TIME ESTIMATION:
AN INVESTIGATION OF METHOD AND INTERVAL VARIABLES

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'Time' is a subject which seems to have fascinated men from the beginning of history! The practical man approached it by inventing machines which (presumably) measured the passing of time, without worrying very much whether the time, and time passing, were the same thing. Philosophers also were interested in time; some of them (notably Whitehead and Alexander) have recently used it as one of the basic concepts in their systems. Psychologists also have been interested in the subject, mostly from a practical point of view, and as a result many experiments relating to time have been carried out.

Knowledge of time estimation can be applied in the area of clinical psychology, for distortions of time are frequently seen in cases of mental illness. Although many studies have been carried out on the ability of different diagnostic groups to estimate time, the results are of limited value only, for basic disagreements about time estimation itself still exist. The three main problems are: first, the method of measuring time estimation is still in the process of being procedurally defined; second, the relationships between the various methods generally accepted as measuring time estimation are still ill-defined; and third, the variables affecting performance still remain to be specified.

It is the purpose of this study, then, to investigate these basic questions, with a view to opening up the way to more valuable clinical studies. More specifically, the aim of this study is to investigate the reliability of, and inter-relationships between, three methods of time estimation, using intervals of varying lengths.

LITERATURE SURVEY

The following represent general reviews of literature on time estimation. Before considering these, however, it is necessary to define several terms which appear frequently in the literature. There are three common methods of investigating time estimation: first, by the method of reproduction, in which the experimenter marks off a certain length of time by two signals, and the subject then attempts to mark off an equal length of time by two signals; second, the method of production, in which the experimenter names an interval and the subject attempts to mark off that length of time by two signals; and third, the method of estimation, in which the experimenter marks off a length of time by two signals and the subject guesses verbally at the length.

By tradition, the method of reproduction is the one most associated with time estimation, and so it will be chosen as the validity criterion for the methods of time estimation used in this study.

Throughout this study, the time 'over-estimation' will be used to refer to the result when the judgement given by the subject, regardless of the method employed, is larger in size than the stimulus interval.

Reviews.

The first reviews in the area of time perception and estimation were published by Dunlap in 1911 (13), 1912 (14), 1914 (15), and 1916(16). In 1931 Triplett (59) published a survey of time estimation from 1886 to the end of the twenties of this century. Two years later Weber(61) published his review which has since come to be accepted as the classic early review in this area. Weber concludes:"... the greatest part of the experimental work on the estimation of time still remains to be done, as many of the most promising aspects of the problem have as yet only been touched upon", (61, p. 249). The latest review is by Gilliland, Hofeld and Eckstrand, (28), published in 1946. Israeli (35) has also made a summary article.

These, then represent general review articles. Attention will now be directed to a discussion of specific variables relevant to the present study.

Clinical Studies.

Since this is a methodogical study, the question can be legitimately raised as to the relevance in contemporary psychology of questions of time estimation. In order to demonstrate that there is interest in, and need for, reliable methods of time estimation, a brief review of the relevant clinical and developmental literature follows.

The clinician (psychiatrist, neurologist, or psychologist) who asks the patient to estimate time by tapping on the table or by some other simple procedure is capitulating to the common belief that a distortion of time is often to be found in psychopathological states, and is also adhering to the rather more questionable belief that such a procedure is an effective method of demonstrating such distortion. Any study, therefore, which investigates the nature of the process involved in time estimation, the nature of distortion of time, or efficient methods of revealing such distortion, is of interest to the clinician.

Although there has been much work done in this area, most of it has been published in French, German, and Spanish, in journals not usually available on this continent. The following is an attempt to integrate the results of such studies, as described in English abstracts and reviews, with those of English studies, and to draw from this integration certain conclusions which, under the circumstances, can be no more than tentative.

Despite the large number of experimental studies, there have been relatively few attempts at explaining the underlying mechanism of time disturbance, even within a particular theoretical framework. Babcock (2) has written a book on the part played by time in schizophrenia and in doing so has developed her own theory. Minkowski (46) has also made some attempt to explain why time disturbance should be a common factor in many mental illnesses. A review article has been written by Israeli (35), covering many of the following studies.

There have been two studies on chronognosia published. The first is a report on a single patient made by Bouman and Grunbaum (6) in

1929. This patient, at the time of examination, showed no signs of mental illness, but had been suffering from a serious shortening of time for a number of years. Eighteen years were estimated as two years. No history of an organic condition was given, although it is always possible that such a condition had passed unnoticed at some earlier period of life. In the second study, Davidson (11) reports seven cases where serious disturbances of time had appeared without other mental symptoms. However, in these the disturbances are ascribed to previous traumatic, alcoholic, and circulatory disturbances of the brain.

Several other authors have published work on time perception and estimation in organics. Guttmann (31) dealt with disturbances in the time sense of organics, particularly in Korsakow's disease, and attributed such disturbances to changes in 'spontaneity'. Schilder (53) has postulated that an organic disturbance of the vestibular apparatus can cause time disturbance. Krauss (39) attributed the time sense to both mental interpretation and a 'primitive sense of duration' which, he asserts, is a function of some part of the midbrain. It is this total, complex process that is disturbed in conditions such as Korsakow's disease. In an experiment on time perception, Fraisse (23) asserts that (psychotic) organics had more difficulty in perceiving simultaneity of two stimuli than other psychotics. In fact, the twelve organics who were his subjects were unable to perceive simultaneity.

Pumpian-Mindlin (50) conducted an experiment on 80 normals and 80 epileptics. He found that the epileptics differed from the normals in making a higher percentage of errors, in being more influenced by the time of day, and in consistently decreasing accuracy of performance as age increased. Cohen and Rochlin (10) reported on one patient with a history of some sort of convulsive disorder and an inability to localize events in past time. They attribute this symptom to disturbed self-awareness.

Meininger (45) in his discussion of distortions in neurosis, comments that disturbance of the space factor is regarded as typical of hysteria, and of the time factor as typical of psychasthenia and compulsive disorders. Dobson (12) conducted an experiment using a number of different conditions, and normal, neurotic, and schizophrenic subjects. He found no significant differences in ability to estimate time. He commented that if it is assumed that anxiety is the common factor in the neurotic group, then the hypothesis that amount of anxiety and length of judgement are positively correlated was not upheld. The neurotics as a group tended to be both more accurate and more consistent. The author explains this by postulating that the neurotics are more highly motivated to do well, and are also more concerned with 'time' itself.

There has probably been more work done on time distortion in schizophrenia than in any other single nosological group. Babcock (2) wrote a book on the subject. As early as 1929 Fischer (21) discussed in detail the types of time disturbance found in various forms of schizophrenia. He concluded that possibly every case involves temporal disorders, which may take the form of objectification, distortion, or disintegration. In a later study, Fischer (22) discussed three schizophrenics and the relationship between space-time and thought disturbance. Horanyi-Hechst has written an article (34) in which he describes four different aspects of time and the part played by disturbances of each of these in schizophrenia. The first is the primitive time sense, a function of the hypothalamus; this is rarely disturbed in schizophrenia. The second is the feeling for time which makes possible the objectification of experiences; this is often disturbed. The third is the so-called gnostic time sense, the marking of experiences with conventional time symbols; this is frequently distorted. The fourth, which is the highest aspect of time, is the ability to experience duration as a unified continuum; this is almost always disturbed.

More general studies on time perception in psychotics have been conducted by Israeli (36) and Fraisse (23). The first of these is a book dealing, in part, with the attitude to the future found in psychotics. The second is a study on psychotics, organic psychotics, and aphasics; of these, the patients with functional psychoses appeared to have the greatest difficulty in perceiving and reproducing short intervals of time, especially when the interval is unfilled.

In 1928 Straus (57) proposed the use of time disturbance as a diagnostic aid to separate endogenous and psychogenic forms of depression. The conception of the past and the present were the major factors involved. Kloos (37) agreed that distortions of time in depressions are universal, but disagreed with the criterion of uniformity suggested by Straus. The disturbance, Kloos postulates, is often a symbolic expression of the state of mind, and may not necessarily vary with the degree of inhibition. Strauss (58) noted that in depressive cases time often seems to 'stand still'. An unreality of time, where the present does not seem continuous with the past, was also noted.

There has been only one study of time perception in delinquents. This was conducted by Barndt and Johnson (4) using 26 control and 26 delinquent boys, matched for age, I.Q., school achievement, and status index. The subjects were each given a sentence, and from this had to continue with a complete story, which was then scored on a six-point scale for duration of the action. The stories of the delinquents were significantly ($p < .02$) shorter. The author concluded that short time perspective is part of the pattern of delinquency.

More interesting data comes from investigations of time estimation ability in mentally retarded subjects. Brower and Brower (8) used 25 subjects, 12 of whom had been diagnosed as cases of endogenous amentia, while the other 13 were expgenous cases. There were 18 males and 12 females in the group. The C.A. ranged from 5.0 to 12.0, the M.A. from 6.0 to 8.25. The experimenters administered, individually, a time orientation questionnaire and a test of time estimating ability. The results showed: first, that time orientation and time estimation are at least partially independent for the exogenous group, but are more closely related for the endogenous group; and second, a 'substantial relationship' was found between intelligence and time orientation. It was concluded that mental ability has more influence upon both time orientation and time estimation than has 'social competence'.

In 1949 Gothberg published an article dealing with the concept of time held by the mentally retarded. Her subjects were 155 children with a C.A. range from 5.0 to 19.0 and an M.A. range from 2.0 to 12.0, and 11 adults with a C.A. of 25.0 to 45.0 and an M.A. of 7.0 to 10.0. Gothberg conducted individual interviews with these subjects, using questionnaire and interview techniques. She concluded, first, that the concept of time in the mentally retarded is closely related to M.A. Second, that C.A., experience, and 'special interests', were minor determinants. Third, that time concepts that are personally related to the child are the first to be developed. Fourth, that knowledge of time divisions does not presuppose ability to tell clock time. Fifth, there is little conception of sequence, relativity or historical time. From these two studies, it seems that in the mentally retarded there is a marked deficit in the conceptual and perceptual aspects of time, and also in the ability to estimate time.

From this survey, it is apparent that there are no data to justify the use of any method of time estimation in differential diagnosis. Straus (57) is the only writer to suggest such a procedure; but there are no experimental results to indicate, for example, that depressives under-estimate and schizophrenics over-estimate. However, one can tentatively conclude that both organic and psychiatric patients show greater variability and less accuracy in time estimation than normal adult subjects; although against this Dobson's results (12) must be set. Apart from this, it can be concluded that where a distortion of time does exist, it can take the form of a distortion of attitude to time (45) or a distortion in the perception of time (6, 11). If this is so, the clinician is presumably more likely to arrive at the disturbance by interview techniques than by a simplified version of a test of time estimation.

Developmental studies.

The development of the concept of time and related terms in children has been investigated by several workers. Rebello (51) in 1934 used a level technique by which a concept was considered 'established' at a certain age if 75% of that age group in his sample responded correctly to it. His 400 subjects, half boys and half girls, were divided into age groups from three to ten inclusive. He found that the concepts of morning and night were established by age four in boys, age five in girls. One's own age at age four in boys, age six in girls; early and late, boys four, girls five; today, yesterday and tomorrow, age six; before and after, boys five, girls four; determination of social time, age eight; abstract actions of past, present and future, age ten. Time divisions and relations of time and space are acquired late.

Four years later Bromberg (7) published a more general, descriptive study in the same area. He concluded that an 'appreciation' of time develops at age five or six, and matures slowly until ten or twelve. The child first understands time in terms of concrete objects (e.g. clocks) and only gradually develops this into the abstract concept of adults.

Friedman conducted two studies. In the first (25) he concludes that the conception of 'a short time ago' is clearer than 'a long time ago', but is still vague, even to a twelve year old. He asserts that time concepts are more closely related to grade placement than to I.Q. In his second study (26), he reports an experiment on 667 pupils in grades 7-12, and 194 adults. He used a series of tests designed to measure comprehension of temporal terms. He found a gradual increase in score, with the average adult level reached in grade 10; he attributed the increase in grades 11 and 12 to selection, for he found a marked correlation between score and I.Q. Historical perspective seemed to be poor in many of the subjects, and they lacked an adequate grasp of terms descriptive of time.

Harrison (32) was interested in the effect of maturation on the development of time concepts. His 160 subjects were drawn from kindergarten to grade 3, and in individual interviews were required to respond to fifty terms culled from the literature. He found the highest correlation between mental age and score (r = .70), slightly less between grade placement and score (r = .66), and even less between chronological age and score (r = .58), although chronological age should be the dominant factor indicating maturation.

In 1946 Ames published a study (1) which gave greater support to the role of maturation in the development of time concepts. She found, on the one hand, marked individual differences within any one age level and I.Q., but on the other hand, a relatively uniform and comparable sequence from child to child. She ascribed this latter phenomenon to maturation. Words indicating present were developed first, then future, then past, with a growth from specific use to generalization.

In an experiment published in 1946 (49) Piaget investigated the development of the concepts of simultaneity, duration, and dissociation of the temporal and spatial. None of these concepts was present at age four, but all were fully developed by age twelve. Fraisse and Vautrey (24) also found that at the five year old level, there is no conception of duration.

Vischer (60) comments on the relative duration at different stages of life, and asserts that Janet's law (that the length of a given period of time appears to be in inverse ratio to the length of past life) is applicable. Both Vischer and Smythe comment on the dominance of the future in young people, which gradually becomes a dominance of the past in old people. Bandura (3) adds that in young children (seven to nine years) the present is the dominant concept. Life is thus seen as a progress from present to future to past.

There has been a tendency to replace these rather general studies of the conceptual development with more specific studies of the ability of children to estimate time. The results of these studies are, as usual, confused by the large variety of experimental methods used.

The first study of this kind was written by Elkine in 1928 (17). He used the method of estimation with eight intervals ranging from five seconds to five minutes. His subjects were 71 children aged 10 to 13, 68 aged 13 to 15, and 13 over 15 years; 68 were male and 84 female. He found large errors, related to the size of the interval, with the most accurate results for the 30 and 60 second intervals. Larger intervals were under-estimated, smaller intervals over-estimated. There were wide individual differences, but boys were more accurate at the longer intervals, girls at the shorter. Elkine concluded that subjective time is determined by the number of motor acts, the psycho-neural organization, and the duration of concentrated attention.

Using the methods of estimation, production and reproduction, Gilliland and Humphreys (29) conducted an experiment on 41 Grade 5 children and 48 college adults, evenly divided for sex. Intervals ranged from 9 to 18 seconds, and half the subjects in all groups were allowed to count. Results showed that adults were 15% to 18% more accurate than children, and that counting increased the accuracy for all. Sex differences were not significant.

Smythe (55) used estimation in the form of a modified method of limits. There were 210 subjects, and the limits of the intervals were .02 seconds and 20 seconds; the subjects had to say whether each interval was longer or shorter than one second. The results showed that there was a tendency in all subjects to overestimate the value of one second. Variability decreased with increasing age. The performance of children 6 and 7 is equivalent, from 8 there is some improvement until 14, at which age the performance is equivalent to that of young and old adults.

From these studies it seems clear that the development of both time concepts and time estimation ability in children depend on a combination of factors involving maturation, intelligence, and grade placement. Mentally retarded children appear to be affected by the same factors, the difference lying in the level at which optimal performance is reached. There are no data relevant to this for delinquent children; however, Barndt and Johnson's study is suggestive and it would be interesting to see whether the difference in time span in stories would be paralleled by a tendency, say, to over-estimate short time intervals.

Method variable

Perhaps the variable which most strongly affects the results of time estimation studies (with interval held constant) is that of method. There are three methods which are called 'methods of time estimation', although this title is applied more as a result of convention than as a description of empirical findings. Actually, very few studies have been conducted on the extent to which each of these methods measures the same thing, and on the extent to which each measures time estimation. Also, there has been very little attempt at justification of the title beyond the assumption of face validity. Because of this, many questions are left unasked and unanswered: for example, whether these methods measure the subject's ability to estimate objective (clock) time, or his ability to estimate subjective (perceptual) time, or do they simply measure his perception of time passing, translated by himself into verbal symbols?

The method variable appears to be a crucial one, and one which must be investigated more fully before time estimation can be used in the applied fields fruitfully. One of the main reasons for the difficulty in comparing different clinical studies lies in the different methods employed in these studies.

The methods which have been used in the investigation of time estimation can be divided into at least three major types[1], and within each of these groups there are various modified forms of the method. The first can be called the method of estimation. In this method the subject must state verbally the amount of time in the interval. His response would be, for example, "three minutes". This method has a serious weakness in the tendency of subjects to give estimates in round figures, for example, "three minutes","four minutes", etc. If the experimenter chooses intervals of round figures he is inevitably influencing the accuracy of the results favourably; if he chooses uneven intervals (e.g. 3 minutes 47 secpnds) he is inevitably influencing the accuracy of the results unfavourably.

The second method is that of production. The subject is asked to produce an interval which is three minutes long. This suffers from the same general weakness as the first method, namely, that the experimenter can materially influence the results by the choice of the interval; for example, the error score would be much higher on an interval of 1 minute 35 seconds than on an interval of 1 minute. Another variable which enters here is whether the subject is required to produce a filled or an unfilled interval -- for example, to press a buzzer for the time or to make bounding clicks.

[1]This division of the methods was made originally by Clausen(9), under slightly different names.

The third is the method of reproduction. The experimenter presents an interval; the subject is required to reproduce it. The interval may be presented as unfilled or filled, and, if filled, may be filled in a variety of ways, e.g. by a buzzer, a metronome of varying speeds, music, a light, etc. The interval can be reproduced in the same way (buzzer) or in a different way (music, unfilled interval bounded by clicks). This method is also influenced by the experimenter's choice of intervals.

A modified method of reproduction has been widely used. This is the method of half-judgements, by which experimenters claim to produce a ratio scale of subjective time. It has all the disadvantages of the method of production.

A general criticism concerns the effect of individual differences on filled and unfilled intervals. One would suspect that it is always incorrect to speak of unfilled intervals except in a relative sense (they are unfilled as compared to filled intervals) for it is quite well established that in a waking state a human mind is never empty or unfilled. One individual may fill the so-called unfilled interval with vague daydreaming, another with mental puzzles, another with reviewing studies, another with actively imagining a ball game or a lively piece of music. In all cases, the 'unfilled' interval is, in fact, filled. Similarly, a filled interval is filled only to the extent that the subject attends to the stimulus; e.g. it may be very easy for a highly anxious subject to disregard completely the metronome and concentrate on his vivid imagining of some hypothetical future catastrophe.

There have been two studies conducted with the aim of investigating the results obtained by the different methods. In the first of these, Gilliland and Humphreys (29) used eight intervals ranging from 9 to 180 seconds and the three methods of estimation, production, and reproduction. They were interested in the variables of age, method, interval, counting, and sex, but their main aim was to compare the performance of fifth grade children with that of adults. No significant differences were found between the three methods, and the only significant interaction involving method variables was one between interval and method when algebraic mean scores were used in the analysis of variance.[1] In discussing this, the authors state: "The F value for variable D[2] barely exceeds the 5% point (5% = 3.2 when df = 2) so that no definite conclusions can be drawn concerning the differences between types of judgements. Inspection of the two-way table,[3] however, shows that reproduction tends to be easier than either estimation or production. This is possibly due to the fact that reproduction scores are not distorted by an incorrect idea as to the length of a second." (29, p. 126) Their conclusion is that "Reproduction of time intervals is perhaps easier than estimation or production, but they all seem closely related to mental processes." (29, p. 129)

In the second study, Clausen (9) divides methods of investigating time estimation into the method of reproduction, the method of verbal estimation (called the method of estimation above), and the method of operative estimation (called the method of production above). In a study on 43 schizophrenics, 19 of whom had frontal lobe lesions, the following results were found: first, the method of reproduction was less consistent

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[1] Analyses of variance were carried out on three sets of scores---arithmetic mean scores, algebraic mean scores, and standard deviation scores. This interaction was not significant when either of the other two sets of scores were investigated.

[2] 'Variable D' is the method variable. F = 3.58, df = 2 with arithmetic mean scores.

[3] Not included in the article.

and reliable; second, the methods of verbal estimation and operative estimation measure the same function inversely; third, the method of operative estimation was to be preferred with these subjects, and also, probably, with normals.

Clausen found no significant difference (at the .01 level) between unfilled intervals and those filled with a buzzer, or between estimates pre-operatively and post-operatively (four and one-half months later). His discussion is interesting in that he attempts an analysis of the processes underlying the various methods. "It seems evident from the results that the task of Reproduction involves a different underlying function than do Verbal and Operative estimation.....The Reproduction task is independent of any relation of personal time to objective time. If an interval of 15 seconds is presented to a subject, he may be able to reproduce it fairly accurately regardless of what his verbal estimation of the interval would be. It could be called 5 seconds or 50 seconds, but the reproduction would still be accurate as long as he is consistent in his judgement from demonstration to reproduction. The Method of Reproduction produces average judgements that are closer to the stimulus interval than is the case in either of the other methods. In spite of this fact, Reproduction shows more instability in the intercorrelations between subtests than do the other two methods. This indicates that Reproduction measures a function of less uniform character than does Verbal or Operative Estimation, and for this reason the latter methods are to be preferred to the Method of Reproduction." (9, p. 759) Clausen continues with an explanatory attempt: "It is difficult to

Table 1

Clausen's intercorrelations for the three methods

		Verbal Estimation	Operative Estimation
Reproduction	O	-.05	.04
	R	-.55	.36
Verbal Estimation	O		-.63
	R		-.42

Note. -- O refers to pre-operative estimates.
R refers to post-operative estimates.

understand this difference between Reproduction and the other two methods. It might be that attention is more easily interfered with if the subject has to concentrate first on the demonstration and then on the reproduction, as is the case in the Reproduction Method, whereas Verbal Estimation and Operative Estimation require attention only for the stimulus interval or the response interval." (9, p. 759)

Clausen's study is interesting in that it is an attempt to clear up some of the obscurities which still abound in the area of time estimation, but, as he says himself: "Since the data on which we have based our conclusions have been collected from schizophrenic patients, it remains to be seen whether they also would be valid for normal subjects. The final answer can of course only be given by analysis of data obtained from normals." (9, p. 760)

A method which differs from these three is that used by Steinberg (56). This consists of asking the subject to count off seconds for a certain period (30 seconds in this case), and seems to be a measure of the subject's perception of the passing of time, in contrast to the methods described above which seem to be aimed at the subject's perception of a unified period of time.

A recent article by Bindra and Waksberg (5) gives an excellent survey and analysis of the various methods of time estimation and of the underlying processes, particularly in their relation to objective and subjective time. Their point of view will be presented in more detail in the discussion.

Interval length.

The most obvious variable connected with time estimation is that of length of interval. Despite the fact that this was one of the first variables investigated, and that it has probably been investigated more often than any other variable, the results are still confused, and few consistent trends emerge. The two basic reasons for this are, first, that a great variety of modifications of the three basic methods have been used, so that it is difficult to find even two studies which use the same method with the same intervals; and second, that the sample of subjects has usually been so small as to allow chance variation to conceal trends in the results.

In 1928 Elkine, (17) using the method of reproduction and child subjects, investigated the intervals 5, 10, 15, 30 seconds, and 1, 2, 3, 5 minutes. He found that the intervals less than 30 seconds were over-estimated, while those larger than 60 seconds were under-estimated. The 30 and 60 second intervals were the most accurately judged.

Using 13 intervals, ranging from 0.2 to 30 seconds, Woodrow (62) was unable to establish a tendency for long intervals to be under-estimated or short ones to be overestimated. However, only eight subjects were used, and the lack of a trend could have been a function of the wide individual differences found in this type of experiment.

Gilliland and Humphreys (29) using the methods of estimation, production, and reproduction, investigated intervals ranging in a logarithmic series from 9 to 180 seconds. Using 48 child and 48 adult subjects, they found a trend towards overestimation of shorter intervals and underestimation of longer ones; they also found that both the percentage error and the variability of results decreased as length of interval increased.

Kowalski (38) was interested in the effects of delay on the reproduction of duration of a flash of light. He used 13 high school students as subjects, and intervals ranging from .5 to 16 seconds, with delays from 2.5 to 30 seconds. Irrespective of delay interval, the two shortest stimulus intervals were regularly overestimated and the longer ones underestimated. Kowalski claims that an analysis of variance indicated that: "stimulus durations, rather than delay intervals, are the significant factors in overestimating or underestimating time duplications".(38, p. 246)

Using the duration of light flashes and buzzer sounds, .033 to .608 seconds, and 2.34 seconds, Philip (47) investigated the effect of including, in a series of intervals, an interval whose duration was known to the subject. Results with 19 subjects showed that without the known stimulus, most intervals were overestimated; with the known stimulus, intervals longer than it were underestimated while those shorter than it were overestimated. That is, judgements regressed toward the length of the known stimulus.

A year later Philip and Lyttle published a study (48) which attempted, unsuccessfully, to establish a relation between reaction time and ability to reproduce visually presented time intervals. No significant degree of correlation was established. Intervals ranging from .73 to 1.7 seconds were used; the relative degrees of over- and under-estimation are unknown.

Clausen (9), whose subjects were 43 schizophrenics, 19 of whom were brain damaged, was also able to demonstrate a tendency to overestimate short (5 and 10 second) intervals and to underestimate long (15 second) ones.

The apparent conclusion to be drawn from these studies is that with both normal and abnormal, child and adult, subjects, there is a trend to underestimate long intervals and to overestimate short ones. It would also seem to be safe to conclude that certain methods (especially the method of reproduction) show up this trend more clearly.

These conclusions, however, cannot be upheld in view of the two criticisms mentioned at the beginning of this section; namely, that it has never been shown, either empirically or theoretically, that the various methods employed are actually investigating the same entity or construct, and that the number of subjects used in most of these experiments is quite inadequate in view of the wide inter- and intra-subject variation which has been conclusively demonstrated in this field. However, there is another, and even more serious criticism which prevents the acceptance of these conclusions. That is the possibility of a tendency for judgements to regress towards the interval of mid-length which has confounded the results of every one of the above experiments. There is no reported experiment which tries to separate the influence of these two variables; the length of the interval relative to the length of the other intervals included in the same experiment, and the absolute length of the interval. As the results now stand, there appears to be much more evidence in support of the hypothesis that the short intervals (i.e. those which fall into the first half of the list when the intervals used are ordered according to length) of an experiment are overestimated while the long intervals (those in the second half of the list) are underestimated; than in support of the hypothesis that short intervals are generally overestimated while long intervals are generally underestimated. The difference, of course, is that if the intervals range from 3 to 30 seconds, in a particular experiment, then the 3 second interval will be overestimated and the 30 second interval underestimated; while if the intervals in an experiment range from 30 seconds to 5 minutes, the 30 second interval will be overestimated while the 5 minute interval will be underestimated. The apparent agreement of the studies reported above that intervals in the 1 to 30 second range will probably be overestimated while those in the 60 second and above range will be underestimated may be due to the fact that most experimenters have chosen their intervals from the same range, about 1 second to 3 minutes.

There is at present, then, no compelling evidence that intervals within a certain range of clock time are overestimated while those in another range are underestimated. One way of testing the hypothesis that such a difference does exist would be by designing an experiment in which a number of buffer intervals at either end of the continuum of length of interval are included. The results of these buffer intervals would then be disregarded. It would be necessary to run a pilot study to determine the number and absolute size of these buffer intervals necessary to completely absorb the effects of regression toward the median interval. For example, to determine whether there is any real tendency for some intervals in the range 5 to 60 seconds to be over- and/or under-estimated, it would be necessary to include, say, ten intervals ranging from .05 to 4.5 seconds, and ten intervals ranging from 1.5 minutes to 5 minutes. It would also be necessary to determine from a pilot study the number of subjects required to give results of sufficient stability for generalization to other subjects.

Motivation.

Motivation is another variable which is relevant to time estimation. Strangely enough, no one investigated its role until 1949; in all the studies conducted before this date, no mention is made of motivation, and no effort is made to control this variable. The background for the study of motivational variables was provided by two studies. The first was published by Rosenzweig and Koht (52) in 1933, and was a report of the effect of 'need tension' on time estimation. Using intervals ranging from 1 to 10 minutes, filled so as to produce different degrees of need tension, the experimenters found a general tendency for intervals filled with a relatively great need tendency to be judged shorter than intervals filled with a smaller degree of need tension. However, Harton (33) found that estimates of mental mazes on which the subject had been told he had failed were consistently estimated as longer than estimates of success periods. If one postulates that believed failure would produce a state of need tension as compared to believed success, then these results are contradictory to those of Rosenzweig and Koht. However, it must be remembered that Rosenzweig and Koht used the method of reproduction while Harton used the method of estimation, and it has not yet been shown that the results from these two methods are comparable.

It was on the basis of this work, then, that Filer and Meals conceived their experiment (20) on the effect of motivating conditions on the estimation of time. They chose to induce different motivating conditions by varying the goals. Using 67 students in each of three groups, and the method of estimation, the experimenters told the first group that they could go home at the end of ten minutes on the task; the second group that they could go home when they had scored 150 words; and the third group that after the test the lecture would be continued as usual. In all cases the test was writing down words beginning with certain letters of the alphabet, and in all cases the subjects were interrupted after 4 minutes 37 seconds and asked to estimate the time since the beginning of the test. Results showed that each of the first two groups were significantly different from the third (control) group, but they were not significantly different from each other; that is, positive goals significantly increase time estimation. The authors postulate that attractive goals affect the psychological distance, and therefore, by implication, the pshchological time.

The other study (44) is entitled: 'Time perception as affected by motivational level, goal distance and rate of progress'. Half the subjects were told they could stop working on the maze if they did well; the other subjects were told they would have to complete the task no matter how they did. Results showed great differences in such variables as perceived rate of progress and perceived distance from end of task when positive motivation was contrasted to low (normal, or non-manipulated) motivation. Meade concludes by attributing the apparent conflict in the results of time studies to a failure to control motivational variables.

The evidence gathered in these four studies appears to be enough to support the assumption that motivation is a relevant variable in studies of time estimation.

Serial position.

Both Eson and Kafka (18) and Falk and Bindra (19) have demonstrated serial position effects on time estimations. Falk and Bindra used the method of production, with forty subjects. They found that the mean for six successive blocks of five judgements each (using a fifteen second interval) increased from block to block, and showed a roughly linear relation. The regression coefficient of the line was significantly different from zero ($p < .01$).

AIMS OF THE EXPERIMENT

It was in the light of this history of time estimation that the following study was conceived and executed. The clinical studies, in particular, indicate that until the interrelationships of the methods are demonstrated, time estimation techniques will be of little use to those interested in psychopathology. The following experiment was designed to clear up basic confusions and inconsistencies by establishing time estimation results for normal adult subjects.

The aims of the experiment were four-fold: first, to investigate the inter-relationship between the three methods over a series of intervals, and to establish the validity of the method of estimation and the method of production, using the method of reproduction as criterion; second, to investigate the reliability of each method over a short time lapse; third, to investigate the effects of serial position; and fourth, to test the hypothesis that the interval which is below the mean in a series of intervals will be overestimated, while that same interval, in a different series in which it falls above the mean, will be under-estimated. In this particular experiment, this hypothesis can be translated: that both the 20 and 25 second intervals will be over-estimated in Group II and under-estimated in Group I, and that the difference between the groups will be significant.

METHOD

Selection of subjects.

The following criteria were set up for the selection of subjects: all subjects were to be females (sex has not been shown to be a relevant variable); aged between 17 and 20 inclusive (age within these limits has not been shown to be a relevant variable); members of the introductory psychology class at the University of Saskatchewan; and to have had no previous (recorded) exposure to psychological experimentation. These criteria were set up for two reasons: first, to reduce the variability between subjects as much as possible; second, to accommodate the study to the resources available to the experimenter.

A card file, which contained in chance order the name, age, sex, timetable, and record of participation in previous experiments of each student taking introductory psychology was then consulted, and appointments were made for the first fifty students who conformed to the above criteria. (Later it was necessary to obtain a further six subjects in the same way, since eight subjects in all failed to keep their appointments.) Each subject then received a printed slip notifying her of the time of her appointment. By choosing the subjects this way, and making it difficult for them to refuse to attend, it was hoped to keep motivation relatively constant, thus keeping inter-subject variation at a minimum.

Treatment.

Before the data collecting began, data sheets were made up, a quarter of them being headed 'Group I, E R P'; a quarter being headed 'Group I, R E P'; a quarter Group II, E R P'; and a quarter 'Group II, R E P'. These were then placed in mixed order in a folder. The first subject was treated as specified on the first sheet, the second subject as specified on the second sheet, etc. By assigning the subjects to the different groups and orders in this way, and running the different groups in this mixed order, it was hoped to eliminate any chance of differential effects of such variables as instrument decay, historical and time factors, experimenter attitude, etc.

Half the subjects were assigned unsystematically to Group I, the other half to Group II, the difference between groups being that those in Group I were given the intervals 5, 10, 15, 20 and 25 seconds, while those in Group II were given the intervals 20, 25, 30, 35 and 40 seconds. The intervals were chosen for two reasons: first, because they are short and therefore are less boring for the subjects; second, because it is postulated that judgements of intervals are affected by the specific intervals included in the series, that is, that the intervals 20 and 25 seconds, which are the only two in common between the two groups, will be judged differently by the groups.

Half the subjects in each group were given their intervals first by the method of estimation, then by the method of reproduction and then by the method of production (order E R P), while the other subjects in each group were given their intervals by the method of reproduction first, then the method of estimation and then the method of production (order R E P). It was not possible, within the limits of this study, to vary the order of the method of production, for it seemed reasonable to suppose that since the same intervals were to be used in all methods, exposure to the names of those intervals, under the method of production, would taint the results of any method which followed it; that is, would bias the subject's responses in favour of those intervals named by the experimenter during the method of production. It was therefore decided to keep the method of production last for all subjects, even though this limits the conclusions which can be drawn about this method in comparison with the other two.

Experimental sessions.

All experimental sessions were run during ordinary lecture hours, in a period which the subject had free. Each subject was met by the experimenter and taken to the experimental room, seated beside a table, and given a metal pencil. The experimenter requested the subject to close her eyes, and keep them closed, and then blindfolded her. The purpose of both the quiet room, and the blindfold, was to reduce environmental distraction, and also to exclude external filling.

If the subject was in Group I, the intervals 5 to 25 seconds were given her each four times, all in random order: 15, 25, 10, 20, 5, 20, 25, 15, 5, 20, 25, 10, 15, 5, 20, 15, 5, 10, 25, 10. This order was constant for each subject in Group I. If she was in the order E R P, then these intervals were administered to her first by the method of estimation, then by the method of reproduction, and then by the method of production, making sixty judgements in all from each subject. For the order R E P, the intervals were administered first by the method of reproduction, then by the method of estimation, and then by production. This was the same for group II, except that the random order of intervals was: 25, 35, 30, 30, 35, 40, 20, 20, 20, 25, 40, 30, 30, 40, 35, 40, 25, 25, 35, 20.

These instructions were given to the subject: "This is an experiment on how well you make judgements." Then followed the instructions for the first method that was to be administered to the subject; instructions for the other two were given just before the beginning of each method. The first set of instructions was followed by: "It is very important that you do not count, or tap your feet, or do anything else to help you in making judgements. I simply want to know how long the interval seems to be, how long it feels to you. Please try to co-operate equally well throughout the whole experiment, so that the results will be even." After the instructions for each of the other two methods, the words "Remember, do not count" were added. The instructions for the method of reproduction were: "I will give you a certain length of time bounded by two clicks, like this" (demonstrates). "I want you to give me back an interval which you feel is just as long as the interval I gave you. Use my second click as your first click, wait until an equal lenght of time has gone by, and then make a click on the table with your pencil. Let's try it" (demonstrates) "good". Estimation: "I will give you a certain length of time bounded by two clicks, like this" (demonstrates). "I want you to guess how long the interval is. Do you understand?" Production: "I will name a certain interval of time and I want you to produce that interval by tapping once on the table, waiting until you think the interval has passed, and then tapping again. Do you understand?" During the methods of reproduction and estimation, the word "ready" was given before each interval. After the first judgement on each of the three methods, the experimenter commented "that's fine", but offered no other comments. Talking between intervals and methods was strongly discouraged. If (as occasionally happened) during the method of production the subject did not make the first click within three seconds of the interval naming, the experimented commented: "tap first".

All estimates were measured by the experimenter with the same stopwatch. Fractions were always taken to the next highest second.

Each subject attended only one experimental session, which lasted between 30 and 50 minutes. The data were gathered during the period 16th February to 3rd March, 1959.

Statistical treatment.

As a result of the foregoing procedure, each subject obtained sixty scores based on four estimates of each of five intervals for each of three methods. Pearson product moment correlations were used to estimate the reliability of each method, and also to estimate the concurrent validity, using the method of reproduction as criterion. A complex analysis of variance was used to investigate the main and interaction effects of the three methods, five intervals, and two orders employed in this study.

RESULTS

Figure I and Table 2 show that, in this experiment, estimation was the least accurate, while production and reproduction were about equally accurate. Intervals were over-estimated by the method of estimation, and under-estimated by the method of reproduction. The method of production resulted in the under-estimation of intervals in Group I, and the over-estimation of intervals in Group II.

Table 2 also shows the effect of serial position: the trend is for estimates to become smaller as serial position increases, with the method of estimation, but larger with the method of production. No trend is apparent for the method of reproduction. Also, estimates tend to become more accurate as serial position increases, the only exception being the results for the method of production, Group II.

Table 3 indicates the reliability of the methods, and shows that the second judgement correlates more highly with the last than does the first, although the difference in most cases is small.

Figure 2 shows a trend for mean scores to increase as interval size increases. Figure 2a shows that on the basis of individual comparisons based on t tests, there is little evidence for a systematic effect due to interval context, in that only one of the eight t tests reached the 5 % level of significance.

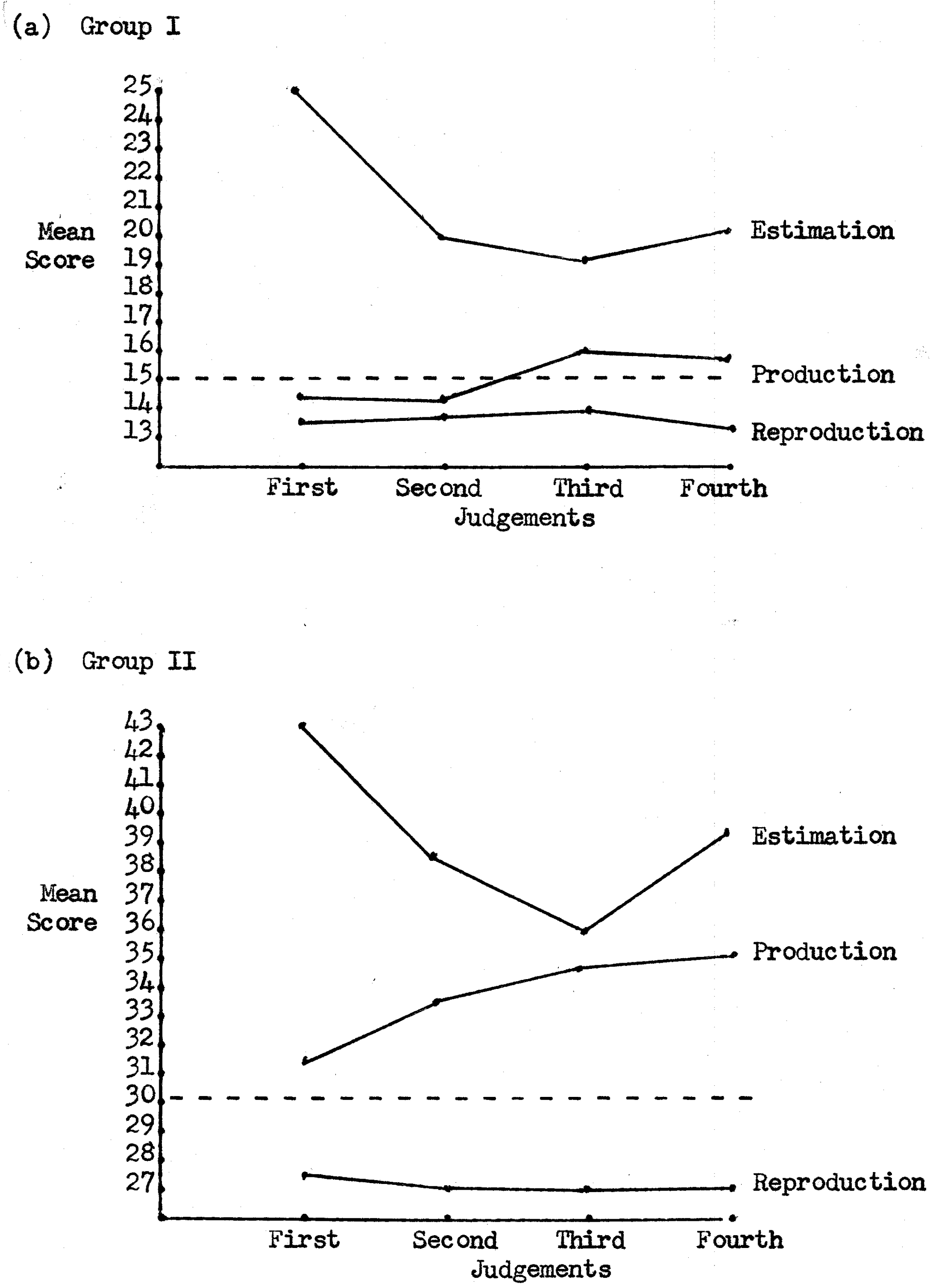


Fig. 1. Showing mean results for methods and judgements, with intervals combined.

Table 2

Mean results for groups, methods, and judgements

	First	Second	Third	Last
Group I:				
Estimation	24.99 $\sigma=10.8$	19.97 $\sigma=10.8$	19.11	19.72 $\sigma=11.7$
Reproduction	13.45 $\sigma=2.7$	13.76 $\sigma=2.6$	14.18	13.22 $\sigma=2.8$
Production	14.56 $\sigma=8.3$	14.74 $\sigma=8.2$	16.07	15.53 $\sigma=9.2$
Group II:				
Estimation	43.53 $\sigma=28.3$	38.55 $\sigma=23.3$	36.27	39.59 $\sigma=29.7$
Reproduction	27.62 $\sigma=5.8$	27.10 $\sigma=4.1$	27.12	27.23 $\sigma=4.2$
Production	31.64 $\sigma=15.0$	33.52 $\sigma=17.4$	34.62	35.21 $\sigma=19.4$

Note. — Intervals are combined.
Standard deviations for third judgements not calculated.

Table 2a

Error Means and t tests of Significance for interval context

	Group I	Group II
20 Second Interval		
Method of Reproduction	-2.5	-0.75
	$t = 2.25$	$p < .05$
Method of Production	1.0	3.5
	$t = 1.4$	$p > .1$
Method of Estimation	10.0	11.0
	$t = .01$	$p > .1$
25 Second Interval		
Method of Reproduction	-2.2	-2.4
	$t = .5$	$p > .1$
Method of Production	-1.0	5.1
	$t = 1.3$	$p > .1$
Method of Estimation	10.0	11.2
	$t = .4$	$p > .1$

Note -- t is test for significance of uncorrelated means. See (42).

$df = 46$.

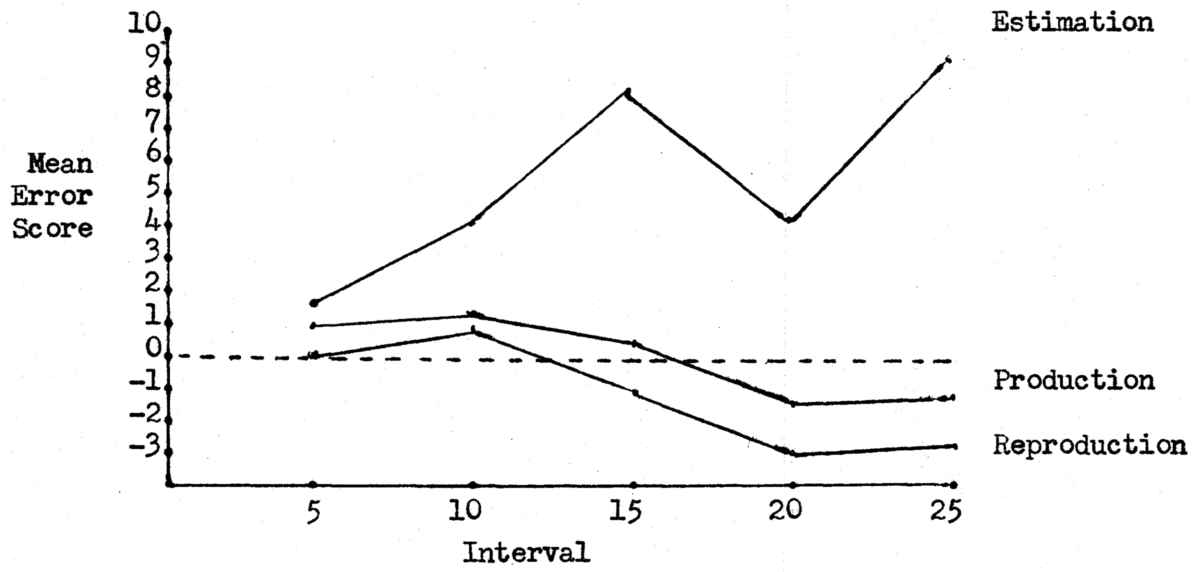
Table 3

Pearson Product Moment Correlation Coefficients for judgements, groups and methods, with intervals combined

	Estimation		Reproduction		Production	
Group I:						
First with last	.70		.40		.84	
	$t = 4.8$	$p < .001$	$t = 2.2$	$p < .05$	$t = 6.2$	$p < .001$
Second with last	.92		.47		.93	
	$t = 9.0$	$p < .001$	$t = 3.2$	$p < .01$	$t = 9.1$	$p < .001$
Group II:						
First with last	.68		.28		.84	
	$t = 4.4$	$p < .001$	$t = 1.4$	$p > .1$	$t = 6.5$	$p < .001$
Second with last	.87		.51		.94	
	$t = 6.6$	$p < .001$	$t = 2.8$	$p < .01$	$t = 9.2$	$p < .001$

Note. -- t is test for significance of correlation. See (42), p. 226. $df = 22$.

(a) Group I



(b) Group II

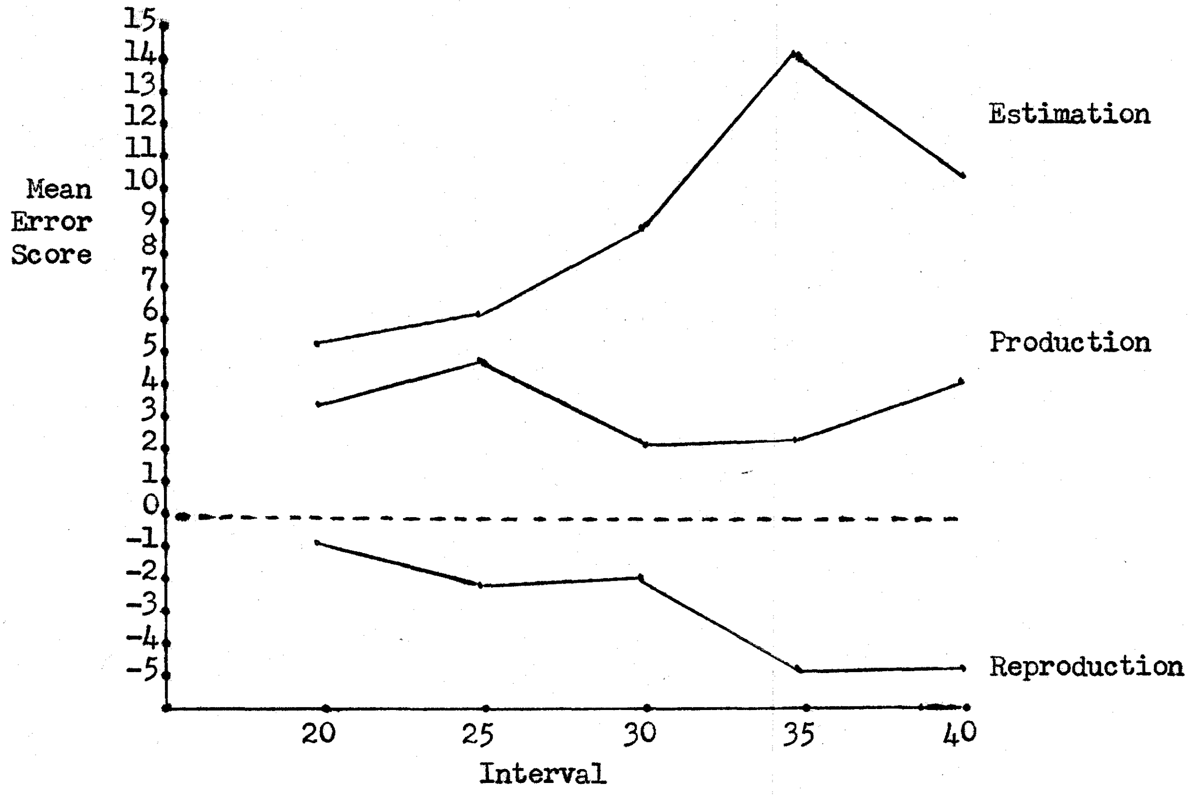


Fig. 2. Showing error scores for intervals and methods.

Table 4 shows that the methods of estimation and production are negatively correlated, to a significant degree; that is, they are measuring the same thing, but one is measuring it in reverse. For short intervals, the methods of reproduction and production are measuring the same thing, to a significant degree, but there is virtually no relationship between these methods with longer intervals. Again, there is no relationship between reproduction and estimation, although there is a consistent negative sign.

The data from each group were converted into error scores plus constant ($k = 66$ for Group I, $k = 120$ for Group II) and treated by complex analysis of variance in the form of treatments x treatments x subjects design, mixed. This is the appropriate analysis where both inter- and intra-subject treatment comparisons are involved.

There is no evidence for an interaction between Order and Method, Order and Interval, or Method and Interval, in either group (Table 5, 6) so it is now legitimate to analyse for Order, Method and Interval main effects in each group.

The null hypothesis with respect to Order effects cannot be rejected for either group.

The null hypothesis with respect to Interval effects cannot be rejected for either group.

The null hypothesis with respect to Method effects can be rejected at the .01 level of significance for both groups. Group I: $F = 15.6$, $df = 2$ and 308, $p < .01$. Group II: $F = 13.2$, $df = 2$ and 308, $p < .01$.

Table 4

Pearson Product Moment Correlation Coefficients for methods and groups, with intervals and judgements combined

	Group I	Group II
Estimation with Production	-.53	-.42
	t = 2.9 $p < .01$	t = 2.2 $p < .05$
Reproduction with Estimation	-.07	-.02
	t = .3 $p > .1$	t = .2 $p > .1$
Reproduction with Production	.56	.001
	t = 3.1 $p < .01$	t = 0.0 $p > .1$

Note. -- t is test for significance of correlation. See (42), p. 226. df = 22.

Table 5

Analysis of variance for errors in time estimation by 24 subjects, for 5 intervals, 3 methods, and 2 orders, Group I

Source	SS	df		V.E.	F
Order	118	1		118	-
Ss in same group (error)	53,270	22		2,421	-
Total between Ss	53,379		23		
Methods	39,504	2		18,752	15.6 $p < .01$
Intervals	4,365	4		1,091	-
Order x Method	2,322	2		1,161	-
Order x Interval	282	4		70	-
Method x Interval	16,062	8		2,008	1.6 $p > .05$
Method x Interval x Order	787	8		98	-
Pooled Ss x Estimates (error)	369,873	308		1,200	-
Total within Ss	445,337		336		
Total	496,716		359		

Note: -- V.E. is the variance estimate.
For procedure, see (41), p. 237.

Table 6

Analysis of variance for errors in time estimation by 24 subjects, for 5 intervals, 3 methods, and 2 orders, Group II

Source	SS	df	V.E.	FF
Order	2,834	1	2,834	-
Ss in same group	300,768	22	13,671	-2
Total between Ss	303,602	23		
Methods	138,084	2	69,042	13.2 $p < .01$
Intervals	1,561	4	390	-
Order x Method	2,167	2	1,083	-
Order x Interval	2,974	4	744	-
Method x Interval	27,653	8	3,456	-
Method x Interval x Order	2,121	8	268	-
Pooled Ss x Estimates (error)	1,604,942	308	5,210	-
Total within Ss	1,785,170	336		
Total	2,088,772	359		

Note. -- V.E. is the variance estimate.
For procedure, see (41), p. 237

The question is still open as to whether all three methods have a differential effect on the size of the error of time estimation or whether it is limited to only certain of the methods used. t tests were therefore calculated for the pairs of methods in each group. The results of these tests are given in Table 7. The differential effects of the methods can also be seen in Figures 1 and 2.

Table 7

t tests of significance for method differences

Group I:			
Estimation and Reproduction	$t = 3.03$	$df = 23$	$p < .01$
Estimation and Production	$t = 1.63$	$df = 23$	$p > .1$
Production and Reproduction	$t = .77$	$df = 23$	$p > .1$
Group II:			
Estimation and Reproduction	$t = 2.68$	$df = 23$	$p < .05$
Estimation and Production	$t = .72$	$df = 23$	$p > .1$
Production and Reproduction	$t = 2.21$	$df = 23$	$p < .05$

Note.— t tests for differences between the means of two small correlated samples. See (54), p.65.

DISCUSSION

Any generalizations based on the results of this study should take into consideration that the subjects used were first year female students.

Serial Position.

Since the analysis of serial position effect in this study is limited to the examination of trends any conclusions must be tentative.

Table 2 shows that although there is a trend for the means of the method of estimation to become both smaller and more accurate as the serial position increases from 1 to 4, there is no consistent trend for the variance to decrease. The other methods do not show any trend for alteration of results as serial position increases, except for the method of production in Group II. This is in contrast to the results of Falk and Bindra, who, using the method of production and a 15 second interval, found that estimates significantly increased as serial position increased. This discrepancy can be accounted for by the fact that in this experiment, the results for the method of production are confounded with order. However, it is interesting to speculate whether the difference in results could also be due to the fact that in the Falk and Bindra study only one interval and one method were used. A study could be conducted in which the effects of serial position on a series of intervals given to all subjects could be compared to the effects of only one of the intervals given to each group of subjects, using three methods, for at present it is not possible to say whether the difference in result is due to difference in method, difference in interval series, or a combination of these factors.

Reliability.

Table 3 shows that the reliability of the methods of estimation and production over a period of about 15 minutes is high, and that there is considerable increase in the reliability when it is calculated on the basis of second judgement with last, instead of first with last. The reliability of the method of reproduction is low.

This table also shows that taken with considerations of economy, there is not enough gain to justify the inclusion of all four judgements of each interval with the methods of production and estimation. In future studies using normal adult subjects, two judgements of each interval could be enough to indicate the stable judgement of that interval, providing the first judgement is discarded as a dummy and the results based on the second judgement alone.

Further studies should be carried out on the relative reliability of the methods with increasing intervals of time.

Validity.

Both the inter-correlation of the methods of production and estimation were significant ($p < .01$, $< .05$)[1]. The results fit neatly into a verbal analysis of the processes underlying time estimation. If time is passing 'quickly' for the subject, he will judge an interval given him by the experimenter as longer than it is (i.e. he will overestimate by

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[1] It should be remembered throughout this discussion that the results for the method of production are confounded with order.

the method of estimation) because it will seem to contain a longer period of time. Again, if time is passing quickly for him, and the experimenter asks him to mark off a specified interval, his interval will be too short (i.e. he will underestimate by the method of production). Therefore, one would expect to find a negative correlation between results from the methods of estimation and production. The results of this study support this ($r = -.53$ for Group I, $r = -.42$ for Group II).[1]

The correlations indicate that the methods of production and estimation measure the same thing (but in a reverse direction) to the extent of 29 %[2] in group I and 17 % in group II, that is, these are more closely related with long intervals than with short ones, but in neither case is the relationship very high.

When reproduction is set up as a standard,[3] neither production nor estimation yield valid measures of time estimates of long intervals, for there is no significant relationship between them. Estimation also is not a valid measure of time estimation of short intervals, but production is, in that the correlation coefficient is .56, which indicates that it is measuring the same thing as reproduction to the extent of 31 %. During the data collection the experimenter noticed that subjects who greatly over-produced the amount of time between their two clicks in the method of reproduction tended to do the same

[1]Clausen gives a similar analysis.
[2]McNemar (42, p.139)
[3]Of the three methods, the method of reproduction is most likely to be chosen as criterion against which to measure the validity of the other two because by tradition it has become the most commonly used method of time estimation.

during the method of production. It could be postulated that it was the similarity of operation which produced this significant correlation rather than any similarity of basic processes, particularly in view of the fact that no such relationship was found with the longer intervals where the greatly increased variance presumably prevents this effect from showing itself.

Interval Context.

The hypothesis that over- and under-estimation are a function of the length of interval relative to the other intervals in a series, rather than a function of absolute length, was not upheld. On the average, both intervals were over-estimated in both groups. (20 seconds: Group I, Mean is 25.0; Group II, 27.5. 25 seconds: Group I, 31.9, Group II 33.0). Also, there is only one significant difference between the estimates of the two groups. Also, no significant differences can be found between the number underestimating the intervals above the mean (20 and 25 second intervals for Group I, 35 and 40 second intervals for Group II) and those underestimating the intervals below the mean ($p > .1$ in all cases). The analysis of variance indicates that there is no significant difference in the size or direction of error on any two intervals in each of the groups, and also that there is no significant interaction between size and direction of error due to interval and the effects of method or order.

In other words, the results indicate that within the limits of this study little difference as a function of interval length exists.

However, the number (without regard to size of error) who overestimated the 20 second interval in Group I was 9, compared to 14 in Group II, while the number who overestimated the 25 second interval was 8 in Group I and 13 in Group II. ($\chi^2 = 3.02$ df = 1 $p > .05, < .1$) The failure to obtain significant differences is probably due to the extremely large variance found in each group of subjects. It is possible that this large variance is masking a real difference and that with a larger number of subjects, in any case, a significant difference would be found. Another study could be set up to test a similar hypothesis among subjects who are 'reasonably accurate' (this could be specified numerically) at time estimation. But even if a significant difference were found, generalization would be very limited, for evidently the population in general is not accurate at time estimation. Generalization would be limited to the degree to which the experimenter had to limit the choice of subjects in order to demonstrate the difference.

However, from observing the subjects during the experimental sessions, an alternative hypothesis presents itself: that some subjects tend to overestimate the short intervals and underestimate the long ones in a series, while others have such a strong tendency either to overestimate or to underestimate that their errors are approximately equal in size, and are in the same direction, for all intervals in a given series. This could be investigated empirically; it is probable that this type of approach (an 'either- or' approach which affirms that the basic processes of time estimation are multiple rather than singular) is the most fruitful for further investigation of under-and over-estimation.

<u>Analysis of variance.</u>

The analysis of variance (Table 5, 6) shows that the only significant variable feeding into the results of each group is method; order, interval, order x interval interaction, order x method interaction, interval x method interaction, order x interval x method interaction, are not significant sources of variance. This analysis is based on size and direction or errors, and shows that within the limits of this experiment error does not increase as interval increases, and also that the order of administration of the methods of reproduction and estimation does not significantly alter the errors of estimations; these two methods do not taint each other. The results for the method of production are confounded with order, so it is not possible to say whether order has a significant effect on the method of production or on any other method included with it in an experimental session.

When further analyzed (Table 7), the results show that in Group I the significant methods effect is due to the difference between the method of reproduction and the method of estimation alone. This indicates that error results of time estimation studies using the two methods cannot be compared. Since the results for production are confounded with order it is possible (although not, of course, likely) that an undemonstrated interaction of these two variables is masking a difference between this method and the methods of estimation and reproduction - that is perhaps this method would yield different results in a different order.

In Group II, both the difference between estimation and reproduction and the difference between production and reproduction are significant. The first of these results corresponds to the result found in Group I, and indicates that with longer intervals and different subjects, the methods of estimation and reproduction still give significantly different error scores. It is impossible to draw a definite conclusion from the second result, since it might be partly or wholly due to order effects or order x method interaction; it is possible (but, especially in view of the non-significance of this result in Group I, highly unlikely) that the failure to find a significant difference between estimation and production in this group is due to the confounding. Although there is no evidence for a practice effect from first to second positions of order, it is possible that by the third method there is a positive effect from practice and this could account for part of the significant difference between production and reproduction.

The final result, then, is: first that, the methods of estimation and reproduction give significantly different error scores; second, the methods of estimation and production do not give significantly different error scores when production is always the third method; third, that with short intervals, the methods of production and estimation do not give significant differences, providing the method of production is kept third; and fourth, that with longer intervals, the methods of production and estimation give significant differences, providing the method of production is kept third.

Underlying processes.

In the method of reproduction, the subject is attempting to reproduce the subjective experience he has just had, of the experimenter's interval. In all three methods, on this view, the basic process is the same, and differences in errors are attributed to three factors: first, differential effects of memory distortions, for different methods and different subjects; second, differential effects of attention span, for different methods and different subjects; and third, differential effects for methods, in that they involve different parts of past experience, and for subjects, in that past experience is different for every subject. A further conclusion is that if any particular set of results shows over- or under-estimation for any particular method, this is of factual interest alone; it does not necessarily indicate anything about the processes underlying that method.

In their article on time estimation methods (5), Bindra and Waksberg make the interesting point that if a subject overestimates by the method of reproduction, this indicates that 'his internal clock ran slower relative, not only to the external clock, but relative also to his own internal clock at the time of the presentation of the standard'. (p. 159) This would suggest that the underlying processes of estimation and production are similar, in that they are both indicators of the speed of the subjects 'internal clock', while those of reproduction are different in that they are indicative of the relative constancy of the speed of the internal clock. A possible conclusion would be to expect a higher correlation between estimation and production, than between production and reproduction, or estimation and reproduction. This was found in this study.

In this connection it is interesting to postulate the reason for the lower reliability coefficients found for the method of reproduction. The reason for this becomes apparent if Bindra and Waksberg's reasoning is taken a little further. On the one hand, they are assuming that the speed of the internal clock remains constant during the experience of the experimenter's interval, and during the subjects reproduction; on the other hand, they are assuming that the speed of the internal clock always changes from one interval to another, and are basing on this assumption their explanation of errors found in reproduction. But they are only forced into these assumptions because it is known fact that it is very rare to find an exactly correct reproduction. So if the assumptions fall, their explanation of errors in judgement breaks down. If we consider two parallel cases, where the standard is five seconds and ten seconds respectively, it is easy to see that the assumptions cannot be upheld, for they are equivalent to saying that in the first case, the speed of the internal clock remains constant for ten seconds, then suddenly changes, but remains at the new speed for the next ten seconds. If, on the other hand, the experimenter had chosen a five second standard, the speed would have remained constant for five seconds, and then changed for the next five seconds. A rather remarkable coincidence, if the change in speed always corresponds to an arbitrary decision previously made by an experimenter!

Rather, it seems better from the point of view of Bindra and Waksberg to postulate that the speed of the internal clock is simply not constant, and therefore errors are made under the method of reproduction, but that these errors cannot give information about the change in speed of the clock, for the change itself is a continuous and unpredictable process, just as the speed of a feather on the wind is continually changing in an unpredictable manner, and the distance travelled during the first ten seconds of flight and the subsequent ten seconds of flight does not necessarily indicate the size or direction of the many changes during the whole period.

In the context of this particular study, it seems preferable to introduce a rather different factor to account for the results - by attributing most of the error under the method of reproduction, and some of the error under the methods of production and estimation, to distortion of memory. It is well known that subjects can rarely reproduce a stimulus exactly - for example draw a line exactly as long as one that has just been shown to them, and this is usually attributed to memory processes interfering with the knowledge of the length of the line. In all three cases, errors also seem to be a function of attention, although again, this factor would seem to be contributing more to the size of the error in reproduction than in the other two methods, simply because the total time span of the trial is twice as long under the method of reproduction as under the other methods. It is easy to postulate that in psychiatric patients the effect of this last factor would be greatly indreased, contributing to the larger errors found in such groups.

It can be said that if the method of reproduction is set up as criterion, the methods of estimation and production are not measuring time estimation. In the method of production, the subject is producing an interval which, subjectively, seems to correspond to those intervals which, in his past experience, have been labelled with this same symbol: 'five seconds'. In the method of estimation, the subject is attempting to reproduce a subjective experience from past experience, which has been labelled with that same label.

If we assume that a subject has a built in timing device, which is reliable for both short and long intervals, over varying periods, and which is externally valid in that it relates accurately to clock time, then all methods would yield camparable results. If, however, the device is not externally valid, then the method of estimation would lead to overestimating, the method of production underestimation (or vice versa), and the method of reproduction would be accurate. If, further, we cannot assume reliability over long periods for the method of reproduction, its accuracy would diminish. This seems to parallel the actual results quite closely. That is the method of estimation did lead to overestimation, the method of production to relative under-estimation, and the method of reproduction to results of low reliab-ility. If we assume that the inaccuracy in the results of the method of reproduction is due to a lack of external validity, then we can say the methods of production and estimation, which are significantly correlated, are valid measures of time estimation, for they are relatively reliable and externally related to clock time (that is, they fulfill both assumptions made above, given a built in timing device) while the method of reproduction is not, in that it is not related to these two methods and contains inaccuracies due to a lack of external validity.

In view of the low reliability of the method of reproduction, and its lack of correlation with the other two methods, it seems that for clinical purposes the method of production is the most promising, while further work should be done on the method of reproduction before it is used as a measure of time estimation.

It should be emphasized that this study was not designed to test any clinical hypotheses, nor to make any contributions towards clinical theory, for this is basically a methodological study. The conclusions of this study only deal with the relative merits of the different methods of time estimation. The study itself provides no conclusion in the clinical area and suggests no specific hypotheses in that area.

SUMMARY

Forty-eight 'normal' female college students between the ages of 17 and 20 were divided into four groups: first, those given the intervals 5, 10, 15, 20 and 25 seconds all in random order, under the method of reproduction, then the method of estimation, and then the method of production; second, those given the intervals 20, 25, 30, 35 and 40 seconds, in the same order; third, those given the short intervals in the order of estimation, reproduction, and production; fourth, those given the long intervals in this order.

The results of this study show no evidence for serial position effects, with series of either short or long intervals, and normal adult subjects. With the same subjects, reliability within experimental sessions was high except for the method of reproduction. Production was the most accurate method, with reproduction next, and then estimation. Intervals were overestimated by the method of estimation, and underestimated by the method of reproduction, while by the method of production short intervals were underestimated and long ones overestimated. With long intervals,the correlation between the methods of estimation and production was higher than that for the methods of production and reproduction. Estimation and reproduction were not correlated. For both groups, the difference between the results of the methods of estimation and reproduction was significant, while for the long intervals the difference between the methods of reproduction and production was also significant. No difference in judgements due to interval length of series could be established.

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APPENDIX 1

1. Raw Data.

Group I, order R E P

Reproduction:

	5				10				15				20				25		
8	7	10	10	10	14	18	17	10	16	19	16	17	14	16	22	24	22	30	29
3	5	4	3	8	8	7	6	11	10	10	10	13	22	11	15	24	18	20	17
3	3	3	5	7	8	9	9	8	14	10	13	17	19	14	13	15	18	22	21
5	4	6	5	8	5	12	8	12	11	10	11	14	15	12	12	30	19	15	16
6	5	5	5	7	8	10	9	10	11	14	11	15	11	18	12	18	17	17	24
6	8	10	9	15	17	15	17	16	22	22	26	32	21	27	19	37	33	34	24
4	7	4	4	10	8	8	7	24	16	13	16	12	13	19	21	29	15	20	16
4	6	7	7	6	12	13	15	11	16	18	16	24	15	21	21	21	19	19	28
4	3	4	9	6	9	11	9	11	12	17	20	14	18	11	20	17	20	28	28
4	6	6	5	11	7	7	9	12	14	19	19	18	25	15	19	20	22	29	19
3	5	4	5	9	13	23	10	14	13	15	10	19	22	20	23	27	29	28	23
5	4	3	3	11	7	18	20	13	18	22	21	13	25	29	14	23	16	34	37

Estimation:

10	5	7	20	40	20	20	30	30	30	35	30	50	45	35	40	60	60	50	60
4	4	4	4	20	10	10	8	15	20	10	20	30	15	15	15	18	25	12	20
10	20	10	15	30	25	25	20	40	30	50	40	35	25	45	60	55	60	70	70
25	20	25	30	30	40	35	30	45	50	50	45	60	45	45	70	60	60	60	65
3	4	5	7	4	12	10	8	7	12	14	15	12	15	14	18	20	18	20	25
5	4	3	4	8	7	6	6	10	8	10	7	8	10	10	7	15	15	15	12
5	4	5	3	10	5	5	5	15	20	10	15	20	15	15	10	30	15	20	20
5	3	3	3	20	5	5	5	45	10	15	10	30	20	15	20	60	25	30	25
5	10	5	5	15	15	15	10	25	15	20	15	30	20	20	25	40	25	30	30
5	5	5	5	10	15	10	10	30	25	20	20	20	40	20	45	45	30	60	30
7	10	15	10	15	15	20	20	30	30	30	15	30	33	45	50	30	45	40	55
5	3	5	5	8	10	12	10	15	12	10	10	10	15	15	20	25	25	20	15

Production:

4	4	5	5	7	6	7	6	8	8	9	7	7	8	8	8	10	7	9	13
5	6	7	7	12	12	16	16	17	17	19	18	25	15	26	30	25	28	33	32
2	2	5	5	3	3	5	3	4	5	5	8	20	5	5	5	9	7	8	10
2	3	3	2	3	3	4	3	5	5	5	5	9	8	7	8	8	7	10	9
5	4	5	5	7	10	7	7	12	13	15	13	13	12	16	19	13	20	27	25
11	8	14	17	28	37	33	33	60	41	57	52	52	59	64	69	62	65	90	70
7	6	7	7	12	12	11	15	13	18	19	11	23	19	22	26	20	31	28	31
6	7	11	14	10	16	20	19	9	22	21	32	17	19	23	35	16	29	46	40
4	4	3	3	12	9	6	5	14	12	11	10	18	13	11	18	23	16	25	16
4	3	4	4	6	6	9	10	7	9	11	8	9	12	13	11	11	17	13	14
2	2	3	3	5	5	5	6	7	6	7	6	9	9	9	8	12	12	11	13
5	5	7	7	10	11	7	8	19	13	18	13	23	14	21	23	25	21	26	15

Group I, E R P

Estimation:

5				10				15				20				25			
10	5	8	3	40	40	20	30	60	50	45	60	60	70	40	50	90	60	80	65
7	3	3	3	10	6	6	8	30	1o	10	12	12	10	18	18	20	25	20	18
10	5	5	15	20	30	20	45	35	35	30	40	40	60	25	30	50	60	60	45
5	5	5	3	39	20	10	8	30	40	10	15	60	25	30	25	60	30	40	30
10	5	5	10	20	10	12	15	45	15	12	15	25	25	15	20	45	20	30	30
5	3	4	3	10	5	5	15	30	15	10	10	20	20	20	12	40	25	15	20
5	5	5	5	10	10	10	10	25	10	20	15	20	15	29	20	32	25	30	25
10	10	5	4	20	15	8	10	45	25	20	15	30	40	30	15	60	45	25	20
19	5	6	4	15	10	6	6	12	20	12	10	20	15	15	15	25	20	25	10
3	5	5	6	8	8	10	8	15	15	12	18	16	18	18	24	20	20	20	25
5	2	5	5	15	5	5	5	60	10	10	15	25	10	10	20	45	30	15	20
5	3	3	4	11	7	5	6	60	7	10	6	12	7	15	11	20	18	20	14

Reproduction:

5	5	4	6	11	6	9	7	10	15	14	8	18	21	14	10	15	25	17	15
6	3	5	4	12	10	11	10	15	16	18	14	25	26	16	18	29	26	18	23
4	4	5	5	6	14	8	11	6	14	11	15	10	14	14	14	18	21	30	15
5	3	6	3	14	9	10	13	14	10	14	12	21	13	15	14	21	19	15	12
4	6	5	4	11	10	8	6	10	18	20	10	16	14	22	12	22	22	15	22
4	3	7	4	9	8	8	12	9	9	16	10	14	12	10	15	15	14	14	22
5	5	5	5	10	8	10	8	17	17	12	12	20	14	21	16	23	26	22	21
5	5	3	4	10	8	6	7	13	13	11	12	19	15	10	12	20	15	19	19
4	4	8	5	10	16	15	10	15	14	2L	20	22	17	16	18	25	30	21	33
4	6	4	6	11	12	11	9	12	16	13	15	19	16	19	15	20	28	19	16
6	6	5	5	8	14	11	10	14	10	17	12	23	31	26	17	35	25	22	24
3	4	5	5	9	10	8	9	11	10	13	10	13	12	14	14	17	24	22	19

Production:

3	2	3	3	6	5	5	5	9	6	7	6	10	9	9	8	10	11	12	8
7	6	7	6	15	14	11	11	23	19	27	18	26	22	33	21	36	36	34	23
11	9	9	7	16	13	10	11	11	18	15	11	14	21	13	15	18	16	21	14
6	6	6	6	8	9	9	9	11	13	10	8	16	12	14	12	15	16	17	18
5	7	9	9	10	12	12	14	11	15	16	19	15	18	21	21	17	23	29	27
5	5	5	5	10	8	10	9	17	23	13	11	21	18	21	12	25	15	20	16
5	5	7	4	9	11	10	11	14	16	19	11	19	18	23	20	22	28	25	23
5	7	6	7	15	15	14	17	29	22	18	26	28	25	28	24	48	41	37	47
4	6	8	7	13	15	11	16	10	17	19	27	18	20	26	27	19	30	27	26
6	6	5	6	11	13	13	11	13	15	20	14	23	19	15	16	21	21	20	26
13	19	12	8	24	17	15	24	29	29	27	21	38	39	36	24	46	52	47	51
5	5	5	6	8	10	7	10	13	11	12	13	12	13	19	16	14	19	17	20

Group II, order R E P

20 seconds:

Reproduction				Estimation				Production			
10	19	22	20	5	15	20	20	12	11	13	11
15	23	31	18	35	35	40	30	14	22	29	18
15	21	11	9	10	20	25	10	35	46	63	58
38	18	29	19	8	10	10	7	53	55	45	37
22	26	25	21	30	15	18	15	32	20	37	41
18	23	21	30	20	15	20	20	17	22	3L	20
20	21	17	23	13	15	10	10	30	36	33	29
15	15	24	25	60	30	60	60	9	8	8	11
22	18	20	25	30	25	20	15	9	10	13	12
14	16	15	14	60	60	60	120	5	5	5	5
14	12	12	8	30	20	20	15	13	10	20	18
18	18	22	18	25	20	20	20	19	22	19	25

25 seconds:

37	24	20	20	15	15	20	25	28	16	14	13
15	16	21	25	25	23	30	35	20	26	34	33
21	19	18	19	45	20	25	15	31	76	70	80
25	17	29	21	20	13	8	10	54	66	60	54
19	30	24	30	30	20	15	15	23	40	43	46
20	25	21	27	45	20	20	25	27	39	26	19
20	14	16	29	25	10	15	10	30	39	40	44
20	20	20	24	45	45	90	120	11	10	13	10
15	22	23	25	25	60	30	45	16	15	13	17
19	18	17	19	90	90	120	90	10	6	8	8
19	20	18	20	38	30	15	25	13	19	20	25
33	22	26	23	30	30	30	25	24	29	31	31

30 seconds:

26	26	33	27	20	20	40	20	22	20	22	27
22	29	34	26	30	40	35	35	16	24	27	25
25	25	18	43	30	25	15	25	49	51	80	73
17	24	38	35	15	10	12	9	85	74	70	72
32	33	34	31	30	20	35	25	33	32	37	47
28	26	33	26	40	60	30	30	28	32	42	22
42	28	32	25	15	20	25	20	46	46	38	48
40	23	23	25	30	80	60	120	10	LO	L71	15
28	30	27	30	30	60	45	45	23	21	17	18
14	33	18	16	120	90	120	120	8	7	10	8
16	14	24	17	40	50	25	45	21	18	21	22
35	30	29	29	30	35	35	40	27	29	28	27

35 seconds:

33	32	23	26	45	30	30	60	30	20	20	23
22	30	33	30	30	40	45	40	27	28	35	36
36	34	31	32	30	40	45	40	37	61	91	116
32	32	26	24	25	13	14	13	88	81	83	84
30	35	40	51	25	22	30	30	37	43	50	59
22	33	26	24	75	75	35	35	41	44	49	41
33	25	25	26	30	25	25	20	57	40	61	56
24	27	34	34	60	60	120	210	9	15	13	12
33	32	35	35	45	45	75	60	22	18	20	23
30	20	23	19	120	150	120	150	10	6	10	13
22	20	18	36	50	60	40	30	17	20	24	35
35	38	35	36	40	40	40	35	29	40	30	34

40 seconds:

31	45	30	47	40	45	35	60	32	24	25	24
38	38	26	39	40	40	30	45	33	56	32	46
30	31	40	45	35	25	20	20	92	123	98	128
55	45	35	35	18	17	10	12	99	127	120	105
38	45	45	58	30	30	30	35	60	59	57	53
38	51	44	24	45	35	40	35	41	42	47	45
43	30	32	40	20	20	25	15	67	57	69	59
25	30	29	33	180	120	120	120	19	20	15	19
41	44	41	40	50	60	60	45	23	19	23	28
17	36	27	34	150	120	120	120	10	15	12	12
25	20	25	25	50	40	30	50	34	29	24	39
40	43	38	28	50	45	40	50	47	39	46	34

Group II, order E R P

20 seconds:

Estimation				Reproduction				Production			
10	15	20	15	16	24	39	18	39	37	35	35
60	60	30	15	15	17	24	18	35	32	43	51
20	30	25	20	18	18	18	15	18	17	17	16
20	15	20	15	13	24	32	23	21	22	19	19
15	15	17	16	23	24	14	18	37	25	24	23
25	30	25	30	7	13	10	20	16	13	17	12
60	80	60	30	18	26	36	34	9	15	12	10
12	10	10	15	13	18	14	23	23	28	27	24
30	30	30	30	24	18	22	14	15	18	18	16
20	30	20	25	17	16	11	16	18	20	20	18
3	7	7	6	12	13	21	24	35	31	50	42
15	20	20	15	15	24	22	18	22	23	21	20

25 seconds:

30	20	15	20	29	25	30	29	35	32	30	33
90	30	30	30	28	26	26	27	28	45	56	57
45	35	30	35	22	19	21	30	22	20	18	22
35	25	20	20	26	37	37	21	29	30	31	33
30	15	17	17	25	27	22	25	35	26	31	33
20	30	30	25	20	13	32	21	19	18	19	13
60	75	60	80	23	24	34	38	10	14	15	15
50	15	15	15	22	21	21	28	35	31	35	32
60	45	45	45	22	28	15	19	20	24	22	28
40	25	30	30	14	18	17	26	14	23	18	17
16	5	5	8	20	20	14	16	25	49	31	26
50	25	20	15	19	20	20	26	19	22	25	27

30 seconds:

30	20	10	15	31	44	41	31	54	50	48	59
150	120	15	30	31	26	25	24	53	52	67	68
50	60	35	30	28	37	31	17	25	27	22	23
30	20	25	15	30	26	25	28	36	32	38	33
20	20	20	20	21	40	46	28	42	32	36	40
25	22	35	40	18	11	25	27	22	20	23	20
90	80	60	90	47	33	28	24	19	14	17	17
25	22	15	20	24	29	29	34	32	33	37	30
60	60	60	60	27	24	35	28	23	25	25	26
30	35	30	40	28	25	21	27	22	24	24	25
5	15	6	12	15	34	14	16	43	38	24	20
30	35	30	30	31	30	28	35	34	36	33	32

35 seconds:

40	30	30	20	39	43	22	32	56	52	45	49
180	120	60	60	42	31	37	27	61	62	55	87
60	50	50	55	40	32	31	33	30	28	26	29
45	35	25	25	33	30	31	26	33	41	37	45
25	20	20	25	31	24	40	33	39	39	40	38
25	20	45	50	20	26	17	30	24	21	29	18
90	90	90	90	53	23	33	31	11	14	19	16
26	22	20	25	29	25	33	30	47	44	42	41
90	45	60	60	34	35	33	22	20	28	30	30
60	60	60	50	23	23	29	21	22	24	26	24
12	5	5	20	32	24	32	30	40	41	41	40
60	40	30	36	37	30	23	40	41	44	43	42

40 seconds:

40	40	25	15	45	37	34	27	81	74	68	47
180	45	60	90	43	40	44	33	58	87	85	103
70	45	40	40	41	34	31	35	31	30	25	31
30	30	30	30	34	38	36	43	47	61	38	40
17	25	25	24	30	32	30	33	48	36	44	42
40	45	45	50	33	32	25	24	29	25	28	23
105	120	120	140	51	27	38	34	18	18	19	24
26	30	20	20	26	36	32	33	47	43	42	54
90	60	120	90	40	33	38	17	34	25	37	38
60	60	60	50	33	34	29	36	27	36	30	29
5	10	12	15	28	25	31	34	53	57	78	80
30	35	30	40	42	40	37	40	51	48	47	46