement to Experiment 1. Experiment 2 was performed in order to obtain estimates of time when the Time Standards within a session were variable.

Factors

Two main factors were selected, Time Standards and Previous Standard. The Time Standard conditions were identical to those in Experiment 1. The Previous Standard conditions were the same as those for the Time Standard main factor.

Experimental Design

The experimental design selected was a treatments by subjects, factorial, complete block, random model with replications.

Subjects

The subjects were 8 physical education undergraduate volunteers who were enrolled at the University of Alberta.

Method

_S_ returned for 4 thirty minute sessions. _S_ received 2 series of 25 trials each. The Time Standards within a series were random with the restriction that each Time Standard must be preceded equally often by every other Time Standard. Thus each _S_ received a total of 40 trials for each Time Standard. All of the other features of the method were the same as in Experiment 1.

Analysis

The analyses were the same as in Experiment 1 with the exceptions that the primary analyses employed a basic two factor experimental design and that _Ss_ were not analyzed on an individual basis.

Other

The Dependent Variables, Task and Apparatus were identical with those of Experiment 1.

III. Experiment 3

Purpose

Experiment 3 was conducted in order to investigate the relationship between time estimation and simple reaction time (SRT).

Factors

Foreperiod Standards was the only factor manipulated. The 5 levels of Foreperiod Standards were 0.5, 1.0, 2.0, 4.0 and 8.0 seconds, time lengths which were equal to the Time Standard magnitudes employed in Experiment 1.

Dependent Variables

The means, medians, standard deviations, SIRs, the intra-subject coefficients of proximity (parametric and non-parametric) were calculated for each S for each Foreperiod Standard Condition for time estimations and SRTs.

The number of legitimate time estimations was also determined for each subject for each Foreperiod Standard condition. A legitimate time estimation was one which preceded the reaction stimulus or which exceeded it by less than 100 milliseconds.

Task

Part A. A simple reaction time task with constant Foreperiod Standards within a session was used. S was required to make two responses; one, a time estimation of when he thought the stimulus-event would appear and the second, a reaction (SRT) to the stimulus-event when actually did occur.

Part B. A simple reaction time design was again selected as Ss task, however, S was required to make only the reaction response (SRT).

Apparatus

Two wooden response handles similar to the ones used in Experiment 1 were used (Appendix A, Illustration 1, section B). The only difference was that the pistol grip held in Ss right hand had two Licon Switches placed in the position normally occupied by the trigger of a revolver.

The Licon Switch controlled by Ss left hand was connected via a Guardian Latching Relay (IR-640U-120A) to a Hunter Decade Interval Timer (DIT-1)(see Appendix A, Illustration 3 to accompany this description) which in turn was wired to a second Hunter Decade Interval Timer (DIT-2). DIT-1 provided the Foreperiod Standard duration required and DIT-2 provided the pulse which initiated the onset of the light source, the tone and Klockcounter 2 (CK-2). DIT-2 was connected to these components via a series of Guardian Latching Relays (Appendix A, Illustration 4). The Licon Switch controlled by Ss left hand was also connected (via Latching

Relays) in series with one of the Licon Switches operated by Ss right hand to Klockcounter 1 (CK-1). This latter Licon Switch was used by S for his time estimation response which was recored by CK-1.

Therefore, by pressing the Licon Switch in his left hand, S initiated the Foreperiod Standard duration and both CK-1 and CK-2. The second Licon Switch controlled by Ss right hand was connected via a Latching Relay to CK-2 and when S closed this Switch it stopped CK-2. Thus, CK-2 recorded Ss simple reaction times.

S actually operated the Licon Switch in his left hand and the time estimation Licon Switch in his right hand with his index digits. The other Licon Switch was controlled with the third digit of the right hand.

Apparatus Calibration

DIT-1 was the same Hunter Decade Interval Timer as was used in Experiment 1 and therefore was already calibrated. DIT-2 was not calibrated since it was only used to provide an initiating pulse to a Latching Relay.

The two Klockcounters used were those employed to calibrate the DIT-1.

Subjects

Eight of the 9 subjects used in Experiment 1 were again tested.

Method

S was instructed to assume the same position as he had for Experiment 1 (Appendix A, Illustration 2). The following instructions were then discussed with him.

(a) S was told that on each trial he had to make two responses, one a time estimation and the other a reaction, both being equally important. S was instructed that by temporarily depressing the Switch in his left hand (as he had done in Experiment 1) he would initiate the beginning of the foreperiod, the foreperiod being the length of time between the depressing of the Switch and the onset of the light source and the tone (stimulus-events). S was then informed that he must estimate the length of the foreperiod (the time estimation response) and this was done by depressing the upper Switch in his right hand when he thought the stimulus-events would occur. His other response was to react as quickly as possible when the stimulus-events did actually commence (SRT). S was then given as many trials as were required to achieve the finger coordination the task demanded with a Foreperiod Standard not used in the study. This was done for each of the 5 one hour sessions S attended.

(b) S was told once again that he was not to mediate (explanations were given).

(c) It was again impressed upon S that the beginning of the foreperiod and hence of each trial was determined by him. He could operate at his own rate. The self-initiated foreperiod was employed in order to reduce the uncertainty effects that a paced warning signal has upon short foreperiods (Davis 1959, 1965).

S received 30 trials for each of 5 sessions in which he had to both estimate time (Foreperiod Standard) and react (SRT) (Part A). The Foreperiod Standard was constant within a session, one session was devoted to each Foreperiod Standard condition.

The first 30 trials in Part A were followed by an additional 30 trials in which S only had to react to the stimulus-events (Part B). All of the procedures were the same for Part B as for Part A except that S omitted the time estimation response. Part B was completed because the data from Part A may not have been useable.

Analysis

Pearson produce-moment correlations were calculated between the time estimation and the SRT responses (Part A) for each of the dependent variable forms (6) previously mentioned. This was done for each Foreperiod Standard condition separately. If the data from Part A was not useable, the time estimations from Experiment 1 and the SRTs from Part B of this experiment could be used. The number of legitimate time estimations was used to determine if the information from Part A was satisfactory.

The purpose of the correlation analyses was to determine if the processes underlying time estimation were operating during the foreperiod, that is, whether time estimation parameters could be used as a basis for predicting those of SRT within a constant foreperiod SRT task.

IV. Experiment 4

Purpose

The purpose of Experiment 4 was to further investigate the role of a priori probability in SRT tasks in which the Foreperiod Standards within a session were variable.

Factors

Three factors, Immediate Foreperiod, Previous Foreperiod and A Priori Probability were selected. The levels for the Immediate Foreperiod and the Previous Foreperiod factors were 1.0 and 4.0 seconds each. The two levels of the A Priori Probability factor chosen were 0.2 and 0.8.

Dependent Variables

Simple reaction time was the only dependent variable measured.

Experimental Design

The experimental design selected was a treatments by subjects, factorial, complete block, random model with replications.

Task

A simple reaction time task with variable foreperiods was used. S had to react as quickly as possible when the second of two light sources came on (SRT).

Apparatus

The same two pistol-grip handles used in Experiment 3 were employed in this experiment (Appendix A, Illustration 1, section B). The Licon Switch controlled by Ss left hand was still connected to DIT-1 and DIT-2 as in Experiment 3. DIT-1 controlled the Previous Foreperiod duration for stimulus-event one (light source). DIT-2 still provided the pulse which initiated stimulus-event one (tone was omitted in this experiment) and in addition was connected via a series of Latching Relays to a third Decade Interval Timer (DIT-3). DIT-3 determined the length of the Immediate Foreperiod which culminated with the occurrence of stimulus-event two (a second light source). The pulse which initiated the second stimulus-event was supplied by DIT-4 (Appendix A, Illustration 4). In addition to thses connections, the Licon Switch operated by Ss left hand was also wired to Klockcounter 3 (CK-3; which was the same Klockcounter used in Experiment 3, CK-1).

Thus when S temporarily depressed the Licon Switch in his left hand, the Previous Foreperiod began resulting in stimulus-event one. The initiation of stimulus-event one triggered the beginning of the Immediate Foreperiod and the onset of CK-3. The Licon Switch controlled by Ss third digit of his right hand was also connected to CK-3 and when this Switch was closed CK-3 stopped, thus recording Ss SRT.

Apparatus Calibration

DIT-3 was calibrated using the same Klockcounters and procedures as in Experiment 1. The settings on the DIT-3 were once again adjusted until the mean scores recorded by the Klockcounters were accurate to within ± 1% of Immediate Foreperiod time lengths required. Based upon these latter scores, the range of Immediate Foreperiod lengths produced for the 20 trials for any Immediate Foreperiod condition was approximately 1% or less of the Immediate Foreperiod magnitude being tested. DIT-4 was not calibrated since it was not required to control a time period.

Subjects

Eight physical education graduate students at the University of Alberta volunteered as subjects for this experiment.

Method

S was instructed to assume a comfortable sitting position with his forearms resting on the table and his hands holding the pistol-grip handles situated in front of him (Appendix A, Illustration 2). The following instructions were discussed with *S*.

(a) *S* was informed that his task was to react (SRT) as quickly as possible when the second (stimulus-event two) of two lights situated directly in front of him came on. *S* was told that by momentarily pressing the Licon Switch in his left hand, he initiated the Previous Foreperiod (the time until the first light came on). When the first light came on *S* was told that he did not have to make an overt response but that the onset of this light meant that the Immediate Foreperiod for the second light had begun. The Immediate Foreperiod was that length of time which had to elapse before the second light (stimulus-event two) came on.

(b) S was told he was not to mediate his responses (explanations followed).

(c) It was emphasized that S controlled the initiation of each trial and that he was to operate at his own pace. S was given a number of practice trials to familiarize himself with the procedure and to insure that he understood his task.

S completed 4 testing sessions of approximately 45 minutes each. Each session consisted of 50 trials. The probability of either the 1.0 or the 4.0 second Previous Foreperiod was always 0.5 and therefore, for any one session, the 1.0 and 4.0 second values occurred equally often. For the first two sessions, the A Priori Probability of the 1.0 second Immediate Foreperiod was 0.8 and thus the 4.0 second condition had an A Priori Probability of 0.2. The A Priori Probabilities were reversed for the Immediate Foreperiod conditions for sessions 3 and 4. This procedure resulted in 10 trials for each cell associated with an A Priori Probability of 0.2 and 40 trials for each of the other cells for each subject. Consequently, only 10 of the 40 trials from each of these latter cells were used for analysis. The 10 trials selected for analysis were those which occurred closest in the series to the trials in which the A Priori Probability was 0.2 since all of these trials had to be used. Thus each subject contributed at total of 10 trials per cell, 80 for the whole experiment.

Analysis

The SRTs (those selected for analysis) for each of the 8 cells were tested for skewness. If the distributions were skewed a Sign Test was performed on each of the main factors, if not, a three-way analysis of variance was calculated.

Chapter 4

Analysis

A total of four experiments were conducted. Experiments 1 and 2 were performed in order to obtain information regarding time estimation parameters. The specific parameters considered were the percentage constant error (PCE) and the coefficient of proximity.

Both a primary and a secondary analysis were carried out for Experiments 1 and 2. Basically, Experiments 1 and 2 were one and two factor designs, respectively. The primary analyses were based upon these basic designs. The secondary analyses were extensions of these basic designs in that additional factors (either Subjects, Repetitions or both) were considered. The purposes of the secondary analyses were to provide information regarding these factors and to serve as a basis for modifying, if necessary, the conclusions warranted by the primary analyses.

Experiment 3 was conducted in order to assess the degree of association between simple reaction time (SRT) and time estimation when the foreperiods in the SRT task were constant. In addition, the possibility that S used the stimulus-event as a basis for modifying his time estimations was examined.

Experiment 4 was designed to examine the influence of a priori probability upon SRT when the foreperiods were variable.

I. Hypotheses

Because of the limited amount of previous experimental work devoted to the issues of concern in the present study only one hypothesis could be formed. Instead a series of questions were posed.

Hypothesis

1. H_1: The coefficient of proximity would remain constant for all Time Standard conditions when the Time Standards within a session were constant. (Experiment 1)

Questions

1. Is the coefficient of proximity a constant for all Time Standards when the Time Standards within a session are variable? (Experiment 2).
2. Is the PCE a constant for all Time Standards when the Time Standards within a session are constant? (Experiment 1).
3. Is the PCE a constant for all Time Standards when the Time Standards within a session are variable? (Experiment 2).
4. Are different conclusions for H_1 and questions 1, 2 and 3 warranted when intra-subject dependent variables are employed as opposed to inter-subject dependent variables? (Experiments 1 and 2).
5. Is average SRT associated with average time estimation? (Experiment 3).
6. Is SRT variance associated with time estimation variance? (Experiment 3).

7. Is the potential feedback information inherent in an SRT design used by S to modify his time judgments? (Experiment 3).

8. Does a priori probability function independently of the Previous Foreperiod Effect (PFE) when the a priori probability for the shorter foreperiods in the range is increased? (Experiment 4).

II. Degrees of Freedom

Unless otherwise stated, Greenhouse and Geissers' (1959) conservative degrees of freedom were used for testing the significance of the F-ratios for both the primary and secondary analyses. The artificially large normal degrees of freedom obtained with repeated measures designs which have been replicated tended to reduce the power of the tests. Since the present Experiments were of an exploratory nature, the conservative degrees of freedom were required to maintain a stringent power level.

Normal degrees of freedom were used for all tests on means.

III. Rejection Level

Unless otherwise stated, the alpha rejection level was 0.01 for both the variance and means tests.

IV. Experiment I

Results

Distributions. Time estimation distributions were tested for skewness for each of the five Time Standards for each subject. No distribution was significantly skewed at the 0.01 level (Appendix B, Table 9). However, when time estimations were combined within each of the Time Standards for all subjects, three of the five distributions were significantly skewed at the 0.01 level of significance (Appendix B,Table 9).

Primary Analyses. A one-way analysis of variance was calculated for time estimation scores (Table 1). The Time Standards main effect was significant at the 0.01 level (using Greenhouse and Geissers' (1959) conservative degrees of freedom). The cell means and the Newman-Keuls test for the main effect are found in Appendix B.

In the Newman-Keuls test (Appendix B, Table 10) mean time estimations were significantly different for all possible pair-wise comparisons between Time Standard conditions at the 0.01 level (using normal degrees of freedom).

Hartley's Test for Homogeneity of Variance for time estimation variance scores (F max = 29.12) was significant at the 0.05 level.

Four additional one-way analyses of variance were calculated for intra-subject and inter-subject coefficient of proximity and percentage constant error scores. In each of these analyses (Tables, 2, 3, 4, 5) the Time Standards main effect was significant at the 0.01 level (using Greenhouse and Geissers' (1959) conservative degrees of freedom for Tables 2 and 4 only). The means for the main effects of these four analyses are plotted in Figures 1 and 2 and are also found in Appendix B, together with the Newman-Keuls tests for the Time Standards treatments.

The application of the Newman-Keuls tests provided the following results. Intra-subject coefficients of proximity for the 0.5 second Time Standard were significantly different from those for any of the other Time Standards, all other comparisons being non-significant (Appendix B, Table 11). These findings were confirmed for the inter-subject coefficients of proximity dependent variable and were extended in that the 1.0 second Time Standard condition differed significantly from the 4.0 and 8.0 second conditions (Appendix B, Table 12).

Intra-subject percentage constant error did not significantly differ for the 8.0 and 4.0 second conditions or for the 1.0 and 2.0 second conditions (Appendix B, Table 13). Intra-subject percentage constant error also did not differ significantly between the 8.0 and 4.0 second conditions (Appendix B, Table 14). All other possible comparisons in Tables 9 and 10, Appendix C, were significant at the 0.01 level using normal degrees of freedom.

Hartley's Test for Homogeneity of Variance for

Table 1

One-way Analysis of Variance, Experiment 1
Time Estimations

Source	df	Conservative df	Mean Squares	F
Time Standards (T)	4	1	4,124,288,000.00	6,221.73[xx]
Error	2695	8	662,884.06	

[xx]Significant at the 0.01 level Greenhouse and Geisser

Table 2

One-way Analysis of Variance, Experiment 1
Intra-Subject Coefficients of Proximity

Source	df	Conservative df	Mean Squares	F
Time Standards (T)	4	1	353.68	14.59[xx]
Error	265	8	24.24	

[xx]Significant at the 0.01 level Greenhouse and Geisser

Table 3

One-way Analysis of Variance, Experiment 1
Inter-Subject Coefficients of Proximity

Source	df	Mean Squares	F
Time Standards (T)	4	1,302,333,220.00	20.41**
Error	25	6,380,346.00	

**Significant at the 0.01 level.

Table 4

One-way Analysis of Variance, Experiment 1
Intra-Subject Percentage Constant Error

Source	df	Conservative df	Mean Squares	F
Time Standards (T)	4	1	513,819,650.00	67.92[xx]
Error	265	8	7,565,141.00	

[xx]Significant at the 0.01 level Greenhouse and Geisser

Table 5

One-way Analysis of Variance, Experiment 1
Inter-Subject Percentage Constant Error

Source	df	Mean Squares	F
Time Standards (T)	4	54,369,600.00	251.62**
Error	25	216,076.37	

**Significant at the 0.01 level.

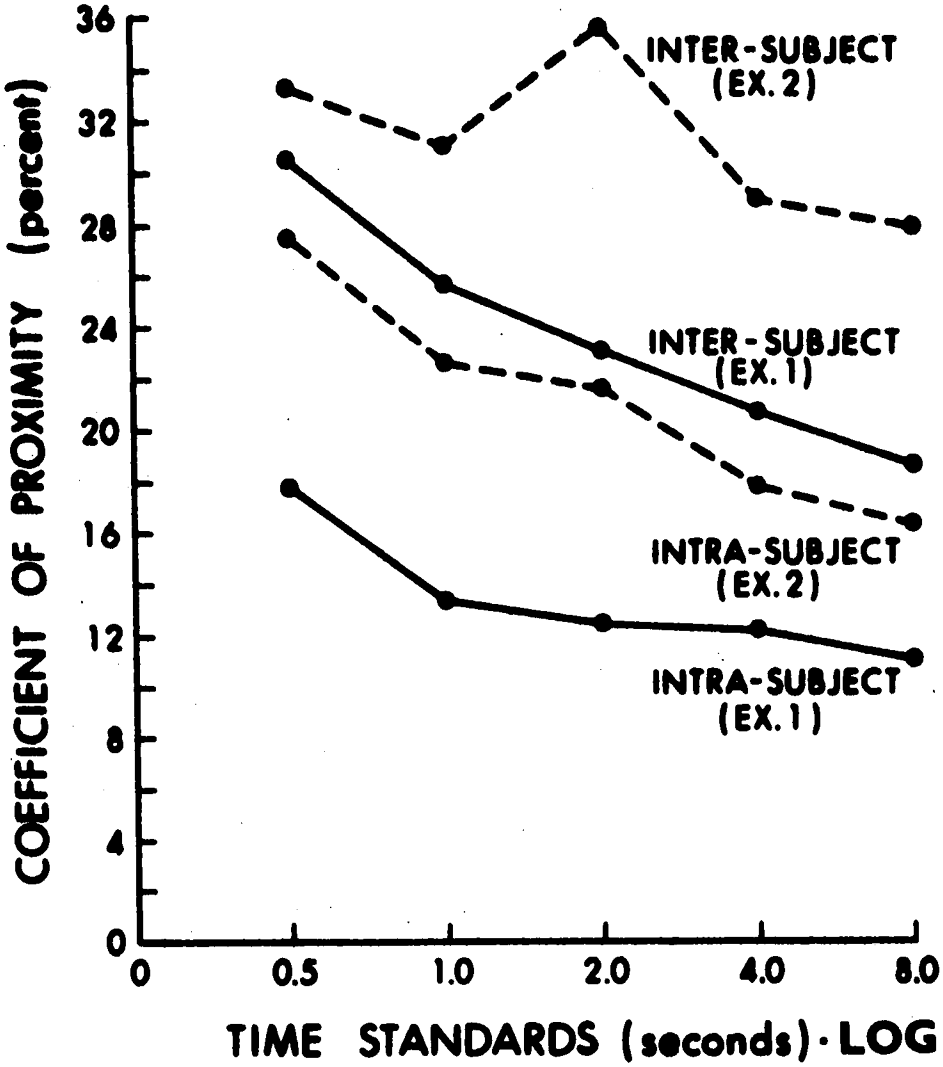

Figure 1: Mean Inter-Subject and Intra-Subject Coefficients of Proximity, Experiments 1 and 2.

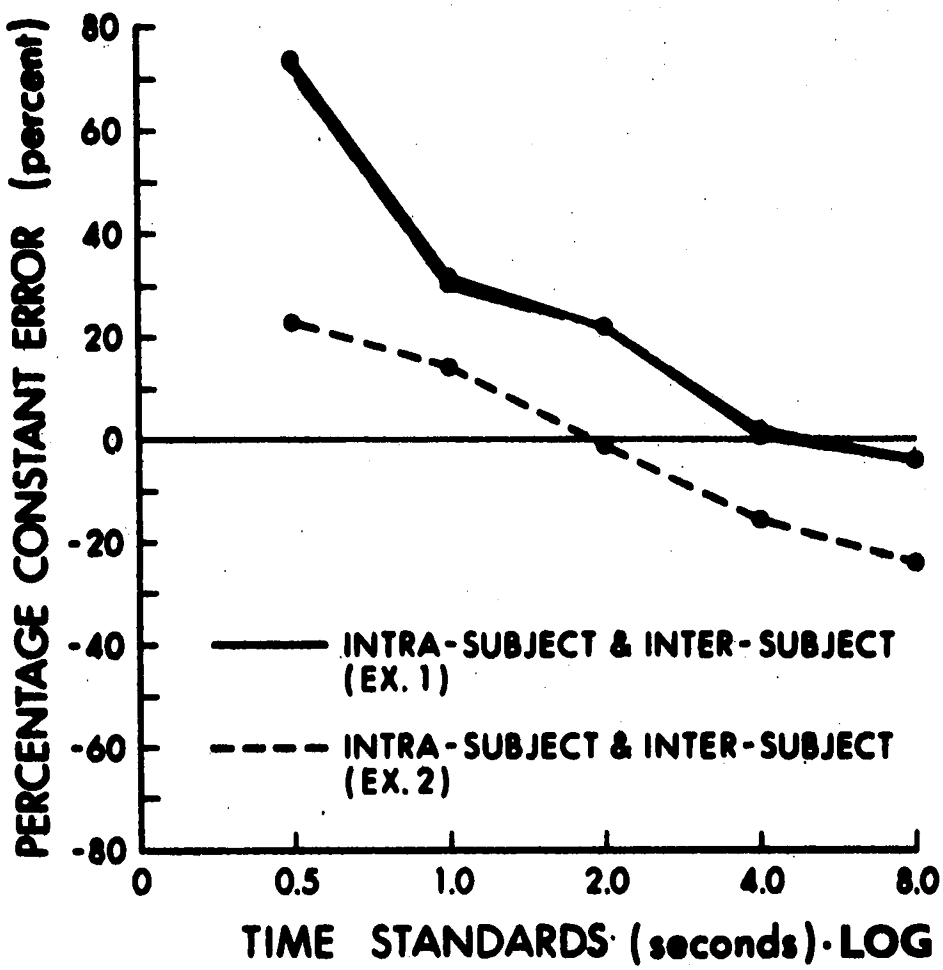

Figure 2: Mean Inter-Subject and Intra-Subject Percentage Constant Error, Experiments 1 and 2.

intra-subject coefficient of proximity variance (F max = 1.99), inter-subject coefficient of proximity variance (F max = 2.84) and for inter-subject percentage constant error variance (F max = 21.64) were not significant at the 0.01 level. However, this test for intra-subject percentage constant error (F max = 8.72) was significant at the 0.01 level.

The absolute numeric values of the intra-subject coefficients of proximity ranged between 11.0% and 14.0% for the 1.0, 2.0, 4.0 and 8.0 second Time Standards (Figure 1). These conditions did not differ significantly (Appendix B, Table 11). The shortest Time Standard had the highest coefficient of proximity, approximately 18.0%; a value which differed significantly from those obtained for the other Time Standards. Although they showed a similar trend, the absolute numeric values of the inter-subject coefficients of proximity were larger than the intra-subject coefficients of proximity for all Time Standards (Figure 1); this difference being in the range of 7.0% to 13.0% (Appendix B, Table 15).

Time estimation variance about the mean of the response distribution increased with increasing magnitudes of the Time Standards (Appendix B, Table 16). These variances can be estimated by multiplying the Time Standard by the appropriate percentage constant error value, adding this value to the Time Standard and then multiplying this score by the coefficient of proximity obtained at that particular Time Standard. This will yield the standard deviation about the mean of the response distribution.

The numeric values of the percentage constant error scores (intra or inter-subject) decreased as the magnitude of the Time Standards increased and were positive for all but the 8.0 second Time Standard (Figure 2). Thus with the exception of the 8.0 second condition, subjects (grouped) overestimated all of the Time Standards. The 4.0 Time Standard was most accurately estimated (Appendix B, Table 15).

The main results of the primary analyses were as follows: (a) the Time Standards main effect was significant for all of the dependent variables used, (b) the absolute numeric values of the inter-subject coefficients of proximity were larger than the corresponding intra-subject values, (c) inter-subject dependent variables produced different Newman-Keuls results than did the corresponding intra-subject variables.

Secondary Analyses. A three-way analysis of variance was performed for the time estimation scores using Time Standards, Subjects and Repetitions as the main factors (Table 6). The noteable features regarding this analysis were that the Subjects main effect was significant at the 0.01 level while the Repetitions main effect was not (using Greenhouse and Geissers' (1959) conservative degrees of freedom). With the Newman-Keuls test applied to the Time Standards main effect (Appendix B, Table 17), time estimations did not differ significantly at the 0.01 level between the 0.5 and the 1.0 second Time Standards. The difference between these two Time Standards was significant using the one-way analysis of variance (Appendix B, Table 10).

A two-way analysis of variance was performed for the intra-subject coefficient of proximity scores using Time Standards and Subjects as the main factors (Table 7). Neither the main effects nor the interaction were significant at the 0.01 level (using Greenhouse and Geissers' (1959) conservative degrees of freedom). However, they were significant at the 0.01 level using the normal degrees of freedom. The cell means are found in (Appendix B, Table 18), and the primary main effects are plotted in Figure 3.

A Newman-Keuls test was applied to the Time Standards main effect for each subject (Appendix B, Table 19) and only for Subject 1 were there any significant differences between Time Standard conditions at the 0.01 level. With the Newman-Keuls test for the Time Standards main effect for all subjects combined, using intra-subject coefficients of proximity, the 0.5 second Time Standard condition differed significantly from all other conditions at the 0.01 level (Appendix B, Table 20).

The significant differences between subjects made it difficult to assign a numeric value to the coefficients of proximity for each of the Time Standard conditions. However, with the exception of Subjects 8 and 9, there was a general trend for the intra-subject coefficients to decrease in magnitude with an increase in Time Standard size (Appendix B, Figure 18).

A three-way analysis of variance was calculated for

Table 6

Three-way Analysis of Variance, Experiment 1
Time Estimations

Source	df	Conservative df	Mean Squares	F
Time Standards (T)	4	1	4,124,288,000.00	384.44xx
Subjects (s)	8	8	78,763,648.00	7.34xx
S x T	32	8	10,728,024.00	35.03xx
Repetitions	59	1	368,218.56	
Error (pooled)[1]			306,252.47	

xxSignificant at the 0.01 level Greenhouse and Geisser

[1]Pooling was done according to Paull's Law (Hays, 1963).

Table 7

Two-way Analysis of Variance, Experiment 1
Intra-Subject Coefficients of Proximity

Source	df	Conservative df	Mean Squares	F
Time Standards (T)	4	1	353.68	6.71**
Subjects (S)	8	1	198.71	3.77**
T x S	32	8	52.73	3.77**
Error	225	8	13.98	

**Significant at the 0.01 level

Table 8

Three-Way Analysis of Variance, Experiment 1
Intra-Subject Percentage Constant Error

Source	df	Conservative df	Mean Squares	F
Time Standards (T)	4	1	513,819,650.00	36.96xx
Subjects (S)	8	8	154,889,120.00	11.14xx
T x S	32	8	13,903,848.00	10.24xx
Repititions (R)	5	1	4,398,492.00	3.24**
Error (pooled)	225	9	1,357,882.64	

xxSignificant at the 0.01 level Greenhouse and Geisser.

**Significant at the 0.01 level

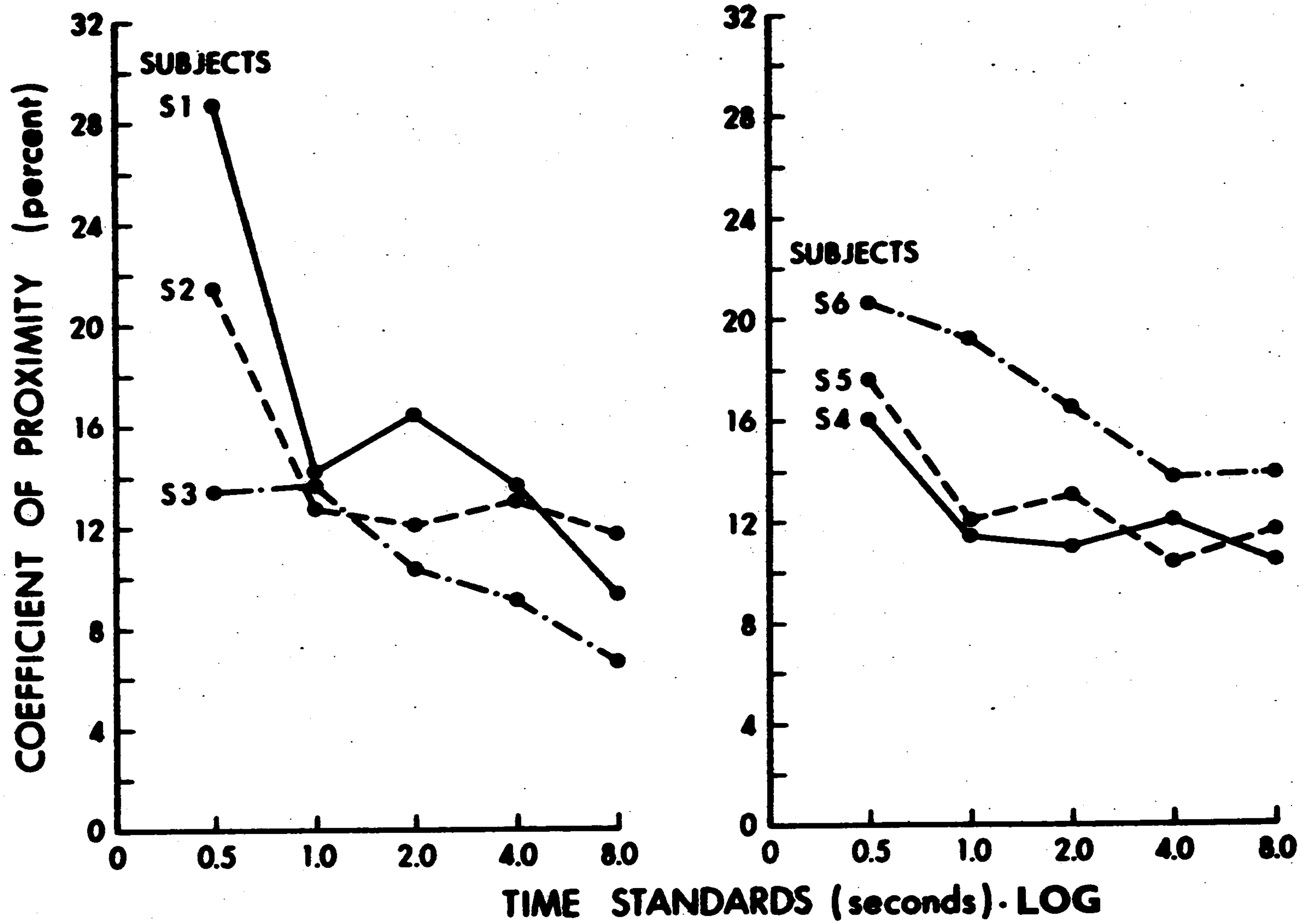

Figure 3: Intra-Subject Coefficients of Proximity for each Subject, Experiment 1.

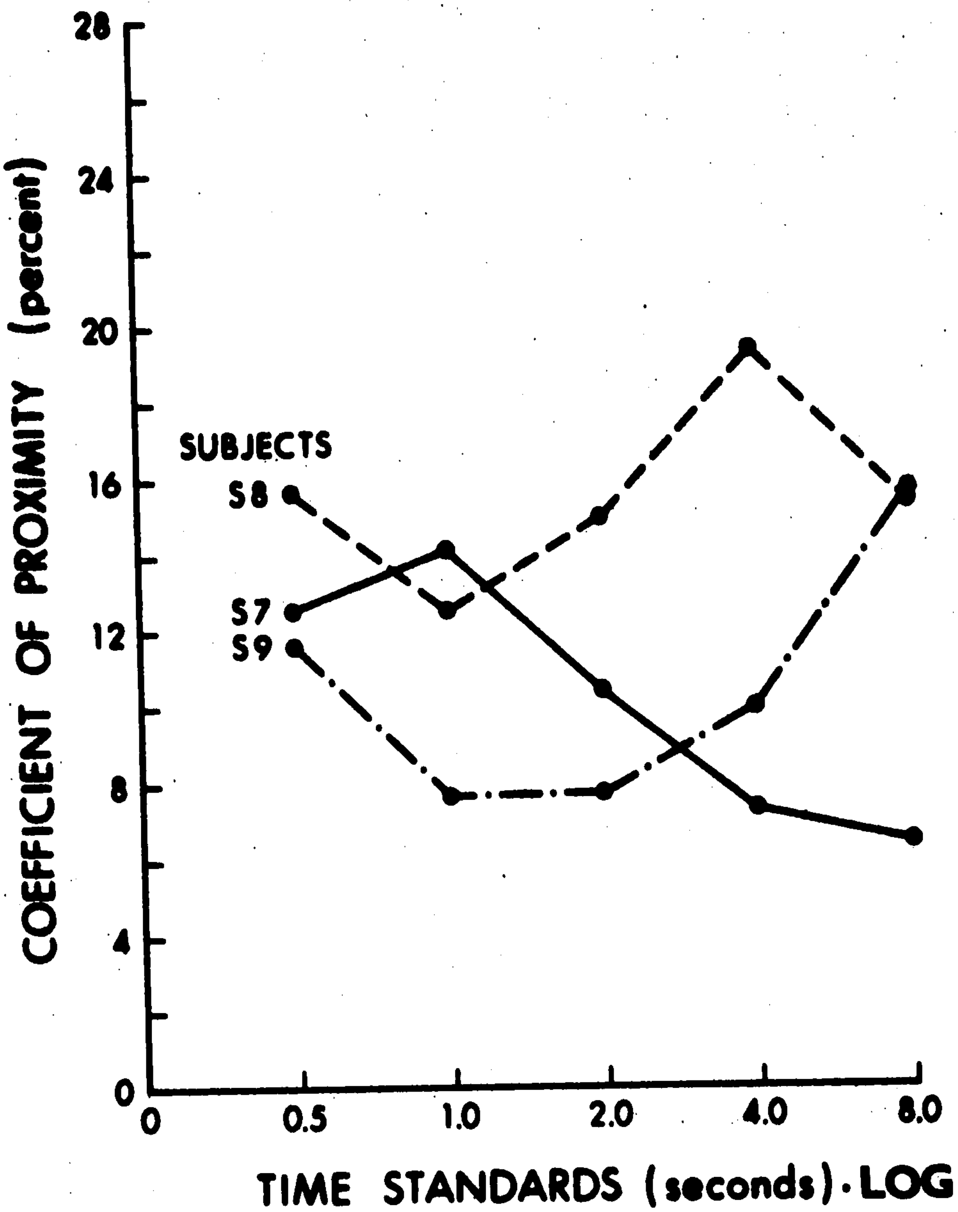

Figure 3 (Continued).

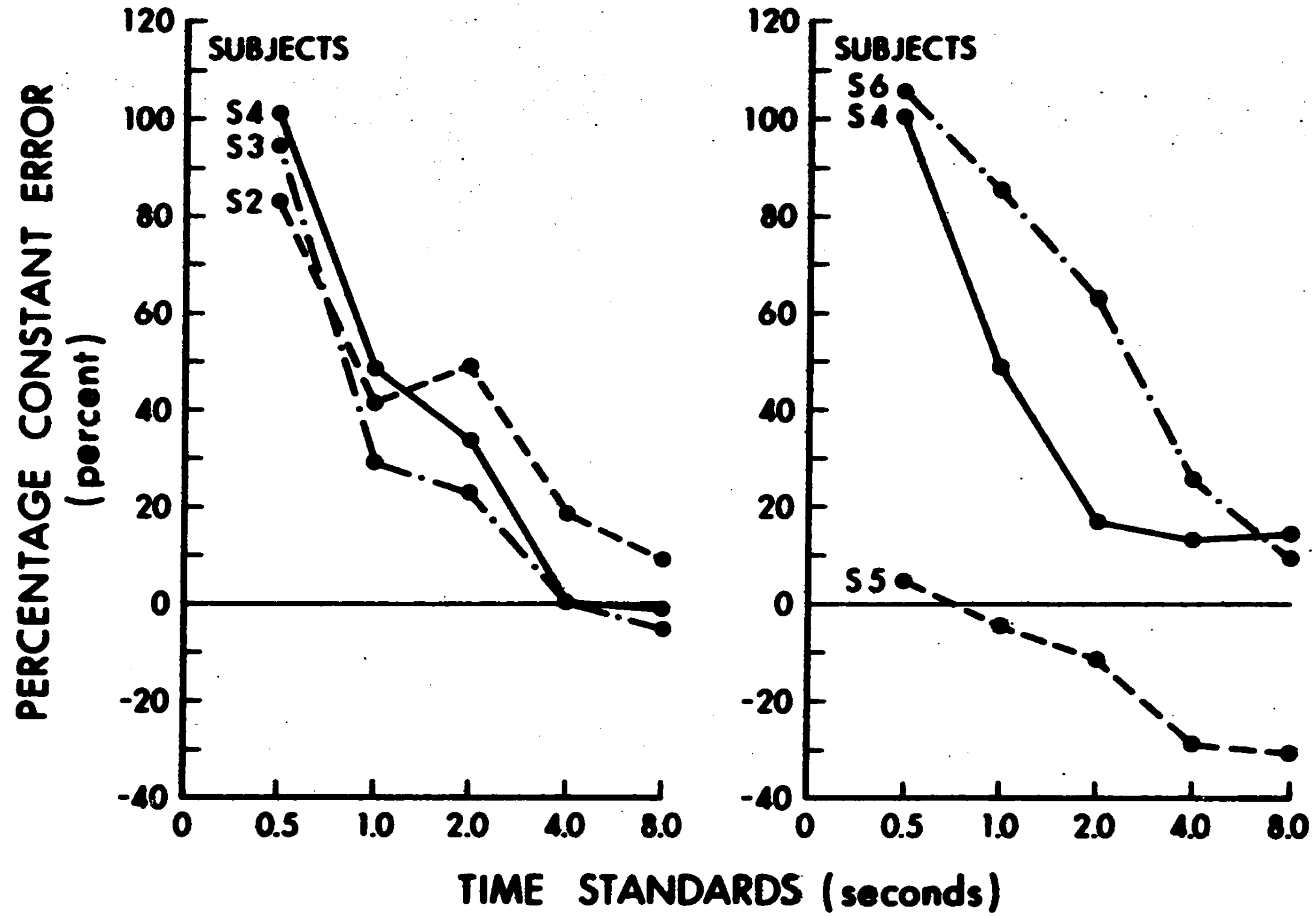

Figure 4: Intra-Subject Percentage Constant Error for Each Subject, Experiment 1.

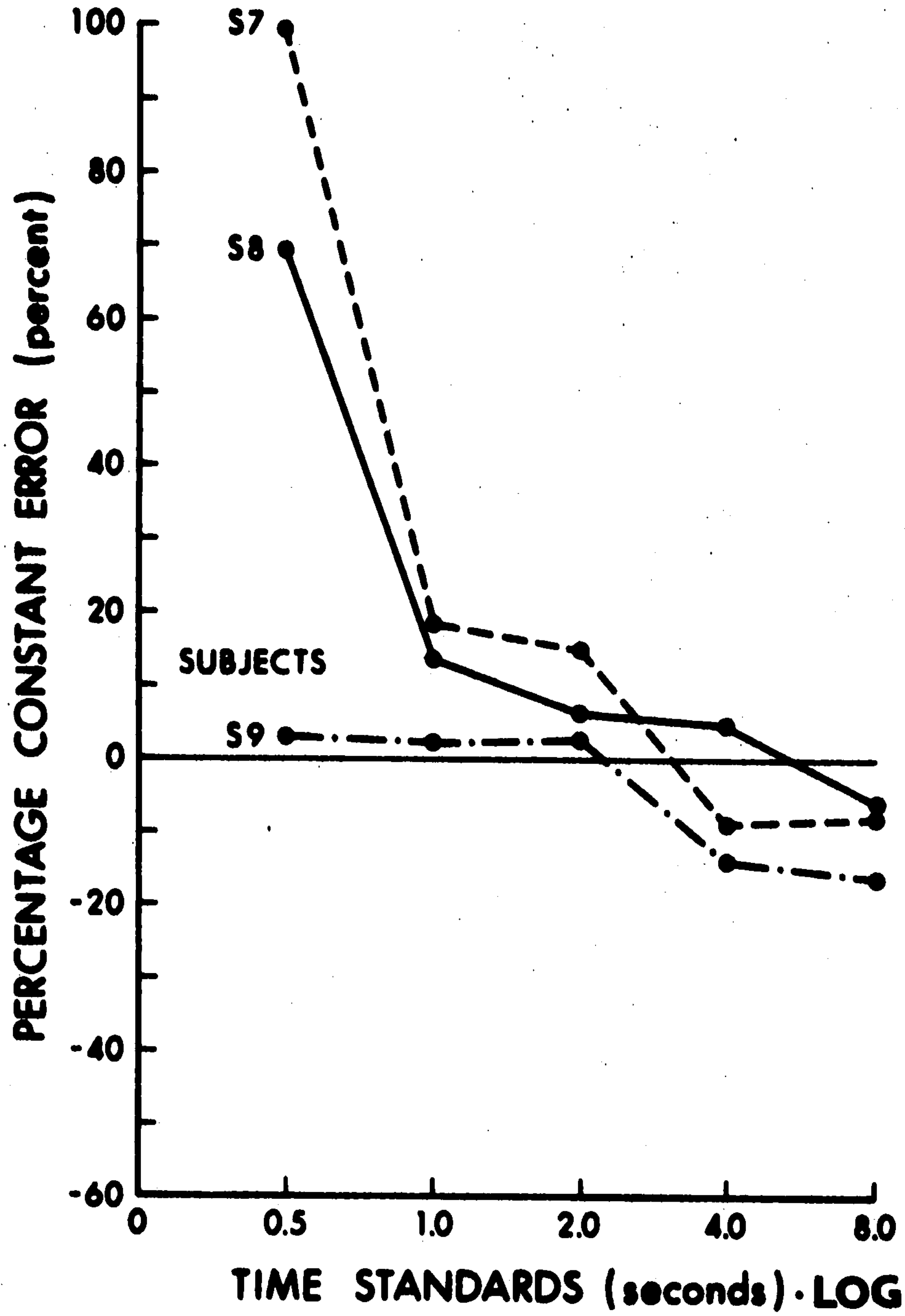

Figure 4 (Continued)

intra-subject percentage constant error scores with Time Standards, Subjects and Repetitions as the main factors (Table 8). Time Standards, Subjects and their interaction were significant at the 0.01 level (using Greenhouse and Geissers' (1959) conservative degrees of freedom). The cell means for the Subjects by Time Standards interaction are found in (Appendix B, Table 21), and the primary main effects are plotted in Figure 4.

The Newman-Keuls test was applied for the Time Standards main effect for each subject (Appendix B, Table 22). With the exception of Subjects 5 and 9, intra-subject percentage constant error for the 0.5 second Time Standard differed significantly from those values for the 4.0 and 8.0 second Time Standards at either the 0.01 or the 0.05 level. For five of the nine subjects, the 0.5 second condition differed significantly from the 2.0 second condition, also at the 0.01 or the 0.05 level.

With the Newman-Keuls test for the Time Standards main factor with all subjects treated as a single group, only the 4.0 and 8.0 second and the 1.0 and 2.0 second pairwise comparisons failed to reach significance at the 0.01 level (Appendix B, Table 22). It appeared that the latter analysis may be the more reasonable because the differences in the magnitudes of the percentage constant errors for the 0.05 and 1.0 second conditions were large (Figure 2). The differences between the 2.0 and the 4.0 or 8.0 second conditions were also large. When the differences between

Time Standards for the PCE variable were tested for each subject separately, the significant differences obtained with the subjects grouped analysis were generally not supported (Appendix B, Table 22).

The decrease in the numeric value of the intra-subject percentage constant error as the Time Standard magnitude increased up to 4.0 seconds was reasonably consistent across subjects (Figure 4).

Discussion

Was the coefficient of proximity for time estimations a constant? The answer to this question appeared to be plagued with contingencies. The preliminary evidence from the primary analyses using either intra-subject or inter-subject coefficients warranted a negative response to the above question (Tables 2 and 3). However, the secondary analysis with intra-subject coefficients (Table 7) did not yield a significant Time Standards main effect (using Greenhouse and Geissers' (1959) conservative degrees of freedom) and therefore, the question of whether the coefficient of proximity was a constant was answered in the affirmative. The discrepancy between these two analyses resulted because of a significant Subjects by Time Standards interaction[1] which became the appropriate error estimate for the F-ratios for the main effects.

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[1] using normal degrees of freedom.

When normal degrees of freedom were used for the secondary analysis of the intra-subject coefficients[1], both the primary and secondary analyses were consistent in rejecting a constant coefficient hypothesis. According to the Newman-Keuls test, (Appendix B, Table 22) the reason for the significant Time Standards main effect, and hence the reason for rejecting a constant coefficient hypothesis was the significant difference between the 0.5 second Time Standard and all of the other Time Standards. Thus, although a constant coefficient hypothesis was not accepted completely, it was supported if the range of Time Standards was restricted; in this case from 1.0 to 8.0 seconds.

An additional reason accepting a constant coefficient hypothesis was provided by testing the Time Standard main effects for each subject (Appendix B, Table 19). Only one subject demonstrated significant differences between the means of the Time Standard conditions.

The answer to the question posed at the beginning of this discussion suggested by the present author was a qualified yes. In a strict sense, the Time Standards main effect was not significant (Table 7) which justified supporting a constant coefficient hypothesis. Two additional reasons for sustaining this hypothesis were that significant differences between Time Standards occurred for only one subject (Appendix B, Table 19) and, both the primary and secondary analyses for

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[1]the term 'coefficient' when used alone refers to 'coefficient of proximity'.

the intra-subject coefficients were indicative of a constant coefficient of proximity for time judgments, assuming the 0.5 second condition was omitted.

The larger intra-subject coefficients for the 0.5 Time Standard necessitated placing a contingency upon accepting a constant coefficient hypothesis. This contingency should be retained until further experimental work with short time intervals (0.5 seconds and less) has determined whether time lengths of these magnitudes represent a unique group.

Woodrow (1930) found constant Weber fractions (coefficients of proximity) existed for restricted ranges of Time Standard values, the magnitudes of these fractions changing from range to range. On this basis Woodrow rejected the existence of constant Weber fractions for time estimations.

Actually, Woodrow's (1930) results could be interpreted as being in agreement with those of this study on the basis that both studies suggested a need to qualify conclusions regarding the constant coefficient hypothesis. Treisman (1963), Snodgrass, Luce and Galanter (1967) and Richards and Livingston (1966) all provided unqualified support for a constant coefficient hypothesis, a conclusion not in total harmony with the one drawn here. In addition, these authors used inter-subject coefficients and not intra-subject coefficients which was the dependent variable used in this study as the basis for accepting a constant coefficient hypothesis. When the inter-subject coefficients were used, the constant coefficient hypothesis was rejected, a conclusion which was in opposition to that of the above authors.

In the primary analyses (Table 3), inter-subject coefficients established a basis for conclusions which were consistent with those for intra-subject coefficients regarding statistical significance. Previous research regarding the possible differences in the conclusions drawn based upon these two dependent variables for constant time intervals was not located. However, McConchie and Rutschmann (1971), using variable time intervals within a session found that when inter-subject coefficients were used, they did not differ significantly over the different Time Standards used. When intra-subject coefficients were employed differences between Time Standards were significant. Based upon the present study, the different conclusions warranted by intra vs. inter-subject coefficients for variable time procedures was not maintained when the Time Standards within a session were constant.[1]

Inter-subject coefficients were larger numerically than the intra-subject coefficients (Figure 1), a finding supported by McConchie and Rutschmann (1971). These larger inter-subject coefficients reflected an increase in the variance measurements of these ratios. The increase occurred because of combining time estimations which differed significantly between subjects

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[1]This was only true for the primary analyses. When the secondary analysis was considered as well, differences in the conclusions drawn did occur for the different dependent variables.

(Table 6). Consequently, the practice of using inter-subject coefficients should be discouraged on the basis that the values (numeric) obtained were larger than would be predicted using the coefficients obtained for each subject separately.

Treisman (1963) and Snodgrass et al (1967) used constant times within a session and inter-subject Weber fractions (coefficients of proximity). They did not find significant differences between Time Standards which were of similar lengths to the ones used in this study. These findings were not confirmed in the present study. One of the reasons for the discrepancy may be that Treisman (1963) found a significant 'lengthening effect' for time estimations which could increase any error estimates. Although there was a good deal of support for the 'lengthening effect' in the literature (Warm, Morris and Kew, 1963; Falk and Bindra, 1954; Emly, Schuster and Lucchesi, 1968) it did not occur in the present study (Table 6).

The absolute numeric values of the intra-subject coefficients combined over subjects (Figure 1) ranged from 11.0% to 14.0% for the four largest Time Standards. These values were consistent with those of Treisman (1963) and Snodgrass et al (1967). However, these numeric values were only approximate in reflecting the actual scores obtained for each subject (Appendix B, Table 18).

The large differences between subjects (which could be considered significant depending upon the analysis accepted) justify the need for further experimental studies which may indicate appropriate ways of regrouping subjects based upon criteria which form more homogeneous groups.

An emphatic answer regarding the appropriateness of grouping data across subjects was not provided on the basis of the present study, however, the indications were that it may depend upon the particular issue being considered. For example, grouping appeared to distort the numeric values of the intra-subject coefficients (see Appendix B, Table 18, for intra-subject coefficient values for each subject).

Whether these distorting effects are meaningful will depend upon the particular use being made of the coefficients, which in turn would then be the basis of deciding whether to group or not. If the issue is the constant coefficient hypothesis, then grouping subjects may not alter the conclusions as is the case in the present study (Table 7, and Appendix B, Table 19). The validity of this latter statement is of course contingent upon the particular analysis accepted. The position taken here is that the grouping of data is a privilege based upon the assumption that it does not violate the uniqueness principle, an assumption which is challenged by the present study. Eventually however, unconditional grouping may prove to be the only reasonable alternative. But, such a justification must await additional work.

With reference to the preceding results and analyses what can be expected of the human operator in terms of time-keeping variability? Generally, time-keeping variance will be a relatively constant percentage of the mean of the time estimation distribution, the order of magnitude being approximately 11.0% to 14.0%. This holds for time lengths ranging from 1.0 to 8.0 seconds. Time Standards of 0.5 second and less may constitute a unique population because the percentages for this time length are usually larger than for the other time lengths.

If statistical tests are not considered relevent for the particular purpose, subjects should be analyzed individually if a high degree of precision is required in estimating the coefficient of proximity. If individual analysis is not done, increased accuracy in prediction is achieved if a decreasing trend in the magnitude of the coefficients with increased time length is expected or incorporated.

In absolute terms, time estimation variance increases as the Time Standard magnitude increases (Appendix C, Table 23), a finding unanimously supported in the literature (Treisman, 1963; Warm, Morris and Kew, 1963; Spivack and Levine, 1964; Snodgrass, Luce and Galanter, 1967). Therefore, if timing variance is to be minimized to optomize performance, shorter time lengths should be selected. For example, starters for various races should use short foreperiods as one method of reducing the number of false starts. This assumes that S is attempting to estimate the time of arrival of the stimulus event in order to reduce his 'true simple reaction time'.

In Experiment 1, the task used was a reproduction accuracy task and therefore, S was required to produce similarity judgments. Therefore the data obtained provided information on how well S responded on the basis of sameness, consequently generalizations to man as a difference detector were not made.

The new coefficients of proximity should not be confused with Weber fractions as has been the case in the literature to date (i.e. Treisman, 1963).

The numeric value of the percentage constant error was not constant for each of the Time Standard conditions employed (Tables 4,5 8). This finding was obtained for both intra-subject and inter-subject PCEs. Percentage constant errors were larger at the shorter Time Stnadards than for the longer Time Standards (4.0 and 8.0 seconds) and these differences were significant (Appendix C, Tables 13, 22). When subjects were tested separately, these results were generally supported (Appendix C, Table 22). Treisman (1963), using inter-subject PCEs, found comparable results.

Grouping intra-subject PCEs did not affect the conclusion drawn in the above paragraph relative to that which would have been drawn based on individual analyses of subjects.

This was not the case, however, when considering the numeric values of the PCEs or the numeric value of the indifference interval.[1] The indifference interval value obtained using grouped intra-subject PCEs was slightly greater than 4.0 seconds (Figure 2), a finding clearly not

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[1]the indifference interval is that time length at which S would theoretically neither overestimate nor underestimate the Time Standard.

the case for 7 of the 9 subjects (Figure 4). Three of the subjects provided no indifference interval at all for the lengths of Time Standards used, and consequently, unlike the others, did not demonstrate a 'range effect'. The differences in the PCE magnitudes between Subjects was reflected in the significant Subjects main effect (Table 8). Thus conclusions regarding the absolute numeric values of PCEs and the 'range effect' based upon grouped data must be considered only as broad generalizations. These may not be useful when attempting to predict individual performance. A reasonable alternative could be to seek criteria which may legitimately be used to regroup subjects.

Woodrow (1934) reported that a large number of his subjects over-estimated all of the Time Standards and Treisman (1963) reported the same results for his first experiment. However, in a second experiment, the 'range effect' was demonstrated (Treisman, 1963). These results were certainly consistent with those of the present study in emphasizing large differences between subjects when time was being estimated. Indifference interval estimates have similarly been plagued with large differences in the values reported by different studies Eg. Kowalski (1963), Kruup (1961), Richards and Livingston (1966).

The significant increases in PCE over sessions found by Treisman (1963) were not found in the present study (Table 8). Treisman (1963) claimed that the 'lengthening effect' was responsible for these increases. In the present study, the Repetitions main factor for time estimations was not significant and therefore a 'lengthening effect' did not occur (Table 6). It was possible that the self-paced procedure used in the present study was responsible for not finding a 'lengthening effect'. Typically, in the paced procedure, the experimenter determined when the time interval to be estimated began and when S was to make his response. Such a paced procedure may have induced a 'lengthening effect'.

Generally, the shorter Time Standards were estimated more accurately (Appendix C, Table 24) than the longer Time Standards. The mean estimates for the 0.5 and the 1.0 second time lengths did not differ significantly. All other pairwise comparisons between Time Standard means resulted in significant differences (Appendix C, Table 17). Thus the shorter time lengths appeared more desirable not only because time judgments at such values were least variable but because S was more accurate with his estimations.

The degree of accuracy which can be expected from the human operator, on a 'best guess' basis for time estimation can be derived on the basis of the PCE values in Figure 2.

The major contributions for Experiment 1 were the following: (a) a constant coefficient of proximity hypothesis was supported but only conditionally, a conclusion which differed from those in the literature in that the constant coefficient hypothesis has been accepted without contingency (the exception being Woodrow (1930)), (b) intra-subject coefficients were preferred to inter-subject coefficients because of the large differences between subjects. Because of such differences the magnitudes of the inter-subject coefficients were artifically inflated, (c) an additional reason for preferring the intra-subject coefficients was that they provided information which was more consistent with that provided when subjects were analyzed individually, (d) grouping of data, even intra-subject variables, was questioned, (e) the 'lengthening effect' prevalant in the literature was not found, (f) PCEs were not constant across Time Standards, a finding which was supported by the related literature.

V. Experiment 2

Results

Primary Analyses. A two-way analysis of variance with Time Standards and Previous Standard as the main factors was calculated for time estimation scores (Table 25). Only the Time Standards main effect was significant (using Greenhouse and Geissers' (1959) conservative degrees of freedom). With the Newman-Keuls test (Appendix D, Table 32) for Time Standards, all comparisons were significant.

Two two-way analyses of variance were calculated, one for intra-subject coefficients of proximity and one for inter-subject coefficients of proximity (Tables 26, 27). Time Standards and Previous Standard were again the main factors. There were no significant main effects or interactions in either analysis (using Greenhouse and Geissers' (1959) conservative degrees of freedom only for the intra-subject analysis).

In addition, a two-analysis of variance was calculated for intra-subject PCEs and for inter-subject PCEs with Time Standards and Previous Standard as the main factors (Tables 28, 29). Neither the main effects nor the interaction were significant for the intra-subject analysis (using Greenhouse and Geissers' (1959) conservative degrees of freedom). Time Standards were significant for the inter-subject analysis (using normal degrees of freedom). With the Newman-Keuls

Table 25

Two-Way Analysis of Variance, Experiment 2
Time Estimations

Source	df	Conservative df	Mean Squares	F
Time Standards (T)	4	1	1,352,818,700.00	3231.73xx
Previous Standard (P)	4	1	1,073,221.00	2.56
T x P	16	1	418,605.00	.45
Error	1375	7	925,396.00	

xxSignificant at the 0.01 level Greenhouse and Geisser

Table 26

Two-Way Analysis of Variance, Experiment 2
Intra-Subject Coefficients of Proximity

Source	df	Conservative df	Mean Squares	F
Time Standards (T)	4	1	6,828,448.00	11.19**
Previous Standard (P)	4	1	742,854.25	1.21
T x P	16	1	614,157.06	1.28
Error	150	6	480,038.50	

**Significant at the 0.01 level

Table 27

Two-Way Analysis of Variance, Experiment 2
Inter-Subject Coefficients of Proximity

Source	df	Mean Square	F
Time Standards (T)	4	47,949,904.00	.07
Previous Standard (P)	4	14,686,896.00	.54
Error	16	18,257,168.00	

Table 28

Two-Way Analysis of Variance, Experiment 2
Intra-Subject Percentage Constant Error

Source	df	Conservative df	Mean Square	F
Time Standards (T)	4	1	134,601,860.00	85.02**
Previous Standard (P)	4	1	1,686,738.00	1.06
T x P	16	1	1,583,154.00	.26
Error	150	6		

**Significant at the 0.01 level

Table 29

Two-Way Analysis of Variance, Experiment 2
Inter-Subject Percentage Constant Error

Source	df	Mean Square	F
Time Standards (T)	4	196,196,760.00	89.30**
Previous Standard (P)	4	2,278,411.20	1.04
Error	16	2,197,136.00	

**Significant at the 0.01 level

test (Appendix D, Table 33) for this latter analysis, PCEs for the 8.0 and 4.0 second comparison were not significantly different.

Secondary Analyses. A three-way analysis of variance was calculated for intra-subject coefficients with Time Standards, Previous Standard and Subjects as the main factors (Table 30). Both Time Standards and Subjects main effects[1] were significant at the 0.01 level (using Greenhouse and Geissers' (1959) conservative degrees of freedom) with all of the other tests being non-significant. With the Newman-Keuls test for the Time Standards main effect (Appendix D, Table 34) the intra-subject coefficients for the following paired comparisons were not significantly different at the 0.01 level; 8.0 and 4.0 second conditions, 4.0 and 2.0 second conditions and the 2.0 and 1.0 second conditions.

The means for the Time Standards factor are plotted in Figure 1 for both the inter-subject and intra-subject coefficients.

Finally, a three-way analysis of variance was calculated for intra-subjects PCEs with Time Standards, Previous Standard and Subjects as the main factors (Table 31). The Time Standard and Subjects main effects and the Subjects by Time Standards interaction were significant at the 0.01 level (using Greenhouse and Geissers' (1959) conservative degrees of freedom). All of the other F-ratios were non-significant.

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[1]Main effects are tested with the F-ratio.

Table 30

Three-Way Analysis of Variance, Experiment 2
Intra-Subject Coefficients of Proximity

Source	df	Conservative df	Mean Squares	F
Time Standards (T)	4	1	6,828,448.00	16.09^{xx}
Previous Standard (P)	4	1	742,854.25	1.75
Subjects (S)	6	6	232,229.20	5.47^{xx}
Error (pooled)	160	19	424,365.94	

^{xx}Significant at the 0.01 level Greenhouse and Geisser

Table 31

Three-Way Analysis of Variance, Experiment 2
Intra-Subject Percentage Constant Error

Source	df	Conservative df	Mean Squares	F
Time Standards (T)	4	1	134,601,860.00	152.18^{xx}
Previous Standard (P)	4	1	1,686,738.00	1.91
Subjects (S)	6	6	106,498,850.00	14.74^{xx}
S x T	24	6	7,224,918.00	8.17^{xx}
Error (pooled)	136	13	884,493.18	

^{xx}Significant at the 0.01 level Greenhouse and Geisser

With the Newman-Keuls test for the Time Standards main effect (Appendix D, Table 35) the adjacent pair-wise comparisons of conditions were not significant at the 0.01 level.

The means for the Time Standards factor are plotted in Figure 2 for both the inter-subject and intra-subject PCEs.

The means for the Time Standard by Previous Standard interaction for intra-subject PCEs, standard deviations and intra-subject coefficients are found in Appendix D, Figures 5,6,7 and Appendix D, Table 36.

<u>Discussion</u>

Was the coefficient of proximity a constant for time estimations when the Time Standards within a session were variable? On the basis of the primary analyses, using intra-subject or inter-subject coefficients, an affirmative answer to the above question appeared justified. McConchie and Rutschmann (1971) used variable Time Standards within a session and they also supported a constant coefficient hypothesis using inter-subject coefficients. However, this hypothesis was rejected when intra-subject coefficients were employed. When the analysis of variance for the intra-subject coefficients was extended in the present study (secondary analysis, Table 30), the Time Standards main effect was significant, a finding consistent with that of McConchie and Rutschmann (1971).

The difference between the primary and secondary analyses for the intra-subject coefficients was due primarily to the fact that the Subjects main factor was significant and to an increase in the conservative degrees of freedom for the error estimate used in the F-ratio. In the primary analysis (Table 26) the Time Standards main effect was significant at the 0.01 level using the normal degrees of freedom. Since the error term in this analysis for the Time Standards main effect was the interaction term, the use of Greenhouse and Geissers' (1959) conservative degrees of freedom was considered unduly stringent. For this reason and in the interest maintaining a reasonable balance in these analyses conclusions were based upon the extended analysis for the intra-subject coefficients (Table 30).

Thus the results of the present study supported the contention that whether the coefficient of proximity was a constant depended upon whether inter-subject or intra-subject coefficients were used in the analyses. When intra-subject coefficients were employed, the constant coefficient hypothesis was rejected and when inter-subject coefficients were used this hypothesis was accepted.

Inter-subject coefficients were larger than the intra-subject coefficients (Figure 1), a fact supported by McConchie and Rutschmann (1971). Which of these two independent variables more accurately reflected the properties of the individual operator was not tested directly. However, indications from Experiment 1 were that intra-subject coefficients (grouped) were to be preferred on an accuracy basis. Grouping data in either[1] manner should be discouraged based upon the consistent significant Subjects main effect. Further research is required regarding the issue of grouping and regrouping.

With the Newman-Keuls test for the Time Standards main factor (Appendix D, Table 34), intra-subject coefficients for the 0.5 second condition were significantly larger than those for all of the time conditions.

The differences between the remaining non-adjacent pair-wise comparisons were also significant at the 0.01 level, a finding not confirmed by the comparable analysis in Experiment 1 (Appendix B, Table 20).

The percentage constant error magnitudes were not constant for time estimations when the Time Standards within a session were variable. This was true whether using intra-subject or inter-subject PCEs (Tables 29, 31). The significance (0.01 level) of the Subjects main effect and of the Subjects by Time Standards interaction for the intra-subject PCEs (Table 31) was further evidence of the high degree of individuality which existed between people when they estimated time. These same effects were significant at the 0.01 level for the comparable analysis in Experiment 1 (Table 8). These results further questioned the appropriateness of grouping intra-subject scores with respect a PCE dependent variable.

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[1]Grouping data can be done either before calculating various parameters (inter-subject) or after calculating various parameters (intra-subject).

McConchie and Rutschmann (1971) did not find significant differences between Time Standards for a PCE dependent variable. The reason for the discrepancy between these results and those of the present study was not readily available. Although McConchie and Rutschmann (1971) generally used smaller time magnitudes with smaller differences between the times than was the case for the present study, it was not likely that this was the reason for the differences. McConchie and Rutschmann (1971) used times which ranged from 400 to 1000 milliseconds. For comparable times in this study, the PCE values were found to differ significantly.

As would be expected, the numeric values of the inter-subject and intra-subject PCEs were identical and thus both were indicative of a 'range effect' (Figure 2) which was much more prominent than the 'range effect' for Experiment 1. This accentuated 'range effect' could have been due to the variable Time Standards procedure. But, since the subjects used in these two experiments were different and since subjects displayed large differences in estimating times (Experiment 1, Appendix C, Table 21), such a conclusion would have been a weak one. In addition, the manner in which the variable Time Standard procedure accentuated a 'range effect' relative to a constant Time Standard procedure was still unresolved on the basis of the present results. This occurred because the Previous Standard main effect was not significant (Tables 25, 28, 29, 31).

It was considered possible (see Chapter 2) that the time estimation made in response to a given time length might be affected by the company it kept. That is, the time estimations made for a given time interval would differ depending upon the time length which immediately preceded it. Such a possibility was suggested by Treisman (1963) who found assimilation effects for time estimations and by the Previous Foreperiod Effect found for Simple Reaction Times when the foreperiods were variable (i.e. Karlin, 1959). The fact that the Previous Standard main factor was not significant for time estimations, as would have been predicted based upon the Previous Foreperiod Effect, supported the precariousness of predicting time-keeping parameters from Simple Reaction Time data. This point will be considered further in the next experiment.

Had present time estimations been affected by the length of the Previous Standard it would have afforded one possible explanation for the 'range effect'. For example, time estimations for a constant Time Standard could have increased as the length of the Previous Standard increased. The only contingency would have been that the Previous Standard be larger than the Time Standard being estimated. Since the shorter Time Standards were preceded most often by longer Previous Standards, subjects would have more likely overestimated than underestimated the shorter Time Standards. Similarly, time estimations for the longer Time Standards in the range may have decreased in magnitude as the length of the Previous Standard decreased. Again, the contingency would have been that the Previous Standard had to be shorter in length than the Time Standard being estimated. Thus subjects would have had a greater tendency to underestimate than to overestimate the longer Time Standards. Hence, a 'range effect' would have occurred. Since the Previous Standard main effect was not significant (Table 31), this explanation seems doubtful.

The means for the Time Standards by Previous Standard interaction for both intra-subject (grouped) PCEs and coefficients as well as the standard deviations are found in Appendix D, Table 36. These values are plotted in Figures 5, 6, 7, Appendix D.

The only noteable feature regarding these values was that the changes in the intra-subject coefficients (Appendix D, Figure 6) followed very closely the changes in the standard deviations (Appendix D, Figure 7) for each Time Standard over the Previous Standards. This indicated that although the mean estimates remained relatively constant for the various Previous Standard conditions for each Time Standard, the variances changed to a greater extent over the Previous Standard conditions. Perhaps this variable should be the one to be examined more closely in the future when testing the effects of the Previous Standard time length.

The numeric values for the inter and intra-subject coefficients obtained with the variable Time Standards procedure were larger than their counterparts obtained with a constant Time Standard procedure (Figure 2). McConchie and Rutschmann (1971) found inter-subject coefficients which had numeric values of approximately 20.0% which was larger than the values reported by Treisman (1963) and Snodgrass et al (1967). These latter authors used constant Time Standards within a session. It was originally thought that the larger inter-subject coefficients found by McConchie and Rutschmann (1971) were due to the fact that they used shorter foreperiods (generally) than did Treisman (1963) and Snodgrass et al (1967). In the literature and in the present study a tendency for shorter time lengths to have larger inter-subject coefficients values was demonstrated. On the basis of the present results it appeared that the larger coefficient values obtained with the variable Time Standards procedure using different ranges of time magnitudes, also held when the time lengths were the same.

The reason for the larger inter-subject coefficients with the variable times procedure was a general increase in the variability of the time estimates and to a decrease in the mean estimates (compare Table 16, Appendix B with Table 37, Appendix D). The smaller mean estimates for the variable Time Standards relative to when the time events were constant were plotted in PCE terms in Figure 2.

The major contributions of Experiment 2 were the following; (a) whether the constant coefficient hypothesis was accepted depended upon whether inter-subject or intra-subject coefficients are used, (b) the percentage constant error was not a constant for time estimations, (c) a 'range effect' was demonstrated but it was not likely due to the effect of the preceding Time Standard length affecting time judgments being made to the present Time Standard, (d) significant Subjects main effects warranted caution in interpreting the preceding results with respect to predicting behaviour of a particular subject and further cautioned against indiscriminantly grouping data for time estimation.

General Discussion for Experiments 1 and 2

Holding the dependent variable constant (intra or inter-subject), conclusions regarding the constancy of the coefficient of proximity for time judgments differed when comparing the constant versus variable time standard procedures. When intra-subject coefficients were used, a constant coefficient hypothesis was accepted for the constant Time Standards procedure and rejected when the Time Standards were variable. When inter-subject coefficients were employed, the opposite conclusions were warranted by the respective procedures.

The percentage constant error was not a constant using either the variable or the constant Time Standard procedure. However, subjects can be expected to demonstrate a 'range effect' to a greater extent with the variable Time Standards procedure. The longer times in the range were underestimated rather than overestimated and they were underestimated to a greater extent, when underestimation occurred in both procedures.

Coefficients of proximity were larger for the variable times procedure than for the constant times procedure because the mean estimates S made were smaller for the variable procedure while his estimation variance increased. Thus different time estimation parameters could be expected from S depending upon whether he was operating in a variable or a constant time event situation. Both procedures were similar in that the Subjects main effect and the Subject by Time Standards interaction were consistently significant factors. One possible reason for the large inter-subject differences for time estimation in the present study was that subjects were not permitted to mediate their time judgments. The employment of mediational techniques to aid time estimation may have had a tendency to reduce the differences between subjects but this possibility awaits further study. However, not permitting the subjects to mediate provided a 'baseline' estimate of how well people can judge time lengths. Consequently any program designed to discover if time-keeping accuracy can be learned could be compared with such values. Unfortunately, the large inter-subject differences may necessitate gaining baseline information on each subject individually before initiating the training program.

VI. Experiment 3

Results

A total of three measures were analyzed; legitimate time estimations, index scores and correlations.[1]

A legitimate time estimate was considered to be one which preceded the stimulus-event or which exceeded it by 100 milliseconds (msec.) or less. The number of legitimate time estimations for each subject for each of the Foreperiod Conditions was calculated for Part A of Experiment 3 (Table 38). Legitimate time estimations varied considerably in number between subjects and Foreperiod Conditions (Table 38). On the average, the 1.0 and the 2.0 second Foreperiod Conditions resulted in the largest number of legitimate time estimations (approximately 75% of the total possible) while the 8.0 second Foreperiod Condition produced the fewest number (approximately 47% of the possible total) (Table 38).

The number of legitimate time estimations were virtually identical for the first and second half series of trials.

An index score--index score = SRT - (TE - FP)[2]--was calculated for each illegitimate time estimation for each subject for each Foreperiod Condition. These index scores were

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[1]Pearson product-moment correlations were used

[2]SRT = simple reaction time
TE = time estimation
FP = foreperiod time length
the scale of measurement was in msec.

Table 38

The Number of Legitimate Time Estimations for Experiment 3, Part A

	Foreperiod Conditions (Seconds)									
	0.5		1.0		2.0		4.0		8.0	
	A	B	A	B	A	B	A	B	A	B
Subjects										
S 1	06	04	14	11	13	13	15	13	07	11
S 2	08	04	12	11	11	05	11	05	06	03
S 3	12	12	11	07	06	06	02	08	03	04
S 4	06	06	08	08	11	09	10	07	09	09
S 5	08	11	13	14	13	13	09	13	09	09
S 6	03	04	04	06	08	10	07	03	05	07
S 7	14	15	12	14	11	14	12	11	10	12
S 9	14	14	10	09	13	10	06	07	05	04
Totals	71	70	84	80	86	80	72	67	54	59

A first 15 trials

B second 15 trials

Table 39

Total Number of Positive and Negative Index Scores
For Experiment 3, Part A

	Foreperiod Conditions (Seconds)									
	0.5		1.0		2.0		4.0		8.0	
	P	N	P	N	P	N	P	N	P	N
Subjects										
S 1	10	10	05	00	04	00	02	00	06	06
S 2	02	16	06	01	07	07	04	09	03	17
S 3	02	04	00	12	02	16	02	18	02	21
S 4	00	18	12	02	06	04	06	07	01	11
S 5	04	07	02	00	03	01	06	02	03	09
S 6	12	11	05	15	03	09	03	08	03	15
S 7	00	01	02	01	05	00	03	04	02	05
S 9	00	09	06	05	06	01	02	15	01	20

P positive index score

N negative index score

then classified as positive or negative and the totals for each classification were obtained for each subject for each Foreperiod Condition (Table 39).

A positive index score indicated that the time estimation response occurred before the SRT response and therefore interfered with it. Such interference occurred in the present study (Table 39).

Since the same subjects were used in both Experiments 1 and 3, time estimations from Experiment 1 were employed for the correlational analyses with the SRTs obtained in Part B of Experiment 3. Average (mean and median)time estimations were correlated with average (mean and median) SRTs (Table 40). Average time estimations and SRT averages for each subject for each Foreperiod Condition are found in Appendix E, Tables 43 and 44. Correlations were also calculated between time estimation and SRT variances (standard deviation and semi-interquartile range (SIR))(Table 41) and between SRT and time estimation coefficients of proximity (Table 42).

SRT and time estimation variances for each subject for each Foreperiod Condition are found in Appendix E, Tables 45 and 46. The coefficients are similarly found in Appendix E, Tables 47 and 48.

If the processes responsible for time estimation were operating during the foreperiod and if they had a subsequent influence upon the SRTs, significant correlations between time estimation and SRT should have resulted. With one exception, the correlations between time estimation and SRT were not

Table 40

Pearson Product-Moment Correlation Coefficients (r)
Between SRT and Time Estimations, Experiment 3
Means and Medians

	Foreperiod Conditions (Seconds)				
	0.5	1.0	2.0	4.0	8.0
Mean	.256	.326	.096	.244	.012
Median	.296	.312	.187	.062	-.051

* an r of .669 was required for significance at the 0.05 level

** an r of .874 was required for significance at the 0.01 level

Table 41

Pearson Product-Moment Correlation Coefficients (r)
Between SRT and Time Estimations, Experiment 3
Standard Deviations and SIRs

	Foreperiod Conditions (Seconds)				
	0.5	1.0	2.0	4.0	8.0
Standard Deviations	.538	.540	.025	.801**	-.192
SIR	.410	.443	-.304	.104	-.243

* an r of .669 was required for significance at the 0.05 level

** an r of .874 was required for significance at the 0.01 level

Table 42

Pearson Product-Moment Correlation Coefficients(r)
Between SRT and Time Estimations, Experiment 3
Coefficients of Proximity

	Foreperiod Conditions (Seconds)				
	0.5	1.0	2.0	4.0	8.0
Coefficient of Proximity (SD/mean)	.588	.371	.004	.574	-1.67
Coefficient of Proximity (SIR/median)	.437	.102	-1.81	-.093	-.206

* an r of .669 required for significance at the 0.05 level

** an r of .874 was required for significance at the 0.01 level.

significant at either the 0.01 or 0.05 levels (Tables 40, 41, 42).

Discussion

Part A of Experiment 3 was designed to provide information regarding changes in time estimations of foreperiod length which may have occurred as a result of continued practice on the SRT task with constant foreperiods. S was asked to make two responses, one being an estimate of when he thought the stimulus-event would occur (foreperiod length estimate) and the other being a reaction to the stimulus-event when it actually did occur (SRT). The original intention was to correlate these two response scores and to discover if the time estimation responses were modified during the course of practicing the SRT task. However, the data from Part A was unsuitable for these purposes because of the fewer than expected legitimate time estimations (Table 38) and the evidence which indicated that in some instances the two response interfered with one another (Table 39).

The procedure used in Part A was moderately successful with the 1.0 and 2.0 second Foreperiod Conditions in that a high number of legitimate time estimations were obtained (Table 38). Perhaps with increased trials and subjects this procedure would have been successful in providing sufficient legitimate time estimations to permit discovering whether they could be modified during the course of practice. The longest Foreperiod Condition provided the largest number of positive index scores (Table 39) which indicated that the SRT response preceded the time estimation response after the stimulus-event had occurred. This finding might be indicative of the fact that S had selected an operating strategy in which he decided not to time estimate at the explicit level, but to merely attend to the SRT response. Such possible strategy selections would also have had to be overcome if legitimate time estimations were to be obtained in sufficient numbers.

There was some indication (see Table 38) from the legitimate time estimations obtained in Part A that S was using the potential feedback from the stimulus-event to modify his time estimations. For example, the 8.0 second Foreperiod Condition had the fewest number of legitimate time estimations (approximately 47%), a fact which would not have been predicted on the basis of the time-keeping information provided by Experiment 1. In Experiment 1, the 8.0 second Time Standard was generally underestimated. Thus the probability that the time estimation response occurred before the stimulus-event in Experiment 3 was higher for the 8.0 second Foreperiod Condition than for the other Foreperiod Conditions. Therefore, the 8.0 Foreperiod Condition should have had a relatively larger number of legitimate time estimations. This may not have occurred because S was attempting to use the feedback provided by the stimulus-event and was attempting to lengthen his time estimations to make them more accurate. In so doing, S may have been lured to time lengths about which he was so uncertain that the stimulus-event continually surprised him.

The shorter Foreperiod Conditions (1.0 and 2.0 second) also provided support for the suggestion that S employed feedback inherent in the SRT task. The 1.0 and 2.0 second Time Standards were generally overestimated by the subjects in Experiment 1 by greater than 100 milliseconds. However, in Experiment 3 for foreperiods of equivalent lengths, 75% of the time estimations were legitimate (Table 38). Thus, these time estimations were reduced in magnitude relative to those which were obtained in Experiment 1. This could have been due to S modifying his time estimations based upon the stimulus-event feedback.

Had it been possible to compare the time estimations for Experiment 1 and Experiment 3 (Part A), additional support for the modification of time estimations within an SRT task may have been obtained.

In a SRT task with constant foreperiods, Temporal Uncertainty was considered to be solely a function of time estimation uncertainty. A reasonable (?) assumption which could have been made was that the changes which occurred in SRT reflected changes in time estimation. That is, all that occurred during the foreperiod was that S estimated time; the time of the stimulus-event arrival. If this did in fact occur, SRT parameters should have been predictable from those of time estimation. Such a relationship was not supported in the present study (Tables 40, 41, 42).

Average SRTs were not reliably predictable on the basis of average time estimations as the correlations between these two variables were low and non-significant at either the 0.01 or the 0.05 level (Table 40). Correlations between SRT and time estimation variances were also non-significant but were larger in magnitude than those for the averages parameter; especially for the shorter Foreperiod Conditions (Table 41). Similarly, the correlations between SRT and time estimation coefficients of proximity were non-significant; however, they too were generally larger than those obtained for the averages parameter (Table 42).

On the basis of these findings the processes responsible for SRT were not identical with those controlling time estimation. This did not mean that the time estimation processes were not involved during the foreperiod but that they were not the only ones operating. As was expected on the basis of Czudner and Marshalls' (1967) results, SRT variances were much smaller in magnitude than those of their time estimation counterparts (Appendix F, Table 45). This fact was also indicative of the possibility that some processes other than time estimation were operative during the foreperiod.

A readiness process was suggested as one possible additional factor which was operating during the foreperiod (Chapter 2). The readiness process could be responsible for the degree of central receptivity for incoming information. There is some indication that the time needed to achieve maximal readiness is between 200 and 500 msec. (Davis, 1959;

Posner and Keele, 1972; Lindsley , 1964). Operating within such a 'rise time' would cause a sizable reduction in SRT variance relative to time estimation variance. The use of time estimation would allow a further reduction in SRT variance because S may not have to operate within the full range of the 'rise time'. That is, if S is accurate enough in estimating time, he could produce a relatively consistent level of readiness at the time the stimulus-event is to occur. Reducing the range of readiness levels which can exist at the time of stimulus-event arrival should result in a reduction in SRT variance. In addition, since a high level of readiness can be maintained for a period of time (Posner and Keele, 1972), time estimation may only have to be 'good enough' to insure a relatively consistent level of readiness at the time the stimulus-event occurs. If this is true, SRTs for different foreperiod lengths will be relatively equivalent even though the time estimation accuracy for these foreperiod times differs significantly.

Karlin (1959) and Moss (1969) both found evidence of an asymptote in SRT as the foreperiod length increased. The asymptote began between 1.0 and 3.0 seconds. Hohle (1965) also found an asymptoting effect for SRTs which began at a foreperiod length of approximately 3.0 seconds. In the present study, mean SRTs were virtually identical for each of the Foreperiod Conditions (Appendix F, Table 39). Thus the initial increase in SRT at the shorter foreperiods found in the literature was not obtained in the present experiment.

However, the equivalence of SRT for some foreperiods was supported. Since time estimations for Time Standards of equivalent length to the Foreperiod Conditions differed significantly over Time Standards in Experiment 1, it appeared that time estimation only needed to be 'good enough' to produce equal SRTs. The equivalence of SRTs for the different foreperiod lengths also precluded their use as differentiators of time estimation accuracy.

In view of the large variances obtained for time estimation in Experiment 1 it was not surprising that S did not simply time estimate during the foreperiod. Although S was instructed to respond as quickly as possible, anticipatory responses were discouraged and thus the large variances for time estimation made the sole use of this process unpractical. The employment of a readiness process was one possible way of optomizing performance by reducing time estimation variance while still using this process in a general fashion. Whether S actually used a readiness process was not determined on the basis of direct evidence such as EEG data; however, on the basis of the indirect evidence such a possibility was not rejected.

The major features of this experiment were: (a) that some process other than time estimation was considered to be operative during the foreperiod, (b) that S appeared to modify his time estimations when performing the SRT task relative to the conditions where he simply had to estimate time (Experiment 1), (c) that although the correlations between SRT and time estimation variances were non-significant, they were higher for the shorter Foreperiod Conditions. This suggested that time estimation was involved to some extent during the foreperiod.

VII. Experiment 4

Results

Simple reaction time (SRT) was the dependent variable analyzed. Three main factors were considered; Immediate Foreperiod (FP), Previous Foreperiod (PFP) and A Priori Probability. Each of these main factors contained two conditions and thus formed a 2x2x2 matrix consisting of 8 cells. A description of the conditions for each cell, the condition number and the median SRT for each of the cells are found in Table 51. The median SRTs for each cell are plotted in Figure 8. The numbers in parentheses refer to the condition number.

The SRTs for each cell were tested for skewness (Appendix G, Table 52). The SRT distributions of 4 of the cells were significantly skewed at the 0.01 level while 6 of the 8 cell distributions were skewed significantly at the 0.05 level.

As a consequence of the significantly skewed SRT distributions, a sign test (Siegel, 1956) was calculated for each of the main factors (Table 51) using 320 paired observations for each test. Because of the larger number of observations, the normal approximation to the binomial distribution was used. The scores obtained were corrected for continuity (Table 51). Both the Immediate Foreperiod and the Probability main factor z scores were significantly different from chance at the 0.01 level (Table 51).

Table 50

The Condition Numbers, Condition Descriptions and Median SRTs For Each Cell Formed by the Main Factors in Experiment 4

Condition Number	Previous Foreperiod (PFP) (Seconds)	Probability of PFP (a priori)	Immediate Foreperiod (FP) (Seconds)	Probability of FP (a priori)	Median SRT (MSec.)
		Condition Description			
1	1	.5	1	.8	228.5
2	4	.5	1	.8	243.0
3	1	.5	4	.2	314.0
4	4	.5	4	.2	322.5
5	1	.5	4	.8	301.5
6	4	.5	4	.8	301.0
7	1	.5	1	.2	253.0
8	4	.5	1	.2	265.0

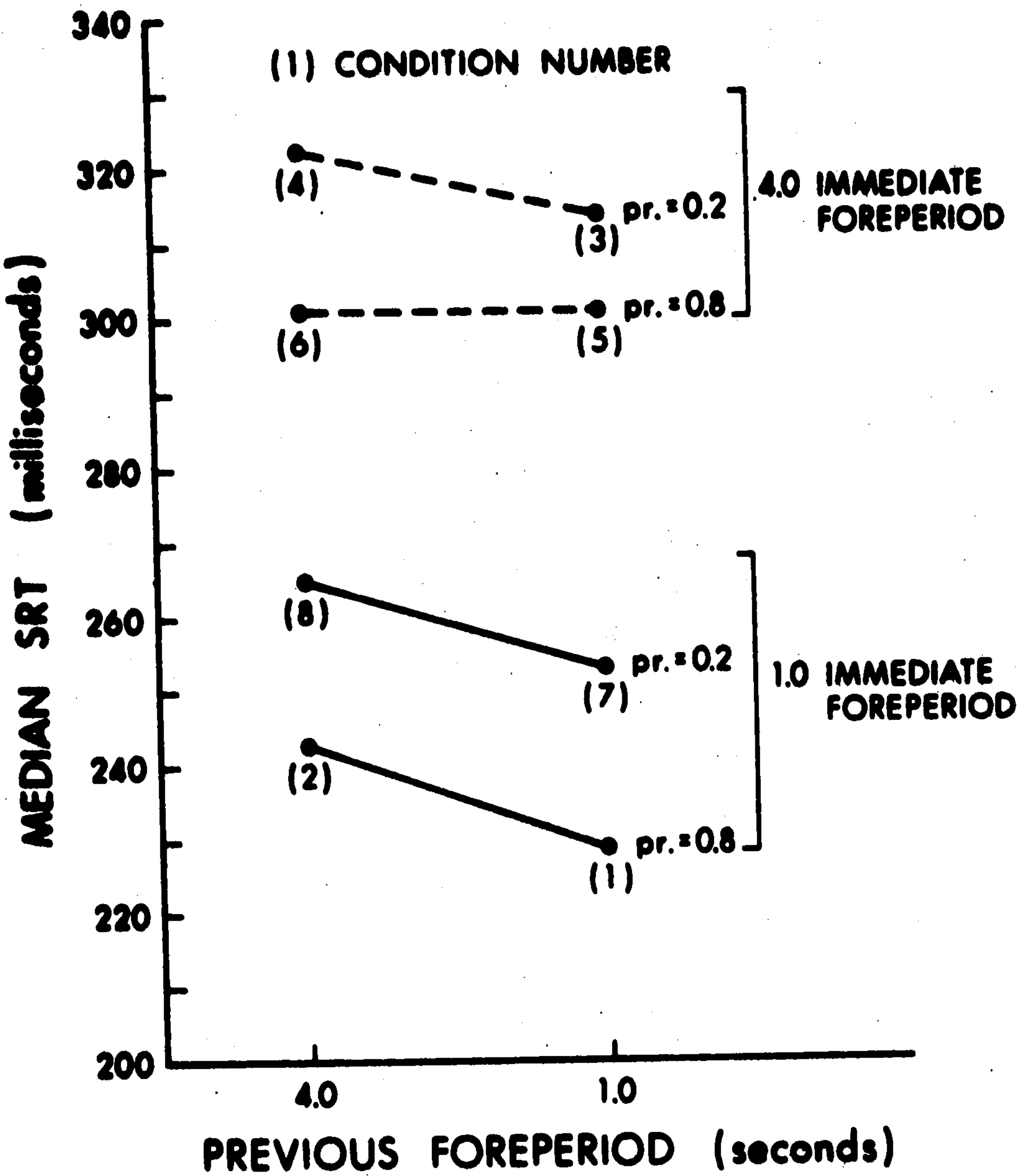

Figure 8: Median SRTs for Each Cell Formed by the Main Factors of Experiment 4.

Table 51

Sign Tests on Main Factors and Selected Condition Comparisons, Experiment 4, Median SRT

Main Factors	Z-score
Immediate Foreperiod (FP)	12.31**
Previous Foreperiod (PFP)	1.74
Probability (A Priori)	3.59**
Condition Number[1]	
2 - 8	3.18**

[1]see Figure 10 or Table 50

**Significant at the 0.01 level.

Discussion

The immediate foreperiod effect (the inverse relationship between average SRT and foreperiod length when the foreperiods are variable) found by Karlin (1959), Moss, (1969), Snodgrass, (1969) and Gottsdanker (1970) was not confirmed in the present study. Although the median SRTs for the 1.0 and 4.0 second Immediate Foreperiod (FP) conditions differed significantly, the median SRT for the 1.0 second FP condition was shorter than the median SRT for the 4.0 second FP condition (see Figure 8). Had the immediate foreperiod effect (IFE) occurred, the reverse order of magnitude between the FP conditions would have resulted.

Karlin (1959) and Moss (1969) both claimed that the IFE was due to the previous foreperiod effect (PFE). Generally, they found that if they increased the length of the Previous Foreperiod to a value which was greater than the Immediate Foreperiod length, the average SRT for the Immediate Foreperiod increased. In the present experiment the Previous Foreperiod main factor was not significant (Table 51) and therefore, a significant PFE was not obtained. The PFE was present to some extent however because the median SRTs for the 1.0 second FP condition were longer when they were preceded by the 4.0 second PFB condition (Figure 8). A PFE was not expected for the 4.0 second FP conditions since this effect occurred only when the Previous Foreperiod was longer than the Immediate Foreperiod (Karlin, 1959; Moss, 1969). The fact that the PFE did not occur in a significant fashion may have been the reason that the IFE was not in evidence.

Zahn and Rosenthal (1966) used variable foreperiods of 1.0 and 3.0 seconds and they found a small but significant PFE. The magnitude of the PFE, although not significant, was larger in the present study. Zahn and Rosenthal (1966) also found that the SRTs for the shorter foreperiod (1.0 seconds) were dependent more upon the proportion of times (a priori probability) it occurred than upon the PFE. This finding was supported by the results obtained in this study. In Figure 8 the median SRT for the 1.0 second Immediate Foreperiod condition were faster when the a priori probability that the simulus-event would occur was increased from .2 to .8. The fact that the a priori probability reduced SRT significantly (Table 51) when the Previous Foreperiod was 4.0 seconds indicated that a priori probability functioned independently of the PFE. That is, when a priori probability for the shorter foreperiods in the range was increased, the possibility of the PFE was reduced because the shorter foreperiods were preceded less frequently by longer foreperiods. When the Previous Foreperiod length was larger than the Immediate Foreperiod and was held constant, an increase in a priori probability still resulted in a decrease in median SRT.

Since an IFE was not found it was not possible to test whether the initial gradient in the SRT-foreperiod curve could be reduced by increasing the a priori probability for the shorter foreperiods.

The magnitude of the significant difference in median SRT between the two Immediate Foreperiod conditions indicated that foreperiod length was the most influential factor affecting SRT (Figure 10). Perhaps it was this factor that offset the IFE. Both Karlin (1959) and (Gottsdanker, 1970) used foreperiod lengths which differed by much smaller values than the difference used here. Hence, length differences might not have been large enough to introduce possible interference because of time estimation accuracy differences. It appeared that a tradeoff in the values of the differences in foreperiod length were required. Gottsdanker (1970) and Requin and Granjon (1969) have demonstrated that by increasing Ss ability to judge time, an increase in the IFE occurred. Gottsdanker (1970) interpreted his results as indicating that the IFE occurred because of what S knows rather than what he doesn't know. Increasing the differences between foreperiod time lengths should have increased what S knew and therefore produced the IFE. However, differences which were as large as the ones used here may have introduced a time estimation factor which interfered with the IFE.

One surprising finding was that median SRT for the 4.0 second Immediate Foreperiod was reduced by increasing the a priori probability (Figure 8). The transitional probability for this Immediate Foreperiod was 1.0 and therefore, if S had been using this information, the a priori proba-ility changes should not have had any effect upon SRT. However, this finding did not necessarily indicate that S did not use transitional probability information. It was possible that the shorter SRTs for the higher a priori probability condition could have resulted because S had more trials (practice) with the 4.0 second Immediate Foreperiod when the probability of it yielding the stimulus-event was high. In Experiment 3, there was a general indication that S modified his time estimations during practice upon a SRT task. Perhaps in Experiment 4 S became more accurate in estimating when the stimulus-event would occur when the a priori probability was high. Hence the reduced median SRT for the high probability condition occurred.

The major contributions of Experiment 4 were: (a) a priori probability functioned independently of the PFE, (b) the IFE was not obtained, (c) even though Ss may have use transitional probability information, SRTs to the largest foreperiod in the range were still affected by a priori probability.

Chapter 5

Summary and Conclusions

Summary

Four experiments were conducted in order to investigate various aspects of Temporal Uncertainty. Temporal Uncertainty was defined as being a function of time estimation uncertainty, the probability structure of the time-events within a task and the possible interaction between these two.

The primary purpose of Experiments 1 and 2 was to provide information regarding two time estimation parameters; coefficients of proximity and percentage constant error (PCE). The major issue regarding these parameters was whether they remained constant (numeric value) for the various Time Standard durations used (0.5, 1.0, 2.0, 4.0 and 8.0 seconds). The influence of different procedures (constant vs. variable Time Standards) and data analyses (grouping data) upon this issue were considered.

Experiment 3 was conducted in order to discover if time estimation was the only process operating during the foreperiod of a simple reaction time task with constant foreperiods. SRT averages, variances and coefficients of proximity were correlated with those for time estimation.

Experiment 4 was designed to extend what was already known about the probability aspect of Temporal Uncertainty.

Specifically, the question posed was does A Priori Probability function independently of the Previous Foreperiod Effect (PFE)?

The following results were obtained: (a) when the Time Standards were constant within a session, a constant coefficient of proximity hypothesis was supported but only conditionally, (b) when the Time Standards within a session were variable, a constant coefficient of proximity hypothesis was rejected, (c) PCE was not a constant for either variable or constant Time Standards within a session, (d) intra-subject coefficients of proximity warranted different conclusions regarding a constant coefficient hypothesis than did inter-subject coefficients. The direction of these differences were not the same for the constant Time Standard procedure as they were for the variable Time Standard procedure, (e) average SRT and SRT variance were not reliably predictable on the basis of average time estimation and time estimation variance (f) there was some indirect evidence which indicated that S used the potential feedback information inherent in the SRT task to modify his time judgments, (f) a priori probability functioned independently of the PFE.

Based upon the results obtained and within the limitations of the present study, the following conclusions were derived.

1. The relationships displayed by time estimation parameters were affected by the procedures and the analyses employed. These discrepancies were due to large inter-subject

differences exhibited when they estimated time. Because of these differences, an attempt must be made to discover if an initial sample of people can be reclassified in such a manner as to improve predictions regarding their performance within the realm of time estimation.

2. The manner in which S reduced Temporal Uncertainty was not resolved. S may have employed several different methods of reducing Temporal Uncertainty depending upon the nature of the task. It cannot be assumed that when the task structure permits, that S simply estimates time. Therefore, the importance of conscious time estimation to the acquisition of motor skills needs to be more thoroughly investigated.

3. The manner in which the time estimation uncertainty and the probability structure associated with the time-events of a task interact warrants further experimental consideration.

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Appendix A

Illustration 1: Subject's View of Apparatus,
(A) Experiments 1 and 2,
(B) Experiments 3 and 4.

Illustration 2: Subject's Position During the Tasks.

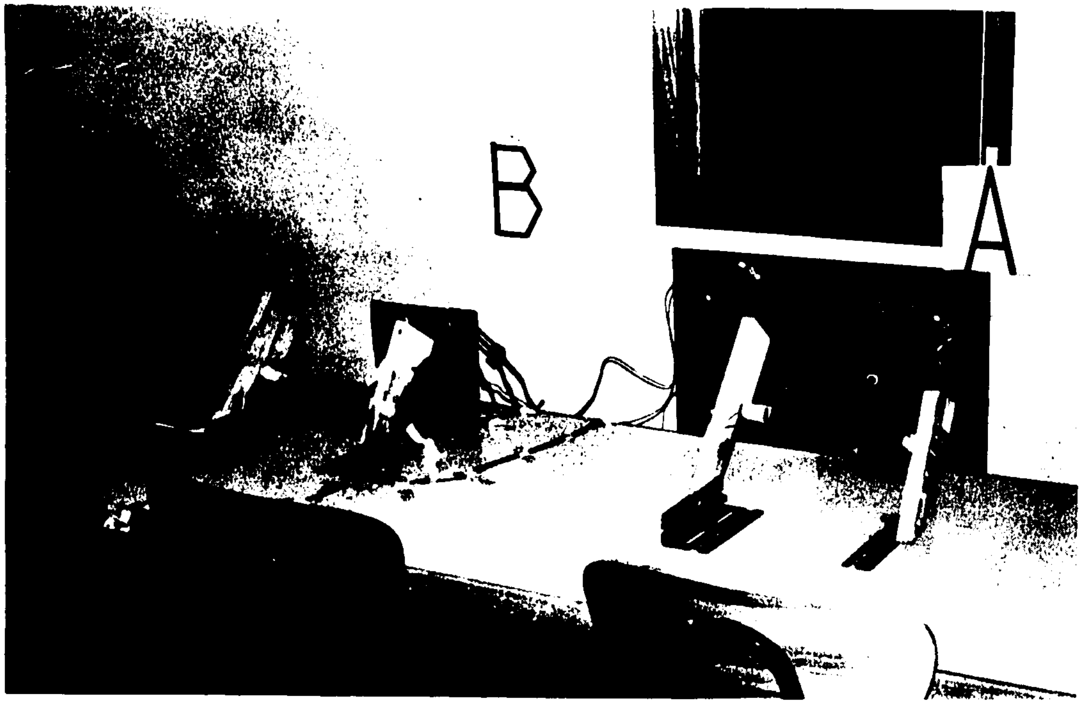

Illustration 1: Subject's View of Apparatus,
(A) Experiments 1 and 2,
(B) Experiments 3 and 4.

Illustration 2: Subject's Position During the Tasks.

Illustration 3: Experimenter's View of Apparatus for Experiments 1 and 2; DIT-Decade Interval Timer, CK-Klockcounter.

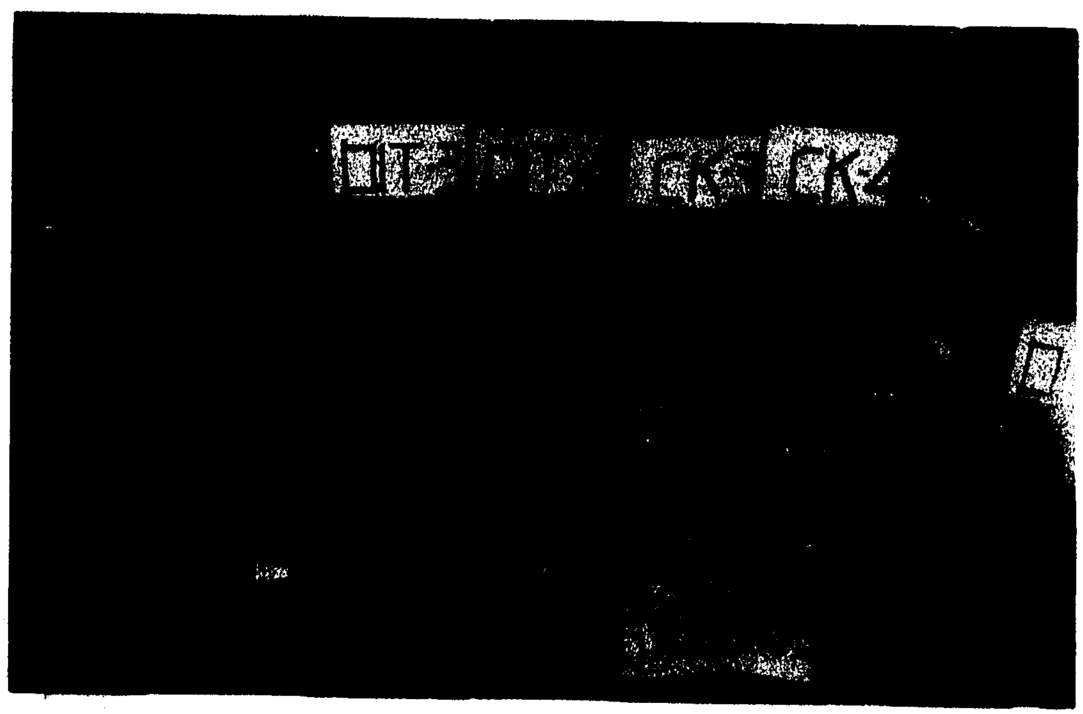

Illustration 4: Experimenter's View of Apparatus for Experiments 3 and 4; Relays-Latching Relays.

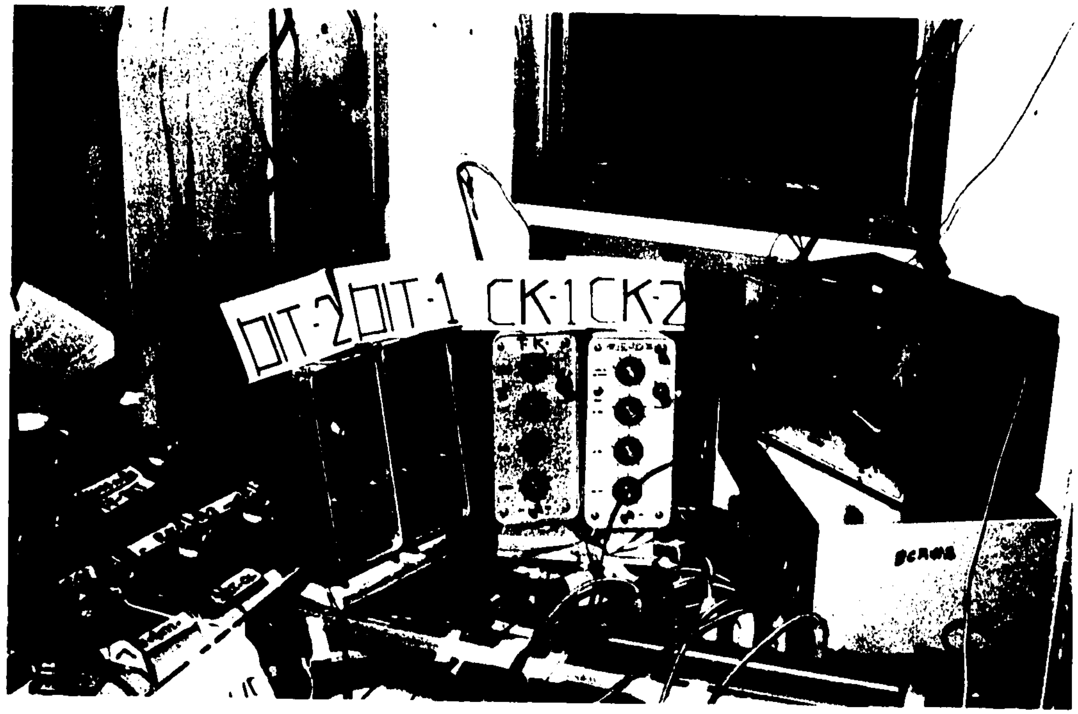

Illustration 3: Experimenter's View of Apparatus for Experiments 1 and 2; DIT-Decade Interval Timer, CK-Klockcounter.

Illustration 4: Experimenter's View of Apparatus for Experiments 3 and 4; Relays-Latching Relays.

Appendix B

Table 9

Skewness Tests for Time Estimations for Each Time Standard for Each Subject and for Subjects Grouped, Experiment 1

Time Standards	Subject 1 Skewness	Subject 1 t-Test	Subject 2 Skewness	Subject 2 t-Test
0.5	-64	-1.19	-16	-.40
1.0	-84	-1.94	21	0.52
2.0	60	0.67	75	1.14
4.0	-76	-0.74	68	0.54
8.0	109	0.83	123	0.71

Time Standards	Subject 3 Skewness	Subject 3 t-Test	Subject 4 Skewness	Subject 4 t-Test
0.5	30	1.42	28	1.00
1.0	17	0.49	23	0.90
2.0	44	0.76	-23	-0.49
4.0	-69	-0.97	-81	-0.67
8.0	-53	-0.69	-166	-1.09

Time Standards	Subject 5 Skewness	Subject 5 t-Test	Subject 6 Skewness	Subject 6 t-Test
0.05	-12	-0.80	-33	0.83
1.0	51	2.26*	17	0.25
2.0	-64	-1.37	144	1.90
4.0	145	1.82	60	0.47
8.0	107	0.73	213	0.93

Table 9 (Continued)

Time Standards	Subject 7 Skewness	Subject 7 t-Test	Subject 8 Skewness	Subject 8 t-Test
0.5	33	1.06	-44	-1.45
1.0	00	0.01	-26	-1.09
2.0	-39	-0.72	-22	-0.37
4.0	33	0.57	-05	-0.03
8.0	42	0.55	-102	-0.49

Time Standards	Subject 9 Skewness	Subject 9 t-Test	Subjects Grouped Skewness	Subjects Grouped t-Test
0.5	01	0.09	-38	-2.48*
1.0	00	-0.03	75	4.28**
2.0	02	0.06	143	4.67**
4.0	69	1.13	137	2.83**
8.0	-188	-0.85	-95	-1.11

**Significant at the 0.01 level

*Significant at the 0.05 level

Table 10

Newman-Keuls Test Applied to Time Standards Main Factor for One-Way Analysis of Variance, Experiment 1

Time Estimations

Treatment in order of totals		8.0	4.0	2.0	1.0	0.5
Totals		465,159 (5)	703,243 (4)	1,119,649 (3)	2,207,600 (2)	4,151,671 (1)
		5	4	3	2	1
	5		238,084**	654,490**	1,742,441**	3,686,512**
	4			416,406**	1,504,357**	3,448,428**
	3				1,087,951**	3,032,022**
	2					1,944,071**
	1					

Truncated range r	2	3	4	5
q99 (r, 2695)	3.64	4.12	4.40	4.60
q99 (r, 2695) n x MSerror	68,867	77,949	83,246	87,030

** Significant at the 0.01 level

Table 11

Newman-Keuls Test Applied to Time Standards Main Factor for the One-Way Analysis of Variance, Experiment 1

Intra-Subject Coefficients of Proximity

Treatments(T) in order of totals	8.0	4.0	2.0	1.0	0.5
Totals	603.63 (5)	660.04 (4)	675.71 (3)	708.89 (2)	949.07 (1)
	5	4	3	2	1
5		54.42	72.08	104.76	345.44**
4			15.66	48.34	289.02**
3				32.68	273.36**
2					240.68**
1					

Truncated range r	2	3	4	5
q99 (r, 265)	3.64	4.12	4.40	4.60
q99 (r, 265) n x MSerror	131.69	149.05	159.18	166.42

** Significant at the 0.01 level

Table 12

Newman-Keuls Test Applied to Time Standards Main Factor, Experiment 1

Inter-Subject Coefficients of Proximity

Treatments(T) in order of totals		8.0	4.0	2.0	1.0	0.5
Totals		114,440 (5)	125,000 (4)	138,620 (3)	154,620 (2)	183,880 (1)
		5	4	3	2	1
	5		13,560	27,180	43,179**	72,440**
	4			13,620	29,620**	58,880**
	3				16,000	45,260**
	2					29,260**
	1					
Truncated range r			2	3	4	5
q99 (r,25)			3.96	4.54	4.91	5.17
q99 (r, 25) n x MSerror			24,501.51	28,090.12	30,379.40	31,988.08

** Significant at the 0.01

Table 13

Newman-Keuls Test Applied to the Time Standards Main Factor for One-Way Analysis of Variance, Experiment 1

Intra-Subject Percentage Constant Error

Treatments(T) in order of totals		8.0	4.0	2.0	1.0	0.5
Totals		518,966 (5)	547,855 (4)	659,105 (3)	710,074 (2)	938,158 (1)
		5	4	3	2	1
	5		28,889	140,139**	191,108**	419,192**
	4			111,250**	162,219**	390,303**
	3				50,696	279,053**
	2					228,084**
	1					

Truncated range r	2	3	4	5
q99 (r,265)	3.64	4.12	4.40	4.60
q99 (r, 265) n x MSerror	73,571.01	83,272.65	88,931.96	92,974.32

** Significant at the 0.01 level

Table 14

Newman-Keuls Test Applied to Time Standards Main Factor, Experiment 1

Inter-Subject Percentage Constant Error

Treatments(T) in order of totals	8.0	4.0	2.0	1.0	0.5
Totals	57,665 (5)	61,321 (4)	73,235 (3)	78,136 (2)	103,336 (1)
	5	4	3	2	1
5		3,656	15,570	20,471	45,701
4			11,914**	16,815**	42,045**
3				4,901**	30,131**
2					25,230**
1					
Truncated range r		2	3	4	5
q99 (r, 25)		3.96	4.54	4.91	5.17
q99 (r, 25) n x MSerror		4,508.94	5,169.33	5,590.62	5,886.67

** Significant at the 0.01 level

Table 15

Cell Means for the Time Standards Main Factor for the Four One-Way Analyses of Variance for Experiment 1, Primary Analyses, Inter and Intra-Subject PCEs and Coefficients

		Time Standards (Seconds)				
		0.5	1.0	2.0	4.0	8.0
Coefficient or Proximity Means	Intra-Subject (grouped)	17.78	13.31	12.52	12.28	11.18
	Inter-Subject	30.64	25.77	23.10	20.83	18.62
Percentage Constant Error Means	Intra-Subject (grouped)	73.64	31.43	22.06	1.45	-3.89
	Inter-Subject	73.27	31.22	22.05	1.49	-3.89

Table 16

Cell Means and Standard Deviations for the Time Standards Main Factor, Experiment 1 Time Estimations

	Time Standards (Seconds)				
	0.5	1.0	2.0	4.0	8.0
Means	861	1302	2441	4088	7688
Standard Deviation	265	343	575	859	1432

Note: Means and standard deviations are in milliseconds.

Table 17

Newman-Keuls Test Applied to Time Standards Main Factor for Three-Way Analysis of Variance, Experiment 1

Time Estimations

Treatments in order of totals		8.0	4.0	2.0	1.0	0.5
Totals		465,159 (5)	703,243 (4)	1,119,649 (3)	2,207,600 (2)	4,151,671 (1)
		5	4	3	2	1
	5		238,084	654,490**	1,742,441**	3,696.5;2**
	4			416,406**	1,504,357**	3,448,428**
	3				1,087,951**	3,032,022**
	2					1,944,071**
	1					

Truncated range r	2	3	4	5
q99 (r,540)	3.89	4.45	4.80	5.05
q99 (r, 540) n x MSerror	296,078	338,701	365,340	384,368

** Significant at the 0.01 level

Table 18

Intra-Subject Coefficients of Proximity for Each Time Standard Condition for Each Subject, Experiment 1

	Time Standards (Seconds)				
	0.5	1.0	2.0	4.0	8.0
Subjects					
S 1	29.45	16.01	18.34	14.25	9.66
S 2	24.97	18.68	13.97	15.62	12.30
S 3	13.13	15.44	13.29	9.29	6.68
S 4	17.27	11.47	12.10	15.27	10.19
S 5	18.61	13.73	15.21	14.41	13.64
S 6	22.61	22.98	18.11	16.34	15.06
S 7	17.22	14.40	9.19	8.48	6.53
S 8	18.39	13.57	16.17	21.30	15.35
S 9	12.07	8.72	9.06	10.61	19.10

Table 19

Newman-Keuls Test Applied to the Time Standards Main Factor for Each Subject and for Subjects Grouped, Experiment 1

Intra-Subject Coefficients of Proximity

Treatment Conditions in Order of Totals

	Subject 1						Subject 2				
Treatments	8.0	4.0	2.0	1.0	0.5		8.0	2.0	1.0	4.0	0.5
8.0		26.2	29.3	42.5	115.5**	8.0		2.6	6.5	7.8	58.5
4.0			3.1	16.2	89.3**	2.0			3.9	5.1	55.7
2.0				13.1	86.2**	1.0				1.2	51.8
1.0					73.9**	4.0					50.6
0.5						0.5					

	Subject 3						Subject 4				
Treatments	8.0	4.0	2.0	0.5	1.0		8.0	2.0	1.0	4.0	0.5
8.0		15.6	23.3	42.5	44.6	8.0		4.1	7.0	22.6	35.1
4.0			7.7	26.3	29.0	2.0			2.9	18.5	31.0
2.0				19.2	21.3	1.0				15.6	28.1
0.5					2.1	4.0					12.5
1.0						0.5					

Table 19 (Continued)

Treatment Conditions in Order of Totals

Treatments	Subject 5						Subject 6				
	4.0	8.0	1.0	2.0	0.5		4.0	8.0	2.0	1.0	0.5
4.0		8.0	9.9	15.9	61.1	4.0		.85	16.8	32.9	41.8
8.0			1.9	7.9	35.8	8.0			15.9	32.5	41.5
1.0				6.0	33.9	2.0				16.6	25.6
2.0					28.0	1.0					8.9
0.5						0.5					

	Subject 7						Subject 8				
	8.0	4.0	2.0	0.5	1.0		1.0	2.0	8.0	0.5	4.0
8.0		5.7	24.8	37.8	46.7	1.0		14.5	16.5	19.0	40.4
4.0			19.1	32.1	41.0	2.0			2.0	4.5	25.9
2.0				13.0	21.9	8.0				2.5	23.7
0.5					8.9	0.5					21.4
1.0						4.0					

Table 19 (Continued)

Treatment Conditions in Order of Totals

Subject 9					
Treatments	1.0	2.0	4.0	0.5	8.0
1.0		.29	13.3	23.6	47.3
2.0			13.0	23.3	47.0
4.0				10.3	34.0
0.5					23.7
8.0					

Subjects Grouped					
	8.0	4.0	2.0	1.0	0.5
8.0		54.4	72.1	104.8	345.4**
4.0			15.7	48.3	289.0**
2.0				32.7	273.4**
1.0					240.1**
0.5					

	Truncated range r		2	3	4	5
	q^{99} (r, 32)		3.89	4.45	4.80	5.05
Subjects	q^{99} (r, 32)	n x MSerror	69.16	79.12	85.34	89.79
Subjects Grouped	q^{99} (r, 32)	n x MSerror	207.58	237.46	256.14	269.48

**Signficant at the 0.01 level.

Table 20

Newman-Keuls Test Applied to the Time Standards Main Factor for Two-Way Analysis of Variance, Experiment 1

Intra-Subject Coefficients of Proximity

Treatments (T) in order of totals	8.0	4.0	2.0	1.0	0.5
Totals	603.63 (5)[1]	660.05 (4)	675.71 (3)	708.89 (2)	949.07 (1)
	5	4	3	2	1
5		54.42	72.08	104.76	345.44**
4			15.66	48.34	289.02**
3				32.68	273.36**
2					240.68**
1					

Truncated range r	2	3	4	5
q99 (r, 32)	3.89	4.45	4.80	5.05
q99 (r, 32) n x MSerror	207.58	237.46	256.14	269.48

[1] The numbers in parenthesis refer to the particular treatment level total in the block it is located.

**Significant at the 0.01 level.

Table 21

Cell Means for Subjects by Treatments Primary Main Effects, Experiment 1, Intra-Subject Percentage Constant Error

	Time Standards (Seconds)				
	0.5	1.0	2.0	4.0	8.0
Subjects					
S 1	101.37	40.71	33.25	.74	-.78
S 2	72.11	41.75	49.35	20.22	9.00
S 3	94.50	29.29	23.07	1.73	-5.02
S 4	100.99	48.54	17.27	13.13	14.38
S 5	4.03	-4.53	-11.84	-23.17	-30.43
S 6	105.88	85.23	62.70	25.66	9.59
S 7	99.10	18.26	15.38	-9.76	-8.49
S 8	69.58	13.68	6.50	5.05	-6.20
S 9	3.04	-.88	2.88	-13.94	-17.12

Table 22

Newman-Keuls Test Applied to the Time Standards Main Factor for Each Subject and for Subjects Grouped, Experiment 1
Intra-Subject Percentage Constant Error

Treatment Conditions in Order of Totals

	Subject 1						Subject 2				
Treatments	8.0	4.0	2.0	1.0	0.5		8.0	4.0	2.0	1.0	0.5
8.0		1,069	20,148	29,397	61,291**	8.0		57,83	19,654	24,216	44,863
4.0			19,349	28,328	60,222**	4.0			13,871	18,433	39,080
2.0				8,979	40,873**	2.0				4,562	25,209
1.0					31,894**	1.0					20,647
0.5						0.5					

	Subject 3						Subject 4				
Treatments	8.0	4.0	2.0	1.0	0.5		4.0	8.0	2.0	1.0	0.5
8.0		4,062	16,851	20,618	59,714**	4.0		649	2,347	21,147**	52,607**
4.0			12,789	16,556	55,652**	8.0			1,698	20,498	51,958**
2.0				3,767	42,863**	2.0				18,800	50,260
1.0					39,096	1.0					31,460
0.5						0.5					

Table 22 (Continued)

Treatment Conditions in Order of Totals

	Subject 5						Subject 6				
Treatments	8.0	4.0	2.0	1.0	0.5		8.0	4.0	2.0	1.0	0.5
8.0		4,062	16,851	20,618	59,714**	8.0		9,641	31,865	45,653**	57,774**
4.0			12,789	16,556	55,652**	4.0			22,224	36,012	48,133**
2.0				3,767	42,863**	2.0				13,788	25,909
1.0					39,096	1.0					12,121
0.5						0.5					

	Subject 7						Subject 8				
Treatments	4.0	8.0	2.0	1.0	0.5		8.0	4.0	2.0	1.0	0.5
4.0		755	15,075	16,810	65,655**	8.0		6,753	7,622	11,929	45,471
8.0			14,320	16,055	64,900**	4.0			869	4,906	38,448
2.0				1,735	50,580**	2.0				4,307	37,849
1.0					48,845**	1.0					33,542
0.5						0.5					

Table 22 (Continued)

Treatment Conditions in Order of Totals

	Subject 9						Subject Groups				
Treatments	8.0	4.0	2.0	1.0	0.5		8.0	4.0	2.0	1.0	0.5
8.0		1,906	11,764	12,000	12,097	8.0		28,889	140,139**	191,108**	419,182**
4.0			9,858	10,094	10,191	4.0			111,250**	162,219**	409,303**
2.0				236	333	2.0				50,696	279,053**
1.0					97	1.0					228,084**
0.5						0.5					

		2	3	4	5
	Truncated range r	2	3	4	5
	q99 (r, 32)	3.89	4.45	4.80	5.05
Subjects	q99 (r, 32) n x MSerror	35,529	40,644	43,841	46,124
Subjects Grouped	q99 (r, 32) n x MSerror	106,586	121,933	131,524	138,374

** Significant at the 0.01 level.

Appendix C

Table 23

Standard Deviations for Each Subject
For Each Time Standard, Experiment 1

	Time Standards (Seconds)				
	0.5	1.0	2.0	4.0	8.0
Subjects					
S 1	296	225	488	574	767
S 2	214	264	417	751	1072
S 3	127	199	327	378	508
S 4	173	170	283	692	933
S 5	96	131	268	443	759
S 6	232	425	589	821	1320
S 7	171	170	294	306	478
S 8	155	154	344	895	1152
S 9	62	86	186	365	1266

Note: Standard deviations are in milliseconds.

Table 24

Mean Estimates for Each Subject for Each Time Standard, Experiment 1

	Time Standards (Seconds				
	0.5	1.0	2.0	4.0	8.0
Subjects					
S 1	1006	1407	2665	4029	7937
S 2	860	1417	2987	4808	8720
S 3	972	1292	2461	4069	7598
S 4	1004	1485	2345	4532	9150
S 5	520	954	1763	3072	5565
S 6	1029	1852	3254	5026	8767
S 7	995	1182	2307	3609	7320
S 8	847	1136	2130	4202	7503
S 9	515	991	2057	3442	6630

Note: Mean estimates are in milliseconds.

Appendix D

Table 32

Newman-Keuls Test Applied to Time Standards Main Factor for Two-Way Analysis of Variance, Experiment 2

		Time Estimations				
Treatments (T) in order of means		0.5	1.0	2.0	4.0	8.0
Means		619 (5)	1,143 (4)	1,981 (3)	3,388 (2)	6,105 (1)
		5	4	3	2	1
	5		542**	1,362**	2,769**	5,486**
	4			818**	2,245**	4,962**
	3				1,407**	4,124**
	2					2,717**
	1					

Truncated range r		2	3	4	5
q^{99} (r, 16)		4.13	4.78	5.19	5.49
q^{99} (r, 16)	MSerror/n	159.7	184.8	200.7	212.3

**Significant at the 0.01 level.

Table 33

Newman-Keuls Test Applied to Time Standards Main Factor for Two-Way Analysis of Variance, Experiment 2

Intra-Subject Coefficients of Proximity

Treatment (T) in order of means		8.0	4.0	2.0	1.0	0.5
Means		7,632 (5)	8,471 (4)	9,906 (3)	11,430 (2)	12,388 (1)
		5	4	3	2	1
	5		839	2,274**	3,798**	4,756**
	4			1,435**	2,959**	3,917**
	3				1,544**	2,482**
	2					958**
	1					

Truncated range r		2	3	4	5
q99 (r, 16)		4.13	4.78	5.19	5.49
q99 (r, 16)	MSerror/n	8,657.50	10,020.00	10,879.50	11,508.40

** Significant at the 0.01 level.

Table 34

Newman-Keuls Test Applied to Time Standards Main Factor for Three-Way Analysis of Variance, Experiment 2

Intra-Subject Coefficients of Proximity

Treatments (T) in order of means		8.0	4.0	2.0	1.0	0.5
Means		1,634 (5)	1,791 (4)	2,185 (3)	2,271 (2)	2,697 (1)
		5	4	3	2	1
	5		157	551**	637**	1,063**
	4			394	480**	906**
	3				86	512
	2					426**
	1					

Truncated range r		2	3	4	5
q99 (r, 160)		3.64	4.12	4.40	4.60
q99 (r, 160)	MSerror/n	400.80	453.60	453.60	506.50

** Significant at the 0.01 level.

Table 35

Newman-Keuls Test Applied to the Time Standards Main Factor for Three-Way Analysis of Variance, Experiment 2

Intra-Subject Percentage Constant Error

Treatment(T) in order of means		8.0	4.0	2.0	1.0	0.5
Means		7,610 (5)	8,264 (4)	9,906 (3)	11,401 (2)	12,319 (1)
		5	4	3	2	1
	5		654	2,296**	3,791**	4,709**
	4			1,642	3,137**	4,055**
	3				1,495	2,413**
	2					918
	1					
Truncated range r		2	3	4	5	
q99 (r, 24)		3.96	4.54	4.91	5.17	
q99 (r, 24)	MSerror/n	1,799.0	2,062.7	2,230.8	2,348.9	

**Significant at the 0.01 level.

Table 36

Cell Means for the Time Standards by Previous Standard Interaction, Experiment 2

Intra-Subject PCEs, Coefficients and Standard Deviations

Time Standards (seconds)		Previous Standard (Seconds) 0.5	1.0	2.0	4.0	8.0
	PCE	31.5	12.0	18.1	23.5	30.9
0.5	C.P.[1]	30.6	25.9	33.7	27.5	17.2
	S.D.[2]	201	144	199	170	112
	PCE	15.9	11.4	15.0	15.7	11.9
1.0	C.P.	21.5	26.05	23.6	21.0	21.4
	S.D.	250	290	271	242	239
	PCE	-08.7	-02.5	03.8	03.7	-01.1
2.0	C.P.	23.6	17.7	20.3	24.0	23.6
	S.D.	431	346	438	497	466
	PCE	-31.0	-14.6	-15.6	-11.6	-13.9
4.0	C.P.	16.2	19.3	18.3	20.3	15.5
	S.D.	448	658	625	716	534
	PCE	-22.4	-25.9	-23.8	-23.7	-21.6
8.0	C.P.	17.1	16.1	15.9	19.0	13.5
	S.D.	1,036	957	966	1,159	935

1 Coefficient of proximity

2 Standard deviation (milliseconds)

Table 37

Cell Means and Standard Deviations for Time Standards
Main Factor, Experiment 2

Time Estimations

	Time Standards (Seconds)				
	0.5	1.0	2.0	4.0	8.0
Means	619	1,143	1,981	3,388	6,105
Standard Deviations	210	357	711	987	1,717

Note: Means and Standard deviations are in miliseconds.

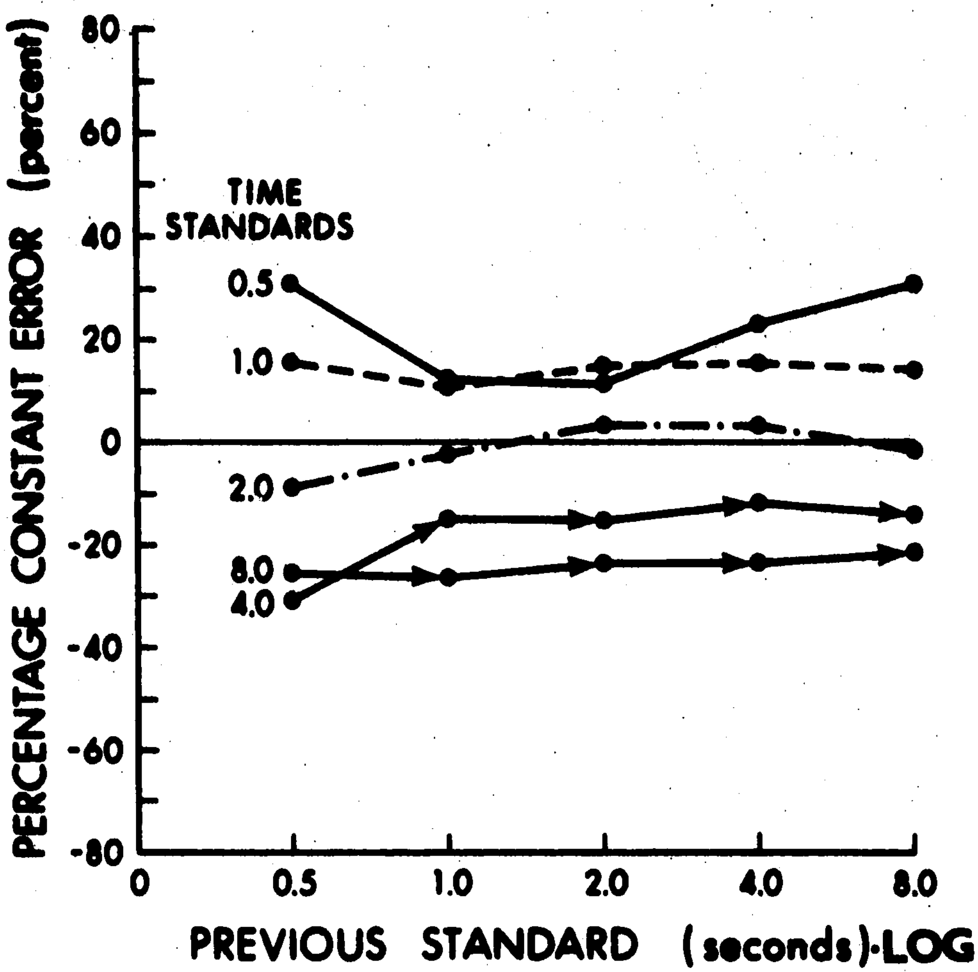

Figure 5: Mean PCE for each Time Standard For each Previous Standard, Experiment 2.

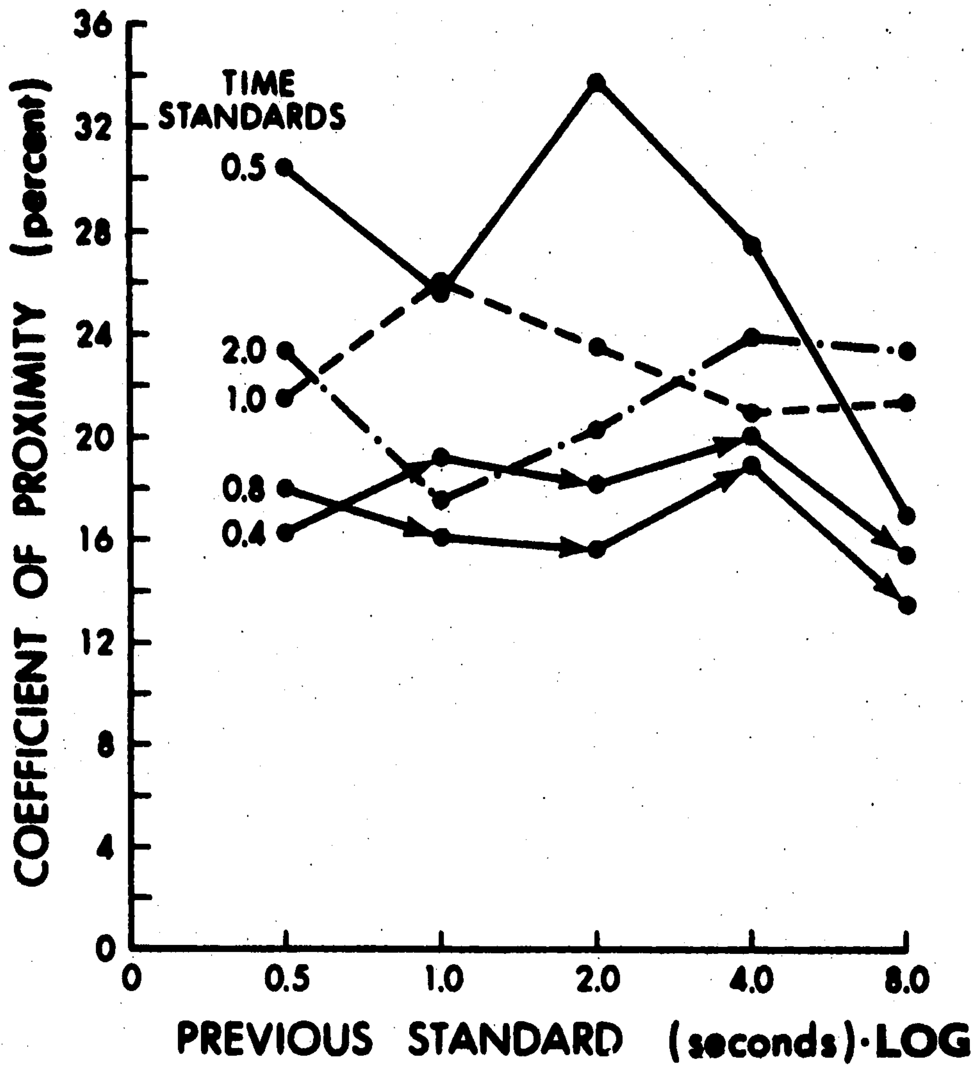

Figure 6: Mean Coefficient of Proximity for Each Time Standard for Each Previous Standard, Experiment 2.

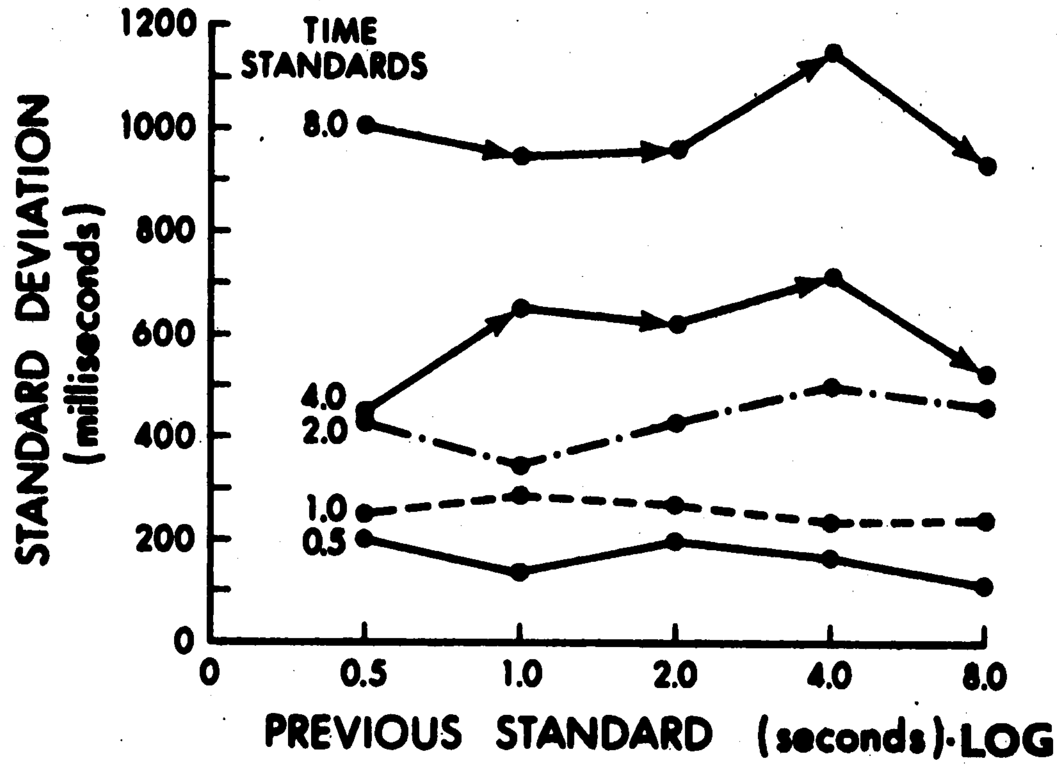

Figure 7: Mean Standard Deviation for Each Time Standard For Each Previous Standard for Experiment 2.

Appendix E

Table 43

Time Estimation (Experiment 1) and SRT Means, Experiment 3

	Foreperiod Conditions (Seconds)									
	0.5		1.0		2.0		4.0		8.0	
Subjects	TK	SRT	TK	SRT	TK	SRT	TK	SRT	TK	SRT
S 1	1006	216	1407	183	2665	173	4029	182	7937	217
S 2	860	155	1417	162	2987	185	4808	167	8720	169
S 3	972	127	1292	138	2461	130	4069	128	7598	132
S 4	1004	141	1485	137	2345	143	4532	146	9150	145
S 5	520	126	954	122	1763	150	3072	149	5565	152
S 6	1029	119	1552	128	3254	122	5026	148	8767	129
S 7	995	118	1182	120	2307	128	3609	140	7320	158
S 9	515	126	991	120	2057	146	3442	139	6630	147

Note: Time Estimation (TK) and Simple Reaction Time (SRT) are in milliseconds.

Table 44

Time Estimation (Experiment 1) and SRT Medians, Experiment 3

	Foreperiod Conditions (Seconds)									
	0.5		1.0		2.0		4.0		8.0	
Subjects	TK	SRT	TK	SRT	TK	SRT	TK	SRT	TK	SRT
S 1	1031	212	1447	189	2634	168	4050	177	7919	202
S 2	861	154	1409	161	2915	187	4774	161	8608	165
S 3	961	126	1289	140	2434	128	4074	125	7640	126
S 4	971	145	1480	135	2357	142	4580	143	9151	141
S 5	533	126	936	119	1792	152	3021	145	5534	152
S 6	1046	119	1831	121	3114	127	4997	132	8669	124
S 7	972	117	1174	119	2314	125	3573	141	7315	145
S 9	514	127	994	117	2059	140	3375	137	6519	146

Note: Time Estimation (TK) and Simple Reaction Time (SRT) are in milliseconds.

Table 45

Time Estimation (Experiment 1) and SRT Standard Deviations, Experment 3

Subjects	0.5 TK	0.5 SRT	1.0 TK	1.0 SRT	2.0 TK	2.0 SRT	4.0 TK	4.0 SRT	8.0 TK	8.0 SRT
	Foreperiod Conditions (Seconds)									
S 1	296.57	28.71	225.40	22.29	488.78	37.72	574.45	23.74	767.07	44.20
S 2	214.93	25.96	264.81	18.49	417.45	32.42	715.28	29.01	1072.87	28.26
S 3	127.70	08.94	199.65	14.19	327.14	16.15	378.11	17.94	508.21	13.45
S 4	173.62	10.65	170.48	18.96	283.83	20.59	692.24	21.19	933.01	24.82
S 5	96.81	17.72	131.12	16.43	268.29	19.38	443.08	27.69	759.56	28.67
S 6	232.79	13.38	425.75	19.29	589.40	13.19	821.73	35.97	1320.85	20.68
S 7	171.40	10.62	170.37	16.34	294.90	15.05	306.20	16.01	478.47	30.65
S 9	62.20	15.27	86.52	13.16	186.51	30.12	365.37	24.20	1266.65	18.75

Note: Time Estimation (TK) and Simple Reaction Time (SRT) are in milliseconds.

Table 46

Time Estimation (Experiment 1) and SRT SIRs, Experiment 3

	Foreperiod Conditions (Seconds)									
	0.5		1.0		2.0		4.0		8.0	
Subjects	TK	SRT	TK	SRT	TK	SRT	TK	SRT	TK	SRT
S 1	404	43	304	33	472	34	832	34	1118	71
S 2	271	32	310	18	526	33	975	23	1493	18
S 3	189	15	246	23	442	30	491	20	581	25
S 4	234	8	200	18	252	21	1000	11	1331	22
S 5	142	27	183	14	400	25	686	27	990	35
S 6	303	15	233	11	460	22	329	28	662	39
S 7	280	15	466	26	618	25	1124	40	1540	35
S 9	91	21	115	20	235	37	370	26	1656	19

Note: Time Estimation (TK) and Simple Reaction Time (SRT) are in milliseconds.

Table 47

Time Estimation (Experiment 1) and SRT Coefficients of Proximity (SD / Mean), Experiment 3

	Foreperiod Conditions (Seconds)									
	0.5		1.0		2.0		4.0		8.0	
Subjects	TK	SRT	TK	SRT	TK	SRT	TK	SRT	TK	SRT
S 1	29.5	13.3	16.0	12.1	18.3	21.7	14.3	13.0	9.7	20.1
S 2	25.0	16.6	18.7	11.4	14.0	17.4	15.6	17.4	12.3	16.7
S 3	13.1	7.0	15.4	10.2	13.3	12.3	9.3	13.3	6.7	10.2
S 4	17.3	7.5	11.5	13.8	12.1	14.3	15.3	14.4	10.2	17.1
S 5	18.6	14.0	13.7	13.5	15.2	12.9	14.4	15.2	13.6	18.8
S 6	22.6	11.2	23.0	15.1	18.1	10.7	16.3	24.2	15.1	16.0
S 7	17.2	8.9	14.4	13.5	9.2	11.8	8.5	11.4	6.5	19.4
S 9	12.1	12.1	8.7	10.9	9.1	20.6	10.6	17.4	19.1	12.7

Note: Time Estimation (TK) and Simple Reaction Time (SRT) are in milliseconds.

Table 48

Time Estimation (Experiment 1) and SRT Coefficients of Proximity (SIR / Median), Experiment 3

	Foreperiod Conditions (Seconds)									
	0.5		1.0		2.0		4.0		8.0	
Subjects	TK	SRT	TK	SRT	TK	SRT	TK	SRT	TK	SRT
S1	39.2	20.6	21.0	17.4	17.8	20.2	20.4	19.2	14.1	35.2
S 2	31.2	20.8	27.6	11.0	18.0	16.8	20.4	14.4	17.2	10.8
S 3	18.6	11.0	19.0	16.2	18.2	23.2	12.0	15.8	7.6	19.8
S 4	24.0	5.6	13.4	13.2	14.8	14.8	21.8	7.2	14.4	15.8
S 5	26.6	21.4	19.4	11.2	22.2	16.4	22.6	18.2	16.0	22.8
S 6	28.8	12.6	25.4	22.2	19.8	18.4	22.4	30.1	17.6	28.2
S 7	28.8	12.6	19.8	8.8	19.8	17.8	9.2	19.8	9.0	24.8
S 9	15.6	16.2	11.4	17.0	11.4	26.8	11.0	19.2	25.4	12.8

Note: Time Estimation (TK) and Simple Reaction Time (SRT) are in milliseconds.

Appendix F

Table 49

Means and Standard Deviations for SRT for Each Foreperiod Condition, Experiment 3

	Foreperiod Conditions (Seconds)				
	0.5	1.0	2.0	4.0	8.0
Means	141	138	147	149	156
Standard Deviation	16.41	17.40	23.09	23.84	26.36

Note: Means and Standard Deviations are in milliseconds.

Appendix G

Table 52

Skewness Tests for Each Cell Formed by the Main Factors in Experiment 4

Condition Number	Skewness	t-Test
1	36.5	5.29**
2	38.0	4.04**
3	16.0	2.22*
4	19.5	2.82**
5	12.0	2.40*
6	20.0	3.08**
7	9.0	1.36
8	5.0	0.71

* Significant at the 0.05 level

**Significant at the 0.01 level