THESIS

Subject THE ESTIMATION OF TEMPORAL INTERVALS.

Name Rita D. MacMullan.

THE ESTIMATION OF TEMPORAL INTERVALS.

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CONTENTS

REPORT

of

COMMITTEE ON THESIS

THE undersigned, acting as a committee of the Graduate School. have read the accompanying thesis submitted by Miss Rita D. MacMullan for the degree of Master of Arts They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts.

Norman Wilde
Chairman

D. F. Swenson

Herbert Woodrow

June 5 1914

The Estimation of Temporal Intervals.

Introduction.

The present paper is the study of the estimation of intervals of time from .5 to 22 seconds in length. The accuracy of the estimation is found in the accuracy of the reproduction by the subject a few seconds after the standard has been presented to him. The interval is a space of time bounded by two auditory stimuli, which are always the same in quality, intensity, and duration. The duration is momentary and is not to be considered in the duration of the interval.

A subject's estimation of an interval can be judged by several methods. The method of ordinary experience is that of comparing an interval with a standard held in memory, the judgment being in terms of seconds, minutes, or other objective units of time. In the laboratory the following two types of method are used. The subject may compare two intervals and judge that one differs from the other in length, and in what direction the difference lies. This comparison is the essential feature in the psychophysical methods of constant stimuli and minimal changes, which have both been used in the estimation of intervals. He may, also, reproduce the length of an interval which has been presented to him by some signal. Of the methods just named, the one which has the greatest advantage for applicability and technical and mathematical simplicity is the method of reproduction. The methods of comparison do not give the estimation of the length of an interval, but only its relation to some other interval. The judgment is "longer" or "shorter" but not of how much longer or shorter, with any degree of accuracy. The threshold for the smallest difference in length between intervals which can be observed may be readily found by these methods, but nothing regarding the greater differences.

I. Historical.

The following summary of the literature will consider only those investigations which have special reference to the present problem, and will be reviewed under the same headings as the conclusions later presented.

1. Constant Error.

Investigations have been extensive on the subject of the existence of a constant error in the estimation of intervals of time. Constant errors may be positive, negative, or lacking. The absence of constant error has usually been found to exist for a small range of intervals only, among a larger number of intervals used in the experiment, and has received the name of the indifference point. Much of the work done has been based on the supposition that there is one length of interval or range of intervals which can be more accurately estimated than any other, and the results which have been found have led to quite radically different hypotheses. It has been thought by some psychologists to be a more or less permanent region, the same for all normal people. Stevens 1) says that there has been a preconceived theory which influenced experiments that there is in consciousness a "unit of time" which serves as the basis of all time estimation. This unit is equivalent to (quoting from Shaw and Wrinch)2) "the interval that lies between the short and long groups, which has been found to be the most accurately estimated interval. It differs in length more or less in different individuals, but in all cases the constant error and mean variation are less as we approximate to it. Here, neither the limiting impression, which influences the judgment of the shorter intervals, nor the originally function of content which influences the judgment of longer intervals, modifies the estimation to any marked degree. This remarkable fact, in connection with the estimation of intervals, that a more or less definite interval is estimated most accurately, and the further fact that as we depart from it in either direction errors arise in judgment, leads us to believe it to be the basis of the estimation of intervals in all cases - a temporal unit."

1) Am. Jour. Psy. XIII, 1902, 1.

2) U. of Toronto St. in Psy. - Series 2, 1898-1900.

Others - Glass 1), Edgell 2), find it differs for different individuals. Others - Mehner 3) have data showing a periodic indifference point, which comes at multiples of the lowest interval. That is, there are a number of intervals, which are all of certain multiples of the lowest, where there is little or no error of estimation. Others, like Münsterberg 4) find no indifference point.

The region of indifference and length of the indifferent intervals are shown in the following table. The region is shown as a few tenths seconds in one case, and several seconds in another. The length also seems to vary from the extreme of less than one second to one hundred and twenty seconds.

The nature of the error of estimation for intervals shorter or longer than those of indifference has not been agreed upon. Both over- and under-estimation for shorter and longer intervals have appeared. (See table)

The explanations offered for these discrepancies in results have been various and inadequate. Fewness of cases and subjects, physiological causes, and attention

1) Phil. St. IV, 1887, 423

2) Am. Jour. Psy. 1903, 14

3) Phil. St. II 1884, 546

4) Beitrage zur Experimentelle Psychologie, 1889.

differences, practice, emotion, etc., are touched upon, but little attention has been given to fundemental differences in technique. This point will be discussed later.

Summary of Literature

on the Constant Error in the Estimation of Intervals.

1 Name.	2 Date.	3 Meth.	4 No.S.& R.	5 Int.used.	6 I.P.	7 Est. Sh.	Lo.
Horing	'64	R & W C	m	.3-1.4	.36-.45	p	n
Vierordt	'68	R & W C	(m			more accur	
		Repr	(s	.25-8	dif by series	p	n
Kollert	'82	LPD	s	.4-1.8	.75	p	n
Mehner	'84	LPD	s	.71-12	.71 & 5 odd mult)	n	p
Glass	'87	AE	s		differs	p	n
Ejner	'89	AE	S.s.R.m.		120	p	p
			" R.s.		120	n	n
Münsterberg	'89	AE	s	6-60	no C.E.		
Stevens L.T.	'86	Repr	m	.36-1.5	.53-.87	n	p
Nichols	'91	Repr	m	.25-1.75	.81	n	p
Münsterberg & Wylie	'94	Cf. filled & unf.				underest where most attention	
Nelson	'02	Cf.	s	3-60	6-12	p	n
Stevens H.C.	'02	Repr	m		2.4-3.7	n	p
Edgell	'03	Repr			differs by subj.	p	n

Explanation of Table.

Column:

1. Name of experimenter.
2. Date of publication.
3. Method (Meth) used. Right and wrong cases (R & W C) and least perceptible difference (LPD) and comparison (Cf) are some form of comparison; reproduction (Repr) and average error (AE) are some form of reproduction.
4. Standard (S) and reproduction (R) single (s) or multiple (m)
5. Intervals (Int) used, in seconds.
6. Indifference point (I.P.)
7. Estimation of the other intervals used (Est), those shorter (Sh) and those longer (Lo) than the I.P. as positive (p) or negative (n).

2. Order.

All three psychophysical methods and their variations have been employed in investigating time.

Data by the methods of "right and wrong cases" and "least perceivable difference", while possibly to some degree not comparable, are yet closely related.

The method of average or mean error,- or reproduction - however, is essentially different. It may be used in several ways, the results of which may not be compared in all points on account of their dissimilarity. Thus the subject may reproduce the standard interval by a third beat, the first and second bounding the standard, the second both ending the standard interval and beginning the subject's reproduction. If the subject gives both beats to bound his interval, there is necessarily a space of time intervening between standard and reproduction which may vary in length. Or the reproductions may be multiple,- the subject beating regularly, for any number of times, the interval between each beat being considered as a reproduction of the standard interval. The standard also may be presented more than once in succession, and in at least one case the subject beat time with the sound giving the standard, continuing his beating (now called reproduction) after the standard has ceased. Stevens (L.T.)1), Nichols 2), and Stevens (M.C.)3), who used multiple norms and reproductions found constant error negative for intervals shorter than those of the indifference region and positive for those above. Nichols 4) says that single reproductions usually give the opposite result.

The effect on the estimation or reproduction of an interval by intervals preceding it has been observed. Discrepancies in his results were said by Estel 5) to be due to a contrast law by which short intervals appear shorter, and long intervals longer, after long and short intervals respectively. Others mention the same effect, but usually neglect, in their results, to show the order used. It is impossible to experimentally show this by the two comparison methods, minimal changes and right or wrong cases.

1) Mind XI, 1886, 393.
2) Am. Jour. Psy. IV, 1891, 60.
3) Am. Jour. Psy. XIII, 1902,1.
4) Am. Jour. Psy. III, 1891, 453.
5) Phil. St. II, 1884, 37

In a comparison of pairs, inequality - i.e., longness or shortness - is a difference between the two, and can not be referred directly to one or the other; if one interval appears "shorter", the other is "longer". Both may be over- or underestimated in respect to another interval. The constant error cannot be distinguished as belonging to one or the other, or both. It may also be noted that there are other intervals of time besides those desired in the experiment which occur during the experiment and which may have similar effect; namely those between the standard and reproduction and those from reproduction to the next standard.

An effect just opposite to that of contrast has been found in some of the experiments where the reproductive methods have been used, with more than one interval at a sitting. Nichols 1) found that practice on an interval makes the reproduction of the succeeding short interval longer and the succeeding long interval shorter. This agrees with the data of Hollingworth 2) on the inaccuracy of mus-

1) Am. Jour. Psy. IV. 1891. 60-112.

2) Inaccuracy of Movement. Archives of Psy. 1909.

cular movement. He found that when standard movements of different lengths were mixed irregularly in a single series, the reproductions of those of middle extent were reproduced most accurately, and that those shorter were lengthened and the longer were shortened in reproduction. In such a series, of course, short intervals will have to be proceeded most frequently by intervals longer than themselves, long intervals by those shorter, and the middle length will have an equal number of both longer and shorter intervals preceding it. Data on movement are analogous to that on time, since the factors, though qualitatively different, are corresponding, in that they are of judgments of magnitudes.

3. Weber's Law.

Weber's law is the generalization that the least added difference of stimulus that can be noticed is a constant proportional part of the original stimulus. Theoretically, the estimation of temporal intervals is subject to this law, as are the perceptions of weight, smell, light, tone, etc., where sensations of like quality but differing in another attribute have been quantitatively studied.

Titchener 1) says, "The differential limen is approximately constant, so the comparison of intervals falls under Weber's law." The experimenters have not all shown proof, however. Mach 2), Vierordt 3), Kollert 4), and Estel 5) say it does not hold: Mehner 6), that it does not hold below 7.1 seconds, but approximately above 7.1 seconds; Glass 7), that it holds approximately; Wundt, that it holds up to 5-6 seconds. Fechner 8), states in a criticism of Estel that nothing irreconcilable with Weber's law can be proved, and his experiments show that the law holds.

4. Attention.

Münsterberg and Wylie 9) and Nelson 10) give experiments on comparisons of empty and filled times,- of those intervals which are blanks, bounded by two stimuli, and those which are durations or repetitions of stimuli. Münsterberg and Wylie find that intervals filled by repeated stimuli were underestimated with respect to those filled by continuous stimuli,- underestimation where the interest of the observer was most engrossed - or attention attracted,

1) A Text Book of Psychology, 1911, 342.
2) Untersuchen über den Zeitsinn des Ohres. Moleschott's Untersuchungen, 1866
3) Der Zeitsinn, 1868.
4) Phil. Stud. I. 1882, 1.
5) Phil. St. II. 1884. 37.
6) Phil. Stud. II, 1884, 546,
7) Phil. Stud. IV. 1887, 423.
8) Ab. d.h.S.G. Wis. XIII, 3.
9) Psy. Rev. I. 1894, 85.
10) Psy. Rev. IX. 1902, 447.

according to the complexity of the filling material. Nelson found that time filled by light sensation (continuous?) was underestimated, compared with empty, but that by filling with flashes (subdivision of the interval) the empty time seemed shorter. She says, in discussion of the first, that psychologically the filled time was more empty, and attention wandered less. In empty time there were more changes in consciousness to remember, so the interval seemed longer, this being in keeping, she says, with the fact that increased mental activity produced by certain drugs makes time seem long.

Titchener 1) says it has been unfortunately supposed that the simplest time experience is the "empty" time between two limiting stimuli; but in fact there is no empty mental time, and the enclosed interval is the duration of something; the simplest time experience is the "filled" time, a duration of a tone, pressure, or obvious mental content. Within certain limits, an interval that is filled by a discontinuous series of sensations appears longer than an empty interval of the same objective length.

Thus, attention is of great importance in the estimation of intervals, but the conditions of the relationship are as yet practically unknown.

II. Apparatus.

Work on the estimation of temporal intervals has been somewhat neglected recently, owing, to a considerable extent, to the tediousness of the technique of the more careful experiments. In the earlier experiments the apparatus was as simple as it was inadequate, consisting chiefly of metronomes and watches, and the accuracy of the measurements depended on the eye or ear of the experimenter. In the more developed apparatus electrical or mechanical connections have been used, making the procedure automatic and thus eliminating the factor of the attention and reaction time of the experimenter (from the records). The time of the reproductions was recorded by vibrations of a tuning fork, the waves of which were marked on the smoked paper of a kymograph. This requires much time for the adjustment of the apparatus and conducting the experiment. The accurate counting of the vibrations is an immense task of both time and patience. This method of recording also has the disadvantage of limiting the length of the intervals used to those which are of brief duration, since the length of time is represented on the paper by spatial extents. It is only in the newer types of kymographs which turn in a spiral that the records of long intervals can be recorded, since in the other kind the length is limited to the time of one revolution of the cylinder. The longer the interval the greater is the labor of the experiment. It was therefore most desirable to find other means of recording the intervals of reproduction. It is also advisable to measure the length of the standard interval in presentation, as its length is difficult to control exactly. Its measurement varies from the exact period between the two stimuli as the subject receives it. It is assumed that the opening and closing of the relay occurs simultaneously with the click of the sound hammer. As the sound hammer works by means of a magnet, there is possibly an error of a few sigma, but this is quite constant. A Hipp Chronoscope measuring 1/1000 of seconds is, for many reasons, a most satisfactory recorder for this purpose. It is easily controlled, has a high degree of accuracy, and is readily placed in circuit with the other apparatus. A current passing through it starts the clockwork and its interruption stops it, or the opposite. The current must be made and broken at the limits of the interval, to be recorded.

The chronoscope was adjusted before each experiment to a Wundt's fall hammer, in the usual manner. The fall hammer was tested by a tuning fork of 250 vibrations per second, twice during the experiments, and its time was found to be exactly the same at both tests, its difference on the two occasions being less than .5, and in a reading of 156 sigma. The chronoscope had a constant error of plus 58 sigma. During the course of an hour's use of the apparatus, the current of the chronoscope circuit weakened slightly, but the amount was quite regular for all hours of experimenting, besides affecting the reading of both standard and reproduction. As the current was quickly restored when the circuit was opened and no sets of experiments took place without at least an hour intervening, the error would be the same in all experiments, and would be practically negligible.

It is also preferable that the subject should control both limits of the reproduced interval, and that the movement should be the same. Any constant error (or reaction time) which occurs in his movement at the beginning is counterbalanced by a similar time at the end of the interval. Should the movements be of a different kind - as first pressure on a key, holding it during the interval and releasing at the end; or of a different place - as pressing two keys; there is inevitably an error in time or a chance for error due to a shifting of attention and muscles during the interval; which destroys the accuracy of the measurement of reproduction. For this reason a key was constructed by successive pressures of which the circuit was alternately opened and closed. The use of this kind of a key is new in the study of time estimation and is a most important improvement in technique.

The diagram shows the principal features of the key. The wooden frame and brass plate which inclosed the wheels, as well as posts, screws, etc., are not drawn. The

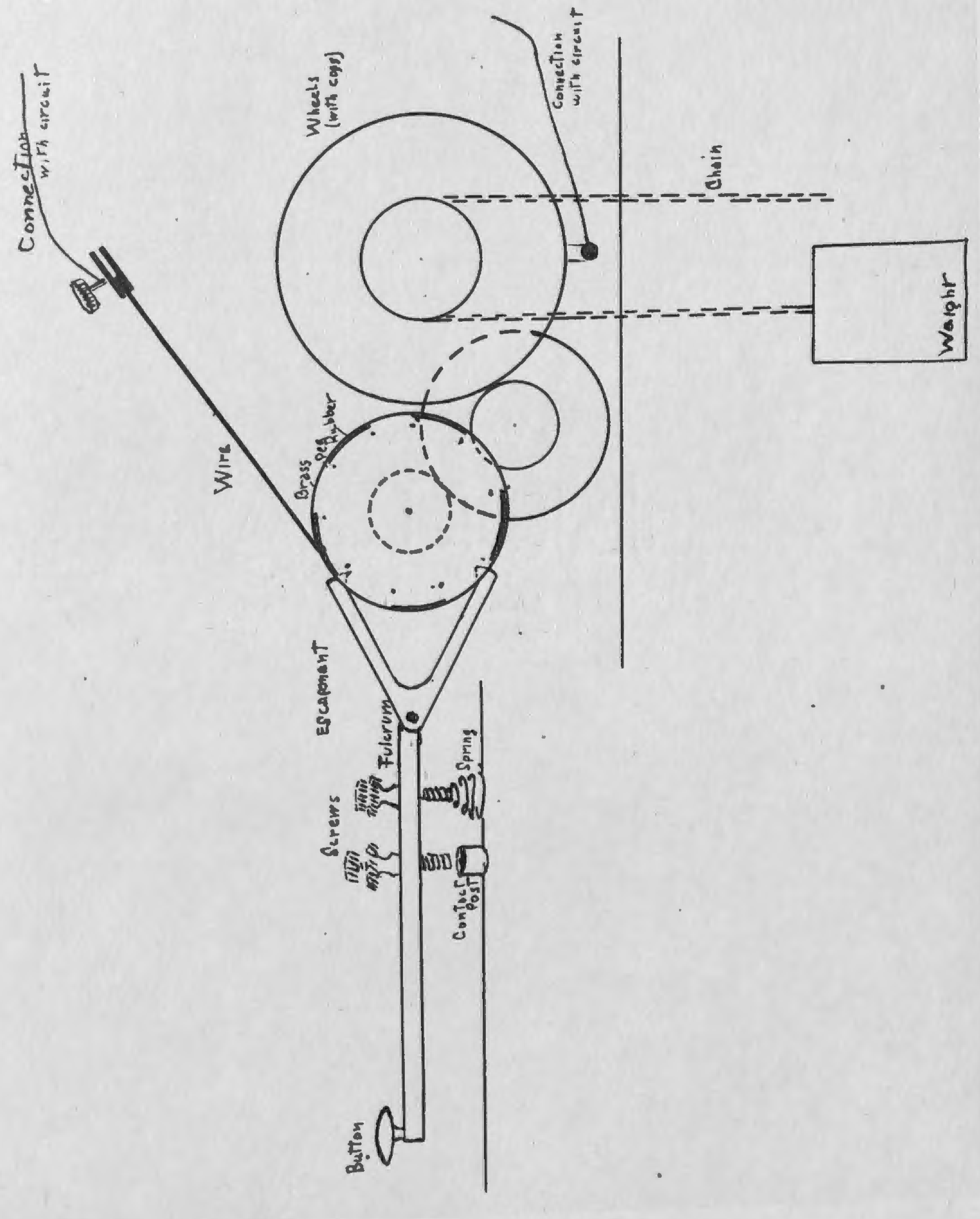
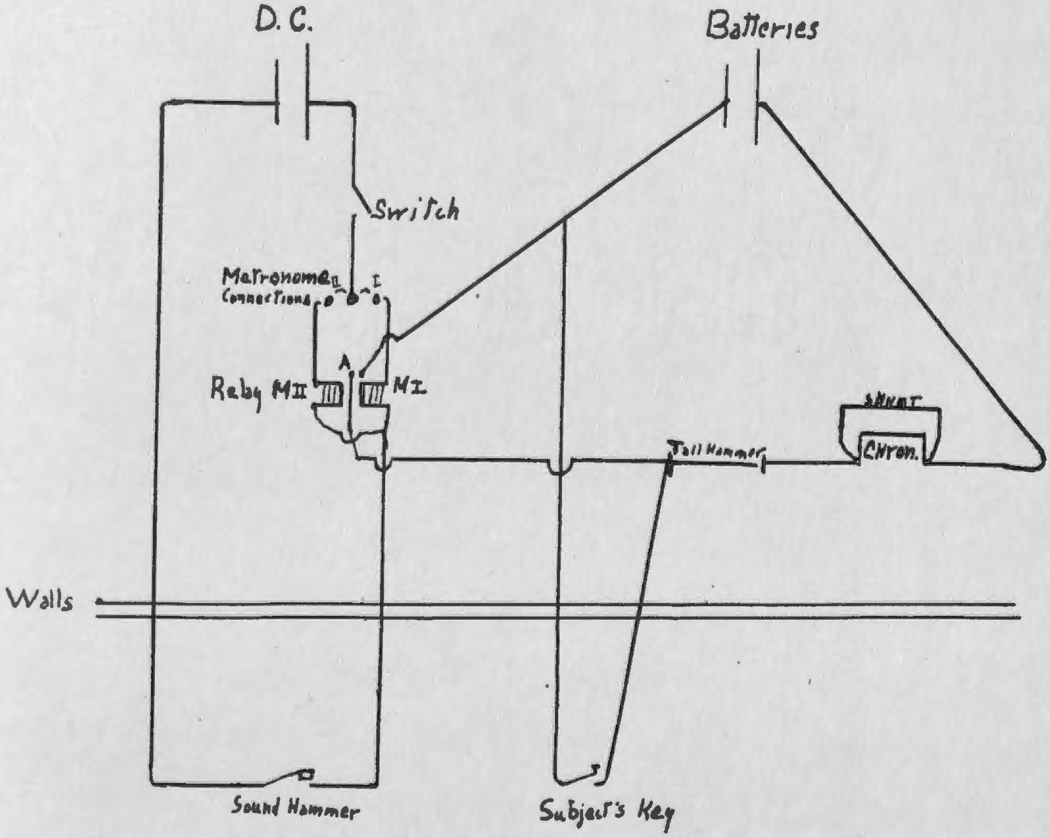


Diagram of Subject's Key.

dotted lines indicate the parts not visible from this view. The subject tapped the wooden button on the end of the bar about four inches from the fulcrum. When released the bar quickly returned to its original position by means of the spiral spring. The other end of the bar, beyond the fulcrum, formed an escapement with two teeth which caught the pegs in the wheel. When these pegs were released, the wheel turned as far as the next peg by the force of gravity, which was exerted by the weight to turn another wheel which connected with the first wheel by cogs on each of these and on the intermediate wheel. These wheels and their connections were of brass so that the current passed through them readily. Alternate sections on the rim of the first wheel between each pair of the ten pegs were of brass and India rubber, so that the circuit was alternately opened and closed as the wheel turned against a wire which pressed constantly on the rim. The subject's tap had to be of sufficient force to overcome the friction of the wheels, the pressure of the wire and the gravity exerted by the weight. The weight and the contact of the wire were so adjusted that the wheel moved swiftly, yet the pressure required in the subject's tapping movement was slight. The subject's tap caused a screw in the bar to strike a metal post with a sharp click. This click and not the tap was simultaneous with the release of the pegged wheel, i.e. the opening and closing of the circuit, and so marked the beginning and end of his reproduction. The standard intervals were presented by clicks of a sound hammer, which were of medium intensity and somewhat similar to those which the subject made. The length of the intervals--the time between the clicks--was controlled by a metronome with mercury cup connections, contact in one cup making the circuit through the chronoscope, and in the other cup breaking it. A switch made it possible to connect or disconnect the metronome and the apparatus. The metronome timed the starting of the chronoscope and was then disconnected, allowing the clock to run. At the desired time (which the experimenter counted by the beats of the metronome), it was again connected, (between the beats) and the clock stopped when the contact in the mercury cup was next made.

The accompanying diagram shows the apparatus schematically. Reference to it will make clear the following description of the procedure. The metronome was started at the desired rate for the intervals to be used, and its switch closed just before contact was made in mercury cup I. The contact closed a direct city circuit and caused the sound hammer to click, at the same time closing the battery circuit through magnet I of the relay, thereby starting the chronoscope clock. Contact in mercury cup II of the metronome caused another click from the sound hammer, and opened the chronoscope circuit through magnet II of the relay, thus giving the time of the interval between the two sound hammer clicks,--the standard interval. The experimenter then recorded the reading of the clock in the two to four second pause which the subject was instructed to allow before giving his reproduction. The connections of the apparatus were so made that the chronoscope circuit could be closed by either of two routes--one through the relay, and the other through the subject's key. During the time previous to this the subject's key had been open. Now the subject tapped the key, closing the circuit, and the clock started; he tapped again, opening the circuit, and the clock stopped. The time of the subject's reproduced interval was now recorded. The whole procedure was then repeated. The subject's key and the sound hammer were in a quiet room in the laboratory of the third floor of the building; the rest of the apparatus was on the fourth floor, out of hearing of the subject.


D. C.
Batteries
Switch
Metronome II I
Connections
A
Reby MII
MI
Shunt
Tall Hammer
Chron.
Walls
Sound Hammer
Subject's Key

Apparatus,

III. Data.

The records are here given of the work of three subjects, six experiments each. Three series of standard intervals were used, twice with each subject. The experiments lasted about one hour a daym abd were done within a period of a week or two for each subject. Series I. consisted of six intervals: .5, 1., 1.5, 2., 2.5, and 3. seconds repeated ten times (one case fifteen times) each, in regular order from the shortest to the longest. This was used the first and third days. Series II consisted of another six intervals, 2, 6, 10, 14, 18, 22 seconds, repeated ten times each, in regular order, beginning with the shortest. It was used the second and fourth days. Series III was an irregular arrangement of the intervals of series II, so arranged in a set of thirty intervals, that each interval was used five times, each time being preceded by a different interval. Thus every interval succeeded every interval but itself, except in the case of the first and last interval of the experiment. These were, though, the middle lengths of intervals, 10 and 17.

The same arrangement was repeated twice, giving a series of the same number of intervals as Series I and II, and was used the fifth and sixth days. The complete pattern of the order was too long to be memorized. The subjects were instructed to give close attention to the experiment, to refrain from counting, tapping, or other similar means of assisting in estimation, as far as possible. They were to attend to each interval as it came, independently, and after two to four seconds to reproduce it by the two taps on the key. This pause was not determined or measured, but subjects with a little practice adopted one of generally uniform length, without difficulty. They were to reproduce each interval as it seemed to be, not what they thought it ought to be or were expecting. The giving of the latter sort of these instructions does not assure that they were carried out in entirety, and does not mean that all subjects went through absolutely the same process during the experiment. It does mean, however, that the experimental conditions were the same for all subjects, and that no subjects were acting in opposition to the imposed conditions.

The subject knew which series was to be used, though he did not know of any system in the irregularity of Series III, that is, that the groups of six intervals contained each of the six and that no interval followed the same interval twice within the thirty intervals. In the regular series a signal, several clicks of the sound hammer, was given at the change in length of interval, and there was usually a longer pause. This was done in order that there might be as little effect as possible from the change of interval. It is likely that the effect of contrasted lengths of intervals is less if it is expected. The suddenness of unexpected change finds the subject's attention not able to adjust so as to perceive the new interval with normal accuracy. The difference in the length of the steps between the intervals was larger than a just noticeable difference, so that there was no possibility of suggesting an increase which could not be perceived.

The chronoscope had a constant error of plus 56. This, of course, affects only the records of standard and reproduction, and does not affect the constant error or the mean variation. In the following tables it has been deducted only from the tables at averages and its presence should be noted in the individual tables.

Chauvenet's[1] criterion for the rejection of doubtful cases was roughly applied. Standard and reproduction intervals which varied from their respective averages by more than three times the mean variation were discarded. Approximately one in twenty cases were therefore not considered in the regular series. No cases were rejected in the irregular series, since irregularity in the results cannot be distinguished as error when such is to be expected as an effect of the irregularity in presentation of intervals, and with so few (generally four) cases where the same conditions of irregularity are found, rejection of any cases seemed unwarranted. It is highly probable, however, that about one-twentieth of the cases - the same proportion as in the regular series - are subject to error.

The tables show each standard and reproduction interval, in sigma, the average and mean variations of both and the constant error of the reproductions, with its mean variations. Each table cntains the work of one subject in

1) Merriam; The Method of Least Squares. 1903, pages 166,228.

one day.

The summarized tables are the average of the two experiments with the same series, and are arranged by subjects. It should be noted that the mean variations in these tables are the average of the mean variations for each day - i.e. of the series of ten, and are not the mean variations of all cases from the average of the twenty.

The abbreviations are St.., standard interval; Repr., reproduction; Av., average ; M.V. , mean variation; C.E., constant error.

The mean variations of the constant error are plotted for each subject and the curves of the three subjects are combined, since they follow the same general direction. The ordinates represent the mean variation of the constant error for each length of interval and the the average length of the reproductions of the interval. The combined curves are found graphically by taking the average of the three curves at points (on the plot) .4 inches apart,- or twice as many points as there were intervals. This was necessary because the average and reproduction were not the same for the different subjects, so did not fall in the same ordinate. When the points on both the abscissasand the ordinates vary from the fixed units, the combined curve more nearly represents the combination of the three curves, the more points at which the graphic averages are taken.

Subject--W. Series--I.A. Regular order.

	.5		1.0		1.5		2.0		2.5		3.0	
	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr
	550	376	1055	862	1548	1986	2068	2819	2515	2429	3142	4518
	429	385	1039	1409	1581	1964	2026	2251	2519	3032	3150	3379
	397	504	1044	1118	1508	1609	2079	2567	2462	3050	3133	3185
	499	480	1083	1214	1521	1472	2052	2168	2632	2856	3135	3322
	511	421	1074	1137	1517	1897	1953	2353	2532	2212	3142	3594
	503	444	1062	1153	1501	1515	1982	1810	2525	3231	3127	3377
	494	415	1055	993	1502	1631	2079	2270	2463	2569	3142	3592
	516	465	1071	916,	1557	1691	2039	2370	2467	2428	3083	4440
	565	564	992	1047	1538	1617	2081	1816	2341	2785	3065	3282
	412	398	1081	1013			2072	1746	2347	3011	3141	4500
Av.	488	435	1056	1086	1530	1709	2043	2217	2480	2760	3126	3719
M.V.	45	42	13	124	23	171	34	266	64	281	21	430
C.E.	-53		+30		+179		+174		+280		+593	
M.V.	38		121		147		153		303		463	

Subject--W. Series--I.B. Regular order.

	.5		1.0		1.5		2.0		2.5		3.0	
	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr
	571	536	1128	2031	1636	1600	2153	2327	2614	3650	3147	3706
	559	461	1129	1419	1614	1878	2108	2358	2671	3784	3160	2962
	588	520	1130	1650	1537	1594	2106	2669	2656	2684	3157	3595
	580	671	1131	1327	1592	1604	2093	2432	2615	3135	3157	3746
	585	650	1140	2140	1675	1761	2093	2528	2727	3169	3156	3114
	588	673	1137	1469	1607	2372	2101	2871	2610	2785	3155	3569
	555	540	1134	1407	1640	1894	2105	2287	2674	2922	3162	3401
	589	782	1134	1601	1554	1948	2090	2372	2597	3067	3163	3962
	585	555	1131	1495	1560	2009	2086	2032	2560	3152	3160	3296
	588	525	1134	1270	1610	1912	2080	2525	2532	3465	3160	3356
Av.	579	591	1133	1581	1602	1857	2101	2440	2626	3181	3158	3471
M.V.	10	82	3	220	34	174	14	167	45	271	3	245
C.E.	+12		+448		+255		+339		+555		+313	
M.V.	77		220		180		171		291		247	

Subject--W. Series--II.A. Regular order.

	2		6		10		14		18		22	
	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr
	2099	2192	6177	5093	10409	11502	14172	12885	18206	16842	22041	24294
	2092	2346	6112	6445	10403	10835	14089	12911	18210	19614	21861	22497
	2114	2000	6202	5988	10311	11238	14069	14201	18176	17712	21860	22222
	2091	2440	6337	6646	10244	9874	14055	17183	18301	16780	21749	26340
	2084	2266	6180	7137	10276	10960	14060	15792	18031	20138	22042	24050
	2100	2215	6110	7945	10343	10359	14157	19760	18163	21005	21948	20216
	2088	2100	6232	9468	10129	10816	14173	15982	18335	22122	22048	22692
	2120	2387	6174	8265	10196	12754	14165	18273	18206	24242	22036	25005
			6223	7333	10236	13525	14235	14409	18181	22928	21774	25268
			6297	8016	10273	11447			18014	21461	22003	24782
					10160	11220						
Av.	2098	2243	6204	7234	10270	11320	14130	15710	18182	20284	21936	23737
M.V.	10	116	54	972	73	717	56	1875	69	2067	100	1464
C.E.	+145		+1030		+1050		+1580		+2102		+1801	
M.V.	118		968		713		1895		2071		1458	

Subject--W. Series--II.B. Regular order.

	2		6		10		14		18		22	
	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr
	2152	2143	5912	6294	9843	8560	14024	12868	18113	17583	21963	21156
	2145	2252	5841	5093	9830	9837	14013	19660	18014	20148	21844	28680
	2134	2623	5947	6152	10068	11484	14067	15781	18009	17525	21918	18857
	2099	2415	5841	6746	10019	10247	14097	17784	17970	20980	21890	23585
	2064	2524	5908	7489	9992	7941	14121	16008	17813	21512	21680	25652
	2112	2186	5902	6843	9885	8819	14126	17027	17877	20755	21640	29723
	2079	2449	5951	7695	9847	12180	14132	15708	17853	15640	21660	20581
	2089	2383	5928	6817	10127	13326	14107	21343	17822	19036	21522	20300
	2112	2443	5942	8741	10141	11077	14050	18530	17788	19204	21660	21497
	2015	2817	5967	6895	10105	9655	14047	20615	17917	23700	21640	26998
					10113	10390						
Av.	2100	2423	5914	6871	9997	10317	14078	17532	17918	19608	21742	23703
M.V.	31	148	24	663	107	1308	41	2054	77	1811	130	3248
C.E.	+323		+963		+320		+3454		+1690		+1961	
M.V.	167		647		1241		2070		1809		3281	

Subject--W. Series--III.A. Irregular order.

	2		6		10		14		18		22	
	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr
	1937	2623	5964	8600	10060	7338	14050	16775	18040	29663	21878	15534
	1958	2090	5950	5525	9792	8882	13795	11010	17828	13878	21748	11479
	1927	2867	5813	6878	9660	18542	13700	19882	17586	19933	21507	12773
	1892	2267	5775	5951	9800	4142	13727	12136	17815	12955	21317	25240
	1897	2503	5913	6622	9865	13577	13497	14350	17755	16772	21470	22341
	1892	1677	5883	6577	9756	11817	13645	11005	17497	13528	21453	18500
	1867	1290	5754	6294	9870	8215	13425	12248	17310	12625	21265	18298
	1854	2082	5775	10181	9561	11500	13524	7990	17335	14955	21255	22395
	1892	1855	5778	4573	9754	13625	13585	16265	17327	16083	21343	21335
	1865	2208	5975	3880	9727	11886	13528	9745	17417	26363	21338	30543
Av.	1898	2146	5858	6508	9784	10952	13648	13141	17590	17775	21457	19844
M.V.	25	347	79	1262	93	3047	136	2821	214	4426	155	4527
C.E.	+248		+650		+1168		-507		+185		-1613	
M.V.	342		1251		3123		2894		4472		4370	

Subject--W. Series--III.B. Irregular order.

	2		6		10		14		18		22	
	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr
	1913	1952	5454	4905	10008	12164	13656	14047	17300	14795	20242	23153
	1826	2520	5925	7835	8958	12183	13895	12980	18073	28035	21742	20833
	1810	2375	6060	6872	9870	13600	13521	9556	17670	12502	21118	17041
	1967	2227	6150	5546	9883	10970	13953	10578	17986	17016	21997	19392
	1924	2145	6130	9308	10046	13590	14090	16367	18195	26532	22005	28090
	1838	2480	5988	5720	9988	7166	13978	13730	17923	14777	21905	22232
	1950	2125	5945	6973	10121	16384	13482	17930	18031	14597	21824	15258
	1982	2848	5930	6048	9822	13234	13920	15338	18100	14695	21830	21792
	1947	2640	5886	6538	9897	10882	13908	11805	17834	23270	21893	25050
	1944	2501	5856	10155	9863	13427	13710	7270	17723	22444	21583	21635
Av.	1910	2381	5932	6990	9846	12360	13811	12960	17883	18916	21614	21448
M.V.	51	216	122	1266	182	1687	175	2526	201	5033	380	2653
C.E.	+471		+1058		+2514		-851		+1033		-166	
M.V.	238		1243		1731		2509		4966		2699	

Subject--L, Series I.A. Regular Order

	.5		1.		1.5		2.		2.5		3.	
	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr
	591	534	1050	963	1542	1411	2103	2011	2517	2975	3118	1992
	614	647	1048	1023	1554	1432	2011	1680	2457	2722	3117	2177
	583	460	1052	902	1578	1389	2069	1839	2523	2372	3122	2028
	586	665	1048	966	1567	1159	2102	1792	2560	1784	3126	2318
	580	616	1048	989	1561	1056	2060	2382	2467	2320	3122	2935
	569	483	1044	898	1590	1278	2039	2254	2509	3497	3118	1768
	581	484	1052	876	1584	1342	2048	1682	2514	2115	3117	2412
	589	495	1059	867	1574	1150	2024	1689	2450	1512	3130	2803
	551	474	1051	996	1578	1585	2044	1624	2512	1707	3129	2538
	581	561	1013	850	1578	1336	2039	1676	2585	2350	3126	2364
	582	441	1045	827	1576	1195	1957	2642	2548	2060	3111	2413
	583	533	1039	962	1579	1241	2049	1834	2570	1867	3110	2049
	578	496			1574	1213	1981	1678	2472	1811	3109	2228
					1574	1335	2062	1434	2499	2127	3102	2856
					1578	1305	2024	1708	2560	2948		
Av.	581	530	1046	926	1572	1295	2041	1862	2516	2278	3118	2349
M.V.	9	58	7	57	9	102	28	246	33	434	6	268
C.E.	-51		-120		-277		-179		-238		-769	
M.V.	54		51		105		246		432		268	

Subject--L. Series I,B. Regular Order.

	.5		1.		1.5		2.		2.5		3.	
	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr
	498	433	1013	1029	1475	1419	1957	2867	2528	2371	3195	2995
	501	450	1011	892	1464	1488	2029	1868	2550	1917	3060	2514
	494	427	1007	1078	1496	1284	2026	2418	2601	2208	3196	2993
	486	450	905	957	1508	1200	1974	1548	2513	2071	3121	3238
	484	434	999	979	1504	1585	1969	1712	2520	2382	3207	1978
	497	443	956	888	1476	1556	1910	2041	2495	2227	3199	2797
	486	475	1016	935	1480	1825	2017	1552	2500	1946	3109	3008
	471	417	1016	1026	1491	1611	1831	1703	2349	1819	3078	3083
	470	458	1015	1052	1504	1347	1914	1753	2337	2032	3058	1912
	466	471	998	951	1543	1877	2008	1855	2500	1651	3191	2571
Av	485	446	994	979	1494	1519	1963	1932	2489	2062	3141	2709
M.V.	10	15	25	54	17	172	48	316	59	189	56	372
C.E.	-39		-15		+25		-31		-427		-432	
M.V.	21		52		172		306		175		362	

Subject--L. Series II-A. Regular order.

	2		6		10		14		18		22	
	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr
	2127	1313	6058	2555	10126	5869	14002	10425	18109	16820	22319	15833
	2084	1346	6059	3946	10155	6160	14035	13874	17996	20821	22227	16235
	2102	1371	6117	3335	10125	6153	14021	12924	17961	12754	22195	18650
	2047	1539	6092	3998	10109	7560	14188	10482	18077	16252	22240	26198
	2088	1583,	6167	3707	10099	8106	14058	12518	18069	11423	22389	17528
	2031	1480	6081	3831	10036	8743	14088	11813	17830	18191	22378	16570
	2059	1637	6099	4359	10044	9490	14025	10660	17872	15338	22732	24893
	2006	1235	6058	5023	9972	10462	14080	18774	17884	18628	23032	30242
	2024	1672	6087	4797	9982	6980	14099	14015	17912	12354	22825	23562
	2041	2116	6105	4320	9966	10415	14153	13776	18070	18607	22634	18319
Av.	2061	1529	6092	3987	10061	7994	14075	12926	17978	16119	22497	20803
M.V.	31	181	24	412	61	1449	47	1747	76	2521	247	4338
C.E.	-532		-2105		-2067		-1149		-1859		-1694	
M.V.	189		516		1487		1734		2512		4168	

Subject--L. Series II-B. Regular order.

	2		6		10		14		18		22	
	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr
	1962	1493	6056	1733	10139	7465	13909	12472	18140	13071	22165	25715
	1984	1368	5927	2749	10200	8534	13939	10316	17965	18185	22154	15268
	1932	1510	6223	2637	10165	8427	14069	9802	18239	22034	22178	22623
	1904	1437	6035	4830	9934	7389	13756	13949	17898	16507	22237	22614
	1918	1689	6190	2734	9889	11907	14499	12609	18060	21830	21997	21148
	1879	1530	6030	7179	9938	13809	14200	12422	17940	25523	21900	16097
	1999	1790	6073	6288	10148	13662	13128	12113	17681	19319	21862	15720
	1931	1813	5846	3152	10156	5817	14458	20211	17780	16635	21711	21777
	1815	1669	6216	6449	10035	14671	14035	16363	17806	17908	21679	21361
	2046	1911	6075	4225	10182	8123			18005	19747		
Av.	1937	1621	6067	4198	10079	9980	13999	13362	17951	19076	21987	20258
M.V.	49	153	88	1597	104	2825	251	1330	130	2581	177	3042
C.E.	-316		-1869		-98		-637		+1125		-1729	
M.V.	149		1578		2796		2268		2357		3043	

Subject--L. Series III-A. Irregular order.

	2		6		10		14		18		22	
	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr
	2157	1548	6218	11997	10351	10742	14364	10717	18283	29705	22528	19665
	2184	1979	6195	5569	10265	6215	14673	10342	18702	19081	22416	19198
	2211	1620	6152	6151	10323	16293	14436	13142	18508	13795	22502	21307
	2124	2148	6216	9206	10287	17290	14223	15691	18163	9083	22373	15372
	2135	1709	6127	3830	10200	13909	14530	11043	18427	8988	22231	8298
	2204	2040	6243	7398	10389	10243	14511	11236	18701	10343	22735	18362
	2184	1533	6477	6805	10467	11446	14386	10791	18528	8360	22888	21237
	2154	1524	6222	4539	10370	5464	14346	16406	18395	13391	22574	21706
	2148	2049	6192	5014	10257	11122	14380	13385	18210	15487	21272	22821
	2218	1660	6232	5473	10338	11916	14334	14603	18260	15485	22384	18017
Av.	2173	1781	6227	6598	10326	11464	14418	12736	18418	14372	22390	18598
M.V.	28	218	54	1803	58	2710	95	1910	155	4454	160	2869
C.E.	-391		+371		+1139		-1682		-4046		-3792	
M.V.	224		1762		2741		1985		4497		2901	

Subject--L. Series III-B. Irregular order.

	2		6		10		14		18		22	
	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr
	2112	1581	6113	4264	10131	8177	14035	8050	17940	12067	22034	12651
	2170	1748	6145	8055	9983	7025	14093	12514	17989	6701	21988	15007
	2182	2006	6135	4487	10207	8334	13990	17275	18107	9627	22009	21857
	2164	2502	6120	3260	10055	10800	13882	13728	17977	13498	21800	18791
	2160	1906	6075	2782	10016	9605	13922	13505	17863	17402	21850	16413
	2143	1659	6091	10044	10000	8008	13917	16523	17849	14571	21862	25181
	2177	1388	6032	3150	10040	9515	13848	15750	17879	11783	21692	25175
	2202	1523	6045	4530	10035	8514	13870	11210	17751	18520	22507	22074
	2153	1646	6045	7008	10013	16680	13762	11154	17765	22793	21497	16901
	2141	1811	6015	5242	9888	11562	13745	14745	17732	18069	21450	15187
Av.	2160	1777	6082	5282	10037	9822	13906	13445	17885	14503	21869	18724
M.V.	19	223	39	1852	57	1815	85	2171	94	3768	212	3492
C.E.	-383		-800		-215		-461		-3382		-3145	
M.V.	223		1849		1846		2198		3861		3387	

Subject--T. Series--I.A. Regular order.

	.5		1.0		1.5		2.0		2.5		3.0	
	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr
	576	857	1106	1359	1597	2578	2177	3488	2813	4385	3165	3902
	564	869	1106	1529	1598	2704	2144	3847	2626	4646	3162	3050
	570	874	1109	2240	1600	3073	2108	3713	2734	3629	3159	2669
	566	729	1104	2340	1594	2935	2114	5113	2678	5184	3167	4221
	570	780	1109	1536	1604	2080	2086	3156	2683	4807	3156	4233
	569	505	1110	2478	1615	2425	2050	3801	2631	3396	3153	3964
	550	652	1116	2107	1595	2417	2065	2070	3148	3927	3163	2651
	569	723	1112	2308	1590	2429	2048	3023	3084	4416	3169	2371
	571	668	1106	2861	1589	2291	2013	2806	2748	5100		
			1116	3159	1589	2501	2045	2319	2695	2588		
Av.	567	740	1109	2192	1597	2543	2085	3334	2784	4108	3162	3383
M.V.	5	108	4	447	6	224	41	658	139	778	4	697
C.E.	+173		+1083		+946		+1249		+1324		+221	
M.V.	91		446		223		625		792		699	

Subject--T. Series--I.B. Regular order.

	.5		1.0		1.5		2.0		2.5		3.0	
	St	Repr	St	Repr	St	Repr	St.	Repr	St	Repr	St	Repr
	564	826	1079	1480	1576	1640	2111	2813	2580	5106	3080	5648
	561	637	1084	1525	1576	2195	2085	3345	2534	2940	3096	4739
	559	890	1085	1848	1578	1628	2093	3278	2479	3707	3106	4889
	564	821	1082	1439	1579	1912	2090	3935	2522	4001	3111	3847
	560	812	1087	1594	1582	2802	2064	3385	2513	3665	3116	3503
	560	852	1081	1324	1579	3327	2062	3810	2478	4470	3106	3729
	559	811	1081	1125	1580	2078	2060	2941	2475	3356	3111	5363
	560	678	1082	1542	1576	2225	2065	4566	2519	4194	3101	4348
			1081	1421	1575	1925	2059	3383	2485	3131	3110	5207
					1582	2888	2074	3538	2544	4550	3112	5405
Av.	561	790	1082	1477	1578	2262	2076	3499	2513	3912	3105	4668
M.V.	2	68	2	134	2	446	15	371	27	552	7	649
C.E.	+229		+395		+684		+1423		+1399		+1563	
M.V.	68		133		444		373		537		652	

Subject--T. Series--II.A. Regular order.

	2		6		10		14		18		22	
	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr
	2052	2290	6016	4383	9862	6914	14029	12031	17756	16250	22214	23252
	2050	2584	5992	4692	9860	10444	14008	14304	17694	22059	22462	25601
	2012	2909	6002	5813	9927	8764	14030	11266	18221	16947	22236	22725
	2056	2646	6013	6055	9939	6601	13838	9700	17629	16630	23345	19991
	2032	2917	5987	4355	9905	9647	13842	11218	18871	20962	22800	24374
	2049	2954	6033	5112	9962	8308	13858	8670	18520	21365	22818	21168
	2058	2805	5971	7189	9919	11074	14032	14557	18327	15672	22625	16781
	2048	2833	5970	7336	9971	11251	13738	15263	18250	19523	22411	22122
			5997	4400	9967	9498	13854	13048	18203	15204		
			6011	8492			13793	11280	18191	15801		
Av.	2045	2742	5999	5783	9923	9167	13901	12134	18166	18041	22614	22002
M.V.	11	177	16	1194	33	1351	98	1727	284	2349	282	1766
C.E.	+697		-216		-756		-1767		-125		-612	
M.V.	183		1201		1350		1723		2365		2253	

Subject--T. Series--II.B. Regular order.

	2		6		10		14		18		22	
	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr
	2108	1814	6116	4012	10154	6800	14516	17028	18496	23764	23296	23231
	2098	2588	6100	3877	10316	9718	14574	16478	18448	25720	22997	22811
	2080	2007	6134	4186	10306	9284	14515	9394	18324	27956	22813	27439
	2105	2214	6141	3221	10275	11333	14885	14177	18293	28672	22891	23363
	2113	2156	6144	4377	10306	11223	14531	14989	18676	23907	22815	25215
	2092	2314	6106	5233	10209	7163	15067	12718	18627	16747	22370	17522
	2087	2369	6091	4567	10238	7792	14650	12312	19011	16485	22643	19398
	2085	2207	6148	4530	10234	9385	14607	14455	18744	24468	22655	20762
	2075	2030	6101	4232			14502	12834	18784	29226	22441	21732
	2095	2330	6147	4658			14889	10523	18937	23492	22657	21279
Av.	2094	2203	6123	4289	10255	9087	14674	13490	18634	24044	22758	22275
M.V.	10	161	20	384	46	1377	164	1935	196	3164	204	2137
C.E.	+109		-1834		-1168		-1184		+5410		-483	
M.V.	181		439		1360		1985		3280		1932	

Subject--T. Series--III.A. Irregular order.

	2		6		10		14		18		22	
	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr
	2163	2213	5842	5421	9700	7495	13194	7750	18241	12202	22244	17285
	2154	1200	6184	2785	10155	4727	14233	9668	18272	11984	22268	12355
	2170	1768	6134	5807	10431	7788	14136	12559	18406	8441	22313	9854
	2123	800	6128	2456	10066	7784	14058	8396	18041	9638	21985	20150
	2105	1201	6051	2183	10052	8674	14089	14371	17967	15869	21993	10476
	2141	1293	6128	7030	10100	7614	14140	19493	18245	13100	22175	13468
	2119	1355	6197	7060	10194	10906	14029	8812	17982	20754	22120	16461
	2105	1780	6093	2800	10077	8230	14090	13607	18026	11121	22020	22117
	2138	897	6110	7047	10117	7460	14178	15824	18083	11453	22123	12380
	2172	1580	6113	2049	10104	11316	14083	9204	18090	20182	22104	4433
Av.	2139	1409	6098	4464	10100	8299	14023	11968	18135	13474	22134	13898
M.V.	21	341	62	2009	100	1000	166	3203	125	3277	93	4084
C.E.	-730		-1634		-1801		-2055		-4661		-8236	
M.V.	331		2025		1388		5098		3350		2059	

Subject--T. Series--III.B. Irregular order.

	2		6		10		14		18		22	
	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr	St	Repr
	1647	1153	6115	6810	10220	10313	14165	18335	18022	12168	22410	17350
	1913	1220	6003	5597	9970	3633	13950	6352	17636	7140	21305	8648
	1926	935	5687	4703	9270	2167	13536	13345	16827	11775	21208	25485
	1734	948	5749	1763	9358	6312	13561	9434	16083	11152	20642	21385
	1752	1178	5740	4695	8690	4924	13063	8070	16465	9507	19187	27537
	1932	836	5930	2101	9450	7725	13129	5270	17454	10628	21637	15716
	1914	811	5237	2011	9600	9571	12904	7300	17839	17215	19989	6325
	1936	1500	5826	4114	9287	10313	13705	9585	17752	12583	20143	15787
	1900	1582	5889	3013	8826	4454	13215	6100	16927	12684	21480	17626
	1907	824	5849	4406	9759	6722	13676	5889	17621	8481	21496	26303
Av.	1856	1099	5802	4021	9443	6613	13490	8968	17265	11333	20950	18216
M.V.	85	228	152	1240	355	2316	331	2967	551	1952	767	5569
C.E.	-758		-1781		-2830		-4522		-5932		-2734	
M.V.	254		1240		2136		2765		1738		5822	

Averages of Series. (Corrected for C.E. of Chronoscope).

Subject--W.

	Av.St.	M.V.	Av.Repr.	M.V.	C.E.	M.V.
Series I.						
.5	477	27	457	62	- 20	57
1.0	1038	8	1277	172	+ 239	170
1.5	1510	28	1727	172	+ 217	163
2.0	2016	24	2272	216	+ 256	162
2.5	2497	54	2914	276	+ 417	297
3.0	3086	12	3539	337	+ 453	355
Series II.						
2	2043	20	2277	132	+ 234	142
6	6003	39	6999	817	+ 996	807
10	10077	90	10762	1012	+ 685	977
14	14048	48	16565	1964	+2517	1982
18	17994	73	19890	1939	+1896	1940
22	21783	115	23664	2356	+1881	2369
Series III.						
2	1848	38	2207	281	+ 359	290
6	5839	100	6693	1264	+ 854	1247
10	9759	137	11600	2367	+1841	2437
14	13673	155	12994	2673	+ 679	2701
18	17680	207	18289	4729	+ 609	4719
22	21479	267	20590	3590	- 889	3534

Averages of Series. (Corrected for C.E. of Chronoscope)

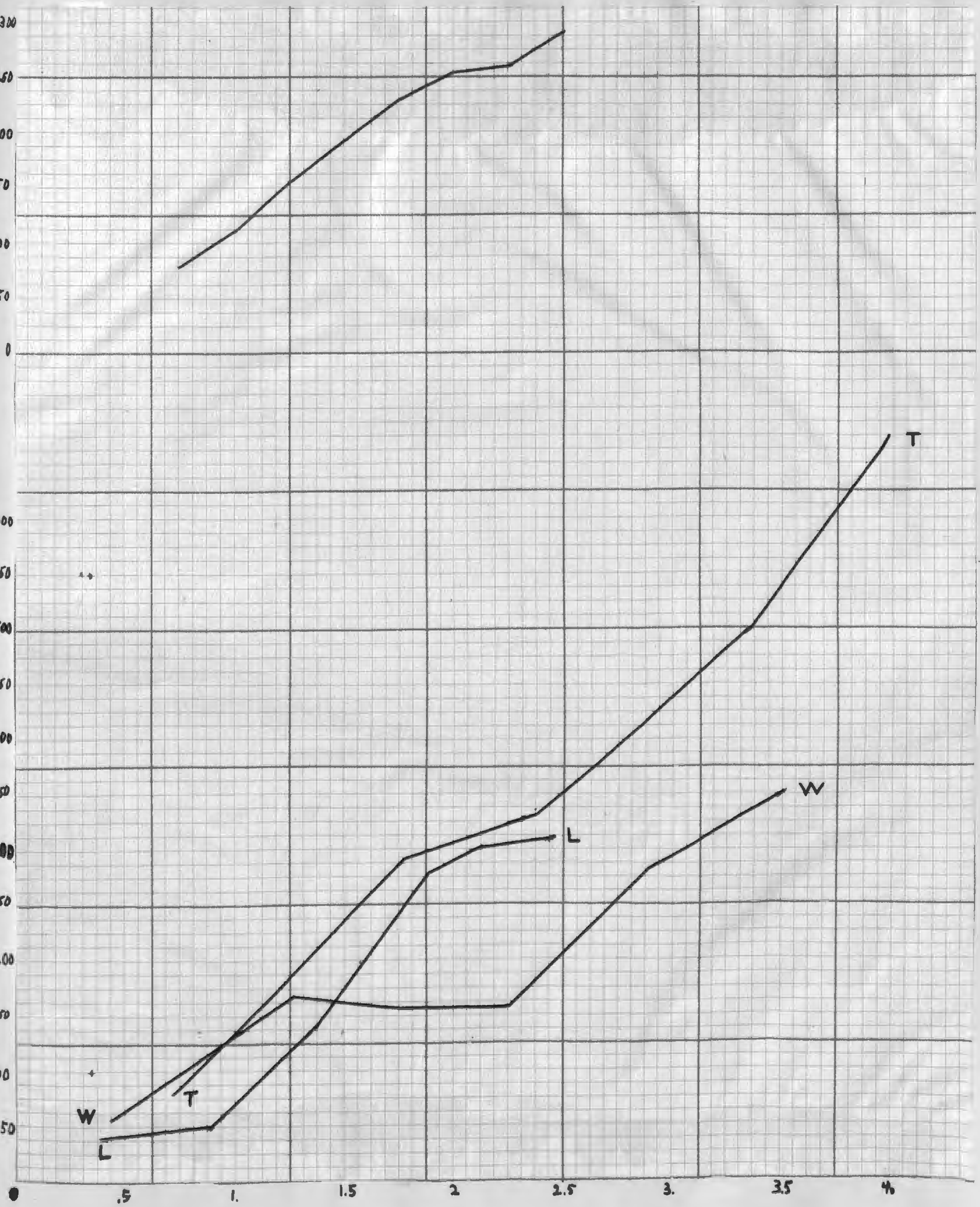
Subject--L.

	Av.St.	M.V.	Av.Repr.	M.V.	C.E.	M.V.
Series I.						
.5	477	9	432	36	- 45	37
1.0	964	16	896	55	- 67	51
1.5	1477	13	1351	137	- 126	138
2.0	1946	38	1841	281	- 105	276
2.5	2446	46	2114	311	- 332	303
3.0	3073	31	2473	320	- 600	315
Series II,						
2	1943	40	1519	167	- 424	169
6	6023	56	4036	1004	-1987	1047
10	10014	82	8931	2137	-1082	2310
14	13981	149	13088	1538	- 893	1999
18	17908	103	17541	2551	- 367	2434
22	22186	212	20474	3690	-1711	3605
Series III.						
2	2110	23	1723	220	- 387	223
6	6098	46	5884	1827	- 214	1805
10	10125	57	10587	2262	+ 462	2293
14	14106	90	13034	2040	-1071	2091
18	18095	124	14381	4111	-3714	4179
22	22073	186	18605	3180	-3468	3144

Averages of Series. (Corrected for C.E. of Chronoscope)

Subject--T.

	Av.St.	M.V.	Av.Repr.	M.V.	C.E.	M.V.
Series I.						
.5	508	3	709	88	+ 201	79
1.0	1039	3	1778	290	+ 739	289
1.5	1531	4	2346	335	+ 815	333
2.0	2024	28	3360	514	+1336	499
2.5	2592	83	3954	665	+1361	664
3.0	3077	5	3969	673	+ 892	675
Series II.						
2	2013	10	2416	169	+ 403	182
6	6005	18	4980	739	-1025	820
10	10033	39	9071	1364	- 962	1355
14	14231	131	12756	1831	-1475	1854
18	18344	240	20986	2756	+2642	2822
22	22630	243	22082	1951	- 547	2092
Series III.						
2	1941	53	1198	284	- 774	292
6	5894	107	4186	1624	-1707	1692
10	9715	227	7400	1658	-2315	1762
14	13700	248	10412	3805	-3288	3931
18	18644	338	12347	2614	-5296	2544
22	21486	430	16001	4824	-5485	3940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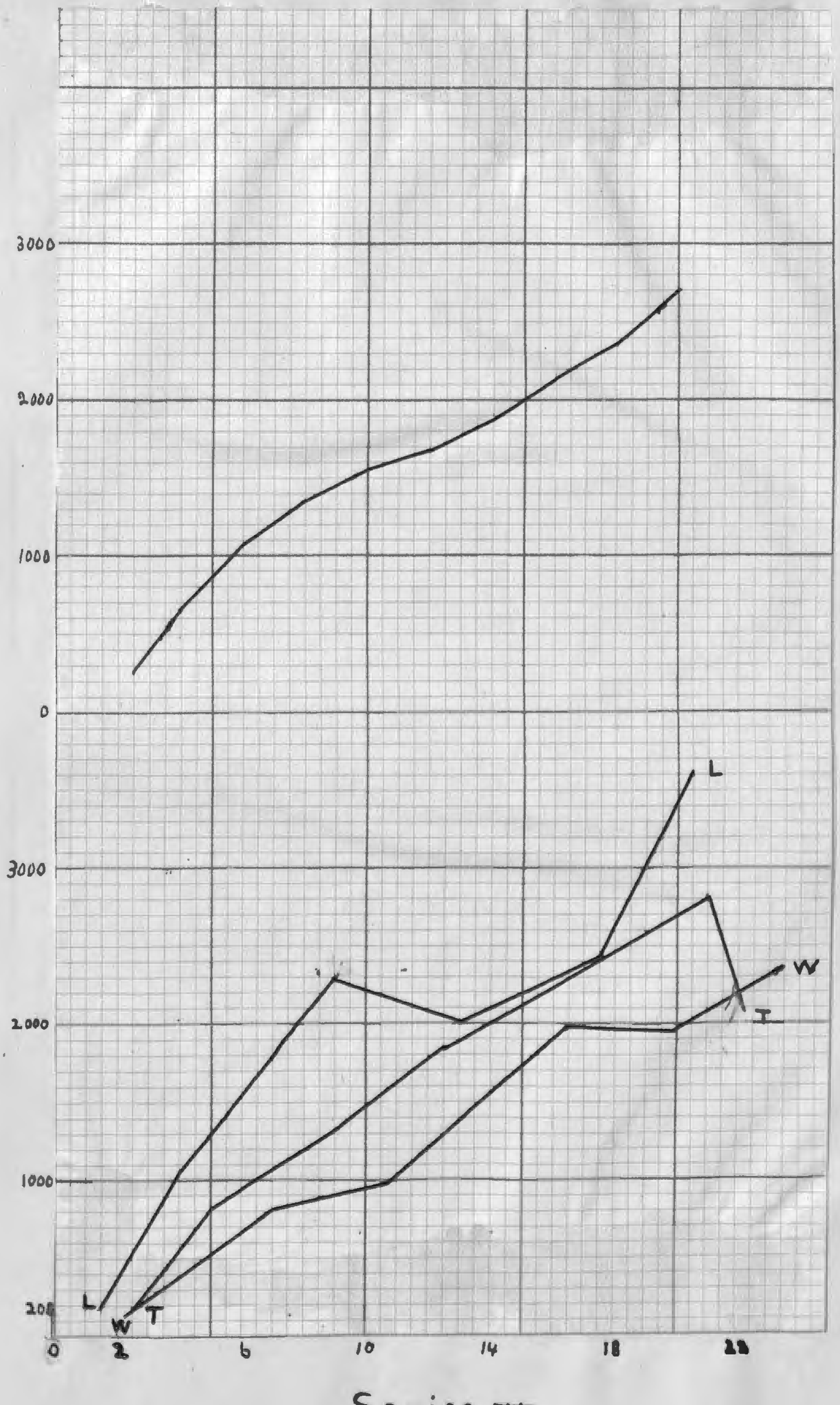
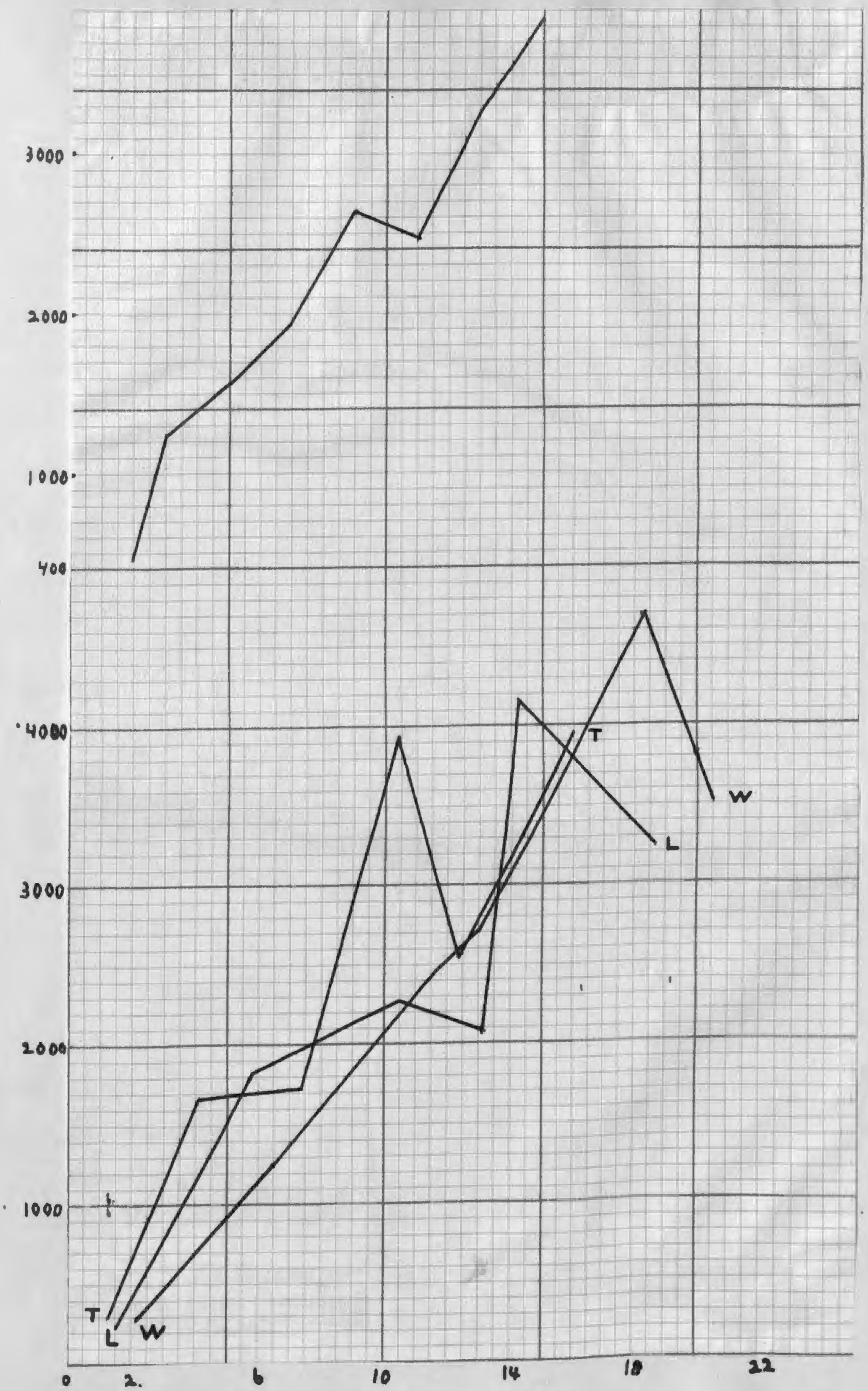
Series I.



Series II.



Series III.

IV. Conclusions:

The number of subjects and data in the present study is not large enough to allow final conclusions on any point. It is, however, sufficiently large to show that many of the published results are inadequate studies of time estimation. The very considerable difference in the results for the three subjects used here, and the fact that results of each are in line with some former investigations, leads to the conclusion that differences in individuals are very important in their time estimation, and that many of the tendencies found by others and considered as universal laws are to be viewed as holding only in the case of a certain class of subjects.

1. Constant Error.

Regular Series.

The regular order of arrangement of intervals in rank of increased length, with repetition of each ten times, as here used, should show the presence of an indifference point, between the limits of the intervals used (.5 - 22 seconds), if such a permanent and independent region is to be found in the perception of time periods. As the time usually found of the indifference point is within these limits, and as the number of intervals used is sufficiently large, thus making the space between successive lengths of intervals small, there are all the conditions for the appearance of an indifference point. Subject L. shows negative constant error throughout in average (Regular series), though a third or more of her reproductions were larger than the standard. The error increases irregularly with increase of length of interval, but nowhere does it so approach zero as to suggest that there is no inaccuracy of estimation at that point. The mean variations of the constant error increase at these lower points, whereas, if they marked increased accuracy of estimation, the mean variation would also approach zero.

Subject W. shows a positive constant error in the average of the regular series except in the shortest interval used, .5 seconds. This underestimation was the case in one day's work only, however. This subject had numerous underestimations in reproductions in most series, though not enough to make the constant error negative. The same things regarding L.'s constant error and mean variation of the constant error apply here, though there is no identity between these subjects.

Subject T. has positive errors at 3 seconds and below, and negative from 6 seconds up with one exception - the 18 seconds interval. This resembles the indifference point, though the mean variations of the constant error are not small at the point of passage of the constant error from plus to minus.

Irregular series.

Irregularity in the arrangement of the intervals, had in one subject only, (W), the effect suggested by 1) Hollingworth,1) of bringing the indifference point toward the middle of the series, with positive errors below and negative above. This subject has positive errors at the 18 seconds interval, however, so that the tendency is not indicated. Subject T. has all negative errors, increasing with fair regularity, with the length of interval, but so

1) Arch. of Psy. 1909, Ch. III.

great and with such large mean variation as to suggest that they are rather guesses than perceptions of lengths of standards. It is noticeable that in the regular series of intervals of the same lengths this subject's constant errors were generally negative. L.'s constant errors are negative with the exception of the 10 seconds interval, this being the same direction as in the regular order.

The results of the present experiment clearly give no indication of an indifference point as a permanent length of time, or as related to the series of the experiment, although it may be possible in some individuals. Subject T. had a very peculiar habit - from which she said she was able to free herself in the experiment - of counting all kinds of spatial and temporal quantities. It is quite possible that the frequency of the occurrence of the same short intervals in consciousness may have made their perception different to her than the longer, less familiar lengths of time; which would account for a difference in constant error of reproduction of short and long intervals. Thus certain individual differences, whether of constitution or experience, may show in the under - or over - estimation, or more accurate estimation of certain intervals.

Neither does it seem probable that all individuals become so adjusted to a series of intervals of different lengths that the middle intervals are perceived or are reproduced with greater accuracy than the others, and that the shorter and longer intervals are influenced by this adaptation. This may be due to the technique of the experiment - i.e. pauses during the series, such that the series does not appear as a whole or of related parts, etc., or to differences in individual attention or perception,

2. Order.

A study of the tables of regular and irregular order shows a considerable difference. The irregular order brought a greater irregularity in the constant error and increased the mean variation of the constant error. The cases for each interval with the same pattern of irregularity are too few to be conclusive, but they show widely different reoriductions, with errors of both directions from zero.

While these cases were not thoroughly examined in comparison with the regular serøes in regard to constant error and mean variation of constant error, yet inspection seems to show quite clearly that short intervals preceded by long and long by short, are far from uniformly either over-or under - estimated. If there is an effect on the interval by that immediately preceding it and different from it, it must be very slight. Regularity, or the part of a standard interval being preceded by itself, repeatedly, does have a decided effect. This seems to be that each repetition of the standard makes its length clearer, and its reproduction more constant, though not more accurate. Subjects said they were "surer" of their reproductions in the regular order, that these were more guesses in irregular order. Such an introspection shows that one presentation of an interval only, and the mixture of intervals of different lengths do not allow a clear idea of the interval to form, and also that the mixture comprises the ideas as they might form. That is, it is possible that a longer pause between each presentation and the next might remove part of the effect from the irregularity of order. Adaptation of attention to the series as a whole, or to the middle of the series, seems not to be so important a factor in causing the effect of the irregularity of the order, except possibly in the case of one subject, W., whose results seem to show over-estimation of intervals below the middle and under-estimation of those above. Nowhere in the data is there evidence of contrast effect of an interval on the succeeding interval.

3. Reproduction Method.

It may be questioned whether a reproduction represents the estimation or judgment of the length of an interval. In the comparison methods two intervals are presented in a similar manner. They are compared in length, and the judgment verbally expressed. In reproduction there is no comparison, in the same sense. The subject has one interval presented to him, and himself attempts to produce an interval equal to it. It is assumed that his judgment is always of equality, that he always gives an interval which he judges is equal to the standard, and that if his reproduction is longer than the standard, the standard is over-estimated in his judgment. This assumption needs verifying, experimentally. The reproduced interval becomes a"judgment" just as it is completed, whereas in the comparison methods the judgment is not instantaneous, but the result of considering both intervals with attention, passing from one to the other, and with judgment suspended until a satisfactory decision is reached. The muscular or nervous factor may enter as a cause of an error, since the time of movement of the finger may not be the same time as the intended movement, i.e., the subject may "think" the end of the interval at an error different from the error of his movement. The reproduction is, however, an immediate or first judgment, with no correction. The subject's consciousness of the standard may, of course, change before the reproduction is completed, but the reproduction is done with as soon as it is made, and is not subject to judgment in retrospection. This method does not show contrast effect of intervals of different lengths, which seems by introspection to occur when they are perceived in close succession. There are several reasons why this should not be so in the present experiment. Two successive standard intervals did not occur very close together, they were separated by the time of the reproduction of the first, and five to ten seconds additional. The reproduction of the first might conceivably either blur or enforce its image, according to its accuracy. If, however, the second interval does appear abnormally long or short, in consequence of the unlike interval preceding it, this error may not be represented in the reproduction. The reproduction is not to be assumed to show the extent of the error of judgment resulting from the contrast, for the contrast feeling is due to surprise or strain of expectation (depending on whether the second interval is shorter or longer), and is most intense at the moment of presentation of the second of two stimuli - in this case the termination of the second interval. But here there is time during the second pause and the beginning of reproduction of the second interval for these surprise and strain feelings to die out, and for the memory of the second interval - which was the only one to which by instruction, the subject's attention was directed - to stand independently, as originally presented.

4. Weber's Law.

The maintenance of a constant error in estimation, which is shown in the extent of its mean variation, is, in the present method, the only basis of comparison of the sensitivity to differences in length of intervals. The curves which combine the curves of the mean variation of the constant error for the three subjects show a straight line, with some irregularity, which is probably due to the small number of cases. The curve of the irregular series is steeper in ascent than the regular. It is thus shown approximately that the mean variation varies as a constant fraction of the interval, and in so doing follows Weber's law, but with respect to the order of the presentation of the intervals. The curve is parallel to the curve of just noticeable differences in the perception of intervals by the method of minimal changes, and so shows a relationship between this method and the method of reproduction here used. The curves show no decided break within the limits of the range of intervals used, indicating that the estimation of intervals follows the one law throughout. Wundt thought the law held only to 5 or 6 seconds, but these results agree with the investigation of attention based on reaction time by Woodrow 1). He found that there is no break in the regularity of the increase of the time of reaction to intervals varying from 2 seconds through 24 seconds. The quickness of the reaction depends on the ability to quickly adapt the attention to react to the stimulus. If the subject can so estimate the time that he knows when to expect the stimulus, his attention will be at a maximum, and the reaction time will be short. The regularity of the increase of reaction times shows that the perception of the intervals varies with their length, following, presumably, a regular law, which holds at least, from 2 to 24 seconds.

5. Attention.

The subjects were not all trained introspectors and could give little information regarding their conscious processes in the estimation and reproduction of intervals. As the introspective aspect of the problem was not emphasized in the experiment, they were not pressed for careful descriptions of their consciousness. Enough was found of the subjects in

1) In preparation.

the different methods to make it quite evident that the degree and direction of attention is of great importance in explaining individual differences in results, and differences at times in the same individual, but not enough to show what the relationship is. As time is not perceived by anything resembling a special sense, but through changes in consciousness, it seems different when attention wanders from one thing to another and when it is fixed on one thing; when it fluctuates and when it is maintained at the same degree. Subjects, after practice, said they attempted to keep attention the same during the reproduction that it had been during the standard interval.

Summary of Conclusions.

1) The constant error in the estimation of intervals by the reproductive method in regard to its direction and the existence(and position) of an indifference point, is a matter of individual variation, and, to some extent, of the order of presentation.

2) The order in which intervals of the same and different lengths are presented has considerable effect on the regularity of the constant error and its mean variation, and is not the same for all individuals.

3) The reproduction method, as here used, will show contrast effects, only slightly, if at all. This method is of such difference from methods of the comparison of two intervals, as to make it essential that conclusions be considered in reference to the method by which the data were obtained.

4) Weber's law holds approximately for intervals from .5 to 22 seconds in duration.

5) The state of attention during the experiment seems of

much importance, but needs further study.

6) The apparatus used in this series of experiments is a great improvement over former apparatus for the reproduction of temporal intervals and is a most important step in the development of technique. The essential features are the subject's key and the use of the chronoscope. By this key the same simple movement by the subject marked both limits of his reproduced interval. The chronoscope is of much greater convenience than the kymograph for the recording of intervals.