TIME PERCEPTION

A STUDY OF SOME PSYCHOPHYSIOLOGICAL FACTORS OF RELEVANCE TO AVIATION

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SUMMARY

Aircrew are familiar with distortion in the apparent duration of elapsed intervals of time, and they are aware of factors which may accentuate this distortion. It is apparent that the content of the interval and the attitude of the individual towards it are of paramount importance in determining punctuality.

Three separate laboratory experiments on Man constitute the basis of this research. Their objective was to investigate a few of the factors thought to be relevant to an understanding of some of the mechanisms which underly the accurate assessment of the duration of an elapsed interval.

In the first laboratory experiment it was shown that the apparent duration of a ten-minute interval was decreased by the performance of a tracking task and increased by exposure of the subject to irrelevant alteration in the environment. By obtaining a quantitative subjective assessment of alertness and a measure of skin resistance change, it was demonstrated that the subjects' level of arousal was increased by both performance of the task and exposure to the environmental distraction. No significant relationship between arousal and apparent duration could be elicited.

In the second experiment it was demonstrated that a 1 kc/s tone increased the apparent duration of a ten-second interval as determined by the method of serial reproduction, but only when it was presented in the judgment interval. No consistent distortion was obtained when the resistance to respiration was increased.

In the last experiment, evidence was obtained which suggests that the relative duration of a one-minute interval is related to the attitude of the individual towards its content - the stronger the view expressed, be it preference in its favour or aversion against it, the longer the apparent duration of the interval.

It is concluded that any composite theory of the mechanism of the perception of time must include an understanding of cognitive and affective processes. To aircrew, as control-system operators, time perception is a matter of practicality; in order to reduce the incidence of human error, it is advised that they rely implicitly on accurate chronometers to assess the duration of an elapsed interval and achieve punctuality.

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INTRODUCTION

Despite the fact that aircrew are performing tasks of increasing complexity, the dangers involved in flying are decreasing. Records of accidents in the Royal Air Force have been kept since 1922, when there were 5.62 fatal accidents per 10,000 hours flown. Since then the rate has fallen to a minimum of 0.25 in 1960 (Directorate of Flight Safety, 1922 - 1961). This improvement can be attributed to more efficient aircraft and to a better knowledge of the causes of accidents which has led to the introduction of new training methods and technical aids.

In recent years a record has been kept of the number of accidents that were attributed by a Board of Enquiry, in whole or in part to pilot error. In 1956, 54 per cent. of fatal accidents were due to this cause, and this proportion has fallen progressively to 33 per cent. in 1961. The fact that pilot error plays such a large part in the causation of accidents provides the incentive to investigate the reasons for the failure of individuals to perform their task adequately.

The classical problems of aerospace medicine are associated with acceleration, altitude and temperature, and the physiological limits for the specific stresses of conventional and extra-terrestrial flight are now well defined. This understanding and the resulting technical developments have contributed much to the improvement in flight safety. However, little is known of the less tangible effects of the neurogenic stress of these factors on the behaviour of an individual and on the quality of his performance (Stewart, 1959). There are at present specific problems in this context in which interest is paramount in the Royal Air Force, and the research constituting this thesis is directed at one of them.

Aircrew have to perform certain duties at specific times during flight, and they have access to accurate chronometers in order that they may do so without error. However, mistakes can still be made due to the crew's failure to appreciate the correct duration of an elapsed interval. Since 1961, there have been at least two major accidents in the Royal Air Force, in which a failure of the aircrew to realise that the aircraft had been airborne for longer than usual was considered as a contributing cause. The following accounts serve to illustrate that accidents happen which might have been avoided if the aircrew had had a better appreciation of elapsed time and a greater realisation of the relevance of distortion in time perception.

(i) The crew of five of a bomber were briefed to carry out a training sortie of six hours, twenty minutes, in the last hour of which they were to be in the vicinity of the base airfield. After this interval had elapsed they continued to carry out the detailed exercise; it was not until six hours, forty minutes had passed that they noticed that the aircraft was short of fuel.

They had not fully appreciated that they had been airborne longer than is usual and the aircraft ran out of fuel on its final approach to landing after six hours, fifty minutes. It sustained damage beyond repair, though the crew were uninjured (classified reference).

(ii) After 40 minutes airborne on a test-flying sortie, a single-seat fighter returned to overhead its base airfield. The pilot noted that he had excess fuel and elected to continue the sortie. Nineteen minutes later the aircraft ran out of fuel on its final approach to landing, though the fuel contents gauge registered that sufficient fuel to land safely was available. The pilot was uninjured, but the aircraft sustained damage beyond repair. The pilot stated afterwards that he had not realised that he had been airborne so long. (Director General of Flying, 1961).

It is of interest that the mean duration of the previous 24 sorties of this aircraft was 33 minutes with a standard deviation of eight minutes. Thus the duration of this particular sortie exceeded two standard deviations from the mean.

There is a wide range in the duties of aircrew during flight and, of necessity, very different degrees of attention are appropriate. In some flights, intense concentration is demanded and the pilot is subjected to considerable physical stimulation, such as during low-level aerobatics; in other flights, such as long range reconnaissance over the sea, there is almost inordinate boredom. The duration of intervals to be assessed also varies greatly; during accurate instrument flying, scanning of certain instruments must be repeated every few seconds, though other tasks need not be performed for much longer intervals. Distortion of time perception may well upset the frequency of carrying out these tasks, and the factors affecting apparent duration may have wide implications. Distortion of time perception reduces the efficiency of aircrew as control-system operators, jeopardising their safety and placing others in danger.

In the understanding of time and the perception of duration, philosophic and physical concepts are involved that require appreciation of the relativity of existence. James (1890) wrote: "But whether our feeling of the time which immediately past events have filled be of something long or of something short, it is not what it is because those events are past, but because they have left behind them processes which are present." Wallace and Rabin (1960), in an important review, distinguished clearly between time perspective - the past, the present and the future - and time perception - the appreciation of duration. It is to the latter, a small portion of the temporal continuum of the former and the processes referred to by James, that the research constituting this thesis is directed.

The difficulty of a fundamental definition of time was recognised by Gilliland, Hofeld and Eckstrand (1946) who could only reiterate after cogent argument that it is one of the two characteristics of movement, the other of which is space. The appreciation of duration thus arises with change and can only be attained by comparison with previous temporal experience. Mach (1900) in a philosophical review considered that "we feel the work of attention as time", though James (1890) in a similar context considered that boredom could be defined as a state when one is aware of time passing. Woodrow (1951) in a standard reference work, wrote that time perception is a variable process and the judgment is dependent on the nature of the experience. Thus, assessment of the duration of an interval is likely to be influenced by change in the environment as reflected in the cerebral sensory inflow and by its relevance to the individual.

Whiteside (1960) in a personal communication suggested to the author to investigate the relationship between apparent duration and degree of wakefulness - arousal; this request pervades the experiments reported in the following studies and determined much of the author's attitude towards the research.

No report in the literature could be found which examined directly the bearing of time perception to aviation. In order to obtain a better understanding of this problem in flight, a formal interview study of aircrew was carried out. As a result of this, a questionnaire was prepared which was completed by a large number of pilots. These studies were associated with the collection of information on other aspects of flight safety. On the basis of the evidence obtained an experiment was carried out aimed to assess in the laboratory the reproducability of the distortions reported. The relevance of the level of arousal to the apparent duration of intervals, of comparable duration to those commonly judged in flight, was examined in detail to investigate Whiteside's hypothesis as a possible mechanism inducing distortion.

Woodrow (1930) drew attention to the relevance of individual attitude in the appreciation of duration. This prompted examination of the use of apparent duration to assess attitude towards environmental conditions present in aviation. This was investigated in two further studies; the first, a preliminary experiment, was done primarily to explore this as a possible means to detect flaws in oxygen-system regulators; the second, as an associated investigation in an experiment done primarily to select the least distracting frequency of flashing light to recommend for use in aircraft as an anti-collision visual aid.

Comment on Methodology An understanding of many problems in clinical research presupposes that it is possible to communicate the desired information from the subject to the observer, and so measure it. As measurement, in its broadest sense, is "the assignment of numerals to things so as to represent facts and conventions about them" (Stevens, 1946), the amount of subjective information, such as on arousal, that can be transferred is limited by the language of common discourse. Though individuals may appreciate their state on a continuum, words, being designed for the communication of less specialised parts of experience, may fail to describe adequately in a quantitative way more than the broadest indications of the subjective experience.

Thus, for accurate measurement of psychophysiological phenomena, it is essential to establish unique modes of communication. In these experiments, simple visual analogues - continuous scales with boundaries clearly defined - were used; the subjects or judges were instructed in the rules in unambiguous terms in the language of common discourse. For example, in order to assess degree of subjective alertness, the subject was presented with a 100 mm. line; he was instructed to regard this as representing the possible degrees of alertness, ranging from a state of sleep at the extreme left, through a region signifying moderate wakefulness in the middle, to a panic-stricken state at the right end. He was asked to mark the line to indicate his assessment of his alertness during a preceding interval (Gedye, Aitken and Ferres, 1961).

The interpretation of marks on continuous scales is governed by the rules under which they are made and necessarily involves the assumption that the rules are obeyed. Then, in further discussion, as long as position of marks are referred to, one can use statements appropriate to position of marks. For example, if an individual is instructed to mark lines to indicate his level of alertness on two occasions, one is entitled to infer that a difference in scores between them indicates a difference in alertness. However, it does not necessarily follow that a mark twice the distance from one end means that the subject was twice as alert. Similarly, if two subjects mark points that give the same alertness score, it cannot be assumed that they wished to convey a state of alertness that is identical, and this interpretation may be invalid unless otherwise substantiated. One can, however, draw attention to what is the mean score for the two subjects in different situations.

Thus marks on continuous scales do not permit liberal comparison between subjects or judges, as each individual may consider the scale differently; but comparison between conditions or data can be made with greater sensitivity and more understanding of degree than with semantic phrases. This limitation is no more than that holding in common discourse, which contains an apparent assumption that the same language, up to a point, is being spoken in order to communicate the information.

It is indeed logical to use a continuous scale with its boundaries clearly defined for a subjective continuum requiring measurement, such as alertness, resistance to respiration or apparent duration, as it is also, of course, logical to use categories for a graded parameter. However, in many experiments in clinical research the special language is often constructed with artificial categories in order to simplify and standardise the communication of a continuous variable. Grading has the disadvantage that much of the available information may be lost, and the meaning of the categories may be open to misinterpretation outwith the control of the experimenter. Also the differences between two adjoining categories may not be the same, and so the results not be amenable to certain sensitive statistical procedures.

In 1947, Metfessel proposed the technique of portioning a fixed quantity of a unit between a set of possible alternatives. Mandler, Mandler and Uviller (1958) used the method to measure the awareness of autonomic activity; they asked subjects to divide a 145 mm. line into two portions, indicating the proportion of time that the specific modality was in conscious thought. In an experiment here recorded, this method is proved ideal to determine the attitude expressed by subjects towards conditions and their relative durations.

With this technique of graphic rating more information is communicated as the number of categories is selected only by the power of resolution available in measurement. The method avoids the important defects inherent in the use of categories and provides quantitative measures which are amenable to standard statistical analyses for continuous variables, such as analysis of variance. Graphic rating provides a technique whose usefulness is advocated to all who require assessment of phenomena on which Man has a view to express on his subjective involvement; evidence will be presented to support this statement.

SECTION II

HISTORICAL REVIEW

The early experiments on time perception were undertaken mostly to verify Vierordt's observation (1868) that there is a tendency to overestimate the duration of short intervals and to underestimate the duration of long intervals. This statement carries the implication that there is an indifferent interval which is accurately estimated. Woodrow (1951) in reviewing the evidence for this concluded that its duration is dependent on the attitude of the individual towards the experience and the characteristics that define it; usually it is acknowledged to be less than a second. These early experiments were also concerned with the accuracy of discrimination and reproduction of intervals of very short duration, but in aviation, as in every-day life, temporal judgments are more commonly required of longer intervals.

As mentioned in the Introduction, no reference could be found in the literature on the direct connection between time perception and flying. However, there are many studies on the effect of occupation on the experience of time, some with apparently conflicting results. The following are examples of conclusions, the evidence for which seemed to the author to have been obtained with particular care.

Mach (1900) observed that when an individual has exerted a severe mental effort, the duration of the elapsed interval appears to have been prolonged. Loehlin (1959) in a factor analysis on the influence of different activities on the apparent duration of intervals confirmed that interest/boredom is the major factor; yet he reported that the more attention demanded by the situation the shorter it appears to be. This has been verified experimentally; Swift and McGeoch (1925) showed that a ten-minute interval was estimated to be less when subjects were actively copying script than when they were listening to a story. Similarly Gulliksen (1927) reported that the estimates of a 200-second interval were less when subjects were mentally working than when sitting passively waiting. Frankenhauser (1959), in a complex series of experiments, also showed that if awareness of time is favoured, the estimate of the duration of an interval is increased; while if retention is not favoured, such as by the presence of a competing task, the estimate is reduced.

The direction and degree of motivation to desire an interval to end is also considered to play an important role in determining apparent duration. Filer and Meals (1949) reported an experiment where estimates of the duration of a 277-second interval were longer when students were motivated strongly to desire the interval to end, so that they could leave class early. Schonbach (1959) reported a similar result on the duration of a 13-minute interval; the estimates were longer when subjects were in a situation of high need (hunger) compared with neutrality. Falk and Bindra (1954) demonstrated that an anxiety-provoking situation (administration of an electric shock at the end of the interval) led to longer production of a requested 15-second interval compared with neutral circumstances. In contrast to this Langer, Wapner and

Werner (1961) showed that the awareness of impending danger (subjects moving on a trolley at a constant velocity towards a precipitous edge) induced shorter production of a requested five-second interval compared with when subjects were moving away from the danger.

These apparently contradictory findings may have resulted from contrasting motivation for the intervals to end. In Falk and Bindra's experiment, subjects knew that the intervals would terminate with pain, so they may have felt that it was to their advantage to postpone its administration; while in Langer, Wapner and Werner's experiment, subjects knew that their anxiety would be relieved at the end of the interval, and it was to their benefit to terminate its duration early. Irwin (1961) in a review concluded that there is evidence to support the hypothesis that the more an individual desires an interval to pass rapidly, the longer it will appear to be.

Degree of task difficulty, anxiety, attitude, motivation and physical alerting influences are all common to flying and may influence aircrew in their correct temporal orientation. Fredericson (1951) suggested that time is experienced as longer because of an increase in neurophysiological activity. If this hypothesis of a relationship between apparent duration and cerebral cortical activity, or level of arousal, could be substantiated, its application would provide a common mechanism which might resolve some of the diversity of opinions of previous workers on distortion in time perception.

Woodrow (1930, 1933) in experiments on the reproduction of intervals, drew attention to the wide differences between subjects, and indeed in an individual subject on different occasions. In recent years, research has increased in an attempt to establish the relationship between personality and temporal perceptual ability. Eysenck (1959), for example, demonstrated that extroverts, as selected by the Maudsley Personality Inventory, estimated five- and ten-second intervals to be shorter than did introverts. Lewis (1932) reiterated the clinical observation of Browne (1874) that disorientation in time is common in mental illness, noting that this is especially so with depersonalisation. Schilder (1936) considered the psychopathology of this observation and more recently the psychodynamics have been reviewed by Du Bois (1954), who concluded that a normal sense of time aids in successful psychological adjustment.

Boardman, Goldstone and Lhamon (1957) demonstrated with the method of comparison an increase in the variability of apparent duration of one-second intervals after the administration of lysergic acid diethylamide, a drug which produces schizophrenic-like behaviour; their results did not reveal distortion in time perception such as they had demonstrated previously in schizophrenic patients by the same experimental method, (Lhamon and Goldstone, 1956). Cohen and Mezey (1961a and 1961b) were unable to demonstrate any differences in time perception between normal and anxious or depressed patients, though depressed patients say that subjectively time appears to pass slowly. Consideration of the available evidence permits the conclusion that time experience is itself a phenomenon dependent on affective life (Fredericson, 1951), and the manner in which a person handles time is very closely linked to the structure of his character traits (Schneider, 1948). Differences between individuals are thus of great relevance, but unfortunately it was not found possible to make these differences a direct object of study in this research.

The relationship between time perception and physiological processes has interested research workers for many years. Francois (1928) observed that the rythm of tapping increased when the body temperature was raised by diathermy. Hoagland (1933) reported an experiment on three subjects in which the rate of counting at a requested uniform rate was faster when they were pyrexial; he suggested the hypothesis that time perception is under the control of a cerebral clock-like mechanism, dependent on the rate of metabolism. Hoagland and Perkins (1935) produced further evidence in support of this, when they demonstrated that the logarithm of the speed of counting at a requested one-per-second was directly proportional to the body temperature when it was raised by diathermy. Gardner (1935) in a very simple experiment could not demonstrate a difference in time perception between hypo- and hyperthyroid patients. Schaefer and Gilliland (1938) confirmed many previous experiments, when they were unable to show any relationship between the accuracy of the estimation of the duration of short intervals (4-27 sec.) and physiological processes, as measured by blood pressure, pulse or respiratory rates.

In reviewing the literature of time perception, one is immediately impressed by the confusion in terminology and apparent contradictions that surround the phenomenon of experience of time. It is only in relatively recent years that the conceptual confusion has been clarified (Clausen, 1950; Bindra and Waksberg, 1956). These authors define the experimental methods available, and the subsequent interpretation of results in relation to the concept of rate of a cerebral clock. Woodrow (1951) in his authoritative deliberation on the subject concluded from his understanding of the previous work that individual performance in assessing apparent duration appears to be sensitive to the exact observations that are used to elicit the information. It is thus essential to list the available methods, and record definitions of those used in this research.

Intervals whose durations are to be assessed may be either 'filled' or 'empty'; that is to say that the signal denoting the interval may either occupy it or not (Swift and McGeoch, 1925). Apart from this, there are available four basic methods :

(i) E s t i m a t i o n   The experimenter exposes the subject to an interval and requests an assessment of its duration. This may be given either <u>verbally</u> in terms of temporal units or <u>spatially</u> in terms of symbols already defined, such as with the use of a clock-face or linear scale.

(ii) P r o d u c t i o n   The experimenter requests the subject to respond after the lapse of a stated interval from a given reference moment.

(iii) R e p r o d u c t i o n The experimenter exposes the subject to an interval (standard) and requests him to respond after the lapse of a subsequent interval (judgment). He may be instructed either that this should be of equal duration or a requested proportion of the standard, such as half (method of fractionation; Gregg, 1951).

Llewellyn-Thomas (1959) modified the method of equal reproduction in order to amplify any induced consistent distortion. He presented the subject with a series of standard intervals of which the duration of the second and subsequent ones were the same as his 'judgment' of the preceding 'standard'. In a sequence of trials, any consistent error will then tend to magnify distortion. This method of serial reproduction has something in common with the use of positive feedback to increase the gain of an electronic amplifier.

(iv) C o m p a r i s o n The experimenter exposes the subject to two intervals and requests him to compare their duration. The information may be either dichotomous, the subject only indicating which is the longer (e.g. Whitely and Anderson, 1930), or by apportioning quantity of how much longer, indicating relative duration. This method is an elaboration of the method of estimation; information obtained in this way can be modified easily to resemble that from the method of estimation if the subject is requested to indicate subsequently the duration in temporal units of one of the two intervals.

It can be seen that the methods of estimation and production must utilise the concept of clock-time as the instructions and results must be communicated between the subject and experimenter in a language of common discourse. This is not required with the methods of reproduction and comparison. It will be appreciated that the method of reproduction is a combination of the methods of estimation and production as fundamentally these are what the subject is requested to do.

There is a fundamental conceptual difference between the methods of estimation and production. With the method of estimation the subject is assessing the apparent duration of an interval whose actual duration is controlled by a reference system; while with the method of production, the subject is controlling the duration of the interval, which is only assessed by the reference system. Bindra and Waksberg (1956) clarified this further when they differentiated clearly for the different methods between objective (clock) time and the subjective sensation of time passing. They pointed out that if the analogy of a cerebral clock is used and a specific situation is reputed to make it go fast, an interval will be underestimated by the method of production and overestimated by the method of estimation; no distortion will be discernible by the reproduction or comparison methods, if the distortion is present and equal in both intervals. Clearly it is imperative that terms such as 'underestimate' and 'overestimate' are avoided in discussion of experiments, unless great care is exercised to define the method under consideration.

Woodrow (1951) considers that the capacity to estimate or produce specific units of time is a judgmental process; this is based on the consciousness of events which are then related to previous experience in conventional units of time. Examination of association between this judgmental process and the factors inducing distortion constitute the basis of this work; however, like most judgmental processes, the appreciation of duration may become impaired under a variety of conditions; it is clear that the relevance of this to aircrew may require a full understanding of all the cognitive and affective processes of Man.

SECTION III

FIELD STUDIES

A. INVESTIGATION BY INTERVIEW *

As the appreciation of the duration of an elapsed interval is a subjective experience, it was thought that information on any distortion in apparent duration could best be obtained by establishing the views of the pilots themselves. Casual conversations with aircrew by the author and his colleagues had suggested that aircrew are aware of many factors which influence their ability to estimate time accurately and are of relevance to their flying proficiency. This account is a small part of an investigation to verify formally these impressions and to assess some relationships between possible other relevant features. The investigation was directed at all factors thought to influence the incidence of accidents due to pilot error; the detailed results of little direct bearing on time perception are omitted from this account.

Method Twelve Javelin, four Lightning and four Hunter pilots were interviewed. These are all high performance fighter aircraft, currently in service in the Royal Air Force. The pilots were selected informally; the author presented himself in routine operational crew-rooms and asked

* Aitken, 1962

for volunteers willing to discuss problems which might influence their flight safety. Each pilot had an interview with the author for about an hour. Particular care was taken to see that the conversations were as unstructured as possible. However, in order to assess certain aspects that might be relevant, and to keep the conversations flowing smoothly so that information was released, the following topics were raised -

(i) Time perception

(ii) Incidents of spatial disorientation (Jones, 1957) with particular reference to precipitating factors

(iii) Awareness of physiological processes such as palpitation, dyspnoea or muscle cramp

(iv) Mistakes that could be attributed to 'unawareness' (Working Party, 1961) with particular reference to associated factors

(v) Specific criticisms of the aircraft workspace, the pilots' control by Air Traffic Control, and their discipline

Results Many features were revealed in the interviews under each heading and the following are the results relating to time perception -

The majority of the pilots made the common observation that while flying, as elsewhere, boredom makes time seem to drag and interest makes it appear to pass faster. This change with interest seemed to be dependent on the nature of the task. It appears to be very true for in-flight refuelling, a manoeuvre requiring very steady and accurate control, when time seems to pass very fast. However, pilots reported that when performing formation aerobatics, another very demanding situation providing great interest, a short interval often appears to be of very much longer duration, certainly in retrospect. These alterations in 'feeling' did not seem to be proportional to the duration of the interval. One pilot, for example, stated that often ten minutes felt like 15 and yet ten seconds felt like 60; conversely, ten minutes felt like three, but ten seconds only felt like seven. One pilot observed that time appears to pass slowly on sorties in which he could describe the nature of the duties as particularly exciting or boring. A number of pilots stated that time seems to pass more slowly when night-flying than when flying during the day on similar duties, and one pilot noticed that when flying over sea, an interval seems to take longer to pass than he would have expected if he had been flying over land. Another pilot noticed that when he is suffering from physical discomfort, such as from pressure on the buttocks, time appears to pass slowly. Another pilot observed that when he is anxious, he does not 'feel' time passing concurrently, but only appreciates that an interval has elapsed in retrospect. Pilots on standby at immediate readiness are entertained with innocuous music over the telebrief, and most of the pilots considered that the time would drag even more than it does if they were not exposed to the music.

To assess the appropriate duration of a sortie, the pilots appear to rely more on the information from the fuel contents gauge than on the elapsed time airborne. They do this despite knowing that the reliability of the fuel contents gauge is poor, and notoriously inaccurate at low fuel states, and its serviceability worse than their service watches. They consider, and rightly so, that the information of fuel contents is more relevant to them than the duration of the elapsed flight-time, but when the latter is unduly prolonged, it appears that they hardly ever suspect a fault in the fuel contents gauge. An example that came to light illustrates this -

> A pilot of a Lightning flew a sortie without a watch. As the flight was very gentle, the aircraft used very little fuel; it landed safely after 80 minutes, when the fuel contents gauge registered the appropriate amount. The pilot considered he had been airborne only 65 minutes; he had relied implicitly on the fuel contents gauge, but he agreed that if it had only been slightly inaccurate, the incidence would have had a more tragic ending.

In summary, pilots reported that interest, even if only attained by music, makes time appear to pass fast and increased stress, such as flying over sea, flying at night, performing aerobatics or suffering from buttock discomfort, makes time appear to pass more slowly. The evidence obtained suggested that apparent duration might be dependent on the demand of the task during an interval and on the amount and relevance of the physical stimulation to which the pilot is exposed by nature of undertaking the task.

Assessment of Results In an attempt to make the results of the interview as quantitative as possible an account of each was transcribed under the five topics to typescript from the original notes. Four judges, all of whom were medical officers, then read each separately in random order; they did not know to which pilot any data referred and they rated the various factors quite independently.

The judges marked finite, continuous scales (100 mm. lines) to convey their assessment of the degree of liability or relevance of that factor for each pilot. They had been instructed that a mark at the extreme left end would indicate that their assessment of liability to disorder in that factor was minimal and that a mark at the extreme right end would denote a maximal score; a mark at the centre of the scale would represent the judges' own assessment of normality, and at intermediate positions, the relative strength of their judgments. The marks were measured to the nearest millimetre from the left end and the values are given in Table I; they were then ranked for each factor, the first having the highest score.

Kendall's coefficient of concordance, W, (Siegel, 1956) was calculated from the rank order of the scores obtained from the judges for each factor. Table II shows the values of W with their significance. It can be seen that there is good agreement between judges on all factors. Thus, statistical examination on the final agreed rank order of the subjects with correlations between factors are permissible. The coefficient of concordance is, however,

Table I

Measurements of liability for each factor by four judges

Factor	Judge	Javelin Pilots											
		1	2	3	4	5	6	7	8	9	10	11	12
Time perception distortion	1	59	50	50	39	52	58	36	58	46	54	46	60
	2	32	41	27	26	28	32	34	39	39	23	31	35
	3	32	44	32	58	40	36	39	47	67	33	54	56
	4	47	48	47	51	48	44	48	48	55	43	46	58
Spatial disorientation	1	13	10	17	17	3	4	18	10	22	23	11	18
	2	35	15	15	19	12	19	68	25	26	61	40	30
	3	22	41	48	31	17	36	74	25	54	49	57	61
	4	33	40	40	29	27	19	51	42	23	49	48	42
Awareness of physiological processes	1	59	13	3	7	13	30	14	7	46	41	18	3
	2	67	30	19	21	15	60	37	21	48	62	19	21
	3	78	62	24	20	12	56	43	37	68	67	69	20
	4	72	58	67	53	57	65	60	69	56	64	59	64
'Unawareness' mistakes	1	57	57	38	50	67	59	20	58	34	29	56	63
	2	47	43	42	47	55	36	43	55	40	37	54	48
	3	46	53	30	26	63	22	36	66	23	53	56	45
	4	48	47	45	40	54	35	42	48	38	45	45	46
Specific criticisms	1	47	59	61	57	29	33	26	59	55	27	43	42
	2	25	49	32	42	24	33	28	37	29	20	22	36
	3	53	52	52	58	42	30	33	57	48	27	29	40
	4	48	47	46	49	43	43	41	48	52	34	46	51
Age : years		34	34	33	34	32	30	37	32	29	32	39	31
Flying hours hundreds		24	16	25	23	26	18	32	13	28	25	35	21

The scores have a possible range from 0 to 100

Table I (continued)

Measurements of liability for each factor by four judges

Factor	Judge	Lightning Pilots				Hunter Pilots			
		13	14	15	16	17	18	19	20
Time perception distortion	1	38	37	53	73	64	73	63	62
	2	22	32	29	47	42	39	30	40
	3	35	29	68	66	60	46	64	50
	4	47	46	49	53	48	54	46	47
Spatial disorientation	1	22	7	15	36	12	13	12	14
	2	39	43	23	63	16	18	16	35
	3	71	54	64	89	80	47	38	18
	4	44	60	37	64	52	49	33	36
Awareness of physiological processes	1	39	27	11	16	32	31	23	34
	2	44	35	44	35	39	65	36	32
	3	46	62	55	53	61	63	72	61
	4	67	56	68	58	61	65	65	60
'Unawareness' mistakes	1	67	17	53	54	38	50	46	41
	2	57	35	52	54	50	36	48	34
	3	60	28	65	62	24	57	29	51
	4	47	42	45	44	42	43	39	46
Specific criticisms	1	54	38	70	45	53	68	63	65
	2	38	29	30	26	31	48	57	44
	3	48	45	65	55	56	69	47	61
	4	45	44	41	36	48	52	54	54
Age: years		25	24	29	22	25	23	25	27
Flying hours hundreds		12	10	12	8	16	7	13	18

Table II

Kendall's coefficients of concordance of the judges' scores with their levels of significance

Factor	W	P
Time perception distortion	0.53	0.01
Spatial disorientation	0.61	0.001
Awareness of physiological processes	0.56	0.001
'Unawareness' mistakes	0.69	0.001
Specific criticisms	0.69	0.001

Table III

Spearman's rank correlation coefficients between the time perception distortion scores and these factors with their levels of significance

Factor	r_s	P
Spatial disorientation	-0.01	N.S.
Awareness of physiological processes	-0.05	N.S.
'Unawareness' mistakes	-0.05	N.S.
Specific criticisms	+0.50	0.05
Age	-0.37	N.S.
Flying hours	-0.33	N.S.

lowest for time perception distortions; this would suggest that it is the most nebulous concept of the factors ranked.

Spearman's rank correlation coefficient, r_s, (Siegel, 1956) was then calculated on the agreed rank order of the subjects for all factors, age, and flying hours. The correlation between liability to distortion in time perception and the other factors are shown in Table III, page 44. It can be seen that r_s is negative for correlation with all factors except 'specific criticisms' which is also the only one that is significant.

A Kruskal-Wallis one-way rank analysis of variance (Siegel, 1956) was carried out on the agreed rank order of each factor to determine if there were any significant differences between the scores from the pilots of the different aircraft types. It was determined that the Javelin pilots were older ($H = 11.6$; $P = 0.01$) and had flown more hours ($H = 12.1$; $P = 0.01$) than the Lightning or Hunter pilots.

It was also determined that the Hunter pilots had higher scores on the 'specific criticisms' scale than the Lightning or Javelin pilots ($H = 6.6$; $P = 0.05$). The reason for this difference between the pilots of the different aircraft was not clearly apparent. The Hunter is a popular aircraft to fly and the explanation may well lie in the type of role these pilots were allotted at the time of the investigation. In order to allow for this, Spearman's rank correlation coefficient was then repeated on the 12 Javelin pilots by themselves; the liability to 'time perception distortions' scores still positively correlate with the 'specific criticisms' scores ($r_s = +0.60$; $P = 0.05$), giving added weight to the original observations on all the pilots. No other differences were revealed.

C o m m e n t Both Dearnaley (1960) and Gedye (1960) have reported that distortion in time perception is not uncommon in aircrew flying at low altitude over a fixed route in a hot climate. This interview study has confirmed that aircrew in general are aware of alteration in apparent duration while flying and that the distortion may jeopardise their flight safety. Distortion seems to be dependent on the effort required for the type of flying and the amount of irrelevant distraction such flying provided.

It appears that the pilots whom the judges considered expressed most severe criticisms were also those considered most liable to distortion in time perception. As a high 'specific criticisms' score may reflect a critical attitude, either due to particular personality characteristics or due to features in the environment that demanded criticism, this relationship confirms that attitude towards the content of intervals is important in assessing apparent duration. It may well be that the difference between the Hunter pilots and the others was due to the particular type of flying in which they were engaged; but the confirmation of the relationship between liability to time perception distortion and 'specific criticisms' in the Javelin pilots alone suggests that it may be due also to the individual personality of each pilot determining the expression of his views.

B. INVESTIGATION BY QUESTIONNAIRE

The previous interview study revealed that pilots are aware of factors that influence their proficiency at the flying task, many of which are divorced from the more tangible or acknowledged features.

A questionnaire study was undertaken to verify in a quantitative way some of the anecdotal evidence previously ascertained, and this account records the results obtained in relation to time perception.

Method The questionnaire containing 265 items was entitled 'Pilot Error and Disorientation - a Questionnaire for Fighter Pilots on some of the Human Factors in Flying'. In addition to questions on time perception, it covered the following topics, the results of which are not presented in this thesis -

- (i) Personal data; age; flying hours
- (ii) Spatial disorientation
- (iii) Flying performance; accidents; mistakes
- (iv) Awareness of physiological processes
- (v) Attitudes towards flying, family and the Air Force

The questionnaire was distributed to 132 fighter pilots; 90 were completed within the subsequent six weeks and were suitable for analysis.

Results

1. The question was asked: "Have you ever disbelieved your watch when flying, afterwards realising that it had, in fact, been correct?"

   Twenty-nine per cent. replied in the affirmative.

2. A question was asked to determine what proportion of their reliance the pilots placed on the fuel contents gauge in contrast to their watch in assessing the appropriate duration of a sortie. They were asked to divide appropriately a 100 mm. line to indicate this. The exact way to answer this type of question by apportioning quantity had been explained carefully in the introduction to the questionnaire.

The marks were measured to reveal the proportion of reliance that the pilots placed on their watch and fuel contents gauge; the distribution of the percentage scores is given in Table IV.

Examination of the scores reveals a skew distribution such that, in fact, the median value denotes that 89 per cent. of reliance is placed on the fuel contents gauge and only 11 per cent. on the watch.

3. Questions were asked to determine the longest and shortest apparent durations of ten-minute intervals that pilots had experienced during defined sorties which could be described as 'boring', 'routine' or 'exciting'.

Table IV

Number of pilots showing proportion of reliance placed on their watch and fuel contents gauge

Percentage reliance placed on:		Number of Pilots
Watch	Fuel Contents Gauge	
90 - 100	0 - 10	3
80 - 89	11 - 20	1
70 - 79	21 - 30	1
60 - 69	31 - 40	2
50 - 59	41 - 50	2
40 - 49	51 - 60	2
30 - 39	61 - 70	4
20 - 29	71 - 80	19
10 - 19	81 - 90	18
0 - 9	91 - 100	38

The results are given in Table V (a). It can be noted that 26 per cent. of the values are ten minutes, the requested duration, and that 65 per cent. of all the values ended in the digits zero or five. The mean estimates from the 85 pilots answering this question are shown in Table V (b).

It can be seen that the more exciting a sortie the shorter a ten-minute interval appeared to be. It can also be seen that the mean values for the longest apparent duration are approximately double those for the shortest; also that the mean range from 4.7 to 21.6 involves a scaling factor of just over two from the requested duration of ten minutes. This latter relationship is also apparent in the skewness of the distribution of the values, transformation to logarithms being required prior to examination of the data by analysis of variance. This analysis (appendix E.1) revealed that the differences between the types of sortie are highly significant for both the longest and shortest apparent durations ($P = 0.001$).

C o m m e n t The aircrew watch is a very accurate instrument, almost never giving false information if read correctly. It is therefore remarkable that, on at least one occasion, almost a third of this group of pilots had had greater faith in their own ability to determine the duration of an interval than in an instrument which they know to be accurate.

In assessing the duration of a sortie, it is natural that greater reliance be placed on the fuel contents gauge than on elapsed

Table V (a)

Longest and shortest estimates of apparent duration of a ten-minute interval

Pilot	Type of Sortie					
	Longest			Shortest		
	Exciting	Routine	Boring	Exciting	Routine	Boring
1	-	-	-	-	-	-
2	20	10	10	5	5	10
3	5	10	15	2	8	10
4	10	14	15	5	8	9
5	10	15	20	3	8	10
6	10	12	20	2	8	10
7	20	18	12	15	12	8
8	20	25	30	3	10	15
9	20	12	12	10	8	8
10	9	15	20	3	8	10
11	10	15	20	5	10	10
12	20	20	10	10	7	7
13	15	15	20	5	12	15
14	10	12	15	10	10	10
15	45	60	99	15	30	99
16	20	15	15	10	5	5
17	10	15	30	5	10	10
18	8	30	20	5	10	10
19	8	2	10	2	2	6
20	10	10	10	10	10	10
21	5	20	40	2	10	15
22	6	9	11	4	7	10
23	7	9	15	3	7	12
24	2	20	30	0	5	10
25	5	15	30	2	10	10
26	15	10	10	3	10	10
27	3	5	6	2	2	2
28	20	15	20	15	7	10
29	10	15	25	4	8	20
30	10	15	30	4	5	10

Table V (a) (continued)

Pilot	Type of Sortie					
	Longest			Shortest		
	Exciting	Routine	Boring	Exciting	Routine	Boring
31	8	13	15	5	10	12
32	10	15	20	5	7	10
33	-	-	-	-	-	-
34	10	15	20	2	10	10
35	6	13	20	4	8	10
36	6	10	30	3	5	10
37	13	13	12	8	8	9
38	10	13	20	5	7	10
39	5	15	30	2	5	10
40	10	12	15	5	8	10
41	10	10	20	8	10	10
42	10	10	20	2	10	10
43	10	12	15	5	8	10
44	10	15	20	5	8	10
45	5	10	20	2	10	15
46	7	13	14	4	7	7
47	8	12	17	5	8	10
48	10	10	15	5	10	10
49	10	15	20	2	8	10
50	6	10	13	2	8	10
51	8	20	30	2	5	12
52	8	20	30	3	10	15
53	8	12	20	4	8	15
54	30	50	70	10	40	50
55	-	-	-	-	-	-
56	5	8	10	2	4	8
57	25	20	30	3	8	10
58	5	3	2	4	2	2
59	10	15	20	3	5	10
60	10	15	20	5	10	20

Table V (a) (continued)

Pilot	Type of Sortie					
	Longest			Shortest		
	Exciting	Routine	Boring	Exciting	Routine	Boring
61	15	10	12	4	5	10
62	10	12	20	2	10	10
63	10	10	10	10	10	10
64	30	20	60	1	5	10
65	5	10	30	2	10	15
66	5	10	30	3	3	20
67	10	10	20	3	10	10
68	30	15	30	15	5	15
69	5	10	30	5	10	12
70	8	10	30	2	8	15
71	7	10	20	3	5	7
72	30	20	30	2	5	10
73	10	15	20	2	5	10
74	3	12	15	2	8	10
75	4	5	20	1	5	15
76	5	7	15	10	13	10
77	15	15	20	4	5	5
78	20	10	20	15	6	15
79	7	12	15	5	8	10
80	20	15	30	2	8	10
81	10	10	20	2	10	10
82	-	-	-	-	-	-
83	8	12	15	5	9	12
84	5	15	30	2	8	15
85	15	12	10	10	8	8
86	-	-	-	-	-	-
87	5	6	7	2	3	5
88	5	10	20	3	10	15
89	1	2	4	0	1	1
90	15	15	20	4	7	10

Table V (b)

Mean estimates of apparent duration
of a ten-minute interval
from 85 pilots

Type of Sortie	Longest	Shortest
Boring	12.0	21.6
Routine	8.2	13.8
Exciting	4.7	11.2

time; fuel reserve, if communicated correctly, dictates endurance, as fuel is used at a variable rate. It is of interest, however, how little reliance these pilots place on elapsed time as the difference between performing a task at the appropriate moment, such as landing, in short range aircraft, and exceeding the endurance permissible is short, and may be even less than ten minutes.

The results of this investigation confirm that the apparent duration of a ten-minute interval is likely to be modified by the degree of excitement, supporting the general impression that boredom makes time seem to drag. As this investigation was a retrospective enquiry, valid interpretation of possible mechanisms inducing the distortion cannot be made. The results may only reflect the pilots' preconceived ideas of what might be expected in similar circumstances; they may have been produced, at least in part, by modification due to inaccurate memory. These findings, however, support the suggestion that the level of arousal might be a relevant factor in determining the apparent duration of an elapsed interval.

Cohen (1954) indicated that there may be a logarithmic basis of time perception. The data obtained on the apparent durations of ten-minute intervals during the different types of sortie tends to support this; the distribution of the scores transformed to logarithms is nearly normal and the differences between the logarithms of the durations of the requested interval and the mean maximum and minimum are approximately the same.

As discussed later, underestimation of the duration of an interval is of more serious consequence than its overestimation as the latter error can be rectified subsequently. Exciting sorties would thus appear to be those on which dangerous errors are most likely. Usually the degree of excitement in flying can be predicted and such distortion can be accommodated by careful application of pre-flight briefing. However, excitement may be produced by an emergency, such as due to pilot error or mechanical failure; a knowledge by aircrew of possible distortion in apparent duration in such situations may reduce the possibility of further danger by exceeding a time-limit.

SECTION IV

LABORATORY EXPERIMENTS

A. THE APPARENT DURATION OF TEN-MINUTE INTERVALS ASSOCIATED WITH CHANGES IN THE ENVIRONMENT *

From the results of the Field Studies and other reports of the experience of aircrew (Dearnaley, 1960; Gedye, 1960), a number of factors appear to affect the ability of pilots to estimate elapsed time accurately. The distorting effect of some of these applicable in different contexts has been investigated by others, as mentioned in the Historical Review. It was considered that the most important pertinent to the present investigation of distortion in apparent duration by aircrew might be summarised -

(i) The demand imposed on the individual by his assigned task

(ii) The amount of irrelevant physical stimulation to which an individual is subjected by virtue of undertaking the task

These were selected for simulation in the laboratory.

As in an investigation of this kind it is desirable to simplify the variables under consideration, it was necessary to replace the intricate control-systems operated by pilots in flight by a simple tracking task in order to provide the means to investigate the first factor. Similarly as the environmental physical changes present in flight provide complex physiological stimulation, it was essential to select simple modalities for reproduction in the laboratory.

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* Aitken and Gedye, 1963

As it was considered likely that an individual's level of arousal would be modified by performing a task, or being exposed to irrelevant physical stimulation, it was essential to measure this in order that its relationship, if any, to apparent duration might be determined. Subjective assessment of degree of alertness and objective measurement of an acknowledged physiological indicant of arousal, skin resistance, were selected to provide the basis for this evaluation. As arousal is sensitive to a multiplicity of factors, it was essential to control those induced exogenously by providing a stable environment, only introducing alteration by design. A dark, soundproof room with controlled communication and facilities to introduce light, noise and angular movement was available at the Institute of Aviation Medicine for such an investigation; consequently these simple variables akin to flying were selected for this experiment. It is of interest that Weber (1933), after reviewing the literature, suggested that an investigation on the estimation of the duration of long intervals might be rewarding if carried out in such an environment.

It was hoped to detect differences not only as a result of the environmental changes introduced, but also between individuals*; this might provide evidence to support the observations that personality and attitude are of relevance in determining the appreciation of duration.

The questionnaire study confirmed previous opinion that pilots expect distortion of a ten-minute interval, the amount being related

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* This part of the experiment was undertaken primarily by Gedye

to the activity and interest of their task. As ten minutes is a convenient interval to study in the laboratory, and is likely to be sufficient to detect changes in arousal, this duration was selected.

Method Eight pilots in current flying practice, who volunteered to help in an experiment, were each isolated under various conditions for four intervals of ten minutes. The conditions were designed to simulate the important factors as summarised above.

Apparatus

The experiment was carried out in a sound-insulated building, divided into isolation and observation rooms by a sound-insulated wall (Fig. 1). The isolation room was a four-metre cube, lined with matt black acoustic tiling.

During an experimental session the subject sat in a chair mounted near the centre of rotation of a turntable placed centrally in the room. He was comfortably supported with a lap-strap, shoulder-harness and head-rest. Once the arrangements for the session were completed the subject and the experimenter could talk to each other at the experimenter's discretion by means of an inter-communication system, but otherwise the subject had no access to events outside the room. The experimenter could also observe the subject irrespective of the lighting of the room, by means of an infra-red image converter. No automatic temperature or humidity control for the room was available, but conditions remained fairly constant during any one experimental session.

The experimental factors, which will be referred to as 'task' and 'distraction', were produced as follows:

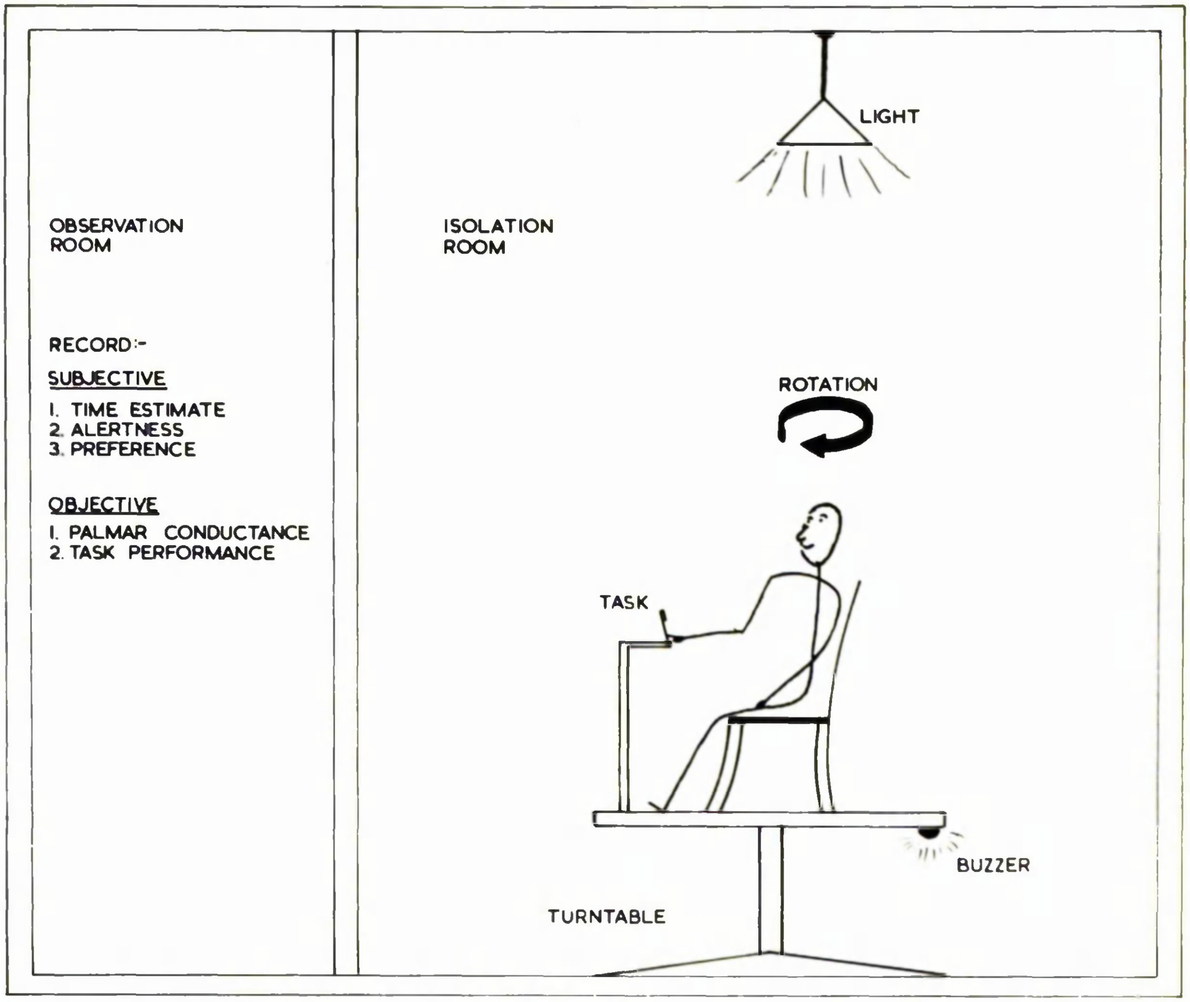

Fig. 1 Diagram of the experimental arrangements.

Preference scores are not reported in detail in this account.

Scores were also obtained of how well the subjects thought that they had performed the task.

Task

Mounted on the turntable in front of the subject was an illuminated display and control panel for a simple two-channel compensatory tracking task; this was similar to that used by Jackson (1958). The display consisted of two centre-zero micro-ammeters mounted side by side. Beneath each was a corresponding control knob, both of which the subject was required to manipulate with his right hand. When performance of the task was requested, the subject was required to correct deviations of the pointers from the central position, and endeavour to keep the pointers as near central as possible for as much of the time as possible. The pointers followed a sinusoidal excursion of 20° amplitude with a period of two minutes. The pointers were 180° out of phase.

Distraction

The turntable could be accelerated and decelerated at about $10°/sec^2$ to an angular velocity of about 40°/sec. Above and near the centre of rotation of the turntable was a 200 watt filament lamp which could be used to illuminate the room. Mounted on the turntable behind the subject was a vibrator and sounding-board which could act as a noise source independent of the turntable motor.

A typical example of a pattern of stimulation is shown in Fig. 2. It can be seen that stimulation was given in three different ways: by having the room in light or in darkness, by having the room quiet or noisy, and by having the subject stationary or rotating. For each kind of stimulation the stimulus was ON for five minutes and OFF for five minutes; it was ON for four periods of

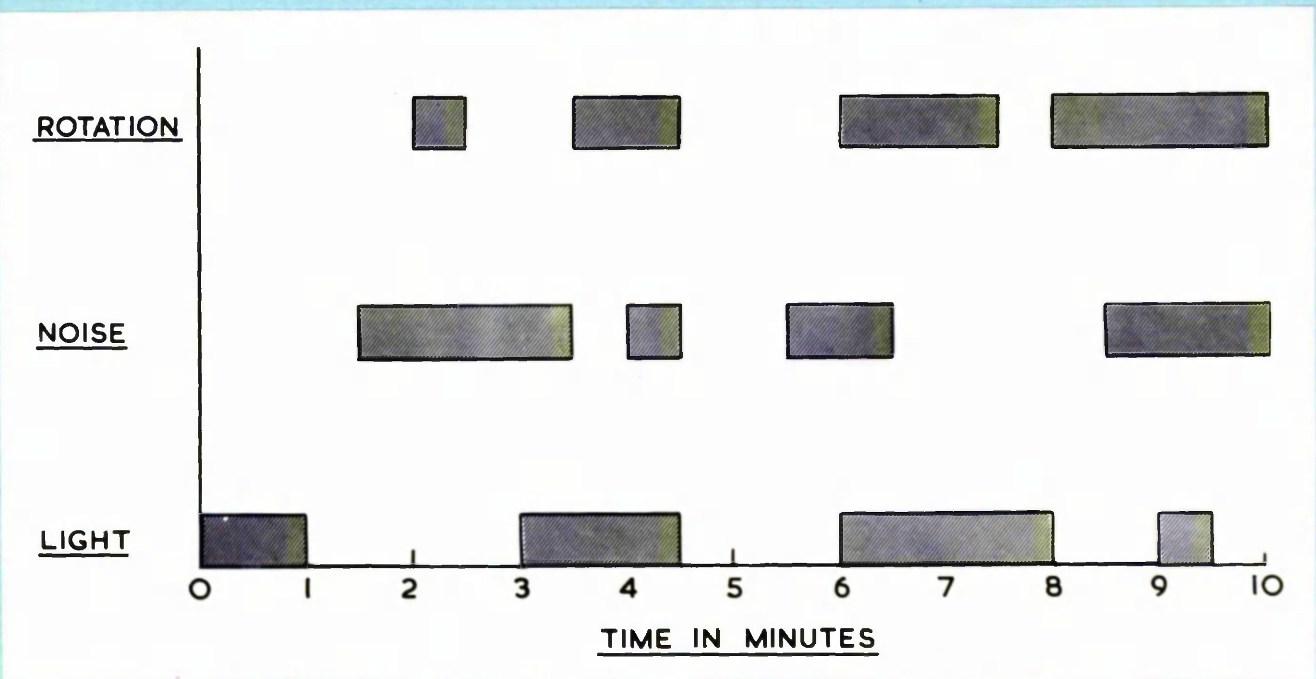

Fig. 2 An example of the pattern of distraction:
Subject 1, task absent.

The notched bars indicate that the stimulus to which they refer was 'on'.

0.5, 1.0, 1.5 and 2.0 minutes and OFF for four similar periods. Orders of these eight periods were allocated to subjects at random in a balanced design for each kind of stimulation independently. This arrangement provided a background of unpredictable irrelevant events while preserving, on average, a uniform amount of stimulation at any chosen moment during the ten-minute interval.

Design

Each subject took part in an experimental session which began at either 10.00 or 15.00 hours; odd numbered subjects had morning sessions, even numbered had afternoon sessions.

The experimental session for the first four subjects, Group A, consisted of four intervals of ten minutes' isolation; successive intervals were separated by five minutes of contact with the experimenter, during which the subjective measurements to be described later were obtained. The intervals were clearly indicated by a red light on the task display panel, which was ON during rest periods and OFF during the isolation intervals. The second four subjects, Group B, had an additional calibration interval preceding the four experimental intervals, as will be explained later.

A factorial design was used so that each subject experienced the four conditions detailed in Table VI. Each group of four subjects formed a latin square, the subjects being allocated at random. They were presented the conditions in the order given in Table VII.

Table VI

Experimental conditions

Factors		Conditions symbols	
Distraction	Task		
Absent	Absent	D_oT_o	A
Absent	Present	D_oT_1	B
Present	Absent	D_1T_o	C
Present	Present	D_1T_1	D

Table VII

Order of presentation to subjects of experimental conditions

Subject		Order			
		1	2	3	4
Group A	1	A	B	D	C
	2	D	C	B	A
	3	C	D	A	B
	4	B	A	C	D
Group B	1	B	D	C	A
	2	A	C	B	D
	3	C	A	D	B
	4	D	B	A	C

Conduct

Each subject was told that the purpose of the experiment was to determine the most acceptable way of spending a short period of time in isolation. The design of the experiment was outlined, the nature of the distraction explained, and the task demonstrated. The measurements and the score sheets were also explained.

Before each interval the subject was instructed whether or not he was to perform the task. During the intervals in which they were not doing the task, subjects were not required to behave in any particular way towards changes in the environment, but were free to attend or not as they chose.

Before starting the experiment subjects were deprived of their wrist watches, so that during the intervals of isolation they had no access to reference time. For subjects in Group A no further comment to time was made. However, subjects in Group B were asked to try not to count anything whatsoever (such as pulse beats or subjective seconds), not to try to maintain an estimate of elapsed time as they went along, and not to modify their final estimates in accordance with any pre-conceived ideas about possible sources of error in estimation. Group B subjects were also told that the four intervals would be of different duration. In order to avoid their necessarily thinking in conventional time units, the design of the experiment was modified; they were given an initial calibration period of ten minutes' isolation during which no measurements were made, there were no changes in the environment, the room was in complete darkness and silence, and the task was not performed. They were told to regard the duration of this period as a standard time interval and to make their estimates of the duration of the following intervals in comparison to it.

This modified technique with subjects in Group B was introduced after the results had been obtained on Group A. Initially it was decided not to take any steps to influence the way in which subjects made their estimates; however, as it became clear that the subjects in Group A were going about the matter in what appeared to be widely differing ways, it was decided to try to produce greater uniformity in the methods used by Group B by introducing the modifications described above.

Measurements

Subjective

<u>Apparent Duration</u> Each subject was given a sheet of paper on which four 25 cm. horizontal lines were drawn, one above the other; he was instructed to regard each line as a linear representation of elapsed time, the extreme left hand end representing the beginning of the interval of isolation to which the line referred. They were asked to indicate where they felt the interval ended by marking the line.

The four subjects in Group A were presented with lines marked every 25 mm. and labelled in minutes from 0 to 50, so that the scale was 0.2 min./mm. (Fig. 3). The four subjects in Group B were presented with similar lines marked only at a point 100 mm. from the left hand end (Fig. 4). They were told that this distance

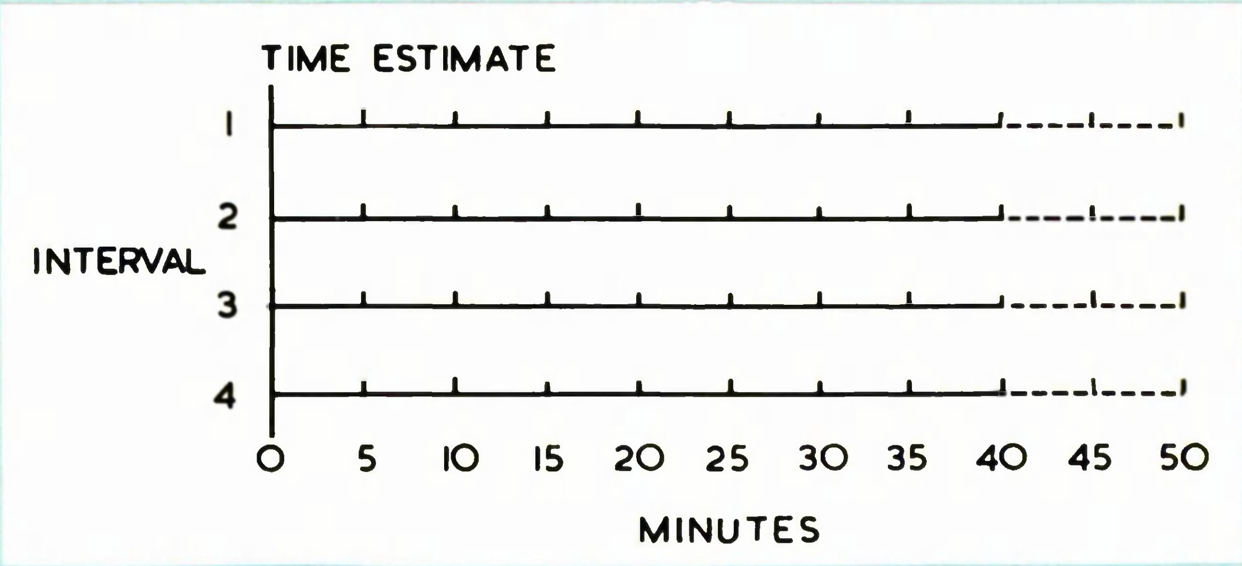

Fig. 3 Score-sheet for the estimation of apparent duration by subjects in Group A.

(Not represented to scale).

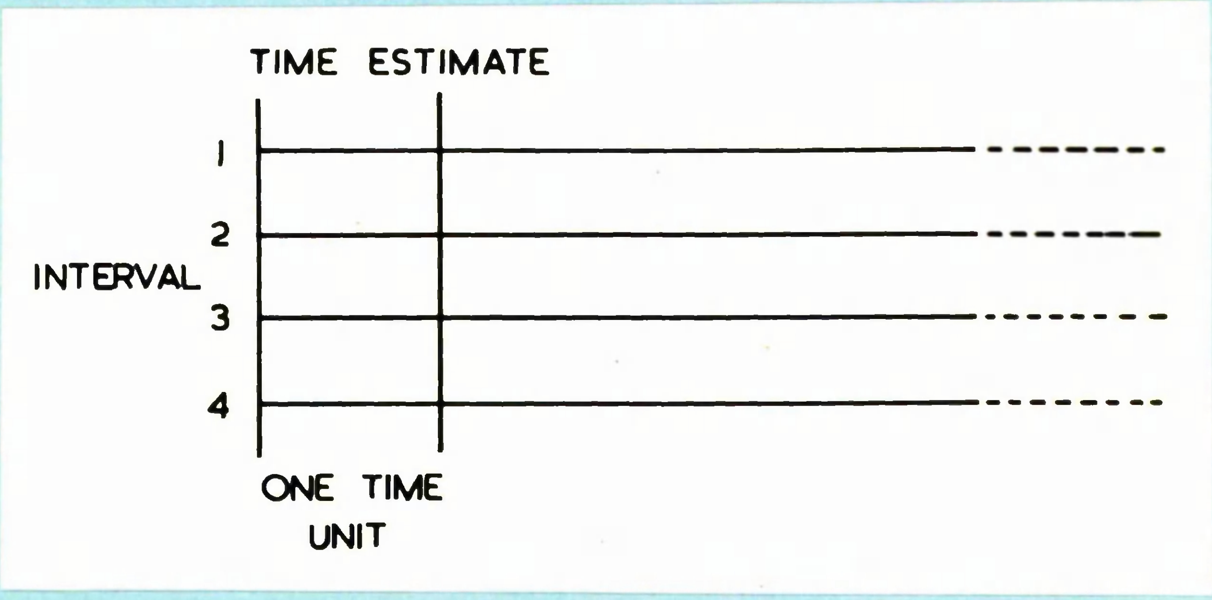

Fig. 4 Score-sheet for the estimation of apparent duration by subjects in Group B.

(Not represented to scale).

represented the standard time interval as demonstrated to them by the period of isolation under basal conditions which preceded the four experimental intervals. This calibration interval lasted ten minutes, so that the scale for the second group of subjects was equivalent to 0.1 min./mm. At the end of the session each subject in Group B estimated the duration of the standard interval, expressing the result verbally to the nearest minute.

The answers were scored by measuring the position of the marks to the nearest millimetre and expressing the result in minutes.

It can be appreciated that the method of spatial estimation was used for subjects in Group A; and that the method of comparison, modified to provide information comparable to that obtained by the method of estimation, was used for subjects in Group B.

Level of Alertness Each subject was given a sheet of paper with four 100 mm. horizontal lines drawn one above the other (Fig. 5). They were instructed to regard each line as a representative of the various possible degrees of arousal, ranging from a state of sleep at the extreme left, through a region signifying moderate wakefulness in the middle, to a state of extreme panic at the right. A representation of a subject's average level of alertness during an interval of isolation was obtained by asking him to mark the line so that the position of his mark gave the best possible indication of how he had generally felt during that time.

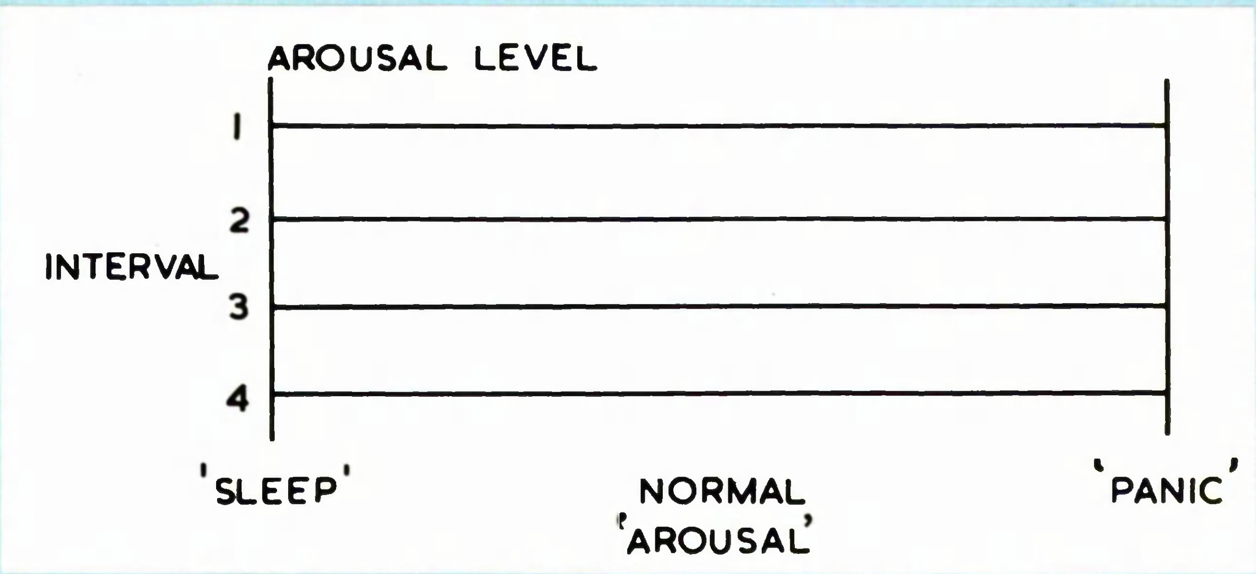

Fig. 5 Score-sheet for the estimation of subjective alertness.

(Not represented to scale).

The answers were scored by measuring the position of the marks to the nearest millimetre and expressing the result on a scale ranging from - 1, representing the extreme left, through 0, representing moderate wakefulness, to + 1, representing the extreme right. This particular convention was chosen in order to emphasise the centre of the line as the most relevant anchor point in this particular study, since the extremes were not actually encountered.

Estimated Performance on Task When appropriate the subject was presented with a pair of lines, one for each of the two channels of the task. He was instructed to regard one end of the line as signifying perfect performance, and any point on the line away from this end a less than perfect performance, the distance of such a point being an indication of how far the performance fell short of perfection. A mark 100 mm. from the anchored end was labelled 'moderate performance'; the subject was instructed to choose a meaning for this which would allow him to indicate expected variations between performances by using only the part of the essentially infinite line that was represented on the paper. The score sheet was very similar to that used for the estimation of apparent duration by subjects in Group B, as reproduced in Fig. 4.

Objective

Skin Resistance The resistance between an electrode on the palm of the left hand and a reference electrode on the left leg was measured every half-minute throughout each interval;

the apparatus used is described in Appendix A and the electrodes in Appendix B.

As the appropriate measure for study appears to be conductance (since parallel conductances are additive), readings were transformed to conductance in micromhos by taking the reciprocal of the resistance in megohms.

Actual Performance on Task   The modulus misalignment of the pointer with the control reference mark was integrated over the ten-minute interval of isolation for each channel separately, and the result expressed in arbitrary units.

General Observations

When the standard questions had been completed, each subject in Group A was asked questions to ascertain how he had carried out the time estimation, and each subject in Group B questioned to find out if he had obeyed the special instructions. In addition, subjects were asked for any general comments on the experiment. They were then told the actual duration of the intervals to which they had been exposed, and their reactions were noted.

Results

Subjective Scores

Apparent Duration   Initially the results from Groups A and B were examined separately. Since in Group A the scores were expressed directly in minutes, no transformation was required before analysis. The estimates of the duration of the calibration interval from the subjects in Group B were 17, 10, 8 and 12 minutes respectively; the scores in standard units were transformed to minutes by using conversion factors derived from these calibrations, and all the values are shown in Table VIII (a).

Analysis of variance (Appendix E.2) showed no difference between Groups A and B, so the results were pooled. There was no difference attributable to order of presentation. There was no significant interaction between the two experimental factors; both produced significant main effects which are shown in Table VIII (b). It can be seen that the mean score with task is lower than the mean score without task (P = 0.01), while the mean score with distraction is higher than the mean score without distraction (P = 0.001).

Alertness The scores are given in Table IX (a). The analysis of variance (Appendix E.3) showed no difference between Groups A and B, so the results were pooled. There were no significant differences with order of presentation (P = 0.01). The mean score for the first two intervals was - 0.34 and the second two - 0.19, so that subjects appeared, in general, to be more alert in the latter half of the experiment.

There was no significant interaction between the two experimental factors; both produced significant main effects which are shown in Table IX (b). It can be seen that the mean scores in the presence of task or distraction are higher than the mean scores without task or distraction respectively. All the means are negative, so the alertness during the experiment is generally below moderate wakefulness.

Table VIII

(a) Duration scores

Subject		Conditions			
		D_oT_o	D_oT_1	D_1T_o	D_1T_1
Group A	1	9.4	10.0	10.4	10.4
	2	15.0	10.0	18.6	12.2
	3	10.6	9.8	14.5	10.0
	4	10.2	8.1	14.5	12.2
Group B	5	12.4	10.0	11.2	15.2
	6	10.0	7.3	11.9	10.0
	7	7.8	6.4	7.9	7.4
	8	13.9	12.0	17.0	14.3
Mean		11.2	9.2	13.3	11.5

Each value is expressed in minutes

(b) Effect of factors on duration scores

Factor	Absent	Present	Difference	P
Task	12.2	10.3	-1.9	0.01
Distraction	10.2	12.4	+2.2	0.001

Each average is the mean of 16 values, two from each of eight subjects

Table IX

(a) Alertness scores

Subject		Conditions			
		D_oT_o	D_oT_1	D_1T_o	D_1T_1
Group A	1	-0.22	-0.10	-0.12	+0.04
	2	-0.14	+0.22	-0.28	+0.02
	3	-0.76	-0.54	-0.66	-0.52
	4	-0.68	-0.34	+0.18	+0.34
Group B	5	-0.40	+0.12	-0.08	+0.08
	6	-0.46	+0.06	-0.34	+0.48
	7	-0.72	-0.06	-0.56	-0.04
	8	-0.82	-0.74	-0.70	-0.74
Mean		-0.53	-0.17	-0.32	-0.04

The scores have a possible range from -1 to +1

(b) Effect of factors on alertness scores

Factor	Absent	Present	Difference	P
Task	-0.42	-0.11	+0.31	0.001
Distraction	-0.35	-0.18	+0.17	0.01

Each average is the mean of 16 values, two from each of eight subjects

Estimated Performance   As there was no evidence of any significant difference in the estimated level of performance between left and right channels of the task, the scores for the two channels were added to give an overall score. Examination of these scores (Table X) shows that four subjects regarded their performance as worse in the presence of distraction, one the same, and three regarded their performance as better. Clearly, distraction had no consistent effect on the estimates.

It can also be seen that the mean scores for the addition of both channels represent marks only about 30 per cent. from perfection towards moderate performance (score 200), so that subjects were, on the whole, confident in their ability to do the task.

Objective Measures

Skin Conductance   The skin conductance values obtained every half-minute during each interval were plotted against time for each subject separately, and the set of graphs examined. For any one subject, the conductance at the beginning of each interval appeared fairly constant; but there was considerable variation in the level between individuals, as might be expected. During each interval, depending on the conditions, the conductance appeared either to remain fairly constant or to fall in a roughly exponential manner. Overall increases in conductance were infrequent, though an initial rise was observed. This has been previously reported as usual in such circumstances (Cattell, 1928).

Table X

Scores of estimated performance on task

Condition	Subjects								Mean
	1	2	3	4	5	6	7	8	
Distraction									
Absent	40	26	17	82	126	98	9	59	57
Present	40	15	35	73	146	110	7	66	61
Difference	0	-11	+18	-9	+20	+12	-2	+7	+4

Each score is expressed in millimeters from the perfection point, and represents the total for both channels

Table XII

Scores of task error

Condition	Subjects								Mean
	1	2	3	4	5	6	7	8	
Distraction									
Absent	908	638	701	752	706	635	756	922	752
Present	819	697	729	615	779	702	752	845	742
Difference	-89	+59	+28	-137	+73	+67	-4	-77	-10

Each score was measured in arbitrary units, and represents the total for both channels

After the preliminary examination of the results, it was decided that, in view of the differing initial levels and the nature of the changes occurring during the intervals, a logarithmic transformation of the conductance values would provide the most appropriate measure for quantitative analysis. Since interest was focused on the change occurring during the intervals, a measure denoting this was derived. The mean log. conductance after 0, 0.5 and 1 minute, and 9, 9.5 and 10 minutes' isolation were calculated for each subject and each condition separately. The differences between them were obtained and the values are shown in Table XI (a).

Analysis of variance (Appendix E.4) showed no significant difference between Groups A and B, so the results were pooled. The variance between subjects was small, suggesting that the measure had reduced successfully between-subject differences. There was no significant interaction between the two experimental factors, and both produced significant main effects, which are shown in Table XI (b). It can be seen that both factors decreased the rate of fall of conductance to about the same extent.

The levels of significance are low, largely because of the big residual variance; this points, perhaps, to the necessity for even more adequate environmental control to reduce extraneous, but controllable sources of variation - for example, humidity, which is known to affect conductance level (Venables, 1955). In Figures 6 (a) and (b), mean values for each comparison are shown plotted against time. It will be seen that the approximation to a linear decay with time is best for conditions without task and

Table XI

(a) Changes in skin conductance

Subject		Conditions			
		D_oT_o	D_oT_1	D_1T_o	D_1T_1
Group A	1	-0.0615	-0.0678	-0.0530	-0.0073
	2	-0.2246	0.0011	-0.1517	0.0155
	3	-0.1077	-0.0234	-0.0242	-0.0812
	4	-0.1783	-0.0112	0.0856	0.0255
Group B	5	-0.1551	-0.0828	-0.0468	-0.0373
	6	0.0024	-0.0365	0.0001	-0.0158
	7	-0.1272	0.0108	-0.1408	0.0161
	8	0.0008	-0.0462	-0.0407	0.0211
Mean		-0.1064	-0.0320	-0.0464	-0.0079

Each value is derived as explained in the text; it represents change in log micromhos and is expressed in a dimensionless unit

(b) Effect of factors on changes in conductance

Factor	Absent	Present	Difference	P
Task	-0.0764	-0.0200	+0.0564	0.05
Distraction	-0.0692	-0.0272	+0.0420	0.05

Each average is the mean of 16 values, two from each of eight subjects

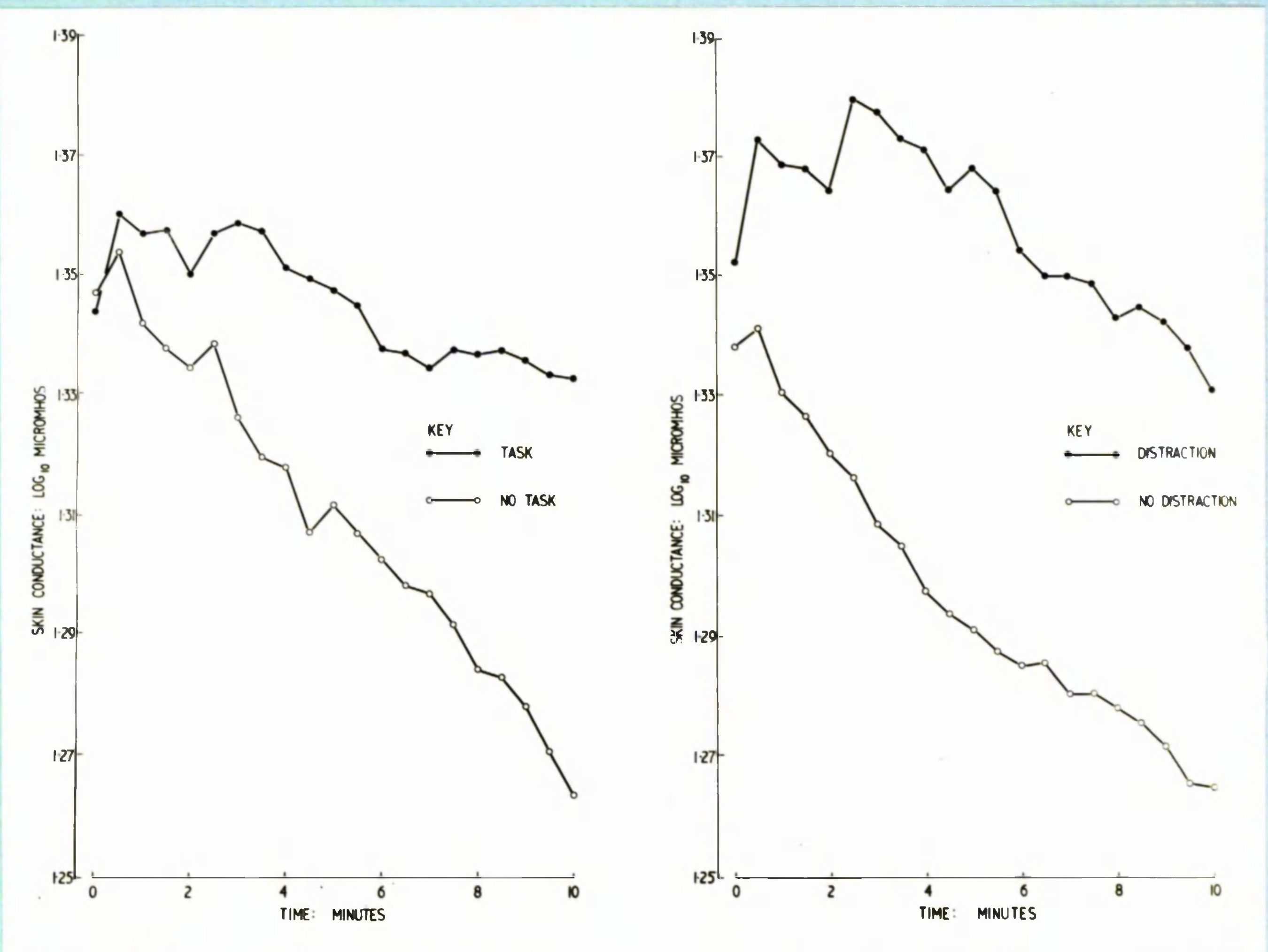

Fig. 6 (a) & (b) **Graphs showing average skin conductance levels.**

Each point is the measurement in log micromhos every half-minute throughout the intervals of isolation under the various conditions :

(a) in the presence and absence of the Task
(b) in the presence and absence of Distraction

Each point is the mean of 16 values, two from each of eight subjects.

distraction, suggesting that one of the effects of the factors is to delay the onset of the decay.

Task Error The values for the integrated modulus misalignment for each subject on the right and left channels in the presence and absence of distraction were examined. Under both conditions the performance on the two channels was similar, so the values were added to give total scores. Examination of these scores (Table XII, page 78) shows that four subjects improved in the presence of distraction and four deteriorated. This was not related to order of presentation.

Spearman's rank correlation coefficient, r_s, between change in task error with distraction and change in estimated performance score was +0.52 (P = 0.01), five of the subjects registering the effect of distraction correctly.

General Observations

Subjects had little difficulty in accepting the techniques of subjective assessment that were used; in particular the notion of arousal as a continuum from sleep to extreme wakefulness appeared to relate to a familiar aspect of their everyday experience. This is borne out by the existence in aircrew vocabulary of a number of words and phrases which specifically relate to various aspects of the concept of arousal.

An interesting distinction was made between arousal in the sense of alertness, ranging from 'sleep' to 'frantic' activity (not necessarily implying fear), and arousal in the sense of anxiety, ranging from a 'relaxed' to a 'panic-stricken' state. As used here, the words appear to be part of normal aircrew vocabulary. It was clear that the continuum used in rating arousal in the present experiment was the former, and that the answers did not imply any particular affective attitude. It is for this reason that the word 'alertness' is used in discussing the scores.

Subjects in Group A, who received no instructions about how they were to make their estimates of duration, adopted a number of methods. While not performing the task, subject 1 counted his respiratory cycles and subject 2 counted his pulse beats; subject 4 made allowance for a pre-conceived notion that time would pass more slowly when unoccupied. In view of this the instructions to Group B subjects were modified to introduce more uniformity of approach. However, essentially the same results emerged from both groups of subjects, suggesting that differences introduced in this way did not modify the overall effect of the conditions.

It is of interest that nearly every subject appeared genuinely surprised when told that each interval was of the same duration.

Discussion also suggested that, in general, subjects preferred the presence of a factor rather than its absence. Gedye in Aitken and Gedye (1963) made a special study of the effect of attitude towards the conditions on the apparent duration scores. He obtained evidence that in the intervals in which subjects were distracted, those who desired distraction the most gave the longest estimates. It appeared also that when subjects were being distracted, they preferred significantly the presence of the task.

The general impression given by these results was that the arousing effect of a particular condition depended on the individual's attitude towards it, the stronger the feeling, whether it be preference or aversion, the longer the apparent duration of the interval. Further evidence to support this conclusion is presented in Experiment C.

Relationships

Skin conductance as an indicant of arousal

The activity of the involuntary nervous system provides an objective, though non-specific measure of cerebral activation which may reflect the level of arousal (Hebb, 1958). There are many physiological indicants and one of the most convenient and sensitive is the skin resistance (Lindsley, 1951). How accurately it reflects the level of alertness can be assessed from the data obtained in this experiment.

Examination of Tables IX and XI shows that both task and distraction increased the alertness scores and produced less decrease in conductance during the intervals of isolation. In order to investigate this relationship more fully, the mean values for the four conditions were plotted against each other (Fig. 7). The linear regression equation was calculated (Appendix E. 5) and was found to be significant ($P = 0.025$); it is drawn in Fig. 7.

The alertness score is a measure of subjective appreciation of arousal; in so far as it can be predicted from observation of the change in skin conductance, the conclusions of Hebb and Lindsley are substantiated.

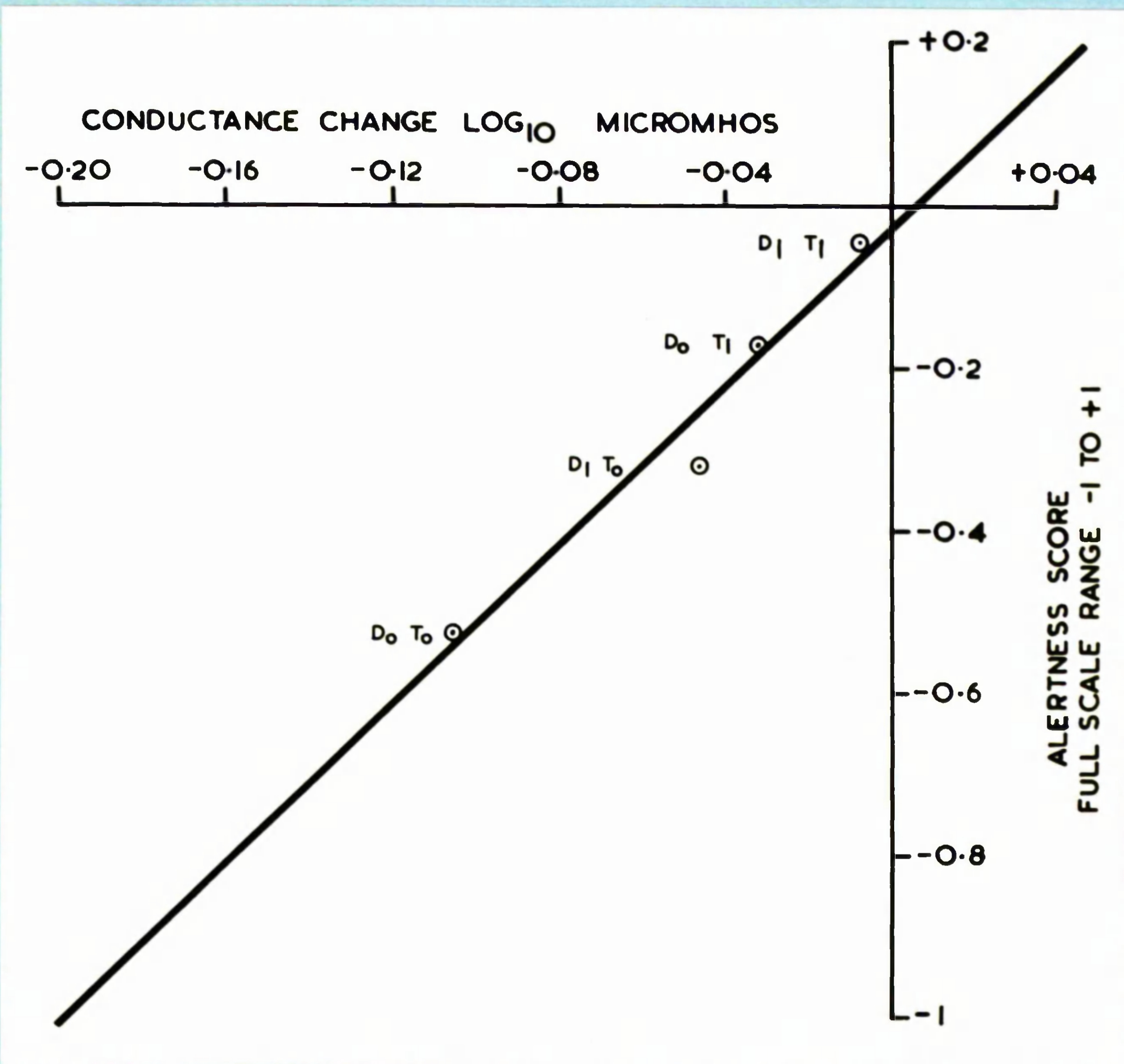

Fig. 7 The relationship between mean change in skin conductance (x) and mean alertness score (y).

The calculated regression equation which is shown plotted is : $y = 4.83x - 0.03$ ($P = 0.025$).

Each point is the mean obtained from eight subjects.

D_0 = distraction absent D_1 = distraction present

T_0 = task absent T_1 = task present

Arousal and apparent duration

It appears, therefore, that both task and distraction raised the level of arousal of the subjects, but produced opposite effects on apparent duration - the presence of the task reduced the estimates of the duration of the ten-minute intervals, while the presence of distraction increased them. It follows that these effects on apparent duration cannot be accounted for completely by arousal changes, and it is thus necessary to decide to what extent, if any, the changes can be ascribed solely to changes in arousal.

An attempt to answer this question was made by carrying out an analysis of covariance between the alertness scores and the duration scores (Cochran and Cox, 1957). The analysis of variance of the duration scores adjusted for changes in alertness (Appendix E.6) revealed only an insignificant reduction in residual variance. However, as there was some reduction, it was considered that examination of the adjusted scores was worthwhile and permissible, though would not necessarily be profitable. The adjusted duration scores were derived by using a correction factor derived from the analysis of covariance, and are shown in Table XIII (a).

The analysis of variance of the adjusted duration scores revealed that there was no difference between Groups A and B, so the results were pooled as in the previous analysis. There was no difference attributable to order of presentation. There was no significant interaction between the two experimental factors; both produced the same main effects, though distraction at a lower level of significance, and these are shown in Table XIII (b).

Table XIII

(a) Duration scores adjusted for alertness

Subject		Conditions			
		D_oT_o	D_oT_1	D_1T_o	D_1T_1
Group A	1	9.3	9.5	10.0	9.5
	2	14.6	8.5	18.6	11.3
	3	12.1	10.6	15.7	10.8
	4	11.5	8.3	13.2	10.4
Group B	5	12.8	8.8	10.6	14.2
	6	10.6	6.3	12.1	7.7
	7	9.2	5.8	8.8	6.7
	8	15.6	13.4	18.3	15.7
Mean		12.0	8.9	13.4	10.8

Each value is expressed in minutes

(b) Effect of factors on adjusted duration scores

Factor	Absent	Present	Difference	P
Task	12.7	9.8	-2.9	0.01
Distraction	10.4	12.1	+1.7	0.025

Each value is the mean of 16 values,
two from each of eight subjects

It can be seen that the directions of distortion are the same; however, the distortion induced by the task is greater and that by distraction less than on the original scores (Table VIII). It is disappointing that no definite conclusion can be based on this finding as only an insignificant part of the variance of the duration scores can be accounted for by the covariance of these scores with the alertness scores. In view of the relationship between alertness and skin conductance, an analysis of covariance between the changes in skin conductance and the duration scores was also carried out. However, as might be expected, it provided no additional information on which to base any conclusions.

Comment The lack of effect of different counting procedures adopted by subjects in Group A to help in their estimation of the duration of the interval, and of the different instructions to subjects in Group B is of interest. From the fact that in this investigation the experimental conditions had similar effects on both groups of subjects, it would seem that such differences in technique exerted little distortion on the answers obtained. Similar conclusions about a slightly different situation were reached by Gilliland and Martin (1940) who found that, while most people spontaneously adopted some kind of counting procedure in experiments on time perception, when they were asked not to count their estimates were almost as accurate. However, with practice and correction they were able to reduce the variability of their performance by counting, so that it can provide a useful aid in certain circumstances. Frankenhauser (1959) conducted her experiments on time perception by instructing the subjects to count apparent seconds.

From examination of the apparent duration scores, it can be seen that six of the 32 estimates were correct. In addition to these there was one other whole minute value ending in the digits zero or five; that is to say, only 22 per cent. of the values were grouped at these digits.

The observation that no change in skin conductance corresponds to an awareness of moderate wakefulness is of interest; in Fig. 7 it can be seen that the regression line cuts the X and Y axes very close to the origin. This point seems worthy of discussion.

The explanation may be that appreciation of change in alertness during an interval is associated with change in skin conductance. When subjects answered this question, they may have considered their level of alertness in comparison with that at the beginning of the interval, signifying direction and magnitude of change by position and distance of their marks from the mid-point. On a long term view, awareness of usual alertness may be midway between the extremes of subjective impression, and be accustomed as moderate wakefulness; similarly on a long term view, skin conductance cannot be drifting in only one direction - it must be fluctuating around a usual level, when a return to it would signify the same cerebral activation state. An experiment to study this relationship in psychopathological affective illness would be of interest.

There is some experimental evidence that change in skin conductance reflects the rate at which subjects fall asleep. It has been known for some time that palmar conductance is low during sleep (Farmer and Chambers, 1925). Richter (1926) found that the level of palmar conductance while asleep closely followed the depth of sleep, the rate of change being related to the depth ultimately reached. He also noted that states of relaxation were accompanied by low conductance both in normals and in narcoleptics (Richter, 1928), who had a rapid fall in conductance before they fell asleep after being left undisturbed (Richter, 1929 a). However, his only published result which can be compared directly with this experiment is a single recording from a spider monkey trained to sleep in an infant's cot (Richter, 1929 b). The rate of fall of conductance in this animal, assessed over the first 30 minutes while falling asleep, was 0.018 log micromhos/min. This value is of the same order as the one obtained by extrapolation from the results in this experiment; by calculation from the regression equation, the change in log conductance corresponding to a state of sleep (alertness score = -1) is -0.22 log micromhos, indicating a rate of fall of -0.022 log micromhos/minute.

As the values obtained were mainly infrabasal, it may be that what was being measured was the rate at which subjects were falling asleep. These findings support the suggestion that an individual spends most of his waking life at a certain basal level of arousal adapted to the requirements of moment-to-moment existence, depending on the energy mobilisation required (Duffy and Lacey, 1946). This basal level might correspond to the centre of the alertness scale and the level of conductance prior to the intervals of isolation. Thus conditions conducive to sleep will initiate a progressive, but slow fall in arousal below this basal level, whereas invigorating conditions will increase it above the basal level - perhaps suddenly, as for instance producing the psychogalvanic reflex, which is followed usually by a slower return to the basal level.

As will be apparent from the introduction, this experiment was undertaken primarily to see whether changes in apparent duration of a ten-minute interval, similar to those observed in certain flying situations, could be induced in the laboratory and whether these changes could be related to the psychophysiological concept of arousal. Though the findings in this experiment do not establish a definite relationship between arousal and apparent duration, they are not completely inconsistent with this hypothesis. As the task and distraction produced opposite and independent effects on the time estimates, and similar effects on arousal, it is concluded that a multifactorial theory of the psychophysiological mechanism of time perception is needed to account for the results. As the levels of arousal during the intervals of isolation were thought to be below moderate wakefulness, perhaps it is not surprising that any effect of arousal level to induce distortion was insignificant. What results would have been obtained if the arousal level of the subjects had been higher can only be speculative; however, if the direction of distortion had been the same, higher arousal would have accounted for more, if not all, of the distraction effect and accentuated the difference induced by the task independently. Thus arousal could still well be one of the mechanisms by which time perception is determined.

While there is really little evidence from this experiment to base a suggestion about the nature of the mechanisms which determined apparent duration, there is nothing inconsistent with a second factor being the way in which the subjects' attention was organised by the conditions during the intervals of isolation. The 'degree of concentration of attention' has often been put forward as an important factor modifying apparent duration. For example, Sturt (1923) in discussing the role of the amount of mental content suggested that the more focused a person's attention and the fewer the changes of attention, the shorter a given interval would appear to be. This would be consistent with the present results, providing that it is accepted that attention is less directed in the presence of distraction and more specifically organised in the presence of the task.

Thus it can be postulated, but unfortunately no more than that, that the apparent duration of the intervals of isolation could have been determined by at least two mechanisms :

(i) Through a mechanism related to the level of arousal; an increase in arousal being associated with an increase in apparent duration

(ii) Through a mechanism related to the degree of concentration of attention; an increase in concentration of attention being associated with a decrease in apparent duration.

Though it is likely that these mechanisms are related, the net result in any condition is dependent on the relative extent to which the opposed mechanisms are implicated.

However, at least one other factor is required to explain completely the mechanisms behind the present results, because distraction still increased the adjusted duration scores. Unfortunately there is no definite evidence with which to speculate on its nature, but in view of the results obtained by Gedye, (Aitken and Gedye, 1963) it may well be associated with attitude.

B. THE EFFECT OF NOISE AND ALTERATION IN THE RESISTANCE TO RESPIRATION ON THE SERIAL REPRODUCTION OF TEN-SECOND INTERVALS

In oxygen systems currently used in military flying, some resistance to respiration is inherent. The annoyance to aircrew from this varies, and the acceptability of a given system depends in part on the degree and quality of the pressure-drop encountered, especially on inspiration. It is usually difficult to assess the degree of irritation as individual comments vary widely. As time perception is simple to assess, even as part of complex experiments on other topics, it was postulated that it might provide a useful method of assessing the acceptability of a given breathing system, or other environmental variable. This is the report of a preliminary study done primarily to determine if alteration in the resistance to respiration might distort time perception in any consistent way. It was assumed that the less the resistance, the more the attitude of the subject would be in favour of that system.

As discussed in the Historical Review, there are available four basic methods for experiments on time perception. Of these Llewellyn-Thomas' (1959) technique of serial reproduction is novel and seemed suitable for the present purpose; if a variable which modifies apparent duration is presented in either the standard or the judgment intervals, a trend should be clearly discernible.

Prior to conducting the experiment, no precedent was known to suggest in which interval, standard or judgment, it would be best to present the variable in order to obtain maximal distortion. A preliminary experiment was thus required to decide this before embarking on the main experiment.

Noise is known to increase error in a serial reaction task (Broadbent, 1953) and to produce distortion in time perception; Jerison (1959) reported that the mean production of a requested ten-minute interval was seven minutes in noise of 110 db. above threshold compared with nine minutes in that of 80 db. Oleron (1952) demonstrated that by increasing the intensity of a 1 kc/s tone from 40 to 90 db. above threshold, the estimations of intervals between 35 and 140 seconds were longer. Noise is a convenient environmental variable and was thus selected to determine the precedent. The frequency of 1 kc/s was chosen as Stevens, Davis and Lurie (1935) demonstrated that the human auditory mechanism is most sensitive to a frequency of this order.

It was felt preferable that presented differences of alteration in the resistance to respiration should be subjectively equal. The technique of marking continuous finite scales which had proved to be successful in the previous experiments was applied in a second preliminary experiment to select equal subjective differences in resistance to respiration.

(i) The effect of noise

Method

Apparatus, described in Appendix C, was constructed to reproduce standard intervals, the durations of which were identical with the preceding judgment intervals.

The subject had before him a green light to indicate when a standard interval was being presented and a red light, a judgment interval. He was provided with a microswitch to terminate the judgment interval when he considered its duration equalled that of the preceding standard.

The subject wore earphones through which a 1 kc/s pure tone at a strength of 80 db. above threshold could be transmitted; this was selected by relay contacts and a switch in a simple circuit utilising the contacts coincident with the end of the standard and judgment intervals. A factorial design was used similar to that in Experiment A. Each of eight subjects experienced the four conditions detailed in Table XIV, and was presented them in the order given in Table XV.

The initial standards were ten seconds and twelve judgments in sequence were made by each subject in each condition, there being a two-minute rest between each condition. All subjects were male members of the laboratory staff; they were given instructions that a random series of standard intervals would be presented which they were to reproduce as accurately as possible in the succeeding judgment intervals. No instructions were given regarding method

Table XIV

Experimental conditions

Factors		Conditions symbol
Standard	Judgment	
Noise	Noise	A
Noise	Silence	B
Silence	Noise	C
Silence	Silence	D

Table XV

Order of presentation to subjects of experimental conditions to determine the effect of noise

Subject	Order			
	1	2	3	4
1	A	B	D	C
2	B	A	C	D
3	C	D	B	A
4	D	C	A	B
5	A	D	C	B
6	D	B	A	C
7	C	A	B	D
8	B	C	D	A

of assessment and, if the subject enquired, he was told that whatever method he used was up to himself. It was ascertained afterwards that, in fact, all subjects counted at a supposed regular rate in order to reproduce the intervals.

Results

The durations of the standard intervals for the eight subjects in each sequence and condition ar e shown in Table XVI. The mean durations for the eight subjects are shown plotted separately for each condition and sequence in Fig. 8. It can be seen that there is only a consistent trend when the noise was presented in the judgment intervals, the duration increasing as the series progresses.

Analysis of variance of the differences between the durations of succeeding judgments (Appendix E.7) showed that subjects differed widely between themselves ($P = 0.001$); there were significant interactions with the order in the sequence ($P = 0.05$) and with the conditions or order which were confounded ($P = 0.01$).

There was no significant interaction between the two experimental factors - the presence of noise in the standard or the judgment. Only noise present during the judgment intervals produced any significant effect. From inspection of Fig. 8 and the average main effects which are shown in Table XVII, it can be seen that noise increased the duration of the judgment intervals, but only when it was present in that interval; it had no distorting effect when presented in the standard interval.

Table XVI

Silence in both standard and judgment intervals

Sequence	Subjects							
	1	2	3	4	5	6	7	8
0	10.35	10.18	10.14	10.13	10.00	10.05	10.15	10.04
1	11.07	10.18	9.45	10.93	10.85	9.92	10.46	10.61
2	11.87	10.81	8.74	10.36	11.58	10.25	10.55	11.62
3	12.19	11.71	9.83	8.94	10.61	11.19	8.64	11.37
4	12.90	11.88	9.73	7.31	8.73	11.40	7.57	11.97
5	13.13	12.20	9.57	7.05	8.35	10.98	6.05	12.35
6	13.44	13.20	10.87	6.61	8.13	11.61	7.09	13.63
7	14.92	13.51	10.58	5.85	7.19	12.07	6.53	12.89
8	15.97	13.27	10.93	4.09	7.40	13.05	6.49	13.21
9	15.79	14.33	10.95	3.65	7.43	13.18	6.48	13.74
10	16.44	14.70	10.88	3.04	7.77	13.38	7.08	14.00
11	16.33	15.70	11.42	3.12	7.59	13.90	6.41	12.90
12	17.51	16.37	12.71	3.26	6.68	14.26	5.94	12.73

Durations of standard intervals in seconds

Silence in judgment and noise in standard intervals

Sequence	Subjects							
	1	2	3	4	5	6	7	8
0	10.16	10.41	10.03	10.33	9.97	10.06	10.16	10.07
1	11.06	9.82	9.19	11.53	10.18	9.96	9.70	9.97
2	10.75	11.17	9.94	9.77	10.27	9.86	9.49	10.42
3	11.78	11.17	9.35	8.56	10.52	9.77	9.43	11.51
4	12.36	11.51	8.91	9.11	10.89	10.47	9.86	12.00
5	13.23	12.83	9.25	8.63	11.31	10.56	10.15	11.53
6	14.49	13.48	9.03	8.63	11.64	11.21	9.98	10.36
7	14.66	13.97	9.31	6.85	11.70	11.68	9.71	7.66
8	14.99	14.86	9.37	6.86	12.10	11.66	8.76	7.47
9	14.96	16.63	9.15	6.24	12.37	11.56	9.00	7.20
10	14.90	16.68	9.61	4.94	12.99	11.51	7.70	7.20
11	15.18	16.97	9.58	4.50	13.50	12.14	7.11	5.94
12	15.49	17.93	9.30	4.16	13.66	12.28	6.73	5.98

Table XVI (continued)

Noise in judgment and silence in standard intervals

Sequence	Subjects							
	1	2	3	4	5	6	7	8
0	10.12	10.11	10.11	10.01	10.04	9.91	10.08	10.15
1	10.38	8.88	10.94	11.82	9.74	10.33	10.17	10.70
2	11.36	9.81	11.16	10.75	11.14	10.26	11.98	10.22
3	12.27	10.18	12.86	11.10	9.97	10.63	11.89	10.61
4	12.89	9.95	10.71	11.33	10.17	11.46	12.88	10.41
5	13.71	9.97	11.77	11.63	10.20	11.61	13.26	10.26
6	14.67	9.90	13.25	12.82	10.85	12.15	13.40	10.84
7	15.93	10.06	16.47	12.61	10.50	12.52	14.14	11.27
8	16.92	10.35	15.90	13.36	11.56	12.78	13.28	10.22
9	17.76	10.97	11.87	14.09	11.94	13.30	12.42	10.24
10	18.89	11.29	12.11	14.16	11.00	13.72	12.25	10.31
11	19.41	11.22	12.22	15.03	11.29	13.57	11.34	10.92
12	20.37	11.92	12.16	14.97	11.79	14.50	11.06	10.41

Noise in both standard and judgment intervals

Sequence	Subjects							
	1	2	3	4	5	6	7	8
0	10.22	10.31	10.22	10.08	10.01	9.95	10.13	10.07
1	10.31	9.33	11.07	10.81	10.44	7.93	9.98	10.16
2	9.99	9.56	10.31	10.72	10.92	8.09	9.47	11.10
3	10.29	9.89	9.52	11.81	10.31	8.31	9.24	11.85
4	10.42	10.45	9.06	13.19	11.08	9.52	9.06	12.23
5	11.34	11.64	10.60	13.77	11.75	10.40	8.68	13.02
6	11.71	12.80	11.01	13.92	11.81	11.52	8.12	13.75
7	11.73	14.03	10.44	15.20	12.46	11.18	6.72	14.43
8	11.80	14.79	10.21	15.51	11.94	12.13	8.89	14.62
9	11.91	15.16	10.91	15.86	13.32	13.63	8.25	14.25
10	12.17	14.54	10.10	15.67	13.00	13.62	8.01	15.60
11	12.29	15.70	10.49	15.62	13.21	13.85	7.61	15.86
12	11.83	15.71	10.68	16.60	14.15	14.00	7.71	16.02

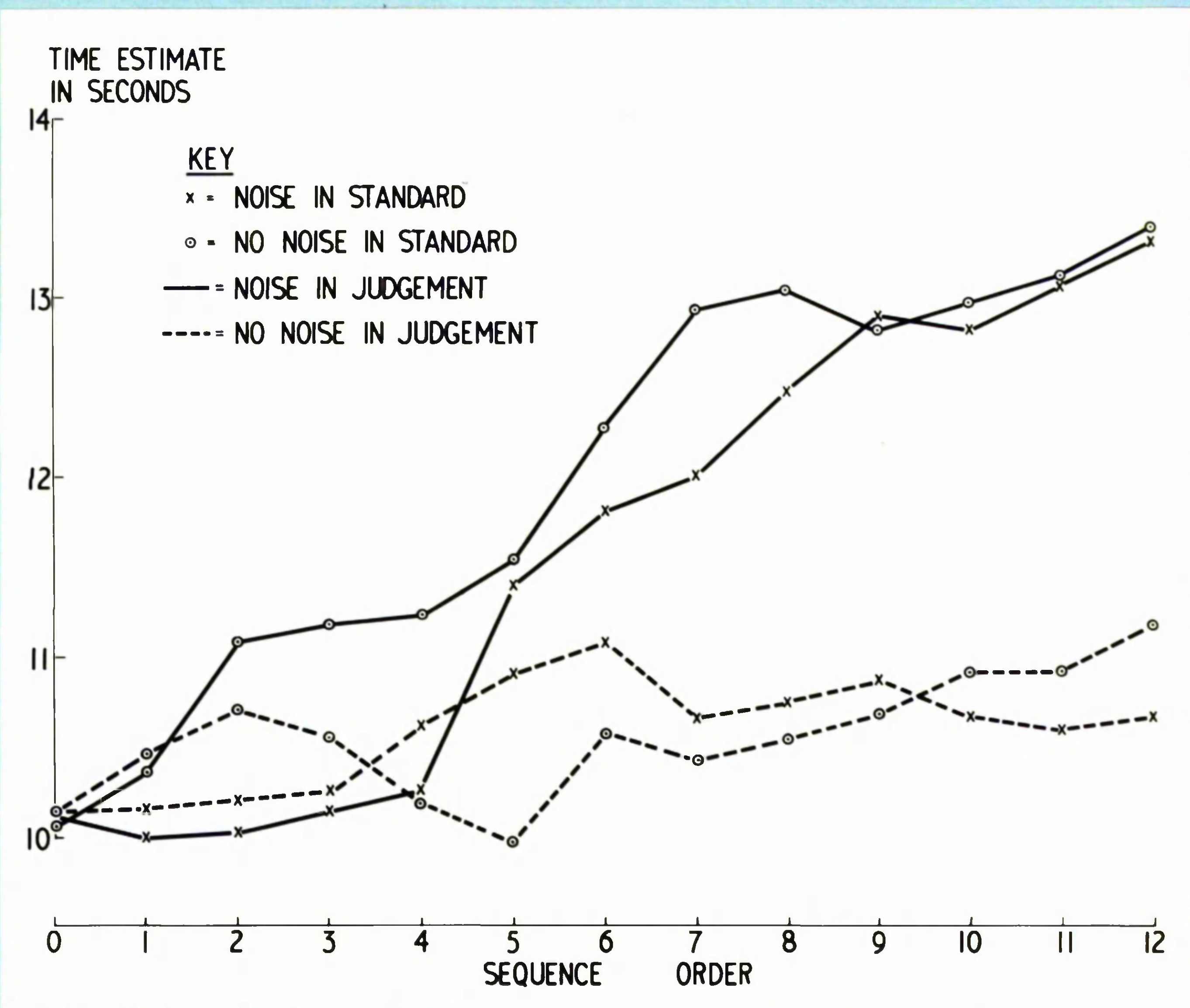

Fig. 8 The effect of noise on the serial reproduction of intervals.

Each value is the mean obtained from eight subjects.

Table XVII

Effect of factors on differences in durations of standard intervals

Factor	Silence	Noise	Difference	P
Judgment	0.066	0.272	+0.206	0.01
Standard	0.183	0.157	-0.026	NS

Each average is the mean of 192 values, two from each of eight subjects for the twelve sequences, and is expressed in seconds

Comment

The presence of noise produced a clear and definite alteration in the environment, with significant distortion in time perception. After the experiment was completed, a reference was found in the literature to a similar result (Hirsh, Bilger and Deatherage, 1956); using the method of reproduction of intervals between 1 and 16 seconds, they demonstrated that when a pure tone (250 c/s at 80 db. above threshold) was presented in the standard, the duration of its judgment was longer (approximately 30 per cent.) when done in the presence of 'white' noise than when the 'white' noise was present (as well as the tone) only in the standard intervals.

The conclusion was thus drawn that in order to create the greatest distortion in the serial reproduction of time, it is likely to be better to present a distracting stimulus in the judgment interval.

(ii) Subjective assessment of resistance to respiration

The Fechner law is commonly acknowledged to represent in an imprecise way that a subjective allocation to a discriminal continuance will be directly related to the logarithm of the magnitude of a sensory stimulus (Thurstone, 1959). The experimental evidence in support of this law was obtained in sensory modalities other than resistance to respiration. A preliminary experiment was thus required to determine if it was applicable to this variable in order to select for the main experiment appropriate values with equal differences on a subjective scale.

Method

A rather crude, but simple apparatus was constructed to allow subjects to breathe through an oro-nasal mask (type P), into the inspiratory side of which valves could be inserted. There were nine valves with known pressure/flow characteristics with nominal values between 0.25 and 4 in. of water resistance; * the pressure drop of each valve was almost constant within the flow range 0.5 - 50 l./min. The apparatus itself had a pressure drop of approximately 1 in. at a flow rate of 20 l./min. on both the inspiratory and expiratory side of the mask; it was less at lower and more at higher flow rates.

Five subjects participated, all medical officers with experience of breathing through aviation oxygen systems. Each subject breathed through each of the nine valves, and through the apparatus only, for one minute on two occasions at the same session. There were thus ten conditions with five subjects participating twice. The order of presentation was selected in a factorial design given in Table XVIII, the conditions being confounded with order at random in a latin square.

Between each presentation, there was a 0.5 minute interval during which the subject breathed only through the apparatus, the added valve having been excluded by turning a Y tap. (This situation still had a pressure drop of about 1 in. at a flow rate of 20 l./min. as mentioned above).

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* The pressure drop is expressed in British lineal measure as the valves had nominal values on this scale

Table XVIII

Order of presentation to subjects of experimental conditions to determine the subjective estimation of resistance to respiration

Subject	Replicate	Order 1	2	3	4	5	6	7	8	9	10
1	1	C	A	B	H	E	I	D	F	J	G
	2	D	I	G	B	A	F	J	C	E	H
2	1	E	J	A	D	B	H	G	I	F	C
	2	A	E	J	F	H	D	I	G	C	B
3	1	J	G	F	E	C	B	H	A	D	I
	2	G	F	H	C	J	A	E	B	I	D
4	1	H	C	I	G	F	J	B	D	A	E
	2	I	D	C	A	G	E	F	H	B	J
5	1	B	H	D	J	I	C	A	E	G	F
	2	F	B	E	I	D	G	C	J	H	A
Symbols		A	B	C	D	E	F	G	H	I	J
Value of resistance added: in. of water		-	0.25	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0

The subject was instructed to convey on a continuous scale his assessment of the resistance to inspiration after each one-minute presentation. He was asked to mark appropriately a 100 mm. line; the left end was defined as denoting that he could detect no resistance and the right end, the resistance he thought would correspond to asphyxia, the centre representing 'moderate' resistance. Previous estimates could not be seen on a subsequent marking.

The marks on the lines were measured to the nearest millimetre and transformed to scores on a scale from 0 representing the threshold to detect resistance to 1 representing asphyxia.

Results

The scores are given in Table XIX. It was ascertained that the mean values for each resistance valve are related linearly to the logarithm of the nominal value of the valves with 1 in. added to account for the approximate apparatus resistance. This relationship is shown plotted in Fig. 9 with the calculated regression equation drawn. It can be seen that the rank order of the mean subjective estimates are all correct except for that corresponding to a resistance of 3 in. of water. It was later established that this particular valve did, in fact, stick and have an abnormal pressure/flow characteristic.

Extrapolation from the regression equation shows that the threshold to detect resistance to inspiration is at a pressure drop of approximately 1 in. of water. It is of interest that this is the value when no valve was inserted into the system; it corresponds

Table XIX

Subjective estimate scores of respiratory resistance : preliminary experiment

Subject	Replicate	Inspiratory resistance valve added : in. of water									
		0.00	0.25	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
1	1	0.01	0.02	0.00	0.15	0.12	0.51	0.64	0.35	0.41	0.79
	2	0.01	0.06	0.02	0.08	0.15	0.47	0.56	0.41	0.48	0.68
2	1	0.00	0.02	0.23	0.08	0.60	0.58	0.60	0.79	0.83	0.86
	2	0.03	0.02	0.07	0.27	0.48	0.60	0.54	0.76	0.87	0.87
3	1	0.02	0.04	0.12	0.27	0.22	0.51	0.52	0.70	0.81	0.84
	2	0.13	0.08	0.26	0.21	0.38	0.74	0.61	0.75	0.65	0.60
4	1	0.00	0.00	0.54	0.66	0.70	0.60	0.62	0.74	0.83	0.81
	2	0.00	0.00	0.25	0.42	0.63	0.78	0.84	0.92	0.77	0.94
5	1	0.00	0.17	0.22	0.16	0.53	0.61	0.47	0.53	0.53	0.65
	2	0.00	0.00	0.09	0.53	0.54	0.56	0.34	0.57	0.72	0.75
Mean		0.02	0.04	0.18	0.28	0.44	0.60	0.57	0.65	0.63	0.78

The scores have a possible range from 0 to 1

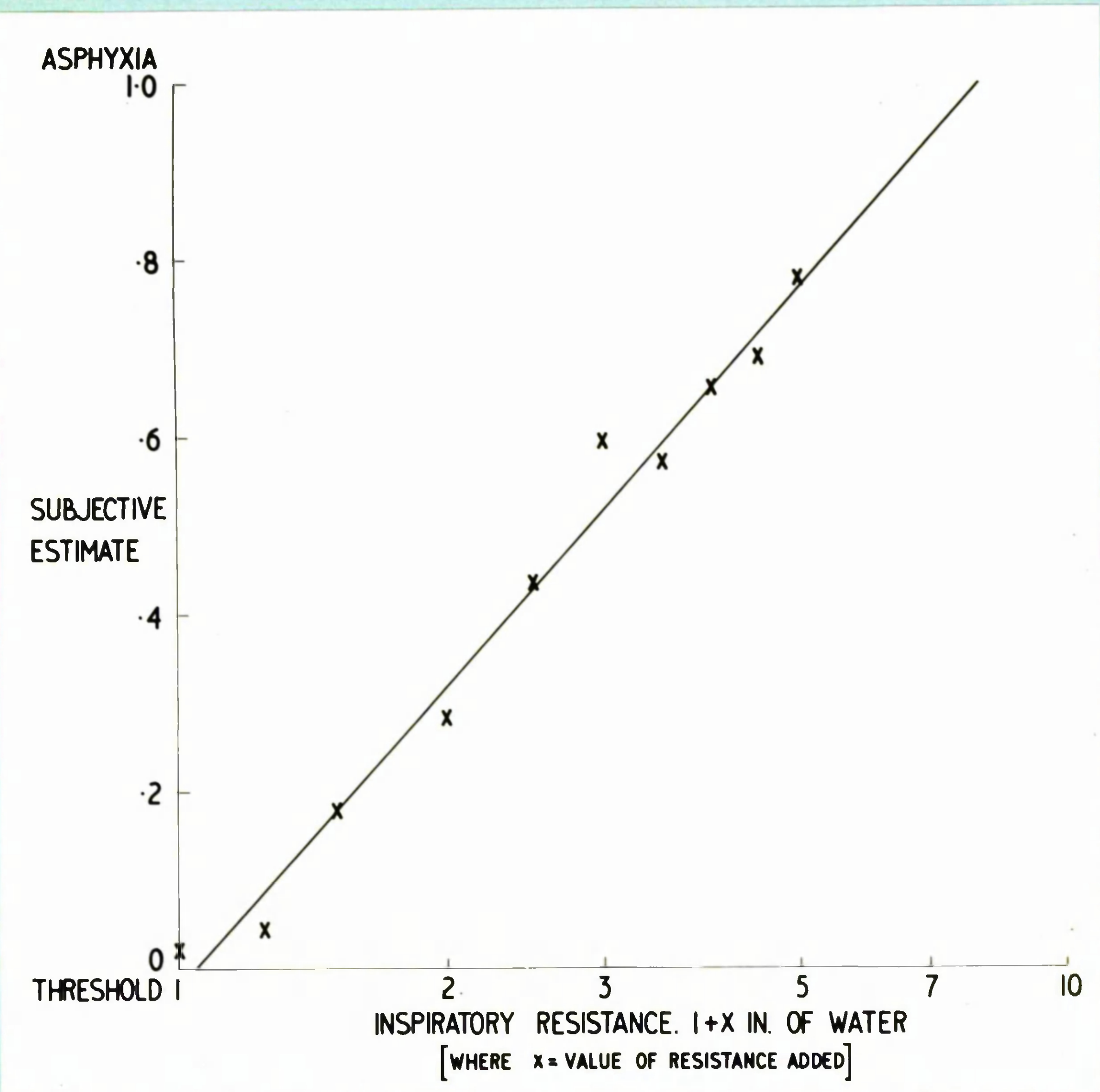

Fig. 9. The relationship between the respiratory resistance (x) and its subjective assessment (y).

The calculated regression equation which is shown plotted is: $y = 1.13 \log. (x + 1) - 0.02$ $(P = 0.001)$ where x = the nominal value of the resistance valve added (Appendix E.8)

Each value is the mean obtained on two occasions from five subjects.

to the approximate resistance of the apparatus itself, both on expiration and inspiration, being breathed through between the experimental conditions, and thus acting in contrast.

Comment

The results are in broad agreement with the Fechner law and confirm that it is applicable to the assessment of the resistance to respiration. The results clearly suggest that, in order to choose values of resistance to respiration that will be spaced equally on a subjective scale, it is appropriate to choose differences that are a constant proportion of each value.

(iii) The effect of alteration in the resistance to respiration

Method

A breathing system was constructed with known pressure/flow characteristics. The inflow to an oro-nasal mask (type P) led directly from a wide-bore tube (I.D. 2.5 cm.) of 75 cm. length; this tube passed through an opaque screen from a Y junction, in the distal ends of which valves could be interposed. The system itself had a pressure drop of less than 0.1 in. of water at an air-flow of 50 l./min. The pressure/flow characteristics of the valves used to provide the resistance to inspiration are shown in Fig. 10. The mask expiratory valve was intact and its pressure/flow characteristic is also shown in Fig. 10.

Eight subjects, male members of the professional laboratory staff, who had not participated previously in a preliminary experiment,

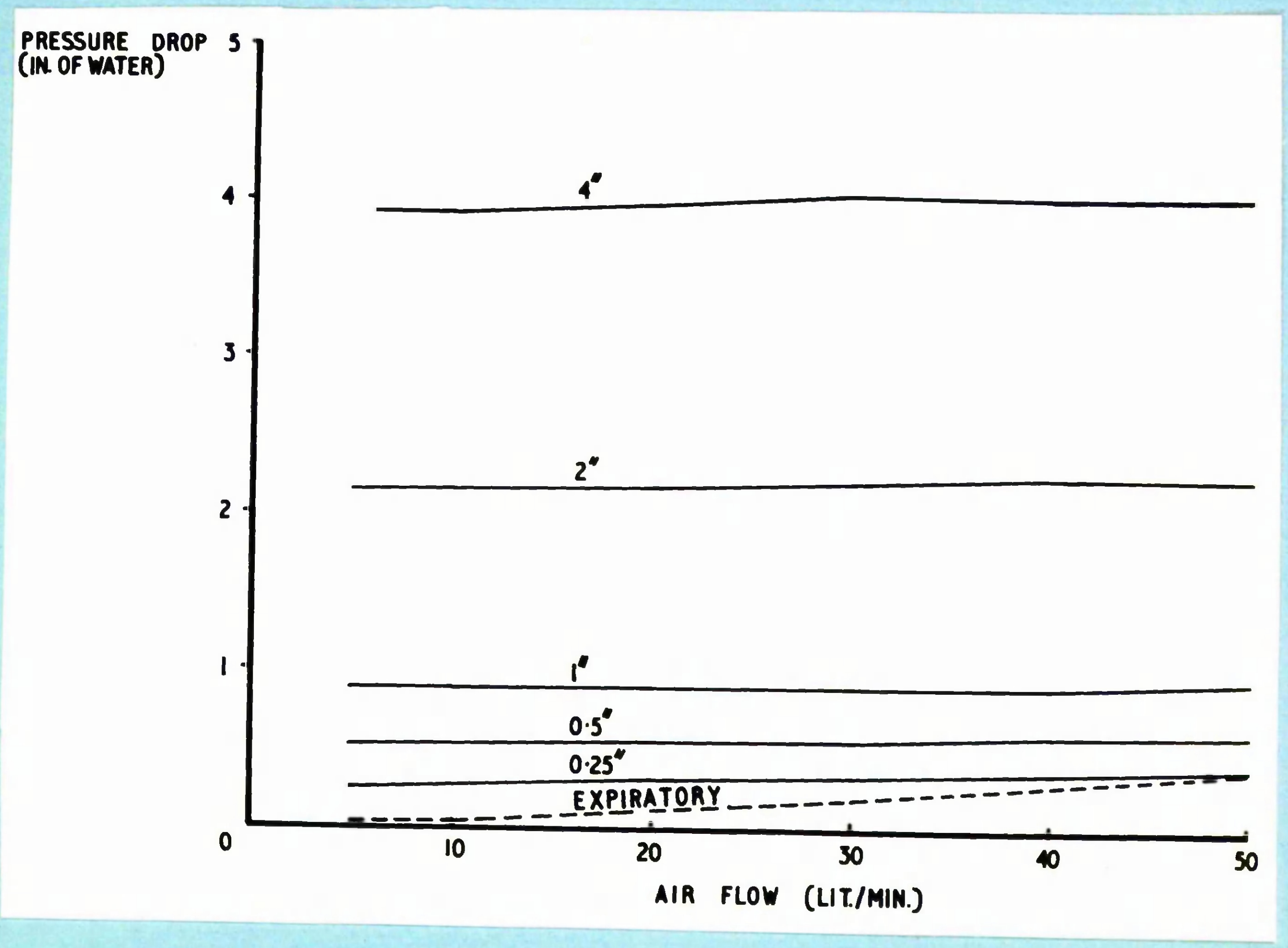

Fig. 10 The pressure/flow characteristics of the valves used to provide resistance to respiration.

sat facing the opaque screen, breathing through the close-fitting mask. Four valves of 0.5, 1, 2 and 4 in. of water nominal pressure drop were used as conditions in the experiment. Each subject breathed through each valve only in the judgment intervals (for the reason determined by the preliminary experiment with noise) for a sequence of 12 trials. These values with equal logarithmic increments were chosen as a result of the evidence obtained in the second preliminary experiment. In the standard intervals, and in the two minutes' delay between experimental conditions the subjects inspired through a valve of 0.25 in. of water nominal pressure drop which was placed in the other arm of the Y junction. The Y junction tap was turned by the experimenter at each changeover.

In order to determine whether the same relationship was present with these subjects between subjective appreciation of the resistance to respiration and the value of the resistance interposed as found in the second preliminary experiment, subjects were asked to express their estimates on similar continuous scales.

For the serial reproduction of time, the instructions to the subjects were the same as in the preliminary experiment with noise. The order of presentation of the four conditions, given in Table XX, was selected in a similar way.

Results

The durations of the standard intervals for the eight subjects in each sequence and condition are shown in Table XXI. The mean durations for the eight subjects are shown plotted separately for

Table XX

Order of presentation to subjects of experimental conditions to determine the effect of alteration in respiratory resistance

Subject	Order			
	1	2	3	4
1	A	B	C	D
2	B	A	D	C
3	C	D	A	B
4	D	C	B	A
5	A	C	B	D
6	B	D	A	C
7	C	B	D	A
8	D	A	C	B

Symbol	A	B	C	D
Value of resistance : in. of water	0.5	1.0	2.0	4.0

Table XXI

Durations of standard intervals in seconds

0.5 in. valve

Sequence	Subjects							
	1	2	3	4	5	6	7	8
0	9.95	9.97	10.06	10.11	9.72	9.93	10.11	9.99
1	10.14	9.38	11.70	8.43	9.41	6.95	9.19	10.14
2	8.88	9.86	10.98	6.42	10.20	6.41	12.38	9.56
3	8.16	8.82	10.85	5.14	8.35	5.87	13.47	10.13
4	7.20	8.97	9.90	5.15	8.20	5.53	20.00	9.69
5	6.51	7.94	8.66	4.94	7.88	5.07	25.59	7.90
6	6.09	7.49	10.06	5.21	8.13	5.29	17.76	8.46
7	6.21	6.60	9.11	4.79	8.10	3.60	17.22	10.55
8	5.65	6.06	10.11	4.78	7.96	2.76	22.27	10.80
9	5.70	6.31	8.77	4.69	7.96	2.55	28.05	10.24
10	5.05	5.88	10.42	4.18	8.04	2.04	27.94	11.01
11	4.27	6.36	10.87	3.98	8.08	1.96	35.73	10.97
12	2.58	7.22	10.16	3.65	7.33	1.86	40.19	11.91

1.0 in. valve

Sequence	Subjects							
	1	2	3	4	5	6	7	8
0	10.02	10.12	10.60	10.08	9.86	10.16	9.96	10.03
1	10.51	10.69	8.88	9.64	9.88	7.81	19.72	10.60
2	11.09	10.84	8.76	8.61	10.25	7.57	26.45	11.17
3	11.18	11.76	8.43	7.00	11.35	6.98	27.61	11.26
4	12.38	8.74	9.37	5.97	11.57	5.55	26.14	11.51
5	12.76	9.03	9.48	5.33	12.02	5.63	23.18	10.60
6	12.88	8.27	9.68	5.82	13.20	4.69	20.34	10.83
7	13.07	9.29	10.16	5.58	12.57	4.45	25.05	11.23
8	11.47	9.06	9.49	5.48	13.23	4.11	21.29	11.38
9	10.30	10.25	8.94	5.41	12.59	3.11	24.59	11.53
10	10.13	9.72	9.87	5.22	12.41	2.15	26.90	11.76
11	9.22	11.21	9.12	3.72	12.47	1.64	37.33	11.83
12	8.42	11.96	9.48	3.39	11.44	1.36	39.82	13.09

Table XXI (continued)

2.0 in. valve

Sequence	Subjects							
	1	2	3	4	5	6	7	8
0	10.07	10.06	9.93	10.07	9.99	9.89	9.92	9.94
1	10.84	8.99	9.51	10.08	9.51	6.72	9.22	10.33
2	10.92	9.85	10.31	9.14	9.83	5.65	14.81	10.07
3	10.14	9.67	8.11	8.76	10.35	5.24	19.21	10.35
4	11.55	10.68	8.64	8.69	10.54	5.22	23.04	10.47
5	12.38	11.92	10.06	8.84	10.69	4.81	20.52	10.62
6	10.96	11.36	10.24	9.88	10.77	5.17	21.73	11.48
7	10.93	10.23	8.33	8.79	10.66	4.91	24.38	11.14
8	10.87	9.75	9.03	8.93	11.42	5.32	31.47	11.43
9	10.53	11.23	11.24	9.84	10.91	5.13	32.90	11.69
10	12.67	12.54	10.52	10.07	10.82	5.15	30.52	10.96
11	11.52	15.38	10.27	10.34	10.87	5.10	38.71	10.45
12	13.32	14.11	11.19	11.09	11.30	4.73	45.61	11.40

4.0 in. valve

Sequence	Subjects							
	1	2	3	4	5	6	7	8
0	10.01	9.98	10.00	10.06	10.11	10.16	9.98	9.98
1	9.99	10.07	9.32	11.42	10.27	7.13	12.45	8.34
2	8.60	11.17	9.02	12.39	11.74	7.37	20.52	6.85
3	8.39	11.51	10.13	10.79	11.27	7.65	16.57	7.23
4	9.60	11.96	8.71	12.37	11.63	6.57	23.90	7.41
5	9.20	13.00	8.63	10.28	14.34	6.19	25.44	6.31
6	9.06	12.57	9.54	7.39	14.55	6.14	18.09	6.79
7	9.18	14.99	9.40	6.82	14.92	6.14	23.79	6.73
8	8.17	15.30	8.30	5.11	14.80	4.94	18.82	6.19
9	7.24	15.48	10.02	3.51	17.27	4.38	17.85	6.95
10	5.97	15.55	9.87	3.82	15.69	3.55	20.41	6.82
11	6.10	18.15	7.42	2.84	15.35	3.26	26.86	6.62
12	5.46	16.92	7.42	1.84	17.49	3.43	25.63	5.69

each condition and sequence in Fig. 11. It can be seen that there is no meaningful consistent trend.

Analysis of variance of the differences between the durations of succeeding judgments (Appendix E. 9) showed that the interaction between subjects and conditions or order (which was confounded) was highly significant (P = 0.001). Inspection of the data showed that in each of the conditions, some subjects tended to increase, some to decrease and others not to distort the durations of their judgments. There were no main significant differences induced by the experimental conditions under trial, though the effect of order of presentation of the conditions was highly significant (P = 0.001). This effect was predominantly produced by two subjects (subjects 6 and 7) whose judgments decreased on the first and third trials, but increased on the second and fourth.

Inspection of Fig. 11 and the average main effects which are given in Table XXII reveals that even if the differences had reached a level of significance, it would have been difficult to postulate a mechanism to explain the average distortions, in view of the fact that their direction did not appear to be in any way related to the level of respiratory resistance.

The subjective estimate scores for the detection of respiratory resistance are given in Table XXIII. The linear relationship between the scores and the nominal values of the valves is similar to that found in the preliminary experiment in that a logarithmic relationship best fits the results. The mean scores for each value are plotted in Fig. 12 with the calculated regression drawn.

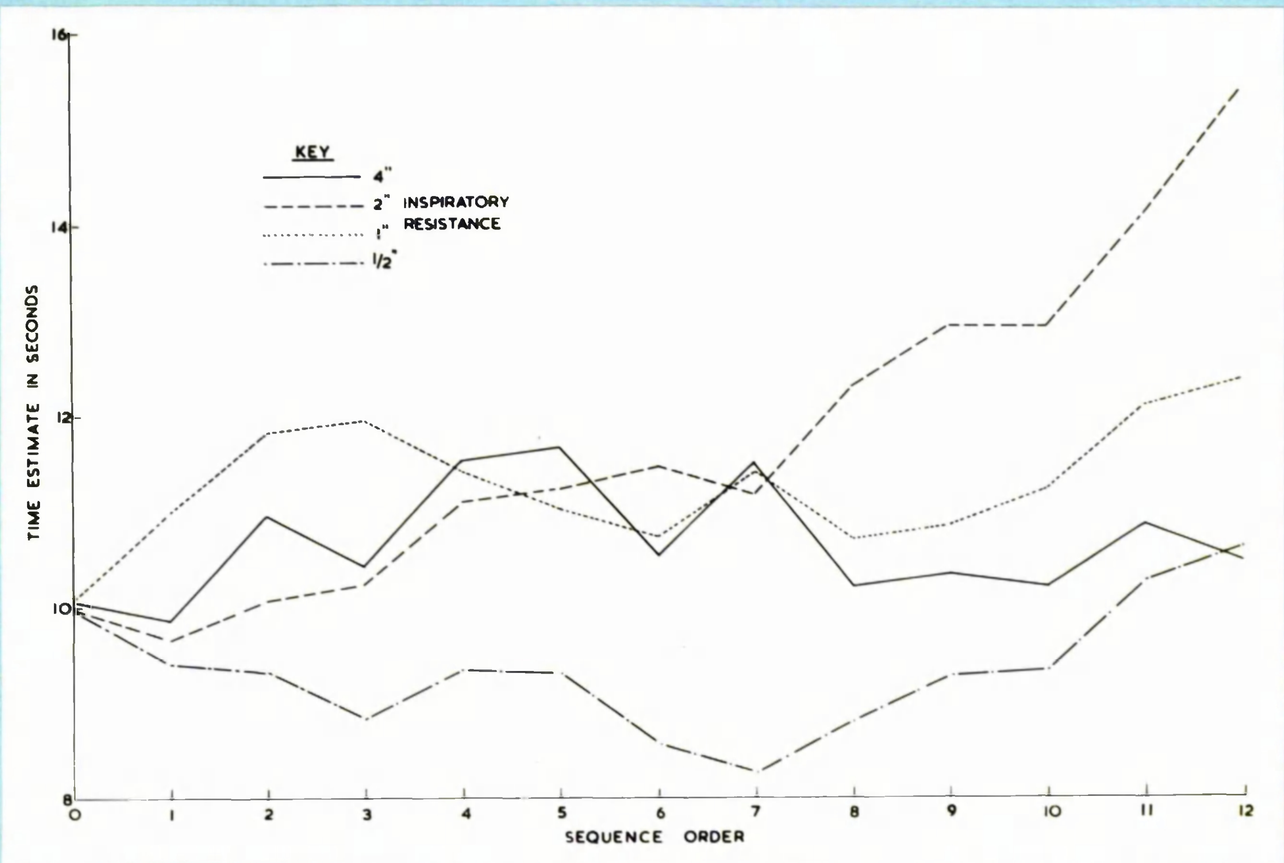

Fig. 11 The effect of alteration in the respiratory resistance during the judgment intervals on the serial reproduction of time.

Each value is the mean obtained from eight subjects.

Table XXII

Effect of conditions on differences in durations of standard intervals

Respiratory resistance : in. of water	0.5	1	2	4
Mean duration difference	+0.053	+0.199	-0.446	-0.038

Each average is the mean of 96 values, one from each of eight subjects for the twelve sequences, and is expressed in seconds

Table XXIII

Subjective estimate scores of respiratory resistance

Subject	Inspiratory resistance valve : in. of water			
	0.5	1.0	2.0	4.0
1	0.06	0.69	0.79	0.88
2	0.49	0.58	0.82	0.88
3	0.01	0.16	0.38	0.48
4	0.49	0.55	0.79	0.87
5	0.00	0.07	0.11	0.36
6	0.01	0.61	0.57	0.79
7	0.07	0.25	0.37	0.67
8	0.11	0.00	0.42	0.51
Mean	0.16	0.36	0.53	0.68

The scores have a possible range from 0 to 1

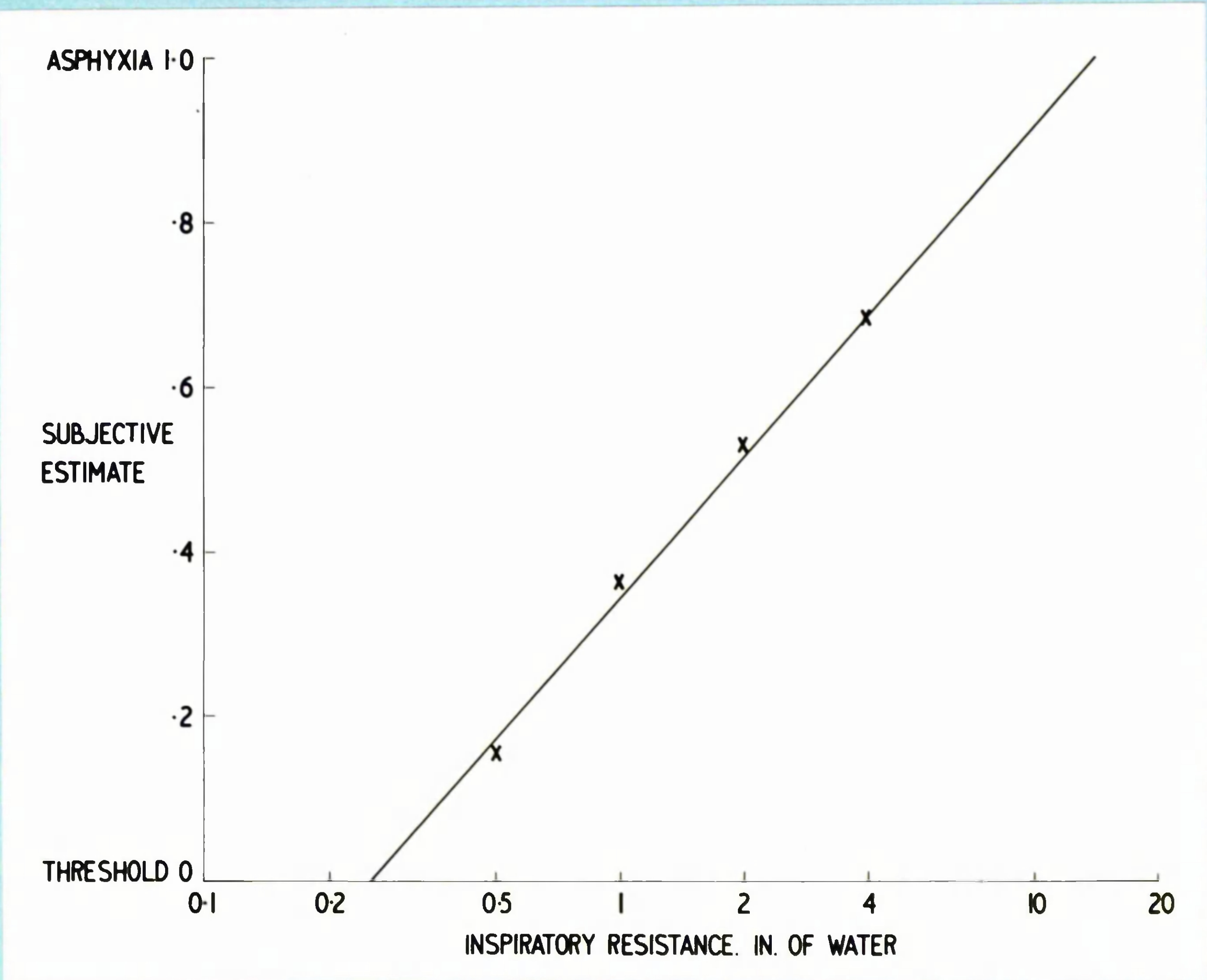

Fig. 12 The relationship between the respiratory resistance used to provide the four conditions (x) and its subjective assessment (y).

The calculated regression equation which is shown plotted is :

$y = 0.58 \log x + 0.34$ ($P = 0.01$) (Appendix E. 10).

Each value is the mean obtained from eight subjects.

Analysis of variance (Appendix E.11) confirms that the differences between conditions are highly significant ($P = 0.001$) and also reveals that the subjects differed between themselves in their scores ($P = 0.001$).

Extrapolation from this regression equation shows that the threshold to detect resistance to inspiration is at a pressure drop of approximately 0.26 in. of water. This value is similar to the resistance to expiration all the time (0.1 - 0.25 in. of water depending on the flow rate) and the comparison resistance on inspiration in the standard intervals and in the two minutes' delay between the experimental conditions (0.25 in.).

Comment

The noticeable dissimilarity in threshold of detection of resistance to inspiration between the preliminary and the main experiment is of interest. In the preliminary experiment, the value of the threshold was approximately equal to the expiratory resistance - 1.0 in. of water; in the main experiment the same finding holds true, though the corresponding value is 0.25 in. of water. It is appreciated that the two experiments were done with different subjects and two breathing systems, but the suggestion of a relationship with a comparison as a reason decreeing the threshold of detection of this perceptual phenomenon begs substantiation; an experiment with this aim in view is required.

The presence of noise produced a clear and definite alteration in the environment, with significant distortion in time perception.

The modification of the environment by the alteration of the resistance to respiration was less effective. Though the differences were clearly appreciated by the subjects, they were less definite and it is unlikely that they produced any great alteration in attitude, or indeed in arousal. Thus in the pattern of response, the differences between individuals and random inaccuracy were likely to have predominated and precluded the detection of differences due to the conditions which were introduced, if indeed they were even produced. As small alterations only in the environmental conditions are likely to be encountered in assessing the acceptability of aircrew life-support equipment, these differences between individuals are likely to exceed the magnitude of an induced distortion due to the conditions under review.

This conclusion refers to the present experiment where the assessment was done with the method of serial reproduction. Time perception studies may, however, indeed be of real benefit if done with more subtle and yet simpler methods as discussed later; they may well provide information on the acceptability of an environmental condition by evaluating the differences between individuals as it is likely that these may be related to other factors, which are of paramount relevance to control-system operators.

C. THE COMPARISON OF THE APPARENT DURATION OF ONE-MINUTE INTERVALS, ASSOCIATED WITH THE FREQUENCY OF A FLASHING LIGHT *

An aircraft flying at night carries two kinds of lights to give information to the pilots of other aircraft - lights to draw attention to the presence of the aircraft in a particular region of airspace, and lights to indicate its orientation. It is generally agreed that to carry out the first function, lights should be flashing (International Civil Aviation Organisation, 1961) as there is evidence that they are more conspicuous than steady lights dissipating comparable mean power (Gerathewohl, 1953).

The two requisites of a flashing light system are that primarily it should provide the greatest probability of being seen from another aircraft, and secondly, it should produce the least annoyance to the crew of the aircraft carrying the lights, by the back-scatter into the cockpit, such as may happen when flying through cloud. This laboratory investigation was concerned primarily with the practical problem to choose the frequency of flashing light that will be least distracting to aircrew flying at night.

To obtain this answer, subjects were to be asked to express their attitude towards the experimental variables. Thus the opportunity was taken to design the experiment to permit examination of the

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* Aitken, Ferres and Gedye, 1963

effect of their attitude to the experimental conditions on time perception and skin resistance, and so relate them all in one experiment.

Method The experimental arrangement is shown in Fig. 13.

The experiment was carried out in the sound-insulated building, which was used in Experiment A. A window in this dividing wall allowed a translucent screen in the experimental room to be illuminated from behind by a lamp (30 watt filament energised by D. C.) in the observation room; the subject sat looking at this screen. A rotating shutter, placed close to the light source, produced intermittent illumination of the screen with equal on - off periods. For practical reasons, five frequencies were selected for study: 1.00, 1.33, 1.67, 2.00, 2.33 c/s. The luminance of the flash was 2.1 cd./m^2 with a light - dark contrast of 9.0 (contrast is given by the expression $\frac{L_2 - L_1}{L_1}$, where L_1 is the luminance of the dark period of the cycle and L_2 the luminance of the bright period).

There were ten subjects - five pilots (subjects 1, 5, 7, 8 and 9) who were in current flying practice, and five who were the first available male members of the Institute staff. The subjects were divided at random into five pairs; each subject had each of the ten possible combinations of two (ignoring order) chosen from the five frequencies. Each pair of subjects had the twenty possible combinations taking order into account. For any pair of frequencies, one subject from each of the subject pairs had the higher frequency

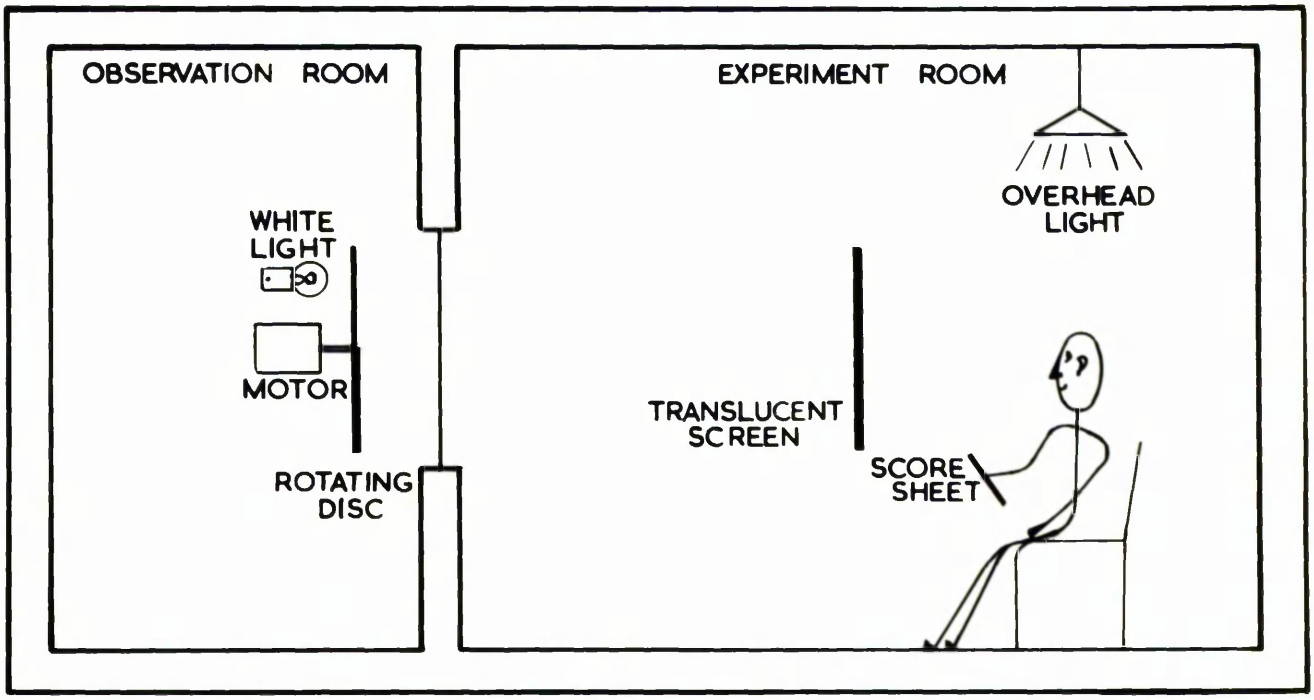

Fig. 13 Diagram of the experimental arrangements.

first. Of the ten pairs given to each subject, in five the higher frequency was presented first. The design was in the form of a 10 x 10 latin square, with subjects as rows and order of presentation as columns, and is given in Table XXIV.

Each flash frequency was presented for one minute, the two frequencies of each pair being separated by 15 seconds. There was a 45-second interval between each pair, during which the overhead light was on, so that the subject could record his judgments of the pair.

After explaining the purpose of the experiment, the subject was told to imagine what it would be like to fly with the flashing light as background, and that he was required to answer two questions :
(i) "Which of the two frequencies would be the more acceptable if you were a pilot flying under the stipulated conditions ?"
(ii) "What was the relative duration of exposure to the two frequencies ?"

Measurements

Subjective

Preference Each subject was provided with a score-sheet on which there was a set of ten horizontal lines, each 100 mm. long arranged one above the other, similar to those used in the previous experiments.

The subject was told that he was to indicate his relative preference for the two frequencies just presented by placing a mark on the line, according to the following rules -

Table XXIV

Order of presentation of frequencies

Subject	Pair order									
	1	2	3	4	5	6	7	8	9	10
1	A:E	B:A	C:D	E:B	C:E	C:B	E:D	B:D	D:A	A:C
2	C:A	E:C	B:E	A:D	B:C	D:B	A:B	E:A	D:E	D:C
3	D:B	B:C	C:A	E:A	A:D	C:D	E:B	E:C	A:B	D:E
4	C:B	B:D	B:A	C:E	E:D	A:C	D:A	D:C	A:E	B:E
5	E:D	D:A	B:C	C:A	C:D	A:E	C:E	E:B	D:B	A:B
6	E:C	D:E	B:D	D:C	B:A	B:E	E:A	C:B	A:C	A:D
7	E:B	E:A	A:D	D:E	D:B	A:B	B:C	C:A	C:D	E:C
8	D:C	B:E	E:D	B:A	A:C	C:E	B:D	D:A	C:B	A:E
9	B:A	A:C	A:E	C:B	E:B	D:A	C:D	E:D	C:E	B:D
10	A:D	D:C	E:C	D:B	E:A	D:E	C:A	A:B	B:E	B:C

Symbols	A	B	C	D	E
Frequencies c/s	1.00	1.33	1.67	2.00	2.33

(i) A mark at the centre of the line would mean that no preference towards either alternative could be expressed

(ii) A mark at the left end of the line would mean that 'under all possible circumstances' the first alternative would be chosen

(iii) A mark at the right end would mean that 'under all possible circumstances' the second alternative would be chosen

(iv) Marks placed between the centre and the ends would signify preference for the alternative represented at the nearest end, the strength of the preference being indicated by the distance of the mark from the centre

The answers were scored by measuring to the nearest millimetre the distance of the marks from the centre and multiplying the measurements in mm. by the factor 0.02 to give them a possible numerical range from -1 to +1. The positive score was used to denote preference for an alternative, and the negative score preference for the opposite alternative. So that for a given alternative, A, of a pair AB, a score of +1 would mean the greatest possible preference for A over B, 0 would mean no preference was expressed, and -1 would mean the greatest possible preference for B over A.

<u>Relative Duration</u> Each subject was asked to score a similar set of lines according to his opinion of the relative duration of the two intervals of flashing light in a pair of frequencies. He was told that the line represented the sum of the two intervals, which was constant throughout the experiment, but that the ratios of the intervals varied from pair to pair. (In actual fact this ratio was unity).

The subject was instructed not to count anything nor to make allowance for any pre-conceived ideas about possible distortions when making his judgments.

The answers were scored by measuring the distance from the centre and transforming as before, so that for a given pair of frequencies A B, a score of +1 would mean the longest possible apparent duration of A, 0 would mean that he considered they were presented for equal durations, and a score of -1 would mean the shortest possible apparent duration of A.

Objective

Skin resistance The apparatus used (Appendix D) was similar in principle to that devised for Experiment A, but it had the elaborations that the balancing was done automatically and the skin resistance was recorded continuously. The electrodes described in Appendix B were again used.

The resistance was measured at the beginning and the end of each presentation of each particular frequency. For reasons that will be discussed later in detail and due to the satisfactory results obtained in Experiment A with this measurement, change in log. conductance was selected as the appropriate unit for evaluation. The difference between the logarithm of the conductance in micromhos (reciprocal of resistance in megohms) at the end of each one-minute interval and the logarithm of the conductance at the beginning was calculated.

Results   A preliminary analysis of the results did not reveal any significant difference between the five pilots and the five laboratory staff, so the two groups can be regarded as having been drawn from the same population and no distinction was made in subsequent analyses.

Preference

The scores are given in Table XXV. It can be seen that a score for one frequency in comparison with another is the same magnitude but with different sign to that for the other frequency to which it is compared.

A special analysis of variance * (Appendix E.12) on the three-factor experiment was applied to the preference scores, the three factors being five subject pairs, ten frequency pairs and two orders. The mean scores for each light frequency were compared using a standard error derived from this analysis.

There are significant differences between the mean scores. A difference between the mean scores at each frequency greater than 0.37 was significant at the 5 per cent. level and 0.50 at the 1 per cent. level.

The highest preference scores were obtained for the two lowest frequencies. There is a negative linear relationship between

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* This had to be adapted by Miss H. M. Ferres from a method proposed by Scheffé (1952) as there was no simple subject variance, their total scores all being equal

Table XXV

Preference scores

Frequency c/s	Comparison frequency	Subjects 1	2	3	4	5
1.00	1.33	+0.20	-0.24	-0.12	-0.22	+0.44
	1.67	+0.12	+0.28	-0.62	+0.48	+0.54
	2.00	+0.14	+0.52	-0.44	-0.40	+0.44
	2.33	+0.44	-0.38	-0.84	+0.68	+0.28
1.33	1.00	-0.20	+0.24	+0.12	+0.22	-0.44
	1.67	+0.12	+0.30	-0.18	-0.54	+0.38
	2.00	+0.54	-0.02	-0.62	+0.74	-0.04
	2.33	+0.28	+0.26	-0.88	+0.52	-0.22
1.67	1.00	-0.12	-0.28	+0.62	-0.48	-0.54
	1.33	-0.12	-0.30	+0.18	+0.54	-0.38
	2.00	+0.72	-0.30	-0.34	-0.12	+0.42
	2.33	+0.46	-0.38	-0.42	+0.76	-0.34
2.00	1.00	-0.14	-0.52	+0.44	+0.40	-0.44
	1.33	-0.34	+0.02	+0.62	-0.74	+0.04
	1.67	-0.72	+0.30	+0.34	+0.12	-0.42
	2.33	+0.22	+0.36	-0.30	-0.50	+0.28
2.33	1.00	-0.44	+0.38	+0.84	-0.68	-0.28
	1.33	-0.28	-0.26	+0.88	-0.52	+0.22
	1.67	-0.46	+0.38	+0.42	-0.76	+0.34
	2.00	-0.22	-0.36	+0.30	+0.50	-0.28

The scores have a possible range from -1 to +1

Table XXV (continued)

Preference scores

Frequency c/s	Comparison frequency	Subjects				
		6	7	8	9	10
1.00	1.33	+0.02	+0.18	+0.16	-0.32	+0.16
	1.67	+0.32	+0.32	+0.30	+0.64	-0.60
	2.00	+0.44	+0.12	-0.42	+0.46	-0.44
	2.33	+0.38	-0.36	+0.66	+0.74	+0.22
1.33	1.00	-0.02	-0.18	-0.16	+0.32	-0.16
	1.67	+0.38	+0.18	-0.10	+0.42	+0.14
	2.00	+0.46	+0.24	+0.36	+0.58	+0.14
	2.33	+0.52	+0.36	+0.50	+0.48	+0.36
1.67	1.00	-0.32	-0.32	-0.30	-0.64	+0.60
	1.33	-0.38	-0.18	+0.10	-0.42	-0.14
	2.00	+0.10	+0.14	+0.42	+0.26	-0.42
	2.33	+0.42	+0.32	+0.36	+0.32	-0.32
2.00	1.00	-0.44	-0.12	+0.42	-0.46	+0.44
	1.33	-0.46	-0.24	-0.36	-0.58	-0.14
	1.67	-0.10	-0.14	-0.42	-0.26	+0.42
	2.33	+0.34	+0.04	+0.44	+0.30	+0.42
2.33	1.00	-0.38	+0.36	-0.66	-0.74	-0.22
	1.33	-0.52	-0.36	-0.50	-0.48	-0.36
	1.67	-0.42	-0.32	-0.36	-0.32	+0.32
	2.00	-0.34	-0.04	-0.44	-0.30	-0.42

The scores have a possible range from -1 to +1

frequency and mean preference score, and the calculated regression is drawn in Fig. 14 where the mean results are plotted.

The effect of order was also significant ($P = 0.001$), but examination of the scores did not reveal any meaningful interpretation for this.

Relative duration

The scores are given in Table XXVI. Examination of the results showed that on no occasion did a subject compare the durations of the intervals to be equal, so that there was always some distortion; the most severe was of the order of 5 : 1 ratio between the durations of the two intervals of the pair presented. There was no grouping around selective values.

A special analysis of variance was completed similarly on the relative duration scores (Appendix E. 13). No significant differences were obtained; the mean values of relative duration at each flash frequency are drawn in Fig 15.

Skin conductance

The changes in conductance for the minutes during which the subjects were exposed to any particular flash frequency are given in Table XXVII. Although 23 per cent. of the values were increases, the mean values for all the frequencies were negative; the interpretation of this finding, in view of the result found in Experiment A, is that the alertness of the subjects was less than moderate wakefulness.

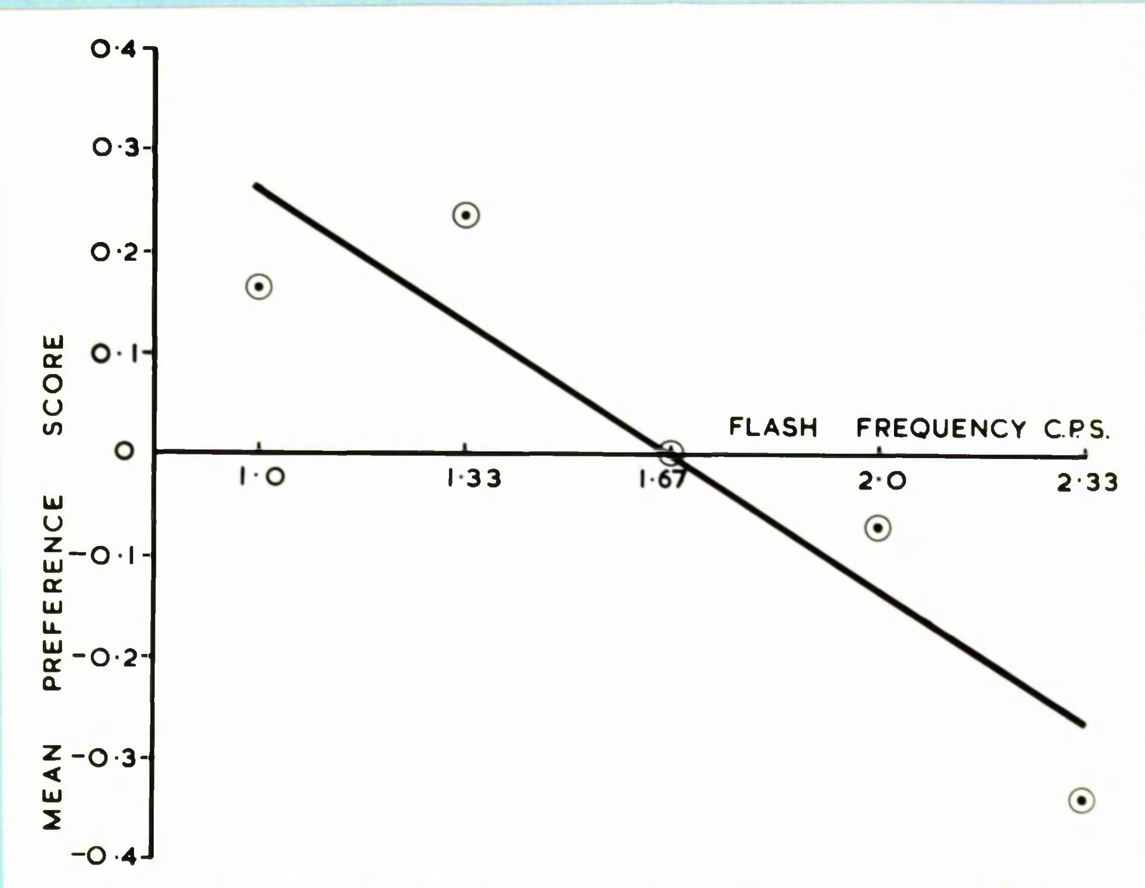

Fig. 14 The relationship between flash frequency (x) and mean preference score (y).

The calculated regression equation which is shown plotted is :

$y = 0.66 - 0.39x$ ($P = 0.05$) (Appendix E.15).

Each value is the mean of 40 readings, four on each of ten subjects, as is the case also in Figs. 15 - 19.

Table XXVI

Relative duration scores

Frequency c/s	Comparison frequency	Subjects 1	2	3	4	5
1.00	1.33	-0.18	-0.24	-0.18	+0.28	-0.30
	1.67	+0.10	-0.36	+0.24	-0.02	+0.30
	2.00	+0.18	-0.28	+0.14	-0.20	+0.12
	2.33	+0.32	-0.46	+0.22	-0.06	-0.30
1.33	1.00	+0.18	+0.24	+0.18	-0.28	+0.30
	1.67	+0.04	-0.16	+0.06	+0.02	+0.30
	2.00	+0.06	+0.02	-0.14	+0.30	+0.04
	2.33	+0.12	-0.04	-0.20	-0.22	-0.14
1.67	1.00	-0.10	+0.36	-0.24	+0.02	-0.30
	1.33	-0.04	+0.16	-0.06	-0.02	-0.30
	2.00	+0.02	+0.06	+0.22	-0.08	+0.30
	2.33	+0.02	+0.04	-0.22	-0.12	-0.30
2.00	1.00	-0.18	+0.28	-0.14	+0.20	-0.12
	1.33	-0.06	-0.02	+0.14	-0.30	-0.04
	1.67	-0.02	-0.06	-0.22	+0.08	-0.30
	2.33	+0.22	-0.26	+0.16	+0.64	-0.32
2.33	1.00	-0.32	+0.46	-0.22	+0.06	+0.30
	1.33	-0.12	+0.04	+0.20	+0.22	+0.14
	1.67	-0.02	-0.04	+0.22	+0.12	+0.30
	2.00	-0.22	+0.26	-0.16	-0.64	+0.32

The scores have a possible range from -1 to +1

Table XXVI (continued)

Relative duration scores

Frequency c/s	Comparison frequency	Subjects				
		6	7	8	9	10
1.00	1.33	+0.26	-0.14	-0.24	-0.30	-0.04
	1.67	-0.02	+0.12	+0.22	-0.10	+0.14
	2.00	-0.10	-0.08	-0.34	+0.16	+0.34
	2.33	+0.02	+0.14	-0.28	+0.24	-0.04
1.33	1.00	-0.26	+0.14	+0.24	+0.30	+0.04
	1.67	+0.14	-0.24	-0.30	+0.10	+0.20
	2.00	-0.02	+0.06	+0.26	+0.14	-0.14
	2.33	-0.24	-0.10	-0.10	-0.02	-0.08
1.67	1.00	+0.02	-0.12	-0.22	+0.10	-0.14
	1.33	-0.14	+0.24	+0.30	-0.10	-0.20
	2.00	-0.14	-0.10	-0.38	+0.20	+0.26
	2.33	-0.14	-0.20	-0.14	-0.28	+0.14
2.00	1.00	+0.10	+0.08	+0.34	-0.16	-0.34
	1.33	+0.02	-0.06	-0.26	-0.14	+0.14
	1.67	+0.14	+0.10	+0.38	-0.20	-0.26
	2.33	-0.20	-0.04	-0.18	+0.18	-0.30
2.33	1.00	-0.02	-0.14	+0.28	-0.24	+0.04
	1.33	+0.24	+0.10	+0.10	+0.02	+0.08
	1.67	+0.14	+0.20	+0.14	+0.28	-0.14
	2.00	+0.20	+0.04	+0.18	-0.18	+0.30

The scores have a possible range from -1 to +1

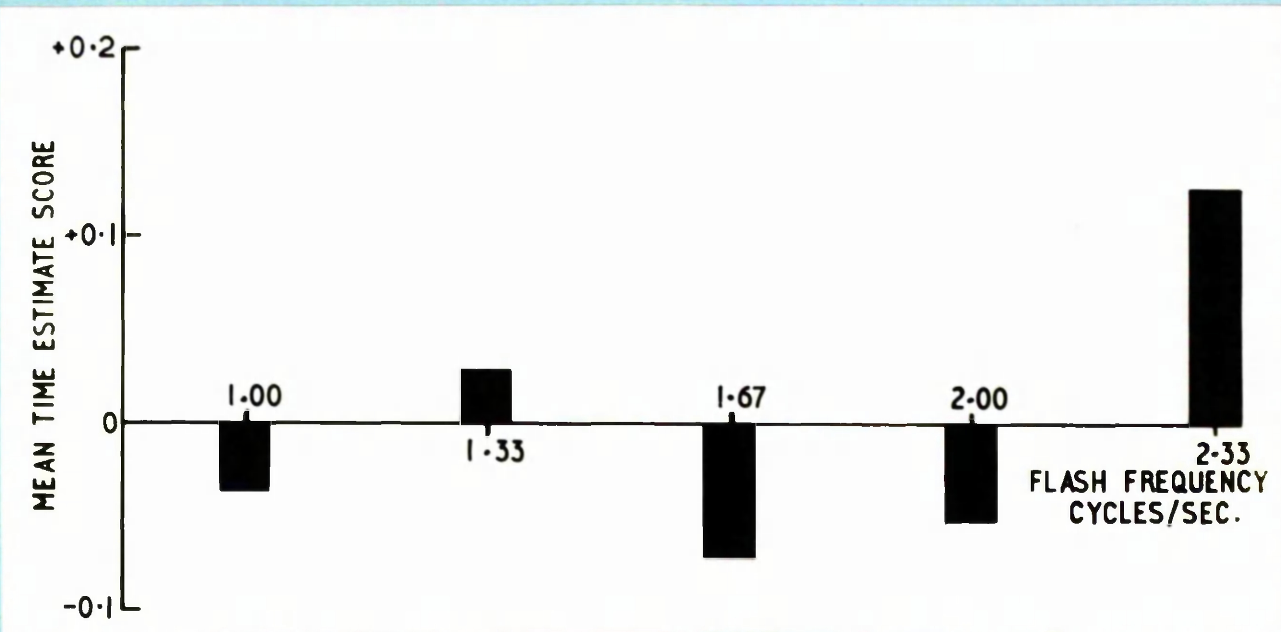

Fig. 15 Relative duration and flash frequency.

Each block represents the mean relative duration score for each flash frequency.

Table XXVII

Changes in skin conductance

Frequency c/s	Comparison frequency	Subjects				
		1	2	3	4	5
1.00	1.33	+0.0035	-0.0116	-0.0119	+0.0042	-0.0119
	1.67	+0.0006	-0.0045	-0.0089	-0.0086	-0.0071
	2.00	-0.0091	-0.0128	-0.0076	+0.0036	0
	2.33	+0.0028	-0.0060	-0.0075	-0.0086	-0.0212
1.33	1.00	+0.0072	-0.0105	-0.0095	+0.0018	-0.0283
	1.67	+0.0026	-0.0136	-0.0208	+0.0100	-0.0044
	2.00	-0.0107	-0.0053	-0.0208	+0.0059	+0.0078
	2.33	+0.0100	-0.0109	-0.0119	-0.0140	-0.0237
1.67	1.00	-0.0082	+0.0034	-0.0086	-0.0077	-0.0087
	1.33	-0.0021	-0.0099	-0.0126	+0.0127	+0.0042
	2.00	+0.0036	-0.0009	-0.0282	-0.0087	+0.0092
	2.33	-0.0020	-0.0009	-0.0138	-0.0018	-0.0160
2.00	1.00	-0.0168	-0.0061	-0.0059	-0.0025	+0.0069
	1.33	-0.0086	-0.0045	-0.0169	+0.0033	+0.0047
	1.67	+0.0114	-0.0097	-0.0182	-0.0107	-0.0199
	2.33	-0.0065	-0.0143	-0.0130	-0.0060	+0.0160
2.33	1.00	+0.0083	+0.0087	-0.0112	-0.0086	-0.0116
	1.33	-0.0030	-0.0064	-0.0145	-0.0045	+0.0152
	1.67	-0.0005	-0.0027	-0.0132	+0.0017	+0.0128
	2.00	-0.0088	-0.0096	-0.0093	-0.0036	+0.0227

The values are changes in log micromhos and are expressed in a dimensionless unit

Table XXVII (continued)

Changes in skin conductance

Frequency c/s	Comparison frequency	Subjects				
		6	7	8	9	10
1.00	1.33	-0.0176	-0.0191	-0.0036	-0.0152	0
	1.67	-0.0433	-0.0120	-0.0115	-0.0212	-0.0007
	2.00	-0.0321	-0.0022	-0.0115	-0.0223	-0.0030
	2.33	-0.0170	-0.0085	-0.0084	-0.0270	-0.0104
1.33	1.00	-0.0433	-0.0181	-0.0046	-0.0112	+0.0114
	1.67	-0.0170	-0.0180	-0.0063	-0.0144	+0.0085
	2.00	-0.0299	-0.0292	-0.0025	-0.0106	+0.0123
	2.33	-0.0270	-0.0023	-0.0146	-0.0077	0
1.67	1.00	-0.0061	-0.0128	+0.0087	-0.0162	-0.0065
	1.33	-0.0424	-0.0198	+0.0073	-0.0261	+0.0027
	2.00	-0.0196	-0.0144	+0.0082	-0.0291	-0.0067
	2.33	-0.0091	-0.0153	+0.0063	-0.0178	0
2.00	1.00	-0.0351	+0.0040	-0.0030	-0.0280	+0.0045
	1.33	-0.0161	-0.0170	-0.0062	-0.0092	-0.0031
	1.67	-0.0323	-0.0262	-0.0193	-0.0136	+0.0033
	2.33	-0.0170	-0.0077	+0.0103	+0.0012	+0.0190
2.33	1.00	-0.0360	+0.0040	+0.0128	-0.0203	+0.0023
	1.33	-0.0191	+0.0018	0	-0.0161	-0.0034
	1.67	+0.0114	-0.0353	0	-0.0110	-0.0015
	2.00	-0.0142	-0.0095	-0.0299	-0.0122	-0.0090

The values are changes in log micrmhos and are expressed in a dimensionless unit

A special analysis of variance was completed similarly on the differences in changes in conductance values for each pair of presented frequencies (Appendix E.14).

The effect of order was significant ($P = 0.05$). Evaluation of the data showed that the mean rate of fall in log. conductance was 0.0059 in each minute of flashing light presentation in the first half of the experiment and 0.0104 in the second. In view of the results obtained in Experiment A, this can be interpreted to indicate that the exposure to the flashing light delayed the onset of decay in conductance level; or conversely, as the novelty of the experimental procedure lessened, so the level of alertness appropriate would be reduced and the conductance change habituated.

The analysis also revealed significant differences associated with the different frequencies; a difference between the mean values at each frequency greater than 0.0018 was significant at the 5 per cent. level and 0.0024 at the 1 per cent. level. The mean values for each frequency are plotted in Fig. 16; it can be seen that the greater decreases occurred at the lower frequencies. There is a positive linear relationship between frequency and mean conductance change and the calculated regression is drawn.

Relationships The relationships between frequency of flashing light and the different measurements have been discussed. Examination of the possible relationships between these measurements is, however, of interest.

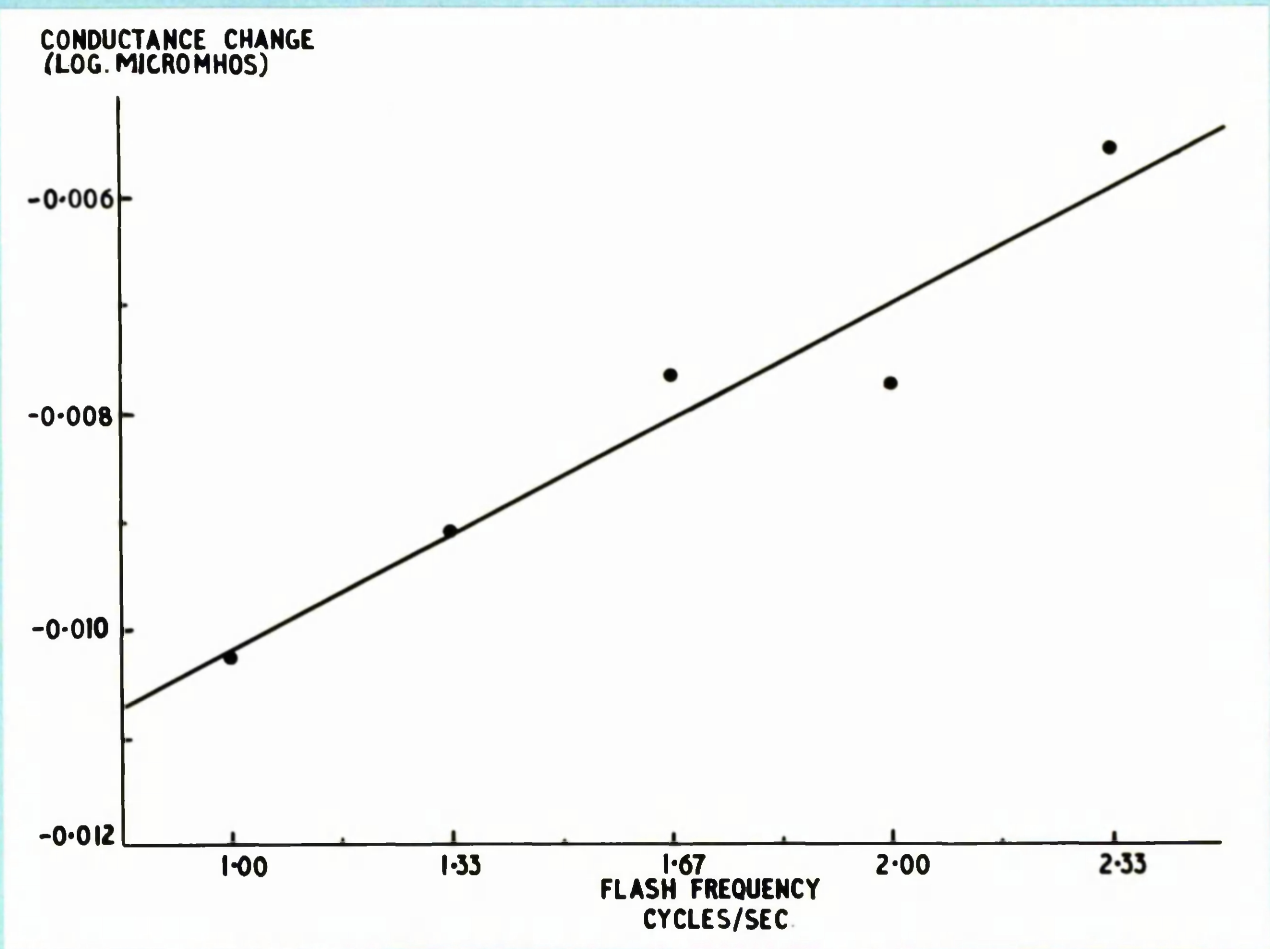

Fig. 16 The relationship between flash frequency (x) and the mean change in skin conductance (y).

The calculated regression equation which is shown plotted is :

$y = 0.0032x - 0.0134$ ($P = 0.01$) (Appendix E.16).

Skin conductance and preference score

The greater decreases in conductance occurred at the lower frequencies, as did the greater preference scores. Fig. 17 shows the points plotted to demonstrate the relationship between the mean conductance change and the mean preference score at each flash frequency.

There is a significant negative linear relationship between mean conductance change and mean preference score. This complementary finding, certainly for these falling conductance levels, is in agreement with commonsense interpretation that the less a simple noxious stimulus is preferred the more arousing it is likely to be.

Relative duration and preference score

Inspection of Figs. 14 and 15 showed that the shortest relative duration score occurred with the lowest modulus preference score, and the longest relative duration score with the greatest modulus preference score. Thus the relationship between mean relative duration score and mean preference score at each flash frequency was plotted, and is shown in Fig. 18. Inspection of this suggests that a parabolic relationship is indeed present.

It is difficult to test the statistical significance of this observation. In an attempt, Fig. 19 shows the points plotted to demonstrate the relationship between the mean relative duration score (y) and the square of the mean preference score (x); a significant positive linear relationship is present ($Y = 1.696(x^2) - 0.069$). Indeed the

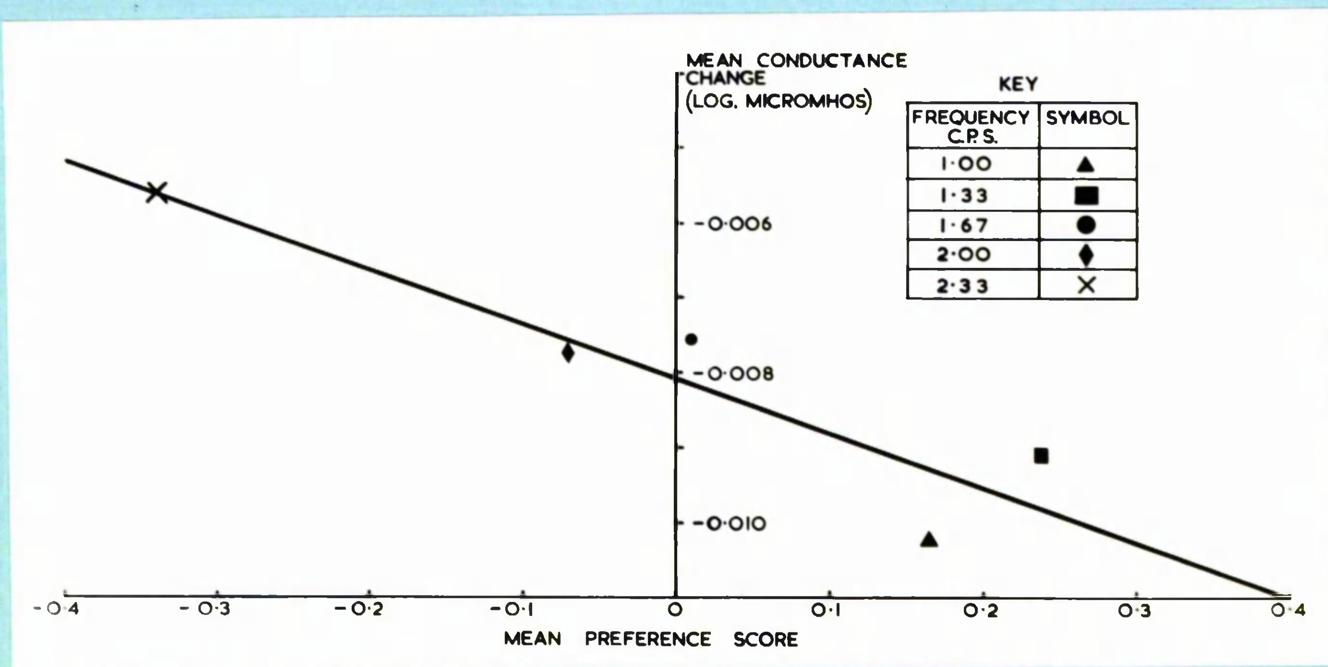

Fig. 17 **The relationship between the mean preference score (x) and the mean change in skin conductance (y).**

The calculated regression equation which is shown plotted is :

$y = -0.0072x - 0.0081$ ($P = 0.05$) (Appendix E. 17).

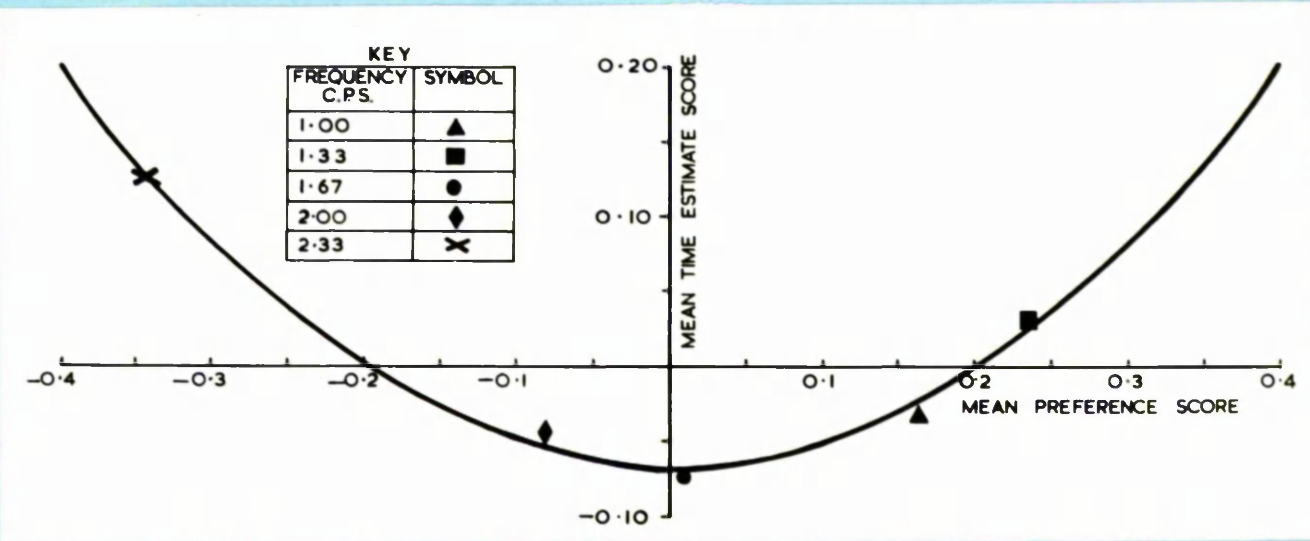

Fig. 18 The relationship between the mean preference score (x) and the mean relative duration score (y).

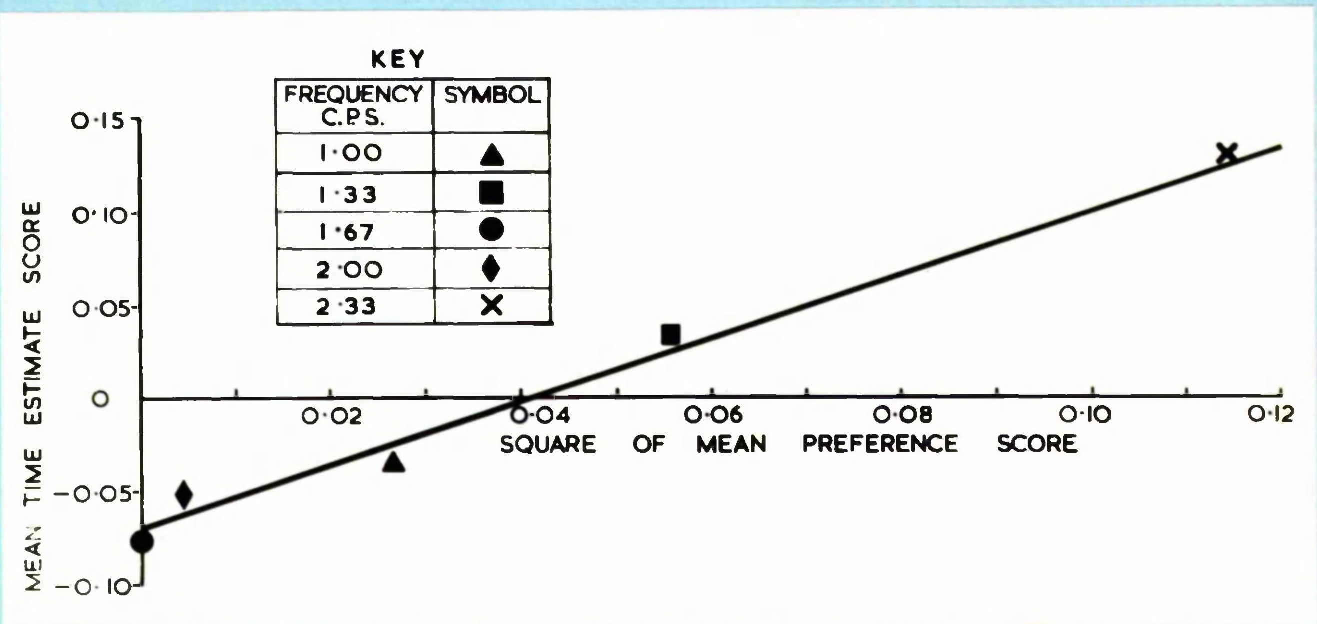

Fig. 19 **The relationship between the square of the mean preference score (x) and the mean relative duration score (y).**

The calculated regression equation which is shown plotted is :

$y = 1.696(x^2) - 0.069$ (P = 0.001) (Appendix E. 18).

parabola plotted in Fig. 18 is the equation $Y = 1.696\ x^2 - 0.069$, and it can be seen how well this fits the observed mean scores.

There is doubt about the validity of this statistical procedure in view of the fact that no significant difference with flash frequency was obtained on the relative duration scores. Thus no further definite conclusion can be drawn beyond the observation that the shortest duration score occurred with the lowest modulus preference score, and the longest duration score with the greatest modulus preference score.

Comment This experiment was undertaken primarily to answer a practical problem - to choose the frequency of flashing light that will be least distracting to aircrew flying at night. The choice seems to lie within the range 1.00 to 1.67 c/s, as within this the greatest preference was expressed and the skin conductance fell the most; the latter suggests that this stimulation had the least alerting influence. This frequency waveband also satisfies the requirement for conspicuity; Gerathewohl (1954) demonstrated that at low contrast (below 1.00) the response times to detect a series of light flashes were shorter at 1 c/s. than at 2 or 4 c/s.

These findings raise the question of the most agreeable frequency for intermittent stimulation in any modality. James (1890) remarked in his discussion of the problem: "There is a certain emotional feeling accompanying the intervals of time, as is well known in music. The sense of haste goes with one measure of rapidity, that of delay with another; and these two feelings harmonize with different mental moods." This suggests that for any mood it should be possible to discover an agreeable rate of stimulation. In an experiment with auditory stimulation in which he listened to metronome strokes at different rates and judged them on a seven-point aesthetic scale, Vierordt (1868) found a frequency providing an interval of 0.62 seconds to be neutral, suggesting the most agreeable frequency to listen to a metronome to be 1.61 c/s. It is of interest that in this experiment at about this frequency, subjects expressed their most indifferent attitude to the flashing light and considered its duration of presentation to be least. Allowing for differences in technique, these results would appear to be sufficiently in agreement to suggest that the most preferred rate of stimulation for any situation may be independent of modality.

Other physiological processes that take place within the frequency waveband 1.00 to 1.67 c/s. are also of interest. Campbell and Whiteside (1950) showed that the mean frequency of induced pupillary oscillations by a slit-lamp is 1.2 c/s. Stark (1959) confirmed that there is an alteration in the servomechanism of the pupil at about 1.5 c/s; the amplitude of the frequency response decreases and a low phase shift alters to a large phase shift above this frequency. The mean heart rate in the resting subject is 1.2 c/s.

Hirsh, Bilger and Deatherage (1956) recorded the observation that patients who become deaf in adulthood complain that time seems to standstill; this provides evidence to suggest that the auditory perception of events is of more relevance in the appreciation of duration than visual awareness. No evidence of this comparison is presented here, but both auditory and visual modalities appear to be relevant.

This more detailed examination has shown that time perception is not purely related to the frequency of stimulation as dictated by the number of events in a given interval. Another factor must be implicated, and this once again may well be the attitude of the individual towards the situation. The relationship between preference and relative duration is tentative evidence to postulate that the stronger the views that are expressed concerning the content of an interval, be they preference in its favour or aversion against it, the longer the apparent duration of that interval. This proposal - and it can only be a hypothesis, because it has not yet been proved - carries with it the assumption that time will appear to pass fastest during an interval in which the individual is indifferent to its content and is consistent with that discovered by Gedye in Experiment A (Aitken and Gedye, 1963).

SECTION V

DISCUSSION

Concept of Arousal The word arousal is derived from the verb 'rouse' which was in use in the 15th century as a technical term in falconry; by the 19th century, the noun 'arousal' referred to the action of stirring or rising up from sleep or inactivity (Murray, 1888 and 1910). Hence, if the word is used in its original meaning, the extent to which someone is aroused can be judged by himself by how alert he feels, and by others by how alert he appears.

Thus measurement of arousal level, or degree of wakefulness, can be obtained by devising a method to quantify semantic phrases used to communicate personal assessment of alertness on the one hand, or objective appearance on the other. Hence the alertness score used in Experiment A is, by definition, a measurement of arousal level, as it was obtained by using a special language in order to quantify accepted semantic terms.

In 1932 a, Duffy introduced into psychophysiology the word 'arousal' as a conceptual term to discuss a similar alteration in generalised muscular activity in two dissimilar situations. More recently, following the discovery that the reticular formation in the brain stem is responsible for alterations in the state of wakefulness (Moruzzi and Magoun, 1949), it has become customary to use the word 'arousal' to refer to the reaction as a result of activity in these structures. In other words, neurophysiologists have applied the term to the level of activation of the arousal mechanism, the cortical electrical activity being desynchronised by upward discharge from lower centres. It should be noted that their term includes the level of sleep as well as wakefulness.

Widespread connections with the reticular formation have now been demonstrated in animals. As well as to the cerebral cortex, there are diffuse projections to mid-brain structures (Starzl, Taylor and Magoun, 1951) and pathways from the cerebral cortex to the brain-stem (Jasper, Ajmone-Marsan and Stoll, 1952). Magoun in 1952 drew attention to the observation that the reticular activating system exerts pronounced facilitatory influence upon lower motor neurone outflows; it thus "subserves behavioural facility and central alertness that characterise the waking state".

Hebb in 1955 formulated the psychological implications of the previous work when he described arousal as a term synonymous with the general drive state; he related this to the earlier concept of motivation, or the energising of behaviour. He emphasised the immediate drive value of cognitive processes, relating this to the neurophysiological evidence of corticofugal projections to the reticular formation, and this has been emphasised by others (Linn, 1953; Benson and Gedye, 1962). This has been demonstrated in Experiment A by the arousing effect of the presence of the task.

It is of interest that the aircrew participating in Experiment A were aware of a differentiation within the term 'arousal', as they were familiar with it in dialect. Some understood it to mean a continuum from sleep to a frantic state - a scale of alertness, while others understood it as an affective term indicating the degree of anxiety between extreme relaxation and panic. This conceptual confusion has been previously acknowledged (Duffy, 1941 and 1951), but Malmo (1957) has emphasised Duffy's plea that no distinction between motivation and emotion is necessarily required in discussing energy mobilisation.

In 1959 Malmo preferred the term 'activation' to refer to the psychological concept, thus leaving the term 'arousal' to the neurophysiologist. In 'activation' he included emotion as well as motivation, and the term was thus associated with other mechanisms as well as the reticular activating system. Lindsley (1958) did not agree with this terminology. In an authoritative and logical review he exhorted that the general term 'arousal' should be used primarily in a behavioural sense, leaving the term 'activation', which he had proposed in 1951, to refer to the neurophysiological mechanism.

Cannon in 1929 drew attention to the relevance of adrenal secretion in the preparation of the body for 'fight or flight' and Selye (1950) was much concerned with the endocrine system when he formulated his theory of stress and the 'general adaption syndrome'. James (1890) considered that change in the environment induced instinctive behaviour patterns with concomitant physiological responses; he attributed the conscious experience of emotion to the sensation of the peripheral responses, though Cannon (1929) attributed it to the cortical discharges from subcortical centres. MacLean (1955) has deduced from his neurophysiological studies that the neuroanatomical limbic system is the common pathway in a variety of viscerosomatic reactions; he presents evidence to conclude that it is intimately concerned with the experience and elaboration of emotion, as suggested by Papez (1937).

In considering the concept of arousal it is implicit to consider the degree of readiness to respond to change in the environment or conscious thought - the level of vigilance. "When vigilance is high, the body is more prepared to respond to an effective stimulus with a more or less appropriate action" (Head, 1923). Vigilance thus involves the ability to perform an adaptive response, and the term is not synonymous with behavioural arousal, neurophysiological activation, subjective alertness or emotional attitude.

Arousal is closely related to emotional attitude and the appropriate level of vigilance, and is experienced as degree of alertness or anxiety. As affect did not really apply in Experiment A, it is worth reflecting on the effect of alteration in arousal on the level of vigilance. Unfortunately, however, no difference, subjectively or objectively, could be demonstrated between the accuracy of task performance in the presence and absence of distraction, when the arousal level was shown to differ.

Stenett (1957 b) has related previously ability at a task (auditory tracking) to the level of arousal as determined by measurement of skin conductance and integrated electromyography. He showed that the level of performance was less efficient at high and low arousal and best at an intermediate level. Similarly Freeman (1940) demonstrated that reaction times were lowest at higher than minimal conductance levels, but that if arousal were higher the reaction times were slower; he suggested that the change in conductance was more determined by the subjective effort required to produce maximum performance than by the level achieved. Duffy, the first to relate muscle tension to behaviour excitability (1930), showed that children who are tense and excitable, made more errors at higher tension at a discriminative task (1932b). Hebb (1955) generalised from data such as these to consider that there is an optimal level of arousal for a task at which the level of cue function will be highest.

Estimation of duration is a task in itself and similarly optimal performance may be associated with a specific arousal level. This is more likely to be important for short intervals, such as ten seconds rather than ten minutes where the necessities of the decision are not really ever present - indeed the objective may be forgotten until the answer is requested.

The lack of alteration in task performance with arousal in Experiment A is no doubt because either the measurement was relatively insensitive or the task demanded insufficient attention, and could be performed adequately at less than optimal vigilance. This inability to detect alteration in error in circumstances where it might be expected is a difficulty often present in the selection of appropriate equipment for control-system operators. It could well be that an assessment of the required arousal level for adequate performance might provide information on which the selection could be made more effectively.

In secondary systems requiring control in flying (e.g. altitude by altimeter reading) while a prime attention-demanding task is being undertaken (e.g. constant rate turn), ease of performance is essential. The best display of this information could perhaps be ascertained by observing the arousal level necessary for recording the information adequately from the alternative systems (e.g. different types of altimeter display). Assuming there is no difference in performance, the system in which the arousal level is least would presumably be the most appropriate.

As arousal is in close association with emotional attitude, it is likely that the activity in the limbic and endocrine systems as well as the reticular formation is involved. The levels of activity in neural and other structures which are believed to subserve this state are regarded as indicants of the individual's level of arousal in so far as they can be shown to be capable of providing a reliable basis for predicting the level of arousal. In the present context this means, by definition,that the skin conductance measure used in Experiment A is an indicant of arousal, because it could be predicted from the alertness score.

As in Duffy's original use of the term 'arousal' in psychophysiology (1932 a), the similarity between the assessments in the two situations in Experiment A (presence of task or distraction) is noticeable. It can be deduced that the activity in the neural and other structures subserving this state was similar, despite the widely differing nature of the environmental changes and the conscious processes involved in performing the task.

In similar context in Experiment C, the relationship between attitude and frequency of visual stimulation with arousal, as assessed by skin conductance change is of interest. Which the conductance change reflected cannot be ascertained, but it is likely that both were responsible in some degree for the resultant level. However, the evidence is not inconsistent, taken in association with the findings quoted in the Comment on other temporal and visual phenomena, that the conductance changes could have resulted predominantly from the perception of the environmental change, through extra-lemniscal pathways. The preference score, and hence the appreciation of duration, could have been a reflection of the level of activity in structures influencing the arousal level.

Skin Resistance

Pavlov (1928) systematically studied physiological responses to changes in the environment and the 'orienting reflex' has been extensively investigated recently especially in the Soviet Union (Razran, 1961). Many of these physiological responses are in common use as indicants to reflect the level of arousal - voluntary and involuntary muscle activity, exocrine and endocrine secretory activity and frequency analysis of the electroencephalogram.

The choice of which to use for a particular purpose is often difficult. The decision can lead to controversial interpretation of results due to the complexity of response between and within individuals. Ax (1953) believes that there is evidence to support the view that there is marked uniqueness within individuals in the physiological expression of different emotions. In contrast Lacey (1956) considers that an individual responds with the same hierarchy of autonomic activity, whatever the emotion or stress. Despite this each indicant has its own advantage for a particular purpose and one of the most convenient and sensitive is the skin resistance (Lindsley, 1951).

Much of the past research on this measurement has been concerned with rapid alterations since Féré reported in 1888 that an emotional reaction is accompanied by a change in skin resistance - a finding corroborated by Veraguth (1906), when he named this the psychogalvanic reflex (P.G.R). Féré attributed these alterations to change in the tone of the skin blood vessels. Earlier Vigoroux (1879) had reported that different areas of skin are at different potential and Tarchanoff (1890) demonstrated that natural alterations occur with different kinds of nervous activity; it is of interest that even then he attributed, what is now accepted as correct, that the physiological mechanism is through the secretory activity of the sweat glands.

The interdependence of the skin potential and resistance has been emphasised by many writers (e.g. Landis and De Wick, 1929; Davis, 1930) and much work has been done on the nature of the measurements and the P.G.R. phenomenon (e.g. Montagu, 1958; Maulsby and Edelberg, 1960; Edelberg, 1961). Lader and Montagu (1962) have demonstrated conclusively that rapid alterations are solely dependent on cholinergic mechanisms; their results confirm the theory that the P.G.R. is the result of pre-secretory activity in sweat glands, repeating the observation of Carmichael, Honeyman, Kolb and Stewart (1941) that the P.G.R. is indication of activity in the sympathetic nervous system.

White (1930) observed that the skin resistance is higher in states of relaxation compared with induced localised or generalised muscular tenseness and this has been confirmed by others (Wenger and Irwin, 1936; Freeman and Simpson, 1938).

Davis (1934) demonstrated that the resistance fall during a mental task (arithmetic) was greater as its complexity increased. In 1957 a, Stennett showed that the amount of alpha component in the electroencephalogram is less at high and low skin resistance levels and maximal between the extremes; the level has thus been related to another criterion of the degree of wakefulness.

In Experiment A skin resistance was related accurately to the subjective appreciation of alertness - a relationship expected in theory by Golla (1921). In Experiment C, it was related clearly to the frequency of a flashing light - the slower the frequency (and consequently the less the environmental change) the greater the fall in conductance; the greater the preference, the greater the fall. The measurement of skin resistance clearly provided rational information capable of logical interpretation.

The problem of choosing an appropriate measure for the quantitative analysis of skin resistance has recently been discussed fluently and logically by Lader (1963), who argues that such a measure must be based on an understanding of the physiological mechanism responsible for the resistance and its fluctuations. It has been demonstrated that the amount of palmar sweat produced (Darrow, 1934 a and 1934 b) and more recently the number of sweat glands in a unit area (Thomas and Korr, 1957) have a rectilinear relationship to the reciprocal of resistance, conductance. All the available evidence points to the resistance being dependent on the number of active sweat glands; as the resistance of each of these must be in parallel, the only valid measure is conductance, since parallel conductances are additive (Freeman and Katzoff, 1942).

The literature on skin resistance reveals that a multiplicity of mathematical transforms have been used in the assessment of this variable. Most of these units were obtained so that data became suitable for certain statistical procedures with little thought applied to the fundamental mechanism behind the measurements. It is of interest that Haggard (1949) drew attention to the fact that the conclusions that could be made from one set of experimental data could be altered by the use of different transforms prior to statistical analysis.

In psychophysiology it is usual to measure the skin resistance as a meter for such a purpose is easier to construct than one registering conductance directly. For reasons given above, it is essential to transform the resistance readings often measured in megohms to their reciprocal, conductance in micromhos, as in Experiments A and C. This transformation gives a measure which reflects the number of sweat glands tonically active at any given moment, and any increase will be related to the proportion of sweat glands activated by the inducing stimulus. As it is usually this alteration that is under study, such as in Experiments A and C, a better appreciation of the data was obtained by examining the change in terms of the original level by using further logarithmic transforms. Indeed Gaddum (1945) pointed out that the scope and accuracy of the conclusions drawn from biological observations are usually increased when the logarithmic transforms are analysed. This procedure reduces wide variability in level between different subjects.

Thus change in log conductance in unit time is logically the most appropriate method for assessment of the skin resistance. The prime transformation to conductance is for fundamental reasons but any modification thereafter is only to obtain the most suitable unit for statistical analysis and interpretation. Much of this argument was elicited by Lader (1963) but it is salutary to reflect that it is not novel. Over 30 years ago, Darrow (1934 a and 1934 b) presented firm evidence to suggest that conductance and change in conductance were the most meaningful units. Later he (1937) and Haggard (1945) advocated change in log conductance as the most appropriate measure from results obtained by measurement of the P.G.R.

It is worth drawing attention, as did Lader (1963), to a small problem in terminology of units. It will be clear that the reciprocal of resistance measured in megohms is known as conductance in micromhos; clearly a logarithmic transform of conductance is known in log micromhos. A change in conductance can be ascribed also the unit micromho. However, as the difference in the logarithms of two values is the logarithm of a ratio, it is clear that change in log conductance is in a dimensionless unit. However, this point need not be laboured as, for ease of discussion, change in log conductance is often, though not correctly, referred to in log micromhos.

It is hoped that the above discussion has presented a rational approach to the use of skin resistance as a measurement in psychophysiological studies. From the present experimental evidence and its widespread successful use, it is clear that it is a measurement of great sensitivity - indeed this is its main drawback, which precludes its use in less controlled circumstances. It is essential to ensure that fluctuation occurs either by design or at random. For this reason, latin-square designs were used in the experiments as serial order was not under direct investigation; the effects, for example, of P.G.R. habituation and electrode polarisation were thus eliminated from biasing the results. All irrelevant sensory stimuli, such as noise and light, were excluded except as the factor under investigation. The experiments were also carried out at the same time each day to avoid diurnal variation (Waller, 1919).

With these controls, skin resistance provided an objective measure on which the other criteria, apparent duration, alertness and attitude could be assessed. It has the advantage over the measurement of muscle activity, for example, that it is uninfluenced by voluntary control and in its evaluation imposes no discomfort on the subject. Without hesitation, it is recommended for use as an ideal indicant of the level of arousal in situations where careful environmental control and experimental design are readily available.

Temporal discriminative process

In clock systems, the principle on which the measurement of the duration of an elapsed interval is based is the production, detection, counting and display of repetitive events. Clearly for any form of biological temporal discrimination or rhythm, there must be the production of psychophysiological events, which can be detected, counted and stored; the accumulated total since some reference moment may then be recalled on request or used to initiate further biological activity. Though there is no experimental evidence available at the present time on the origin of the psychophysiological events, examination of the fundamental parts of the temporal discriminative process permits discussion on where distortion of apparent duration might be induced.

The rate of production of events from a hypothetical source will influence the size of the accumulated total in a given interval. In 1889, Munsterberg suggested that awareness of psychophysiological processes, such as the amount of peripheral or respiratory muscular activity, could be the basis of the ability to assess the duration of an elapsed interval with some degree of accuracy. The source of psychophysiological events need not be unique between individuals (as stated in Experiment A by the subjects in Group A) or indeed in the same individual when different types and durations of interval are to be estimated. Whatever it is, be it consciously perceived as by some subjects in Group A in Experiment A, or unconsciously by subjects in Group B, one would expect a faster rate of production in the intervals in which subjects were more aroused, and in the more aroused individuals. There was some evidence in Experiment A to favour this, but no statistical significance to support it conclusively.

A second part of the temporal discriminative process where distortion could be induced is the threshold of detection of events emanating from the hypothetical source. From the previous discussion of the concept of optimal cue utilisation at a specific arousal level, it can be appreciated how this might apply similarly to the detection of events for assessment of duration. Increased arousal may not only lead to faster production of events from the hypothetical source, but may also either increase or decrease the threshold of ability to detect them, depending on the relative position of the optimal level of arousal. This impaired ability to detect events may be the explanation of the relevance of degree of concentration of attention to extraneous events as suggested in Experiment A, as one must attend less to an appropriate source in the presence of competing interests. Indeed people often say that if their mind wanders, when it returns they have no idea how long has elapsed since they lost the track of environmental events.

Though an indicant of arousal was not measured in Experiment B, it is highly probable that during the presence of noise the subjects were more aroused; and that the differences in respiratory resistance were unlikely to have produced markedly contrasting levels. The arousal levels of the subjects, and their degrees of concentration of attention, in the judgment intervals (where they had to make an ultimate decision and were thus required to participate actively) may have been higher than that in the standard intervals (when they were in a passive role). This complexity excludes rational understanding of the role of arousal on the assessment of duration in this experiment, even if it had been measured.

Thirdly, distortion will be induced by inaccurate memory of the intervals under review. Awareness of repetitive events, be their source exogenous or endogenous, can be appreciated by Man in clock-time units only by comparison with previous temporal experience. James (1890) wrote: "Internal perception is the perception of time, and of events as occupying a date therein, especially when the date is a past one, in which case the perception in question goes by the name of memory." This observation draws attention to the integrity between the awareness of time and memory, and James continued: "In general, a time filled with varied and interesting experiences seems short in passing, but long as we look back. On the other hand a tract of time empty of experiences seems long in passing, but in retrospect short."

This apparent contradiction of experience, alluded to in Field Study A, emphasises the need for care and the difficulty in interpretation of observations. The comparison between the results obtained in the Field Studies and the Laboratory Experiments must take into account the influence of long-term memory on the distortions reported. In the interviews and the questionnaire it was reported that time seems to drag with boredom, and yet in Experiment A there was a suggestion that apparent duration was longer when individuals were more alert - this being a dissimilar experience to that quoted from James above.

Intact memory processes are clearly required for adequate orientation in time and ability to discriminate accurately between durations of intervals. In the neurological amnesic syndrome, Korsakow (1890) in his original description emphasised the disorder in time perception; he attributed this to the severe defect of retention without deterioration in intellect or conscious level.

The necessity of intact thought processes for correct temporal orientation has already been commented upon.

The observations of James (1890) are salutary; he drew attention to the analogy between visual after-images and the variable decay of memory stores as a basis of distortion in time perception: "The phenomenon of 'summation of stimuli' in the nervous system proves that each stimulus leaves some latent activity behind it which only gradually passes away"; and later: "There is at every moment a cumulation of brain processes overlapping each other, of which the fainter ones are the dying phases of processes which but shortly previous were active in a maximal degree. The amount of the overlapping determines the feeling of the duration occupied. What events shall appear to occupy the duration depend on just what processes the overlapping processes are."

The effect of attitude towards the content of an interval has been known to be relevant to time perception for many years (Woodrow, 1930), though the irrelevancy of the <u>direction</u> of attitude (preference or aversion) postulated by the results in Experiments A and C is novel. Attitude is determined by complex mental processes, involving heredity, maturity of personality, motivation and previous experience. It can be appreciated how these might influence the detection and recall of the accumulated total of events emanating at a variable rate from the hypothetical psychophysiological source. Though little evidence from these experiments is presented on the individual aspects of attitude, their specific contribution must not be overlooked if examination of differences between individuals is required.

Woodrow (1951) drew attention to the great variation between individuals, and indeed within individuals on different occasions in the perception of time. The degree of inaccuracy is often striking. One need look no further for examples than the results of the memories of ten-minute intervals while flying as determined in Field Study A: the overall mean was 12.5 minutes - an error of 25 per cent, or indeed also the results in Experiment A, where the overall mean was 11.3 minutes - an error of 13 per cent. This, of course, accounts why Man must rely on chronometers, by which to judge and correct the accuracy of his frequent assessments for everyday fellowship and punctuality.

In contrast, the temporal rhythms of many biological systems are highly efficient (Richter, 1960); circadian cycles of such a variable as temperature, or a monthly one, menstrual, are two physiological examples of usual great regularity. Time may be very strictly adhered to by animals both in physiological and behavioural phenomena. For instance Cohen (1954) mentioned that bees can be conditioned to return to a fixed place for sugar every three to six hours with only a few minutes' error. The ability of an individual to be aware of clock-time while asleep has been studied (Brush, 1930); Omwake and Loranz (1933) reported that half of their subjects awoke within 30 minutes of an unfamiliar stated time on half the requested occasions, one subject indeed often awakening right at the requested time.

And yet laboratory experiments on time perception, such as the present ones, show wide differences between individuals. Though this subject variability is the principle behind the critical evaluation of the results, it does not provide a basis for conclusions about these differences between and within individuals; it does, however, draw attention to the uniqueness of a perceptual phenomenon.

The establishment by laboratory experiments of possible relationships, albeit not the only ones, between apparent duration, and arousal and attitude, taken in conjunction with results obtained with psychiatric patients by Orme (1962), permits emphasis on the role of personality traits in time perception; a further inditement of the association is the suggestion from the interview study that the more critical an individual the more liable he may be to experience distortion in apparent duration. These observations are encouragement for further experimental enquiry to explore some aspects of differences in personality, such as those reported in the Historical Review.

There is tentative evidence from the experiments here recorded that increase in the level of arousal, the degree of attention and the attitude of the individual toward the content of the interval (be it preference or aversion) all lead to increase in apparent duration. Alteration in which mechanism must remain entirely speculative, but this approach permits the following generalisations to be submitted, for which further elucidation is demanded in the future:

(i) A person will report an interval in which he is more aroused to appear longer than another of equal duration

(ii) A person will report an interval in which he detects more events to appear longer than another of equal duration

(iii) A person will report an interval in which his attention is more specifically directed and less diffusely organised to be shorter than another of equal duration

(iv) A person will report an interval in which he experiences a stronger attitude, be it preference or aversion, to be longer than another of equal duration

One of the values of this multifactorial hypothesis is that it provides a standpoint from which to integrate into a consistent picture many observations. It permits a valid explanation of apparently contradictory findings as the mechanisms may work in opposition; the direction of distortion of apparent duration must depend on the net degree each is implicated, and thus this explanation allows examination of previous inconsistencies and accommodates the diversity of opinions of previous workers.

It can be appreciated that the comprehension of the combination of each of these known distorting variables on the elucidation of time perception is complex. Full understanding of the mechanisms behind temporal discrimination is of necessity still speculative, but, for reasons discussed in regard to arousal, they may include function in the limbic, reticular activating and endocrine systems. James (1890) recorded: "This feature of the brain process, whatever it be, must be the cause of our perceiving the fact of time at all." It is clear that any future composite theory on the mechanisms behind assessment of duration must include an understanding of much of the cerebral functioning of Man.

Methodology in time perception experiments

As the evidence demands the conclusion that the cerebral processes underlying accurate assessment of duration are complex, it is essential to simplify techniques in experiments done to extend understanding of the phenomenon and the psychophysiological mechanisms underlying its accuracy. In Experiment B, it was shown that an environmental stimulus - noise - distorted apparent duration, but only in the judgment or production part of the reproduction of the intervals under consideration; evidence to help to understand the underlying mechanisms was thus difficult to appreciate as why the experimental factor should only be so acting could not be assessed fully. By similar reasoning to wish for simplicity, unfortunately only with hindsight, the method of <u>serial</u> reproduction fails to introduce any advantage. Amplification of distortion is not required, if the reference system used to assess the apparent duration has sufficient resolution.

These remarks apply to an experiment by Frankenhauser (1959). With the method of reproduction of ten-second intervals, she showed that the administration of the drug pentobarbitone increased the duration of the judgment interval, while metamphetamine decreased it. She suggested that this difference was due to alteration in alertness, but further explanation seems to be required. If the drugs had been acting uniformly in both the standard and judgment intervals, any distortion induced on time perception should have been undetectable due to the fundamental difference between the estimation and production parts of the method. Use of the method of reproduction, in any of its forms, prohibits detailed examination of the mechanisms behind induced distortion as drugs must act during both parts. Any distortion must be due to selective action and Frankenhauser's deduction must be incomplete. The same comment applies to an experiment by Costello (1961) who used the method of serial reproduction without success when trying to detect distortion in apparent duration by the drug meprobamate.

In a review, Wallace and Rabin (1960) report that previous studies suggest that verbal estimation is less accurate than other methods in assessing apparent duration. However, from the evidence of lack of differences between Groups A and B in Experiment A, and from examination of the literature, the author concludes that there is no convincing evidence that the avoidance of the language of clock-time achieves any advantage - as long as adequate precautions are taken in the collection of the information.

With the method of estimation, the selection of experimental design and programming of factors under consideration is simpler than with a method involving production; the duration of the interval under investigation is always under the control of the experimenter. It would, for example, have been impossible to produce the balanced, and yet unpredictable pattern of distraction in Experiment A if the methods of production or reproduction had been used.

In measurement in time perception, the visual analogue of space is hallowed by everyday usage, such as the 'length' of an interval. This spatial representation is probably the reflection of the nature of the display on most time-measuring devices - the position of the hands on a clock, the shadow on a sundial or indeed the position of heavenly bodies.

This equating of distance with time has been used successfully in a previous experimental study (Cohen, Hansel and Sylvester, 1953). The practical advantage of spatial estimation is that the tendency, inherent in verbal methods for estimates to end in the digits zero or five (Yerkes and Urban, 1906) is reduced. The information obtained in Field Study B, on the apparent duration of defined ten-minute intervals, as a result of a corollary of the method of verbal estimation provided 65 per cent. of the answers ending in these selected digits. This was reduced to 22 per cent. with the method used in Experiment A and in Experiment C there was no grouping around selective values.

Thus the methods of spatial estimation and quantitative comparison have an inherent appeal. However, a criticism of the latter method as used in Experiment C has become apparent. The statistical analysis required for the assessment of the significance of any observed differences is complex and not readily available. In the plan of the experiment, it had been hoped to assess the effect of arousal, as measured by skin conductance change, on distortion in apparent duration. An analysis of covariance to remove this effect, if any, might have revealed significant differences in apparent duration induced by the frequency of the flashing light, and a more conclusive relationship to attitude. Unfortunately this compilation was not statistically possible. This could have been avoided if subjects had indicated at the end of the experiment, with the method of spatial estimation, the duration of exposure to each of the ten pairs of frequencies which they had been told was always constant.

In conclusion of consideration of methodology in time perception studies, it is resolved that a method using spatial estimation is likely to be the most satisfactory for future experimental studies. Whether the best method for the collection of the information is a modification of quantitative comparison is still an open question.

In a treatise on the logic of symbolic language, Craik (1943) stated that the ultimate test of the usefulness of a procedure is the extent to which consistent and meaningful results emerge from its use. In the research constituting this thesis, spatial representation of opinions in terms of graphic rating has been used throughout. Consistent measurements have been obtained which have been suitable for valid and meaningful interpretation. The degree of success of this objective can only be judged after assessment of the results by the unbiased reader.

Practical implications This thesis is not concerned with the philosophy of time in relation to the other physical dimensions; it is the report of work done to answer essentially practical problems, and so achieve a better understanding of how Man relates with his environment. This discussion will now close with consideration of the implications of the conclusions from these experiments to operational situations.

In certain flying procedures, the pilot may ESTIMATE the duration of an interval that has elapsed since some reference event, though he is not necessarily required to do so. These could be intervals in which a pilot is waiting for instructions before proceeding to the next stage of a flight, for example, waiting at the runway for permission to take-off. The task load during these intervals may be relatively small, but the pilot may be exposed to environmental stresses, such as flashing lights or excessive heat. The net effect of the circumstances causing the delay may then be over-estimation of its duration, the degree of this being dependent on the attitude of the pilot towards the distracting features. In consequence there may be an alteration in concomitant affective behaviour, such as a feeling of boredom, frustration or anxiety; this may lead to a further tendency to over-estimate the duration of the delay. Due to this, the pilot may become more prone to mistakes during an important phase of the flight, jeopardising his safety and that of others.

Concentration of attention on an absorbing task during a delay, may also distort apparent duration. For example, compilation of a navigational flight plan may lead to under-estimation of the duration of the interval; in this false belief that more time is available, less of the task than required may be completed during the delay.

Certain other situations in flying require the PRODUCTION of the duration of a predetermined interval, with performance of some operation after it has elapsed. Usually a member of aircrew has a watch to assist him, but as this is often not displayed in a way that allows it to be easily inspected during the routine scanning of his instruments, it may only be looked at when he estimates that the time elapsed is approaching the time at which the operation is required. It may even be disbelieved, in view of the fact that nearly a third of the pilots in the questionnaire study stated that they had done so on at least one occasion.

Under-production of a given interval will result in the individual expecting the event before it is due. Gedye (1960) has recorded an example of this in a low level flight task when, at constant speed over a fixed route in excessive heat, a land mark was expected to appear at a certain time after leaving a previous land mark; when it did not appear, the navigator checked his watch and found that a shorter time had elapsed than he thought; this resulted in doubt about the accuracy of the watch, and created uncertainty in his mind about the reliability of his navigational computations. Errors such as this are most likely to be induced by environmental distraction, and thus modifying applicable features such as heat stress, flashing lights, resistance to breathing, excessive noise, and angular or linear accelerations are of importance.

Circumstances leading to over-production of a given interval are particularly important as once a mistake has been made it is too late for it to be rectified. Tasks which are absorbing and situations to which the individual feels little attitude are particularly likely to be prone to this irremediable error, such as during standard exciting sorties. For example, if a pilot believes himself to have been airborne for a shorter time than he in fact has, he may not notice a low fuel state because to him it is unlikely in view of the time he believes has elapsed. As the majority of pilots place most of their reliance on the fuel gauge to judge the appropriate duration of a sortie, and the gauge is notoriously inaccurate when there is little reserve, the disastrous mistakes recounted in the

Introduction might have been avoided if the crew had been aware of the possibility of this type of distortion.

Education of aircrew in the relevance of time perception may reduce the incidence of distortion in apparent duration. It is clear they must be advised to rely implicitly on a readily accessible display of time, especially for critical decisions of a production nature. It may well be thought prudent to provide some periodic reminder of the amount of time elapsed on a sortie, but the wisdom of this depends on the assimilation of all features contributing to the complexity of the flying task.

SECTION VI

CONCLUSIONS

1. Aircrew are aware of factors affecting the apparent duration of an elapsed interval. The most important of these seem to be :

   (i) the demand imposed on the individual by his assigned task

   (ii) the amount of irrelevant physical stimulation to which he is exposed by virtue of undertaking the task

2. There is tentative evidence from an interview study of 20 pilots to suggest that the more critical the pilot was of features related to flying, the more liable he was to experience episodes of distortion in apparent duration.

3. Most pilots could remember having made mistakes in the assessment of the duration of an interval. Twenty-nine per cent. of 90 pilots reported that at some time while flying they had disbelieved their watches, though on subsequent verification found them to be correct.

4. To assess the appropriate duration of a sortie, aircrew rely more on the information obtained from the fuel contents gauge than on the duration of an elapsed interval obtained from observation of clock-time.

5. Pilots' memories of the assessment of apparent duration of ten-minute intervals in flight were dependent upon the type

of sortie flown - the more exciting, the less the apparent duration. The average maximum distortion is about twice the minimum; the average maximum distortion is more and the minimum less from the requested interval by a factor of two, suggesting that the relationship between subjective and objective time may be logarithmic.

6. The effects of two relevant factors on distortion of apparent duration were investigated in the laboratory on eight subjects. It was found that the time estimates of a presented ten-minute interval were increased by the presence of irrelevant physical distraction and decreased by the performance of a tracking task.

7. During the ten-minute intervals fall in skin conductance was reduced and the quantitative subjective assessment of alertness was increased by the presence of the two factors under investigation. For this group of subjects in this experiment it was possible to predict an alertness score from measurement of the rate of change of skin conductance. The measurements indicated that the arousal level of the subjects was mainly below moderate wakefulness during the ten-minute intervals.

8. The presence of irrelevant physical distraction did not alter significantly the performance at a tracking task. Change in performance was predicted by the subjects sufficiently accurately to be significant.

9. A 1 kc/s. tone increased the mean apparent duration of a ten-second interval as determined by eight subjects with the method of serial reproduction, but only when it was present during the judgment interval. No consistent distortion was obtained when the resistance to respiration was increased.

10. The subjective assessment of the resistance to respiration is related to the logarithm of the pressure-drop interposed in the breathing system, thus obeying the Fechner law. There is tentative evidence to suggest that the threshold to detect resistance to respiration may be dependent on a comparison resistance available during the assessment.

11. Within the range 1.00 to 2.33 c/s. there is a relationship between the on : off frequencies and the attitude of ten subjects towards them - the lower the frequency, the more it is preferred in comparison to the higher frequencies.

12. The on : off frequency at which there was least distraction from a flashing light was within the range that is also most conspicuous and at which certain visual physiological phenomena occur.

13. Within the same frequency range, the rate of change of skin conductance was related to the on : off flash frequency - the lower the frequency, the greater the fall from the initial level. The rate of change of skin conductance could be predicted from the attitude of the individual towards the

content of the interval - the greater the preference, the greater the fall indicating less arousal.

14. The estimates by quantitative comparison of the relative duration of presentation of the flashing light were not related to the different frequencies. The frequency to which subjects were most indifferent was, however, the frequency that had the shortest apparent duration; and the frequencies to which subjects expressed the strongest views, be it preference for or aversion against, were the frequencies that had the longest apparent duration.

15. There is tentative evidence to support the suggestion that apparent duration may be determined in part by the attitude expressed towards the content of the interval - the stronger the view expressed, be it a preference in its favour or aversion against it, the longer the apparent duration.

16. In order to reduce the incidence of pilot error accidents, the following practical recommendations are made, based on evidence obtained in this research :

(a) Aircrew should have access to accurate chronometers, which are visible at all times

(b) Aircrew should be reminded of the duration of an elapsed interval, when critical, either by a pre-set automatic visual or auditory device or by Air Traffic Control

(c) Aircrew should be educated to be aware of the possibility of distortion in apparent duration, especially during an emergency; they should be advised to rely always on temporal as well as spatial instrumentation in order to remain correctly orientated in flight

SECTION VII

APPENDICES

A. SKIN OHMETER: MARK 1

An ohmeter circuit, designed after the principle described by Withers (1956), was constructed as shown in Fig. 20. A potential (85 V) was applied across a 12 M ohm resistance in series with the subject to ensure a relatively constant current of about 7 μA. The difference between the potential across the electrodes on the skin and a variable potential derived from a 10-turn helical potentiometer was amplified and displayed on a voltmeter across the cathode follower (12 AU 7).

The apparatus was balanced by hand every half-minute by turning the helical potentiometer; when there was no difference in potential displayed on the voltmeter, the skin resistance could readily be calculated from the potentiometer reading. With this circuit it was possible to measure skin resistance within the range 0 - 300 K ohms. This was derived from choosing appropriate resistances in the two balancing parts of the circuit:

$$\frac{\text{Skin resistance}}{\text{Potentiometer: max 25 K ohms}} : \frac{12 \text{ M ohms}}{1 \text{ M ohms}}$$

The apparatus was balanced before use by inserting known fixed resistances in place of the skin electrodes, thus checking its calibration.

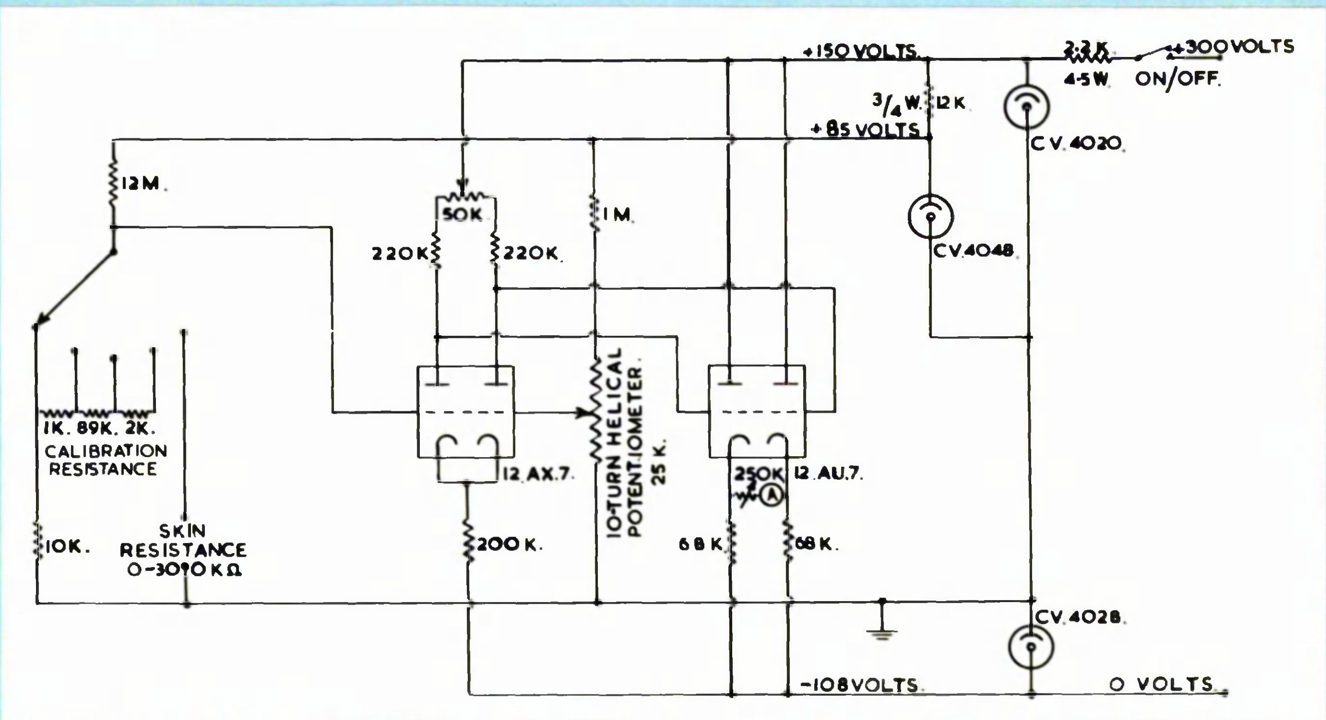

Fig. 20 Circuit diagram of the Skin Ohmeter, Mark 1.

Full scale deflection of the voltmeter was set at ± 2.5 K ohms; reading the potentiometer to the nearest third of a division (0.5 mm.) of the 100 on its dial, it was possible to record skin resistance to the nearest 100 ohms. One complete turn of the potentiometer was equivalent to a change of 30 K ohms in skin resistance.

The voltages required for the circuit were derived from a standard power pack with three neon stabilisers as shown in Fig. 20.

B. SKIN RESISTANCE ELECTRODES

Palm A dome of copper gauze, 65 mm. in diameter and 20 mm. high at the centre, was fashioned with a brass plate across its base. The plate was perforated so that there was free circulation of air; a bolt projected from it to which the electrical lead and retaining strap could be attached. The complete unit was electroplated with silver. The dry electrode fitted snugly into the palm of the left hand, contact with which was maintained by pressure from a rubber strap round the dorsum of the hand. The skin was not prepared in any way. Approximately 3.5 cm^2 of electrode was in contact with the skin.

Leg A simple silver plate of 20 cm^2 was attached to the left leg; the skin was scratched and saline-moistened electrode jelly interposed to reduce the resistance as much as possible. This electrode was at earth potential.

As the area of contact on the leg was approximately six times that on the palm, and every endeavour was made to reduce the resistance through the contact and skin of the leg, it was hoped that fluctuations in the skin resistance measurements were due mainly to changes in the palm.

It was also hoped that polarisation would be at a minimum as the current passing through the palm contact was only approximately $2 \mu A/cm^2$, the electrodes were silverplated and free evaporation of sweat from the palm was possible. Blank and Finesinger (1946) demonstrated that with dry electrodes, the accumulation of sweat increases the effective area of electrode contact, then apparently reducing the skin resistance; however, this criticism does not apply if free evaporation of sweat is possible. A current of $2 \mu A/cm^2$ also minimised drift due to injury to membrane properties of the skin found at currents greater than $11 \mu A/cm^2$ (Edelberg, Greiner and Burch, 1960).

C. SERIAL REPRODUCTION APPARATUS

Two accurate 0.5 rev./min. synchronous electric motors (Smith: Type 200) were attached to the plates of two electromagnetic clutches (Croft: Type 2/IN), the other plates of which were connected by a shaft through a potentiometer as shown in Fig. 21. The direction of rotation of the shaft could be altered by engaging one or other of the clutches as both motors rotated in a clockwise direction and intervals could be denoted by the specific angular displacement of the shaft and potentiometer by each motor. Hence, the duration of the interval, from the moment a direction of rotation was established by a radial arm breaking contacts until the direction was reversed, was the same as the succeeding interval, while the arm retraced its path to re-break the contacts. The maximum interval obtainable was 119 seconds, and this was due to the bar making another set of contacts which reversed the direction of rotation as a safety facility to avoid the shaft over-running a full circle.

The electrical circuit was constructed as shown in Fig. 22. When energised, clutch X was engaged, the shaft thus rotating in one direction; green lights indicated to the experimenter and the subject that this interval was a standard. When the radial arm on the shaft reached the contacts to break them, relay A was released and clutch Y engaged, thus reversing the direction of

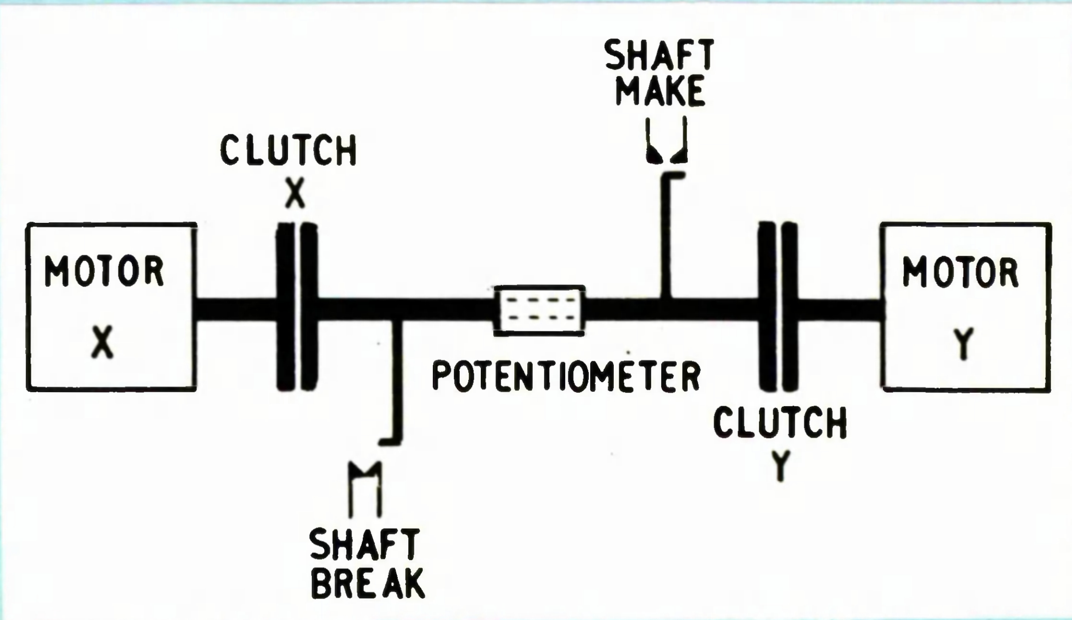

Fig. 21 Diagram of mechanism of serial reproduction apparatus.

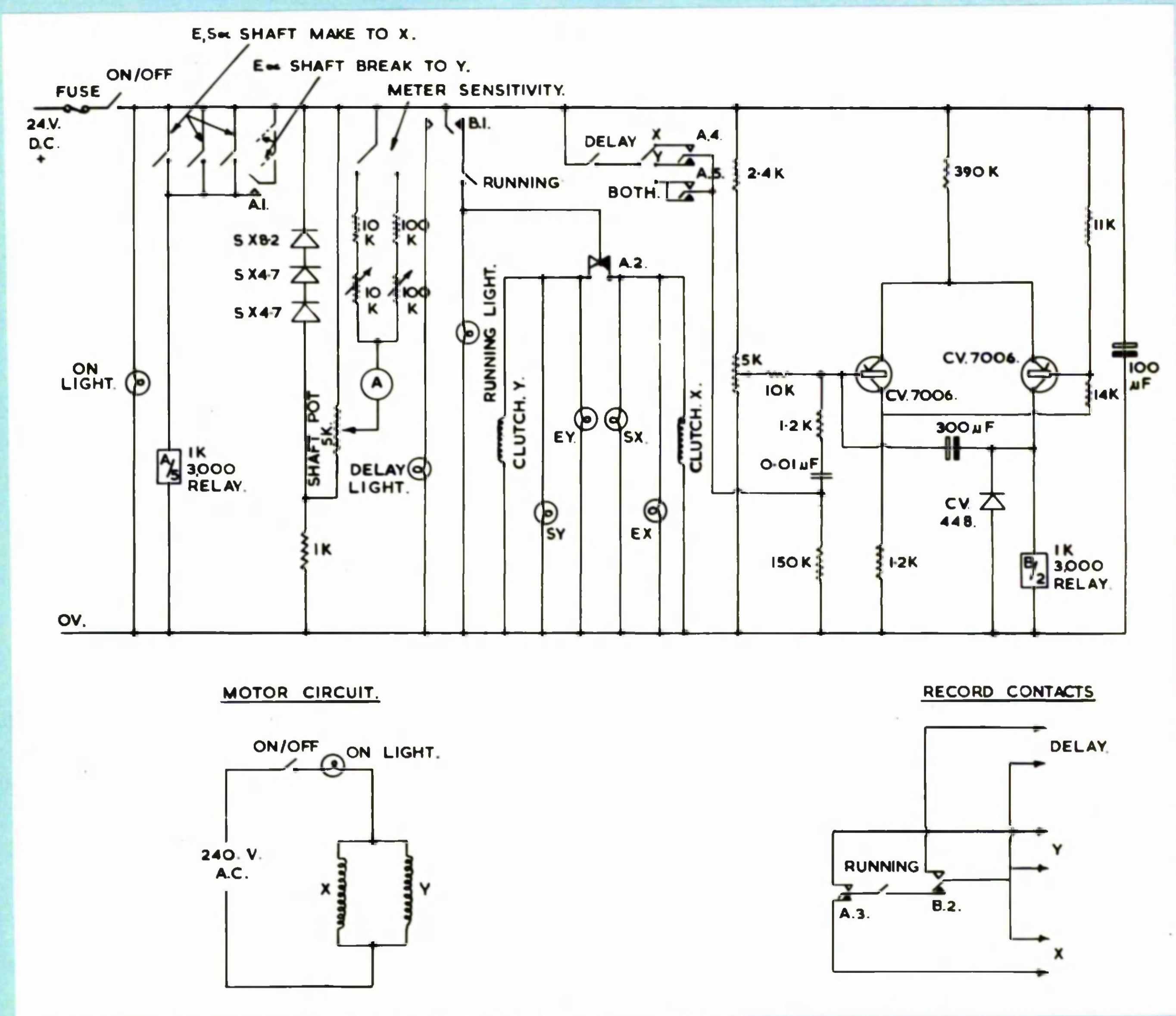

Fig. 22 Circuit diagram of serial reproduction apparatus.

E : experimenter
S : subject
X : standard
Y : judgment

rotation of the shaft; red lights indicated that this interval was a judgment. The duration of the standard was thus determined by the initial position of the shaft. It was the subject's task to depress a microswitch which re-energised relay A when he thought that the elapsed time of a judgment equalled the duration of the preceding standard. In serial reproduction the subsequent standard was thus of the same duration as the previous judgment.

The potentiometer gave a signal linearly related to shaft position and this was displayed to the experimenter on a meter with half-scale deflection representing 10 or 100 seconds. Contacts were available to record the duration of either the standard or the judgment and these were coupled to a Dekatron counter (Ericsson: Type 101A) which measured either interval to the nearest 0.01 second. The apparatus was tested and found to reproduce a standard to within 2.5 per cent. accuracy. The apparatus was noiseless except for the relay clicks at the changeover. The subject was situated out of sight of the apparatus and had before him a red and a green light and a microswitch. The experimenter had available on the apparatus suitable switches and lights to control the shaft in any position and direction of rotation.

Incorporated in the apparatus was a circuit which could provide a delay of up to ten seconds after either the judgment, the standard, or both; this was not used in the experiments here reported.

D. SKIN OHMETER: MARK 2

The skin ohmeter Mark 1 was efficient in obtaining the desired information in Experiment A. It suffered from the inconvenience that it required to be operated continuously by hand, and that it could not produce a continuous record of the monitored variable. The apparatus was thus elaborated to overcome these two difficulties, and yet retain its inherent simplicity.

The basic circuit (Fig. 23) is similar to that described in Appendix A. The principle of the modification is that any imbalance voltage registerd across the output of the cathode follower (12 AU 7) is used to control a velodyne motor which turns the helical potentiometer in the direction to correct the voltage imbalance; it uses the principle of negative feedback.

The transistorised control circuit of the velodyne motor (Type 88x) is shown in Fig. 24 (Barber, 1960). The output from the amplifier circuit is used to alter the mark-space ratio of the current to the field windings of the motor. When no voltage difference across the output from the amplifier circuit is present, the motor is stationary.

A power pack, whose circuit diagram is given in Fig. 25, was constructed to provide the various required voltages.

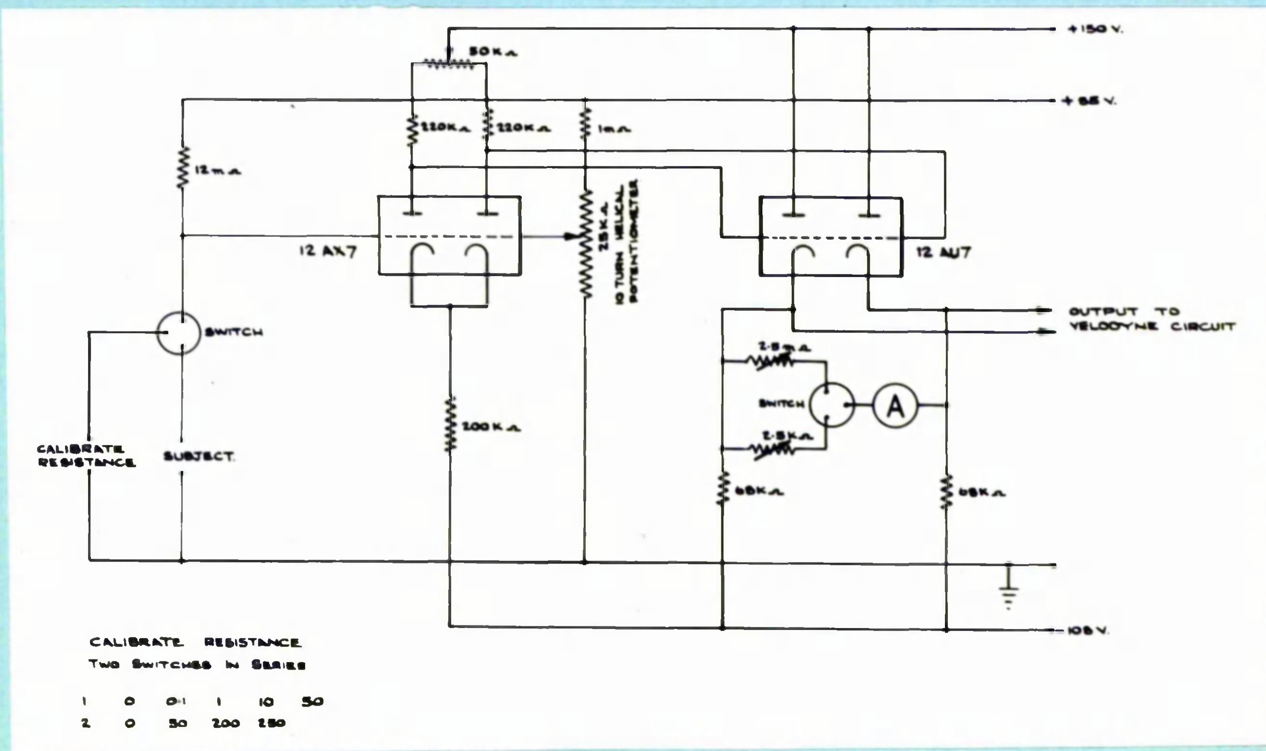

Fig. 23 Circuit diagram of the amplifier part of the Skin Ohmeter, Mark 2.

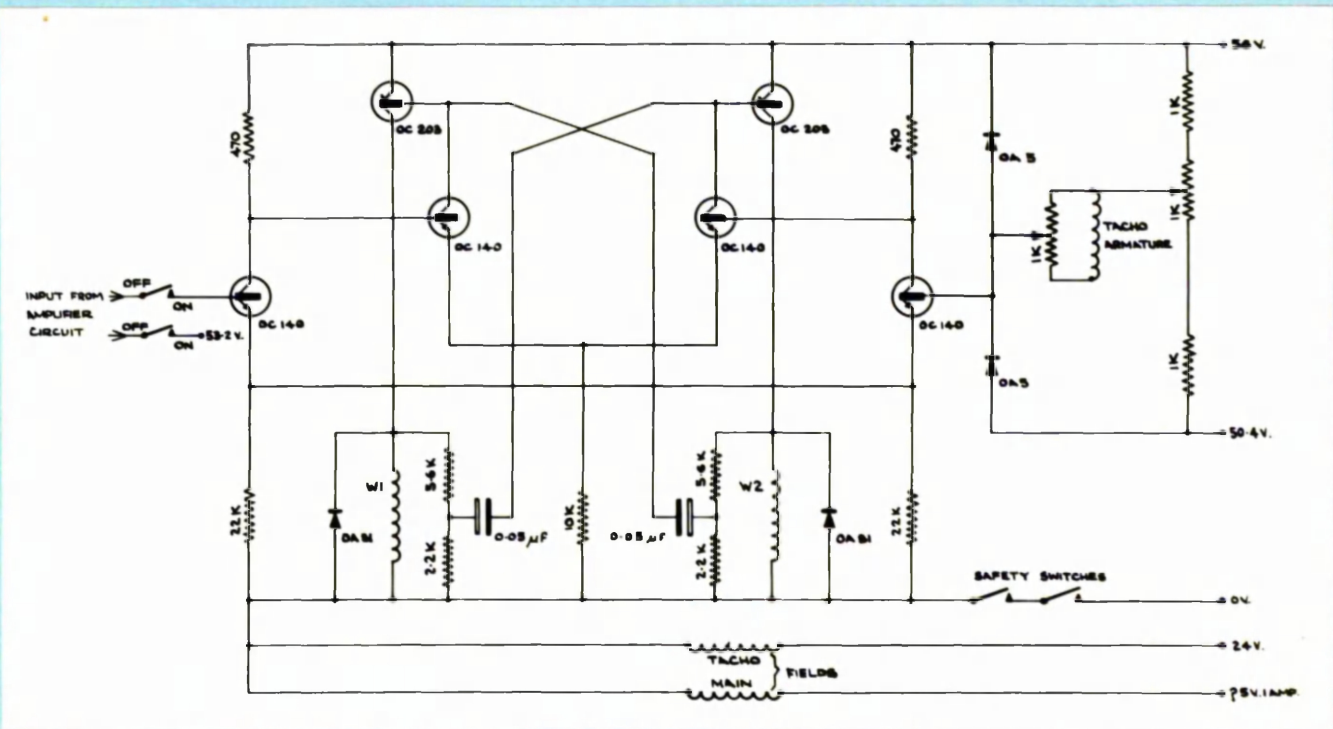

Fig. 24 Circuit diagram of the velodyne motor control part of the Skin Ohmeter, Mark 2.

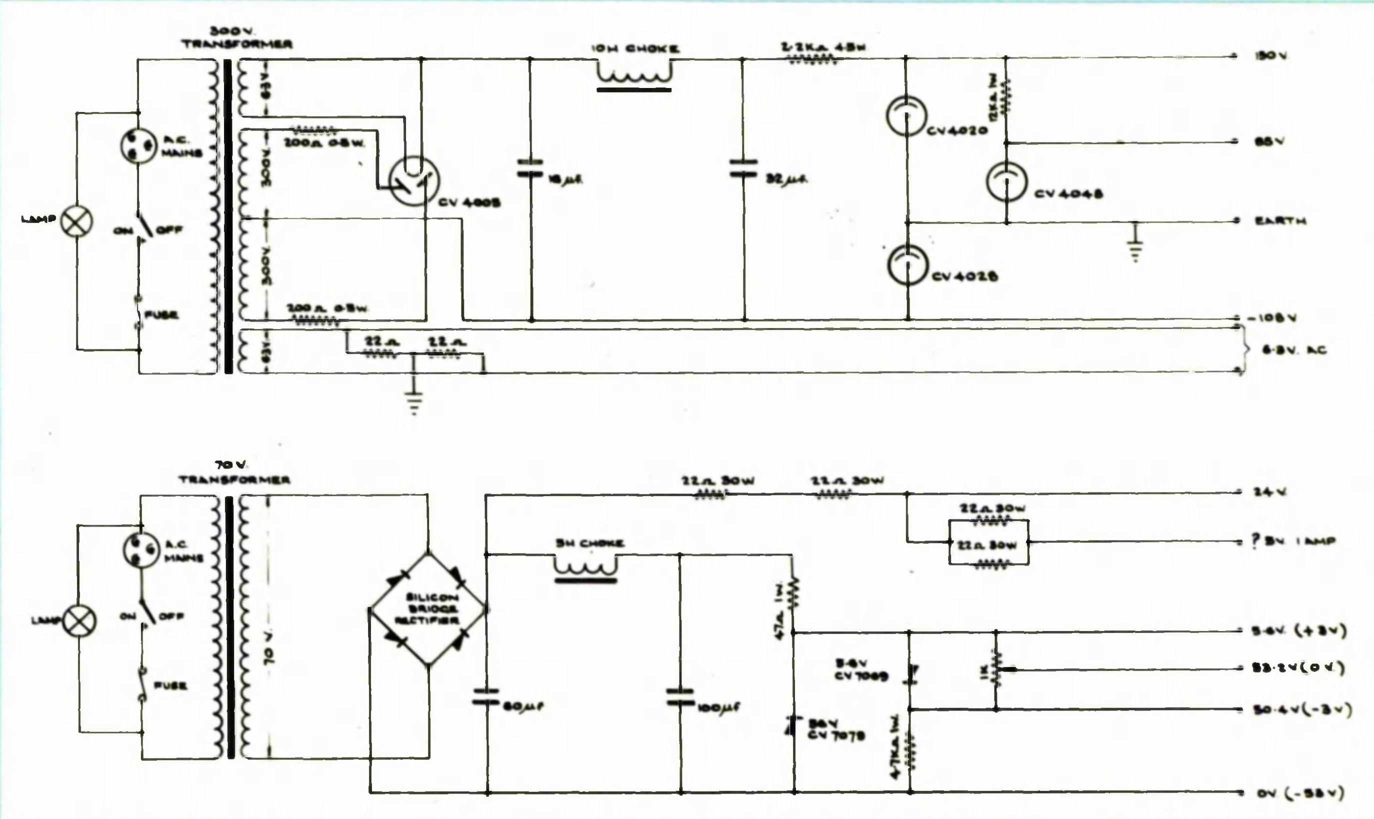

Fig. 25 Circuit diagram of the power pack part of the Skin Ohmeter, Mark 2.

The mechanical linkages between the shafts of the ten-turn helical potentiometer and the velodyne motor were constructed with precision gears. Within these linkages were placed a two-way cam-switch and an auxiliary continuous-turn potentiometer. For each revolution of the main ten-turn helical potentiometer, the motor turned 25 and the auxiliary potentiometer 10 revolutions. Thus the ratio of turning of the auxiliary to the main potentiometer was 2.5 : 1.

As described in Appendix A, the skin resistance could be measured from 0 - 300 K ohms by reading the position of the tapping arm on the ten-turn helical potentiometer. Thus one revolution of it indicates a change of 30 K ohms and hence one revolution of the auxiliary potentiometer 12 K ohms.

The two-way cam-switch changed over at 0° and 180° on each revolution of the auxiliary potentiometer. Through it either ± 2V from earth were applied across the potentiometer (Fig. 25), thus giving an output from - to + 2V proportional to the position of the wiper arm during each revolution. The voltage swing was transferred to a pen recorder, calibrated at a skin resistance of 200 ohms/mm. on paper. The actual level of skin resistance within the 12 K ohms range was measured; outside this range it was calculated by counting the number of changes of the cam-switch since a reference reading was noted during calibration.

Safety switches were incorporated in the velodyne motor control part of the circuit to stop the motor if the imbalance voltage

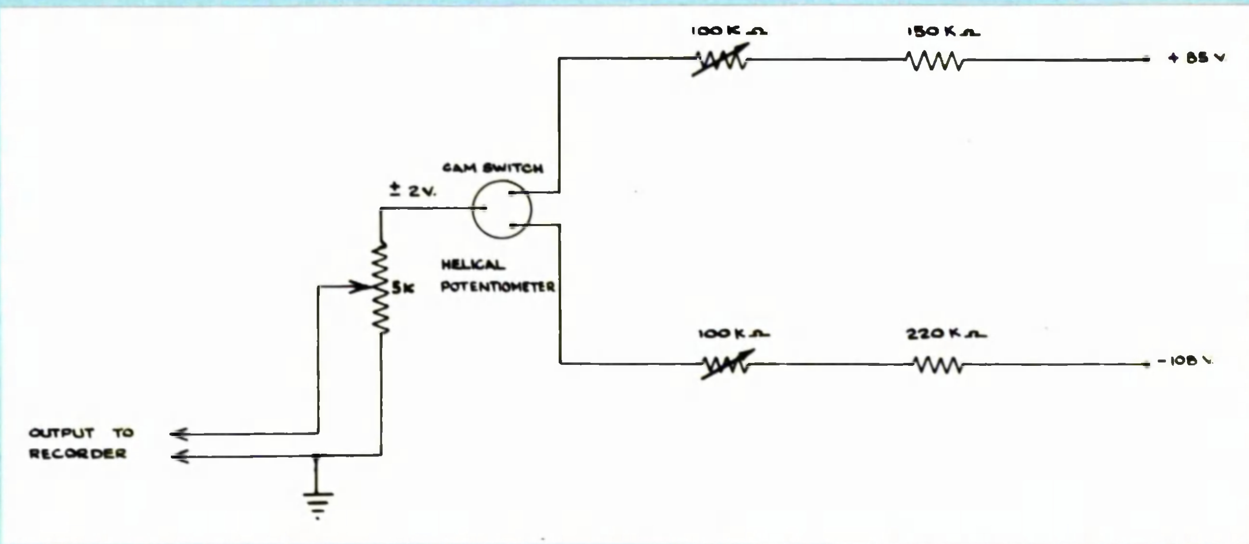

Fig. 26 Circuit diagram of the recording part of the Skin Ohmeter, Mark 2.

remained and the motor threatened to turn the main potentiometer beyond its capacity - in other words, if the skin resistance was greater than 300 K ohms such as if the contacts open-circuited.

The appropriate parts of the circuit could be balanced and checked with calibration resistances. The voltmeter was still incorporated in the circuit to keep a check that the output to the velodyne was balanced. The voltmeter could be read at variable gains as on Mark 1; it was in fact read at either 2.5 K ohms or 250 K ohms representing full-scale deflection.

E. STATISTICAL ANALYSES *

* Analyses 5, 11, 15, 16, 17 and 18 were compiled by the author

Estimates of apparent duration of ten-minute intervals (Table V)

The analysis of variance of x' was completed after the transformation x' = log x, where x = estimate in minutes

Source	df	SS	MS	F	P
Pilots (P)	84	13.521657	0.160972	11.8	0.001
Sorties (S)	2	12.386412	6.193206	116.5	0.001
Longest v. Shortest (L)	1	11.453110	11.453110	278.3	0.001
P x S	168	8.934162	0.053180	3.9	0.001
P x L	84	3.456906	0.041154	3.0	0.001
S x L	2	0.720304	0.360152	26.5	0.001
Residual	168	2.283391	0.013591		
Total	509	52.755942			

Duration scores (Table VIII)

The analysis of variance was completed on the direct scores

Source	df	SS	MS	F	P
Group	1	3.92	3.92	0.17	
Subject/Group	6	140.28	23.38	-	
Order	3	9.71	3.24	1.35	
Factors -					
Distraction (D)	1	37.85	37.85	15.76	0.001
Task (T)	1	28.13	28.13	11.71	0.01
D x T	1	0.06	0.06		
Residual	18	43.22	2.40		
Total	31	263.17			

3 ANALYSIS OF VARIANCE

Alertness scores (Table IX)

The analysis of variance of x' was completed after the transformation $x' = 50\,(x + 1)$, where x = alertness scores on possible range -1 to +1

Source	df	SS	MS	F	P
Group	1	144.50	144.50	0.16	
Subject/Group	6	5,264.50	877.42	-	
Order	3	1,161.75	387.25	6.05	0.01
Factors -					
Distraction (D)	1	561.13	561.13	8.77	0.01
Task (T)	1	1,984.50	1,984.50	31.02	0.001
D x T	1	28.13	28.13		
Residual	18	1,151.50	63.97		
Total	31	10,296.01			

Changes in skin conductance (Table XI)

The analysis of variance of x' was completed after the transformation of x' = 10,000 x, where x = change in log micromhos as specially derived

Source	df	SS	MS	F	P
Group	1	108,462	108,462	0.28	
Subject/Group	6	2,358,295	393,049	-	
Order	3	2,224,716	748,239	2.35	
Factors -					
Distraction (D)	1	1,412,460	1,412,460	4.44	0.05
Task (T)	1	2,549,847	2,549,847	8.02	0.05
D x T	1	257,583	257,583		
Residual	18	5,723,053	317,947		
Total	31	14,634,416			

Mean change in skin conductance and mean alertness score (Fig. 7)

The analysis was completed on the transformed figures $u = -100x$ and $v = -100y$, and yielded the regression: $v = 4.8271u + 3.273$. Hence $y = 4.83x - 0.03$

Conditions		$D_0 T_0$	$D_0 T_1$	$D_1 T_0$	$D_1 T_1$
Mean change in conductance (log micromhos)	x	- 0.1064	- 0.0320	- 0.0464	- 0.0079
Mean alertness score (possible range - 1 to + 1)	y	- 0.53	- 0.17	- 0.32	- 0.04

Source	df	SS	MS	F	P
Due to regression	1	1,229.33	1,229.33	45.20	0.025
Residual	2	54.40	27.20		
Total	3	1,283.73			

Duration scores adjusted for alertness (Table XIII)

The analysis of covariance was completed after the transformation $x' = 50(x + 1)$ where x = alertness score, possible range from -1 to +1 (Table IX). The original duration scores, in minutes, y, (Table VIII) were analysed untransformed

Source	df	SS_{xy}	df	SS	MS	F	P
Group	1	23.80	1	5.75	5.75	0.22	
Subject/Group	6	-197.63	5	132.87	26.57	-	
Order	3	-33.26	3	13.36	4.45	1.94	
Factors -							
Distraction (D)	1	145.73	1	14.96	14.96	6.52	0.025
Task (T)	1	-236.25	1	23.52	23.52	10.25	0.01
D x T	1	-1.31	1	0.32	0.32		
Residual	18	69.78	17	38.99	2.29		
Total	31	-229.14		229.77			
Due to Regression	1			4.23	4.23	1.84	
Residual	17			38.99	2.29		
Total	18			43.22			

The adjusted duration scores, y', were obtained by substitution in the following formula, where $b = 0.06$ for the transformed data -

$$y' = y - 0.06x' + 2.24$$

Differences between durations of succeeding judgments; preliminary experiment on the effect of noise (from Table XVI)

The analysis of variance of x' was completed after the transformation $x' = 100x$, where x = the differences between the durations of the succeeding judgments in seconds

Source	df	SS	MS	F	P
Conditions (C) -					
Standard (T)	1	656	656		
Judgment (J)	1	40,837	40,837	8.53	0.01
T x J	1	256	256		
Order	3	20,070	6,690	1.40	
Subjects (S)	7	186,192	26,598	5.56	0.001
Sequences (Q)	11	43,562	3,960		
S x C (Confounded with order)	21	227,678	10,842	2.27	0.01
S x Q	77	467,774	6,075	1.27	0.05
Residual	261	1,249,313	4,786		
Total	383	2,236,338			

Mean subjective estimate score and the logarithm of the respiratory resistance; preliminary experiment (Fig. 9)

The analysis was completed on the transformed figures, $v = 100y$ and $u = \log(x + 1)$, and yielded the regression: $v = 112.80u - 2.03$. Hence $y = 1.13 \log(x + 1) - 0.02$

Inspiratory resistance added: In. of water	x	0.0	0.25	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Mean subjective estimate score: (range 0 - 1)	y	0.02	0.04	0.18	0.28	0.44	0.60	0.57	0.65	0.69	0.78

Source	df	SS	MS	F	P
Due to regression	1	6,776.47	6,776.47	429.05	0.001
Residual	8	126.35	15.79		
Total	9	6,902.82			

Differences between durations of succeeding judgments; main experiment on the effect of alteration in the resistance to respiration (Table XXI)

The analysis of variance was completed on the direct scores, the differences between the durations of the succeeding judgments in seconds

Source	df	SS	MS	F	P
Conditions (C)	3	22.17	7.39	1.96	
Order	3	50.64	16.88	5.94	0.001
Subjects (S)	7	8.63	1.23		
Sequences (Q)	11	12.65	1.15		
S x C (Confounded with order)	21	295.97	14.09	3.75	0.001
C x Q	33	131.11	3.97	1.06	
S x Q	77	8.95	1.41		
Residual	228	856.00	3.76		
Total	383	1,386.12			

Mean subjective estimate score and the logarithm of the inspiratory resistance ; main experiment (Fig. 12)

The analysis was completed on the transformed figures, $v = 100\,y$ and $u = \log 2x$, and yielded the regression; $v = 57.88\,u + 17.11$. Hence $y = 0.58 \log x + 0.34$

Inspiratory resistance : In. of water	x	0.5	1.0	2.0	4.0
Mean subjective estimate score : (range 0 - 1)	y	0.16	0.36	0.53	0.68

Source	df	SS	MS	F	P
Due to regression	1	1,518.16	1,518.16	328.40	0.01
Residual	2	9.25	4.63		
Total	3	1,527.41			

Subjective estimate scores of resistance to respiration; main experiment (Table XXIII)

The analysis of x' was completed after the transformation x' = 100 x, where x = subjective estimate score of resistance to respiration within possible range 0 to 1

Source	df	SS	MS	F	P
Subjects	7	12,701	1,814	10.67	0.001
Conditions	3	12,219	4,073	23.96	0.001
Order	3	106	35		
Residual	18	3,068	170		
Total	31	28,094			

Preference scores (Table XXV)

The analysis of x' was completed after the transformation $x' = 50\ (x + 1)$, where x = preference score within possible range −1 to +1

Source	df	SS	MS	F	P
Frequencies	4	4,090.26	1,022.57	4.83	0.01
Deviations from subtractivity	6	382.54	63.75		
Average preferences	10	4,472.80	447.28	2.12	-
Order	10	11,138.80	1,113.88	5.26	0.001
Means	20	15,611.60	780.58	3.72	-
Error; subjects and order	10	10,702.80	1,070.28	5.07	-
Residual	70	14,833.60	211.90		
Total	100	41,148.00			

Relative duration scores (Table XXVI)

The analysis of x' was completed after the transformation $x' = 50\ (x + 1)$, where x = relative duration score within possible range -1 to +1

Source	df	SS	MS	F	P
Frequencies	4	511.48	127.87	1.13	
Deviations from subtractivity	6	625.82	104.33		
Average durations	10	1,137.30	11.73	1.01	
Order	10	991.70	99.17		
Means	20	2,129.00	106.45		
Error; subjects and order	10	1,107.90	110.79		
Residual	70	7,882.10	112.60		
Total	100	11,119.00			

Changes in skin conductance (Table XXVII)

The analysis of variance of x' was completed after the transformation of x' = 10,000 x, where x = change in log micromhos as specially derived

Source	df	SS	MS	F	P
Frequencies	4	56,190	14,047	3.93	0.01
Deviations from subtractivity	6	123,206	20,534	5.75	–
Average scores	10	179,396	17,940	5.01	–
Order	10	96,765	9,677	2.71	0.05
Means	20	276,161	13,808	3.87	–
Error; subjects and order	10	1,067,832	10,678		
Residual	70	249,909	3,570		
Total	100	1,593,902			

Mean preference score and the frequency of flashing light (Fig. 14)

The analysis was completed on the transformed figures, v = 1,000 y and yielded the regression: v = 656.47 - 394.05 x. Hence y = 0.66 - 0.39 x

Frequency of flashing light: c/s.	x	1.00	1.33	1.67	2.00	2.33
Mean preference score: (range -1 to +1)	y	0.16	0.24	0.01	-0.07	-0.34

Source	df	SS	MS	F	P
Due to regression	1	172,183	172,183	17.08	0.05
Residual	3	30,311	10,103		
Total	4	202,494			

Mean change in skin conductance and frequency of flashing light (Fig. 16)

The analysis was completed on the transformed figures, v = 1,000 y and yielded the regression: v = 3.20 x - 13.39.
Hence y = 0.0032 x - 0.0134

Frequency of flashing light: c/s.	x	1.00	1.33	1.67	2.00	2.33
Mean conductance change	y	-.01023	-.00909	-.00765	-.00772	-.00558

Source	df	SS	MS	F	P
Due to regression	1	11.3855	11.3855	41.75	0.01
Residual	3	0.8182	0.2727		
Total	4	12.2037			

Mean change in skin conductance and mean preference score (Fig. 17)

The analysis was completed on the transformed figures,
$u = 1{,}000\,x$ and $v = 10{,}000\,y$, and yielded the regression:
$v = -80.54 - 0.072\,u$. Hence $y = -0.0081 - 0.0072\,x$

Mean preference score: (range -1 to +1)	x	0.164	0.236	0.009	-0.070	-0.339
Mean conductance change: log micromhos	y	-.01023	-.00909	-.00765	-.00772	-.00558

Source	df	SS	MS	F	P
Due to regression	1	1,052.37	1,052.37	18.85	0.025
Residual	3	168.00	56.00		
Total	4	1,220.37			

Mean relative duration score and square of the mean preference score (Fig. 19)

The analysis was completed on the transformed figures, $u = 10{,}000x^2$ and $v = 1{,}000y$, and yielded the regression: $v = 0.16958u - 68.68$. Hence $y = 1.696(x^2) - 0.069$

Square of mean preference score (range 0 to 1)	x^2	0.026896	0.055696	0.000081	0.004900	0.114921
Relative duration score (range -1 to +1)	y	-0.034	+0.030	-0.071	-0.051	0.126

Source	df	SS	MS	F	P
Due to regression	1	25,404.88	25,404.88	452	0.001
Residual	3	169.12	56.37		
Total	4	25,574.00			

SECTION VIII

REFERENCES

AITKEN, R.C.B. (1962)

Factors influencing flight safety; report of an interview study of aircrew.
Air Ministry, Flying Personnel Research Committee Memorandum. No. 192.

AITKEN, R.C.B, FERRES, H.M. and GEDYE, J.L. (1963)

Distraction from flashing lights.
Aerospace Med. 34, 302-306.

AITKEN, R.C.B. and GEDYE, J.L. (1963)

The apparent duration of a ten-minute interval.
Air Ministry, Flying Personnel Research Committee Report. No. 1216.

AX, A.F. (1953)

The physiological differentiation between fear and anger in humans.
Psychosom. Med. 15, 433-442.

BARBER, D.L.A. (1960)

A transistor motor-speed control circuit.
Electron. Engng. 32, 720.

BENSON, A.J. and GEDYE, J.L. (1962)

Some supraspinal factors influencing generalised muscle activity.
In Symposium on Skeletal Muscle Spasm, ed. Turnbull, P.C. pp. 31-50. Leicester. Franklyn, Ward and Wheeler.

BINDRA, D. and WAKSBERG, H. (1956)

Methods and terminology in studies of time estimation.
Psychol. Bull. 53, 155-159.

BLANK, I.H. and FINESINGER, J.E. (1946)

Electrical resistance of the skin: effect of size of electrodes, exercise and cutaneous hydration.
Arch. Neurol. Psychiat, Chicago. 56. 544-557.

BOARDMAN, W.K, GOLDSTONE, S. and LHAMON, W.T. (1957)

Effects of lysergic acid diethylamide (LSD) on the time sense of normals: a preliminary report.
Arch. Neurol. Psychiat, Chicago. 78, 321-324.

BROADBENT, D.E. (1953)

Noise, paced performance and vigilance tasks.
Brit. J. Psychol. 44. 295-303.

BROWNE, W.A.F. (1874)

The perception, etc, of time as a feature in mental disease.
J. Ment. Sci. 19. 519-532.

BRUSH, E.N. (1930)

Observation on the temporal judgement during sleep.
Amer. J. Psychol. 42. 408-411.

CAMPBELL, F.W. and WHITESIDE, T.C.D. (1950)

Induced pupillary oscillations.
Brit. J. Ophthal. 34, 180-189.

CANNON, W.B. (1929)

Bodily changes in Pain, Hunger, Fear and Rage.
2nd ed. pp. 37-65. London. Appleton.

CARMICHAEL, E.A, HONEYMAN, W.M, KOLB, L.C. and STEWART, W.K. (1941)

A physiological study of the skin resistance response in man.
J. Physiol. 99. 329-337.

CATTELL, R.B. (1928)

The significance of the actual resistances in psychogalvanic experiments.
Brit. J. Psychol. 19. 34-43.

CLAUSEN, J. (1950)

An evaluation of experimental methods of time judgement.
J. exp. Psychol. 40. 756-761.

COCHRAN, W.G. and COX, G.M. (1957)

Experimental Designs.
2nd ed. pp. 45-94. London. Chapman and Hall.

COHEN, J. (1954)

The experience of time.
Acta Psychol, Hague. 10. 207-219.

COHEN, J, HANSEL, C.E.M, and SYLVESTER, J.D. (1953)

A new phenomenon in time judgement.
Nature, Lond. 172. 901.

COHEN, S.I. and MEZEY, A.G. (1961a)

The effect of anxiety on time judgement and time experience.
J. Neurol. 24. 266-268.

COHEN, S.I. and MEZEY, A.G. (1961b)

The effect of depressive illness on time judgement and time experience.
J. Neurol. 24. 269-270.

COSTELLO, C.G. (1961)

The effects of meprobamate on time perception.
J. Ment. Sci. 107. 67-73.

CRAIK, K.J.W. (1943)

The Nature of Explanation.
p. 27. Cambridge. University Press.

DARROW, C.W. (1934a)

The significance of skin resistance in the light of its relation to the amount of perspiration.
J. gen. Psychol. 11. 451-452.

DARROW, C.W. (1934b)

The significance of the galvanic skin reflex in the light of its relation to quantitative measurement of perspiration.
Psychol. Bull. 31. 697-698.

DARROW, C.W. (1937)

The equation of the galvanic skin reflex curve.
I. The dynamics of reaction in relation to excitation-background.
J. gen. Psychol. 16. 285-309.

DAVIS, R.C. (1930)

Factors affecting the galvanic reflex.
Arch. Psychol. 115. 1-64.

DAVIS, R.C. (1934)

Modification of the galvanic reflex by daily repetition of a stimulus.
J. exp. Psychol. 17. 504-535.

DEARNALEY, E.J. (1960)

Endurance of aircrew in low level flight.
Air Ministry, Flying Personnel Research Committee Memorandum. No. 135.

DIRECTOR GENERAL OF FLYING. (1961)

Annual summary of aircraft accidents.
Ministry of Aviation (Research and Development).

DIRECTORATE OF FLIGHT SAFETY (1922-1961)

Annual Reviews. Air Ministry.

DuBOIS, F.S. (1954)

The sense of time and its relation to psychiatric illness.
Amer. J. Psychiat. 111. 46-51.

DUFFY, E. (1930)

Tension and emotional factors in reaction.
Genet. Psychol. Monogr. 7. 1-78.

DUFFY, E. (1932a)

The measurement of muscular tension as a technique for the study of emotional tendencies.
Amer. J. Psychol. 44. 146-162.

DUFFY, E. (1932b)

The relation between muscular tension and quality of performance.
Amer. J. Psychol. 44. 535-546.

DUFFY, E. (1941)

The conceptual categories of psychology: a suggestion for revision.
Psychol. Rev. 48. 177-203.

DUFFY, E. (1951)

The concept of energy mobilization.
Psychol. Rev. 58. 30-40.

DUFFY, E. and LACEY, O.L. (1946)

Adaptation in energy mobilization: changes in general level of palmar skin conductance.
J. exp. Psychol. 36. 437-452.

EDELBERG, R. (1961)

The relationship between the galvanic skin response, vasoconstriction, and tactile sensitivity.
J. exp. Psychol. 62. 187-195.

EDELBERG, R, GREINER, T. and BURCH, N.R. (1960)

Some membrane properties of the effector in the galvanic skin response.
J. appl. Physiol. 15. 691-696.

EYSENCK, H.J. (1959)

Personality and the estimation of time.
Percept. Mot. Skills. 9. 405-406.

FALK, J.L. and BINDRA, D. (1954)

Judgement of time as a function of serial position and stress.
J. exp. Psychol. 47. 279-282.

FARMER, E. and CHAMBERS, E.G. (1925)

Concerning the use of the psycho-galvanic reflex in psychological experiments.
Brit. J. Psychol. 15. 237-254.

FÉRÉ, C. (1888)

Note sur des modifications de la résistance éléctrique sous l'influence des excitations sensorielles et des émotions.
C.R. Soc. Biol, Paris. 40. 217-219.

FILER, R.J. and MEALS, D.W. (1949)

The effect of motivating conditions on the estimation of time.
J. exp. Psychol. 39. 327-331.

FRANÇOIS, M. (1927)

Contribution a l'étude du sens du temps.
Année psychol. 28. 186-204.

FRANKENHAUSER, M. (1959)

Estimation of Time: an experimental study.
pp. 39, 64, 87-95. Stockholm. Alwquist and Wiksell.

FREDERICSON, E. (1951)

Time and aggression.
Psychol. Rev. 58. 41-51.

FREEMAN, G. L. (1940)

The relationship between performance level and bodily activity level.
J. exp. Psychol. 26. 602-608.

FREEMAN, G. L. and KATZOFF, E. T. (1942)

Methodological evaluation of the galvanic skin response with special reference to the formula for R. Q. (recovery quotient).
J. exp. Psychol. 31. 239-248.

FREEMAN, G. L. and SIMPSON, R. M. (1938)

The effects of experimentally induced muscular tension upon palmar skin resistance.
J. gen. Psychol. 18. 319-326.

GADDUM, J. H. (1945)

Lognormal distributions.
Nature, Lond. 156. 463-466.

GARDNER, W. A. (1935)

Influence of the thyroid gland on the consciousness of time.
Amer. J. Psychol. 47. 698-701.

GEDYE, J. L. (1960)

The reactions of aircrew to the demands of a novel low-level flying task.
Personal communication; Unpublished report.

GEDYE, J. L, AITKEN, R. C. B. and FERRES, H. M. (1961)

Subjective assessment in clinical research.
Brit. med. J. 1. 1828.

GERATHEWOHL, S.J. (1953)

Conspicuity of steady and flashing light signals: variation of contrast.
J. opt. Soc. Amer. <u>43</u>. 567-571.

GERATHEWOHL, S.J. (1954)

Conspicuity of flashing light signals of different frequency and duration.
J. exp. Psychol. <u>48</u>. 247-251.

GILLILAND, A.R, HOFELD, J. and ECKSTRAND, G. (1946)

Studies in time perception.
Psychol. Bull. <u>43</u>. 162-176.

GILLILAND, A.R. and MARTIN, R. (1940)

Some factors in estimating short time intervals.
J. exp. Psychol. <u>27</u>. 243-255.

GOLLA, F.L. (1921)

The objective study of neurosis.
Lancet. <u>2</u>. 215-221.

GREGG, L.W. (1951)

Fractionation of temporal intervals.
J. exp. Psychol. <u>42</u>. 307-312.

GULLIKSEN, H. (1927)

The influence of occupation upon the perception of time.
J. exp. Psychol. <u>10</u>. 52-59.

HAGGARD, E.A. (1945)

Experimental studies in affective processes.
II. On the quantification and evaluation of 'measured' changes in skin resistance.
J. exp. Psychol. <u>35</u>. 46-56.

HAGGARD, E.A. (1949)

On the application of analysis of variance to GSR data.
II. Some effects of the use of inappropriate measures.
J. exp. Psychol. 39. 861-867.

HEAD, H. (1923)

The conception of nervous and mental energy.
II. 'Vigilance': a physiological state of the nervous system.
Brit. J. Psychol. 14. 126-147.

HEBB, D.O. (1955)

Drives and the C.N.S. (Conceptual Nervous System).
Psychol. Rev. 62. 243-254.

HEBB, D.O. (1958)

A Textbook of Psychology.
p.81. London. Saunders.

HIRSH, I.J, BILGER, R.C. and DEATHERAGE, B.H. (1956)

The effect of auditory and visual background on apparent duration.
Amer. J. Psychol. 69. 561-574.

HOAGLAND, H. (1933)

The physiological control of judgements of duration: evidence for a chemical clock.
J. gen. Psychol. 9. 267-287.

HOAGLAND, H. and PERKINS, C.T. (1935)

Some temperature characteristics in man.
J. gen. Physiol. 18. 399-408.

INTERNATIONAL CIVIL AVIATION ORGANISATION (1961)

Proposal for anti-collision light.
Secretary-General's letter to all member states.
AN3/24.1/61/82.

IRWIN, F.W. (1961)

Motivation and performance.
Annu. Rev. Psychol. 12. 217-242.

JACKSON, K.F. (1958)

The multiple tracking task.
Air Ministry, Flying Personnel Research Committee Report. No. 1072.

JAMES, W. (1890)

The Principles of Psychology.
Vol. 1, pp. 605-642. Vol. 2, pp. 442-485. London. MacMillan.

JASPER, H, AJMONE-MARSAN, C. and STOLL, J. (1952)

Cortifugal projections to the brain stem.
Arch. Neurol. Psychiat, Chicago. 67. 155-171.

JERISON, H.J. (1959)

Effects of noise on human performance.
J. appl. Psychol. 43. 96-101.

JONES, G.M. (1957)

Review of current problems associated with disorientation in man-controlled flight.
Air Ministry, Flying Personnel Research Committee Report. No. 1021.

KORSAKOW, S.S. (1890)

Ueber eine besondere form psychischer storung combinirt mit multiples neuritis.
Arch. Psychiat. Nervenkr. 21. 669-704.

LACEY, J.I. (1956)

The evaluation of autonomic responses: toward a general solution.
Ann. N.Y. Acad. Sci. 67. 125-163.

LADER, M.H. (1963)

Effect of cyclobarbitone on the habituation of autonomic responses.
Ph.D. thesis. Univ. Lond. Unpublished.

LADER, M.H. and MONTAGU, J.D. (1962)

The psycho-galvanic reflex: a pharmacological study of the peripheral mechanism.
J. Neurol. 25. 126-133.

LANDIS, C. and DeWICK, H.N. (1929)

The electrical phenomena of the skin: (psycho-galvanic reflex).
Psychol. Bull. 26. 64-119.

LANGER, J, WAPNER, S. and WERNER, H. (1961)

The effect of danger upon the experience of time.
Amer. J. Psychol. 74. 94-97.

LEWIS, A. (1932)

Experience of time in mental disorder.
Proc. R. Soc. Med. 25. 611-620.

LHAMON, W.T. and GOLDSTONE, S. (1956)

The time sense: estimation of one-second durations by schizophrenic patients.
Arch. Neurol. Psychiat, Chicago. 76. 625-629.

LINDSLEY, D.B. (1951)

Emotion. In Handbook of Experimental Psychology.
ed. Stevens, S.S. pp. 473-516. New York. Wiley.

LINDSLEY, D. B. (1958)

The reticular system and perceptual discrimination. In Reticular Formation of the Brain.
ed. Jasper, H.H, Proctor, L.D, Knighton, R.S, Noshay, W.C. and Costello, R.J. pp. 513-534. London. Churchill.

LINN, L. (1953)

Psychological implications of the 'activating system'.
Amer. J. Psychiat. 110. 61-65.

LLEWELLYN-THOMAS, E. (1959)

Successive time estimation during automatic positive feedback.
Percept. Mot. Skills. 9. 219-224.

LOEHLIN, C. (1959)

The influence of different activities on the apparent length of time.
Psychol. Monogr. 73. No. 474.

MACH, E. (1900)

Die Analyse der Empfindungen und das Verhältniss des Physischen zum Psychischen.
pp. 157-168. Jena. Fischer. Translated (1906).
pp. 245-261. New York. Dover Publications.

MACLEAN, P.D. (1955)

The limbic system ('visceral brain') and emotional behaviour.
Arch. Neurol. Psychiat, Chicago. 73. 130-134.

MAGOUN, H.W. (1952)

An ascending reticular activating system in the brain stem.
Arch. Neurol. Psychiat, Chicago. 67. 145-154.

MALMO, R.B. (1957).

Anxiety and behavioral arousal.
Psychol. Rev. 64. 276-287.

MALMO, R.B. (1959)

Activation: a neuropsychological dimension.
Psychol. Rev. 66. 367-386.

MANDLER, G, MANDLER, J.M. and UVILLER, E.T. (1958)

Autonomic feedback: the perception of autonomic activity. J.abnorm.soc.psychol. 56. 367-373.

MAULSBY, R.L. and EDELBERG, R. (1960)

The interrelationship between the galvanic skin response, basal resistance and temperature. J.comp.physiol. Psychol. 53. 475-479.

METFESSEL, M. (1947)

A proposal for quantitative reporting of comparative judgements. J.Psychol. 24. 229-235.

MONTAGU, J.D. (1958)

The psycho-galvanic reflex: a comparison of A.C. skin resistance and skin potential changes. J.Neurol. 21. 119-128.

MORUZZI, G. and MAGOUN, W.H. (1949)

Brain stem reticular formation and activation of the EEG. Electroencephalog.clin.Neurophysiol. 1. 455-473.

MUNSTERBERG, H. (1889)

Beiträge zur Experimentellen Psychologie. Heft 2. pp. 1-68. Freiburg. Akademische Verlagsbuchhandlung von J.C.B. Mohr. Cited by Nicholls, H. (1890). The psychology of time. Amer.J.Psychol. 3. 453-529. (519-522).

MURRAY, J.A.H. (1888-1910)

A New English Dictionary on Historical Principles. Vol.1, p.455. Vol.8, p.835. Oxford. Clarendon Press.

OLERON, G. (1952)

Influence de l'intensité d'un son sur l'estimation de sa durée apparente.
Année psychol. 52. 383-392.

OMWAKE, K.T. and LORANZ, M. (1933)

Study of ability to wake at a specified time.
J. appl. Psychol. 17. 468-474.

ORME, J.E. (1962)

Time estimation and personality.
J. Ment. Sci. 108. 213-216.

PAPEZ, J.W. (1937)

A proposed mechanism of emotion.
Arch. Neurol. Psychiat, Chicago. 38. 725-743.

PAVLOV, I.P. (1928)

Lectures on Conditioned Reflexes: twenty five years of objective study of the higher nervous activity (behaviour) of animals.
Trans. by Gantt, W.H. and Volborth, G.
New York. International Publishers.

RAZRAN, G. (1961)

The observable unconscious and the inferable conscious in current Soviet Psychophysiology: interoceptive conditioning, semantic conditioning and the orienting reflex.
Psychol. Rev. 68. 81-147.

RICHTER, C.P. (1926)

The significance of changes in the electrical resistance of the body during sleep.
Proc. nat. Acad. Sci. Wash. 12. 214-222.

RICHTER, C.P. (1928)

The electrical skin resistance; diurnal and daily variations in psychopathic and in normal persons.
Arch. Neurol. Psychiat, Chicago. 19. 488-508.

RICHTER, C.P. (1929a)

Pathological sleep and similar conditions studied by the electrical skin resistance method.
Arch. Neurol. Psychiat, Chicago. 21. 363-375.

RICHTER, C.P. (1929b)

Physiological factors involved in the electrical resistance of the skin.
Amer. J. Physiol. 88. 596-615.

RICHTER, C.P. (1960)

Biological clocks in Medicine and Psychiatry: shock-phase hypothesis.
Proc. nat. Acad. Sci. Wash. 46. 1506-1530.

SCHAEFER, V.G. and GILLILAND, A.R. (1938)

The relation of time estimation to certain physiological changes.
J. exp. Psychol. 23. 545-552.

SCHEFFÉ, H. (1952)

An analysis of variance for paired comparisons.
J. Amer. statist. Assoc. 47. 381-400.

SCHILDER, P. (1936)

Psychopathology of time.
J. nerv. ment. Dis. 83. 530-546.

SCHNEIDER, D.E. (1948)

Time-space and the growth of the sense of reality; a contribution to the psychophysiology of the dream.
Psychoanal. Rev. 35. 229-251.

SCHONBACH, P. (1959)

Cognition, motivation and time perception.
J. abnorm. soc. Psychol. 58. 195-202.

SELYE, H. (1950)

The Physiology and Pathology of exposure to Stress: a treatise based on the concepts of the General Adaptation Syndrome and the diseases of adaptation.
Montreal. Acta.

SIEGEL, S. (1956)

Nonparametric statistics for the behavioral sciences.
pp. 184-193, 202-213, 229-238. London. McGraw-Hill.

STARK, L. (1959)

Stability, oscillations, and noise in the human pupil servo-mechanism.
Proc. Inst. Radio Engrs. N.Y. 47. 1925-1939.

STARZL, T.E, TAYLOR, C.W. and MAGOUN, H.W. (1951)

Collateral afferent excitation of reticular formation of brain stem.
J. Neurophysiol. 14. 479-496.

STENNETT, R.G. (1957a)

The relationship of alpha amplitude to the level of palmar conductance.
Electroenceph. clin. Neurophysiol. 9. 131-138.

STENNETT, R.G. (1957b)

The relationship of performance level to level of arousal.
J. exp. Psychol. 54. 54-61.

STEVENS, S.S. (1946)

On the theory of scales of measurement.
Science. 103. 677-680.

STEVENS, S.S, DAVIS, H. and LURIE, M.H. (1935)

The localization of pitch perception on the basilar membrane.
J. gen. Psychol. 13. 297-315.

STEWART, W.K. (1959)

Behaviour in conventional and extra-terrestrial flight: some future aspects of Aviation Medicine.
Nature, Lond. 184. 578-582.

STURT, M. (1923)

Experiments on the estimate of duration.
Brit. J. Psychol. 13. 382-388.

SWIFT, E.J. and McGEOCH, J.A. (1925)

An experimental study of the perception of filled and empty time.
J. exp. Psychol. 8. 240-249.

TARCHANOFF, J. (1890)

Über die galvanischen erscheinungen in der haüt des menschen bei reizungen der sinnesorgane und bei verschieden formen der psychiscen thätigkeit.
Pflug. Arch. ges. Physiol. 46. 46-55

THOMAS, P.E. and KORR, I.M. (1957)

Relationship between sweat gland activity and electrical resistance of the skin.
J. appl. Physiol. 10. 505-510.

THURSTONE, L.L. (1959)

The Measurement of Values.
p. 32. Chicago. University Press.

VENABLES, P.H. (1955).

The relationship between PGR scores and temperature and humidity.
Quart. J. exp. Psychol. 7, 12-18.

VERAGUTH, O. (1906)

La réflexe psycho-galvanique.
Arch. Psychol. Genève. 6. 162-163.

VIERORDT, C. von (1868)

Der Zeitsinn nach Versuchen.
Tübingen. Cited by James, W. (1890).
The Principles of Psychology. pp. 616 and 619.
London. MacMillan.

VIGOROUX, R. (1879)

Sur la role de la résistance éléctrique des tissues dans l'éléctro-diagnostic.
C. R. Soc. Biol. Paris. 31. 336-339.

WALLACE, M. and RABIN, A.I. (1960)

Temporal experience.
Psychol. Bull. 57. 213-236.

WALLER, A.D. (1919)

Concerning emotive phenomena.
II. Periodic variation of conductance of the palm of the human hand.
Proc. Roy. Soc. B. 91. 17-31.

WEBER, A.O. (1933)

Estimation of time.
Psychol. Bull. 30. 233-252.

WENGER, M.A. and IRWIN, O.C. (1936)

Fluctuations in skin resistance of infants and adults and their relation to muscular processes.
Univ. Ia Stud. Child Welfare. 12. 143-179.

WHITE, M.M. (1930).

Relation of bodily tension to electrical resistance.
J. exp. Psychol. 13. 267-277.

WHITELY, P.L. and ANDERSON, J.C. (1930)

The influence of two different interpolations upon time estimation.
J. gen. Psychol. 4. 391-401.

WITHERS, W.C.R. (1956)

A simple psychogalvanometer.
Electron. Engng. 28. 36-37.

WOODROW, H. (1930)

The reproduction of temporal intervals.
J. exp. Psychol. 13. 473-499.

WOODROW, H. (1933)

Individual differences in the reproduction of temporal intervals.
Amer. J. Psychol. 45. 271-281.

WOODROW, H. (1951)

Time perception. In Handbook of Experimental Psychology, ed. Stevens, S. S. pp. 1224-1236.
New York. Wiley.

WORKING PARTY (1961)

A discussion of the problem of unawareness.
Air Ministry, Flying Personnel Research Committee Memorandum. No. 171.

YERKES, R.M. and URBAN, F.M. (1906)

Time-estimation in its relation to sex, age and physiological rhythms.
Harv. psychol. Stud. 2. 405-430.