ON THE TIME-SENSE.

By Lewis T. Stevens.

The experiments which form the basis of this article have been in progress during the past two years: the greater portion of them were performed, under the supervision of Professor G. Stanley Hall, in the Psychophysical Laboratory of the Johns Hopkins University, Baltimore; the results there obtained have received confirmation from additional experiments made in the Physiological Laboratory of Professor Henry P. Bowditch, at the Harvard Medical School, Boston. The method of experimenting was somewhat similar to that of Vierordt,[1] and consisted, in a general way, in impressing upon the mind intervals of time by means of a metronome, and in reproducing the same after the metronome had been stopped.

The apparatus employed in the research was a horizontal-drum kymographion of Marey, with horizontal-screw attachment, by means of which was obtained a continuous spiral tracing. A delicate time-marker, writing upon the sooted-paper coating of the drum, was attached to the vertical support seated upon the horizontal screw, and by the revolution of the latter was made to proceed slowly from one end of the drum to the other. A tuning-fork, or a vibrating rod,[2] and a resistance-coil were placed in the same electrical circuit with this time-marker. In a shorter circuit with the tuning-fork were placed a mercury-cup and a compound lever; this latter being so constructed that by depressing one end with the finger the other extremity (hook-shaped) was made to dip into the cup of mercury and thus close the circuit. When the hooked extremity was out of the mercury-cup, the time-marker registered the oscillations of the tuning-fork, but by tapping the lever the fork was shifted into the shorter circuit, and its vibrations failed for a moment to be recorded. By tapping the lever, therefore, at the beginning and the end of an interval of time, the interval could be recorded upon the sooted paper, and its length be subsequently determined by counting the number of vibrations between two successive interruptions on the tracing. This end was attained at one stage of the investigation by inserting a Morse's key into the same circuit with the tuning-fork and the time-marker, and thus directly breaking the circuit; but the key possessed the disadvantages of requiring a considerable amount of muscular force to press it, and of

[1] See References at the end.

[2] In five out of the seven series of experiments to be reported, a tuning-fork vibrating 50 times per sec. was used; in the remaining two series, in order to render the task of counting out the tracings less tedious, a rod making 10 vibrations per sec. was employed.

making, at the same time, a sharp click. What influence the introduction of muscular force into the experiment would exert upon the time-sense, beyond that of fatigue, is not definitely known; and the same can be said for the influence of sensory impressions. But it was desirable to exclude, as far as was possible, all probably complicating conditions from the method, and, consequently, for the Morse's key was substituted the compound lever, which worked noiselessly and with the least possible resistance.

The individual under experiment tapped the lever synchronously with the beats of a metronome. When he had become perfectly familiar with the given interval, the drum was set in motion and the first round of the tracing was taken, with the metronome still beating; the latter was then stopped, while the person kept on tapping the lever at the same rate. The average of the intervals recorded in the first line of the tracing was the standard time; the rest of the tracings gave successive reproductions of this standard.

At first, the duration of each experiment was from two to three minutes, but this brought on fatigue so rapidly that it was impossible to obtain more than four or five experiments at one sitting. It was, therefore, reduced to one minute, under which condition ten or even more could be readily made at one time. In the discussion of the results, the reproductions for the first minute only will be considered in those cases where the experiments extended beyond that time.

Between two successive experiments there was an intermission of at least three minutes; in the majority of the series its length was from five to ten minutes.

In the majority of experiments the standard intervals ranged between ·36 sec. and 1·5 secs.; there are several observations for ·27 sec., and only one for 2·9 secs.

Experiments, to the number of 135 in all, were performed upon seven different individuals. Of these, 114 point to this fundamental principle:—That there is an interval of time (the value of which varies between ·53 and ·87 sec.) which can be reproduced with considerable accuracy; but with all other intervals an error is made, which is *plus* for those above and *minus* for those below the so-called indifference-point.

These will be spoken of as the "regular" experiments.

The remaining 21 follow no recognised law, and, in contradistinction to the 114, will be called the "irregular" experiments.

A. *Regular Experiments.*

The value of the standard interval being from ·53 to ·87 sec., and the duration of an experiment one minute, each experiment consists in reproducing the standard interval from about 40 to

150 times, according to its length. To condense the results for publication, a certain amount of averaging has been necessary. In the following Tables, the first figure in each column represents the value of the standard, expressed in thousandths of a second; the second figure, the average of the reproductions of the standard for the first five seconds; the third, the average of the reproductions for the second five seconds; and so on, to the end of the experiment.

In Tables II., III. and IV. are given only a fraction of the total number of experiments performed upon the subjects; in these cases, those experiments are selected for publication which show the average amount of variation. In Tables I., V., VI. and VII., one or several regular experiments are omitted from each for the reason that they are mere repetitions of one or more of those which are given.

I.—O.S. 12 EXPERIMENTS, ALL REGULAR.

1·440	·966	·830	·740	·710	·677	·610	·590	·480	·360
1·477	1·006	·857	·748	·728	·666	·604	·582	·474	·348
1·454	·993	.860	·754	·708	·670	·590	·564	·464	·346
1·500	·990	·853	·754	·714	·672	·582	·556	·462	·348
1·515	1·038	·860	·754	·708	·670	·584	·546	·452	·338
1·498	1·013	·853	·734	·700	·678	·588	·560	·448	·328
1·536	1·000	·850	·754	·712	·668	·594	·542	·452	·342
1·494	1·032	·870	·742	·714	·680	·578	·544	·446	·338
1·522	1·015	·850	·742	·700	·670	·580	·552	·446	·336
1·510	1·028	·875	·752	·706	·654	·588	·560	·444	·334
1·570	1·041	·868	·768	·710	·654	·600	·554	·440	·332
1·543	1·046	·882	·770	·722	·674	·590	·556	·440	·332
1·580	1·008	·852	·764	·714	·680	·596	·548	·470	·326

II.—I.I.H. 36 EXPERIMENTS, OF WHICH 5 ARE IRREGULAR.

1·360	·937	·730	·653	·593	·525	·492	·442	·410	·360
1·448	·960	·749	·657	·591	·522	·481	·442	·398	·351
1·498	·908	·786	·667	·596	·520	·491	·432	·400	·351
1·475	·939	·757	·641	·593	·542	·486	·446	·403	·351
1·470	·985	·783	·663	·589	·540	·489	·445	·400	·351
1·547	1·018	·767	·675	·600	·540	·484	·456	·408	·349
1·545	1·035	·783	·659	·600	·532	·482	·436	·400	·350
1·510	1·065	·729	·676	·600	·519	·490	·442	·405	·345
1·530	1·062	·757	·670	·611	·524	·491	·427	·403	·352
1·485	1·101	·783	·670	·600	·492	·490	·425	·389	·349
1·487	1·126	·783	·689	·600	·512	·490	·422	·413	·349
1·543	1·153	·800	·691		·510	·486	·418		·351
1·525	1·163	·800			·534	·494	·426		·347

III.—H.P.B. 38 Experiments, of which 6 are irregular.

1·250	·900	·800	·731	·708	·640	·594	·569	·540	·488
1·263	·917	·817	·729	·714	·631	·588	·561	·564	·480
1·275	·917	·800	·743	·707	·625	·587	·550	·524	·475
1·323	·922	·850	·737	·693	·625	·578	·563	·533	·467
1·318	·928	·833	·734	·714	·619	·589	·559	·520	·464
1·268	·960	·850	·743	·714	·625	·596	·556	·524	·463
1·323	·980	·833	·729	·710	·625	·601	·561	·518	·466
1·350	·940	·862	·729	·719	·633	·603	·569	·550	·469
1·367	·960	·888	·757	·729	·639	·600	·570	·520	·476
1·400	1·023	·850	·757	·700	·640	·613	·563	·520	·490
1·450	·994	·867	·817	·743	·639	·635	·589	·546	·436
1·423	·946	·818	·817	·729	·669	·615	·587	·528	·474
1·433		·868	·808	·729	·675		·597	·527	·480

IV.—F.S.L. 18 Experiments, of which 3 are irregular.

1·467	1·100	·875	·822	·746	·727	·662	·620	·476	·387
1·517	1·109	·883	·817	·731	·728	·660	·628	·464	·379
1·577	1·168	·860	·826	·714	·698	·635	·595	·468	·377
1·540	1·212	·839	·828	·706	·700	·608	·585	·463	·366
1·530	1·158	·835	·824	·737	·692	·633	·602	·466	·370
1·534	1·170	·857	·842	·718	·667	·616	·607	·458	·359
1·572	1·166	·831	·799	·716	·692	·617	·595	·461	·357
1·501	1·095	·855	·833	·733	·688	·610	·598	·447	·377
1·474	1·163	·877	·806	·739	·711	·623	·603	·449	·364
1·555	1·140	·884	·788	·736	·712	·621	·598	·467	·357
1·515	1·140	·884	·791	·710	·716	·607	·605	·454	·362
1·530	1·129	·883	·795	·703	·700	·623	·587	·455	·362
1·473	1·150	·925	·791	·713	·708	·632	·600	·456	·354

V.—G.S.H. 9 Experiments, of which 2 are irregular.

1·535	·826	·721	·636	·508	·268
1·670	·823	·713	·613	·492	·261
1·687	·821	·712	·608	·496	·259
1·573	·802	·697	·620	·488	·262
1·677	·794	·701	·618	·505	·261
1·680	·849	·691	·611	·492	·260
1·650	·824	·683	·616	·488	·266
1·640	·824	·705	·608	·479	·262
1·713	·810	·702	·623	·499	·269
1·587	·837	·681	·620	·482	·271
1·676	·802	·681	·617	·472	·262
1·763	·834	·704	·628	·470	·268
1·703	·801	·694	·604	·480	·264

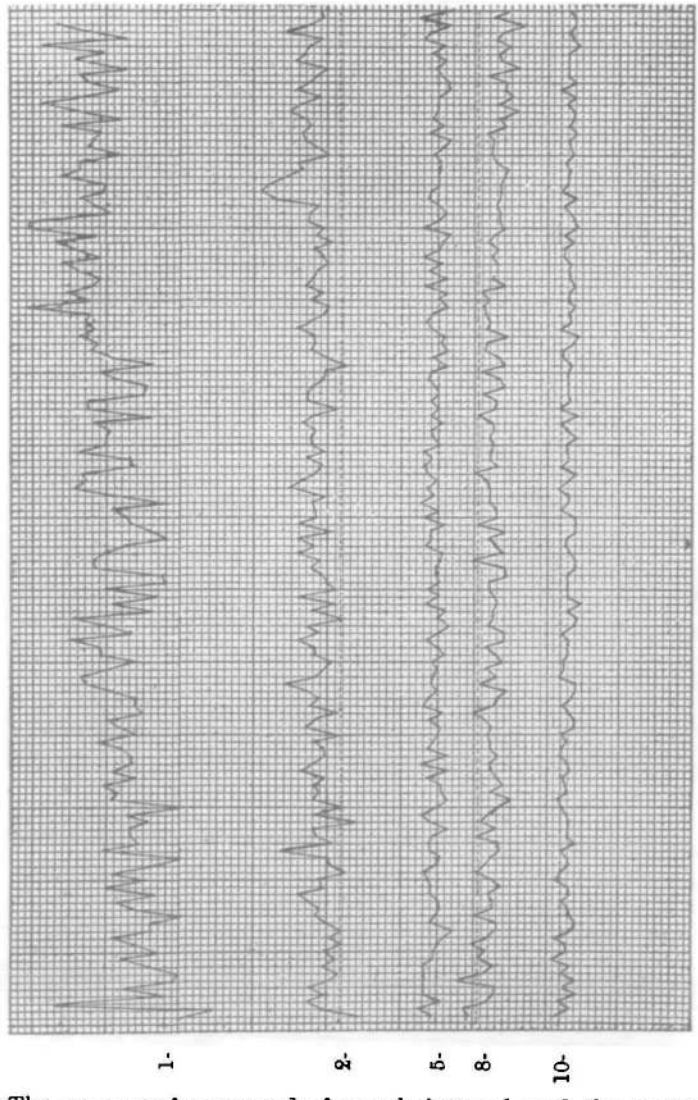
VI.—L.T.S. 11 EXPERIMENTS, OF WHICH 1 IS IRREGULAR.

1·480	·750	·744	·660	·590	·500	·360	·260
1·371	·777	·787	·660	·583	·494	·356	·245
1·494	·807	·789	·667	·580	·462	·351	·259
1·556	·830	·743	·653	·588	·486	·348	·258
1·544	·792	·794	·654	·583	·490	·335	·254
1·516	·815	·803	·636	·578	·496	·346	·261
1·537	·829	·791	·640	·548	·490	·347	·256
1·540	·823	·786	·659	·547	·488	·345	·251
1·574	·850	·789	·653	·562	·490	·367	·252
1·574	·890	·776	·651	·564	·496	·337	·252
1·587	·870	·783	·680	·571	·486	·332	·250
1·552	·870	·851	·657	·569	·494	·342	·246
1·536	·875	·809	·653	·580	·492	·332	·248

VII.—H.H.D. 11 EXPERIMENTS, OF WHICH 4 ARE IRREGULAR.

1·458	·979	·730	·600	·472	·400
1·488	1·006	·751	·597	·462	·390
1·436	·970	·718	·602	·458	·394
1·589	·998	·726	·588	·438	·369
1·602	·955	·739	·596	·434	·365
1·694	·941	·731	·600	·447	·356
1·693	·994	·734	·605	·436	·344
1·663	1·050	·733	·585	·482	·340
1·582	1·021	·726	·596	·435	·335
1·647	·999	·732	·562	·442	·333
1·683	1·011	·735	·559	·442	·340
1·688	·987	·718	·579	·434	·335
1·619	·971	·747	·590	·442	·345

A glance at these Tables shows that, in each case, short intervals are shortened and long intervals are still further lengthened in their reproduction; and that somewhere between the two extremes is an interval, in the reproduction of which there is made practically no error. These points are more plainly seen in the annexed series of curves, which represents, in detail, experiments 1, 2, 5, 8, 10 of Table I. Each mm. of ordinate represents ·02 sec. The dotted line for each curve (opposite which the number of the experiment is placed) represents the level of the standard interval above the common base-line. The curve is obtained, in each case, by joining with straight lines the upper limits of the ordinates, the lengths of which represent the value of successive reproductions of the standard interval. The ordinates are separated from each other by a space of 1 mm. Where no error is made in reproducing the standard, the curve hugs the dotted line, as is the case with the middle one. Where an error is made, the curve recedes more and more from the dotted line, according to the amount of the error; and is above or below it, according as the error is *plus* or *minus*.



The amount of error made for each interval, and the position of the indifference-point, are better shown in the following Tables, which represent the experiments in a still more compact form. In the first column of each are placed the standard intervals; opposite these, in the second column, are the averages of the total number of reproductions for one minute; and in the third column is shown the amount of error made in each case.

	Standard.	Reproduced.	Error.
I.	1·440	1·517	+ 5·4 per cent.
	·966	1·018	+ 5·4 „
	·830	·861	+ 3·7 „
	·740	·753	+ 1·8 „
	·710	·711	+ ·1 „
	·677	·670	− 1·0 „
	·610	·590	− 3·3 „
	·590	·555	− 5·9 „
	·480	·454	− 6·3 „
	·360	·337	− 6·4 „
II.	1·360	1·502	+ 10·5 „
	·937	1·043	+ 10·3 „
	·730	·773	+ 5·9 „
	·653	·669	+ 2·4 „
	·593	·598	+ ·9 „
	·525	·524	− ·2 „
	·492	·488	− ·8 „
	·442	·435	− 1·6 „
	·410	·402	− 2·0 „
	·360	·350	− 2·8 „
III.	1·250	1·349	+ 7·9 „
	·900	·953	+ 5·9 „
	·800	·845	+ 5·6 „
	·731	·758	+ 3·7 „
	·708	·717	+ 1·3 „
	·640	·637	− ·5 „
	·594	·600	+ 1·0 „
	·569	·569	0·0 „
	·540	·528	− 2·2 „
	·488	·474	− 2·9 „
IV.	1·467	1.527	+ 4·1 „
	1·100	1·150	+ 4·5 „
	·875	·868	− ·8 „
	·822	·812	− 1·2 „
	·746	·721	− 3·4 „
	·727	·701	− 3·6 „
	·662	·624	− 5·7 „
	·620	·599	− 3·4 „
	·476	·459	− 3·6 „
	·387	·365	− 5·7 „
V.	2·850[1]	3·410	+ 19·7 „
	1·535	1·668	+ 8·7 „
	·826	·819	− ·9 „
	·721	·697	− 3·3 „
	·636	·616	− 3·2 „
	·508	·487	− 4·1 „
	·268	·264	− 1·5 „

[1] This experiment was not included in the preceding Tables, because of the impossibility of dividing it up into periods of 5 seconds.

VI.	1·480	1·548	+ 4·6 per cent.
	·750	·836	+ 11·5 „
	·744	·792	+ 6·5 „
	660	·655	− ·8 „
	·590	·571	− 3·2 „
	·500	·489	− 2·2 „
	·360	·345	− 4·2 „
	·260	·253	− 2·7 „
VII.	1·458	1·615	+ 10·8 „
	·979	·992	+ 1·3 „
	·730	·733	+ ·4 „
	·600	·588	− 2·0 „
	·472	·446	− 5·5 „
	·400	·354	− 11·5 „

These Tables show very plainly the main point of the paper, namely, that the error made in the reproduction of the longer intervals is *plus*, of the shorter ones, *minus*; and that at some point between the two extremes the error approaches zero.

The value of this indifference-point is found not to be constant, but to vary for different individuals between ·53 and ·87 sec., the average being about ·71 sec. The position of the indifference-point is not so accurately defined in Case III. as it is in the others. The reason for this is not evident. Of the six regular experiments made for intervals from ·55 to ·70 sec., the mean value of the standard interval is ·61 sec., and the average of the error of reproduction is ·3 per cent., the individual variations not being, algebraically, more than 1 per cent.

With reference to the amount of variation, the number of experiments is, in the majority of cases, not sufficient to give the results a quantitative value. The amount of variation depends upon the fixedness of the attention on the work, and upon the experience which one has had in estimating and holding intervals of time. The complaint was made quite frequently by several of the gentlemen of their inability, at times, to keep their whole attention upon the experiment; and subsequent examination of such experiments showed that the error made was either contrary to the law above stated, or was in the proper direction but abnormally large in amount. The effect of practice was well seen in Case III., where a great number of observation swas made. In the first few experiments very large errors were made; but as the work proceeded, they gradually diminished in amount, until they reached, on the average, the size that is represented, for the various intervals, in the Tables. Tables I. and II. were obtained from gentlemen who are musicians by profession; in the second case, where numerous experiments were made, the uniformity in the amount of variation was a noted feature from the very start. Moreover, in both these cases there was not that difficulty which was experienced by certain of the others, in grasping the longer intervals of time.

Diversion of attention and small experience are, therefore, regarded as the cause of the great irregularity in the size of the errors that is observed in the last four Tables.

The first three Tables, however, possess a certain quantitative as well as qualitative value; and in these it is observed that the error gradually increases in amount, as the indifference-point is moved from, in either direction. As to the manner of variation, examination of the curves (p. 398) reveals two remarkable points. (1) The constant zig-zag of individual records. This is a peculiarity which was observed in all the curves plotted.[1] Of the series of curves published, the upper one shows about 19 cases only out of about 140 in which two sequent variations are in the same direction. This would seem to indicate that an interval is judged more correctly after it is completed than before, and that correction is made for its error in the next reproduction, according to a standard which the mind carries but to which the hand (or perhaps the will during the interval) cannot be accurately true. The origin of this peculiarity would, therefore, appear to lie not in the judgment, but in the execution. (2) In all of the curves plotted, there were observed more or less distinctly still larger and more primary waves. The prominence of these varied greatly; in some of the curves they were apparently absent, in others they were decidedly marked. On p. 398, three such waves are plainly seen in the first, and one each in the second and fourth curves; in the third and fifth they are not so evident, but their existence is shown by enlarging these curves. Taking into consideration all of the curves that were plotted, it may be stated that these waves are no more prominent for one interval than for another, as the published curves would indicate. The length of these waves, expressed in fractions of a minute, varies, in the majority of cases, between ·6 and ·9 min., and averages ·73 min.[2] This rhythmical variation seems to be not in the execution, but rather to have its origin in a rhythmical variation of the standard carried in the mind. That this is connected with the rhythmical changes in the nutritive condition of the cerebral centres, as produced by the vaso-motor rhythmical constriction of arterioles, it would be rash to deny or affirm, or, perhaps, even to suppose.

B. *Irregular Experiments.*

The following are all of the irregular experiments, given in the form best adapted to show the direction and amount of variation:—

[1] 24 in number, representing experiments from Cases I., IV., V., VI.

[2] The lengths of those detected in the curves obtained from Case I. vary between ·63 and ·86 min., and averaged ·73 min. The average of 15 from Case IV. is ·73 min.; of these 12 vary between ·62 and ·88 min., and the values of the remaining 3 are ·56, 1·06, and ·91 min. 11 waves from Case V. vary between ·62 and ·95 min., and average ·72 min. 9 from Case VI. vary between ·61 and ·89 min., and average ·73 min.

	Standard.	Average of the total number of reproductions.	Error.
II.	·800	·798	− ·3 per cent.
	·515	·535	+ 3·9 „
	·506	·526	+ 4·0 „
	·500	·523	+ 4·6 „
	·471	·494	+ 4·9 „
III.	·960	·960	0· „
	·933	·929	− ·4 „
	·647	·681	+ 5·3 „
	·615	·645	+ 4·9 „
	·588	·619	+ 5·3 „
	·493	·510	+ 3·4 „
IV.	·920	·908	− 1·3 „
	·796	·862	+ 8·3 „
	·734	·783	+ 6·7 „
V.	1·115	1·072	− 3·9 „
	·733	·746	+ 1·8 „
VI.	·614	·620	+ 1·0 „
VII.	·632	·657	+ 4·0 „
	·626	·635	+ 1·4 „
	·552	·591	+ 7·0 „

The irregularities consist in reproducing accurately long, in shortening long, and in lengthening short intervals. It must be stated that, in the attempt to get pure results, all those experiments were excluded in which fatigue or inattention spontaneously stated by the subject entered, but no others. The examination of such experiments, however, revealed the fact, that the effect of fatigue is to make the error for short intervals *plus* instead of *minus*, and to increase the amount of variation made in the reproduction of long intervals; and that individuals under experiment are apt, when inattentive, to shorten long and prolong short intervals. Some of these experiments, at least, are, therefore, regarded by the author as those in which fatigue and diversion of attention were existing but not acknowledged conditions. The accurate reproduction of long intervals is regarded as the chance result of the mutual neutralisation of the two opposing factors, the natural tendency to slow, and the effect of inattention.

The conclusion drawn in this paper, with reference to the direction of the variation made in estimating long and short intervals, is in direct opposition to that of previous investigators. Vierordt (1), receiving time-impressions from the beating of a metronome and after the lapse of a short while reproducing them,

found that the reproduced interval was longer than the standard when this was small, shorter when it was great; and that between the two extremes was an interval which could be reproduced quite accurately. This indifference-point was not the same for different individuals, but varied between 1·5 and 3·5 secs. For himself, when the impressions were conveyed through the sense of taste, this interval was from 2·2 to 2·5 secs.; when through the sense of hearing, from 3 to 3·5 secs. These values were obtained when a short time elapsed between reception and reproduction; with the increase or diminution of this, the indifference-point was found to grow longer or shorter.

According to Mach (2), whose experiments were performed according to the method of just perceptible differences, the recognition of the inequality of two intervals of time, one interval following immediately upon the other, is the most delicate at about ·37 sec.; and the further from this point the standard interval recedes, the greater must be the difference between the standard and the interval for comparison, in order that they be recognised as unequal. There is, however, considerable discord in his results, which detracts from the value of his conclusions.

Kollert (3) began the long series of experiments that have been performed in Wundt's laboratory. His experiments were performed according to the method of just perceptible differences. Two metronomes were used, the pendulum of each of which was placed in an electrical circuit along with an electro-magnet, so that by the momentary opening of the current a double vibration of the pendulum of the metronome could be effected, and thus an interval of time be marked out. One of the metronomes beat at a rate which was constant for a single series of observations; the other gave out various intervals for comparison with the standard. An intermission occurred between the two intervals, which in length was equal always to the standard. The pendulum of the second metronome was shortened, until a just perceptible difference was observed between its time and that of the first; after which it was elongated, until the subject detected a difference between the two. The mean of these two just perceptible differences gave the error made by the individual under experiment in his estimation of the constant interval. Experiments were made upon seven individuals for intervals extending from ·4 to 1·5 sec. The majority of these experiments confirm the general law laid down by Vierordt, but fix the indifference-point between ·7 and ·8 sec. The remaining, which constitute about one-fourth of the total number of experiments, are called anomalous. In three of the five series of anomalous experiments, the tendency seems to be to bring the value of the indifference-point up to 1 to 1·2 secs.; in the other two, long intervals are prolonged and short ones still further shortened. Wrong decisions were chiefly made for ·4 and ·5 sec.

Estel (4) and Mehner (5) have extended these investigations, using, practically, the same method, and have incidentally fixed

the value of the indifference-point at ·71 sec., as well as shown that the law of Vierordt is applicable, in general, to intervals considerably greater than 1·5 seconds. Their papers, however, deal mainly with the influence of contrast, the multiplicity of the indifference-point, and the validity of Weber's law for the time-sense; their valuable conclusions will not be reported, inasmuch as the experiments in question do not bear upon them.

From this short and very incomplete account of previous experiments, it will be seen that in all cases the conclusion is drawn, that the natural tendency is to subtract from long intervals and to add to short intervals, in reproducing or estimating them. The conclusion drawn in this paper is exactly the reverse. With reference to the value of the indifference-point, however, my results and those of recent investigators are in harmony.

I have no means of forming an opinion as to the cause of the discrepancy between my own results and those of others. The method used by Wundt's students is entirely different from mine. In one, comparison is made of two intervals, and the process is purely mental; while the other consists in catching an interval and reproducing the same, and, of course, in doing so, certain physiological and psychological moments (the exercise of the will, the origination of motor impulses and their transmission along efferent fibres, and the latent period of muscular contraction), in addition to the mental process, enter into the experiment. Whether these factors enter and, if so, how, or whether (as is barely suggested by the anomalous results) fatigue and inattention may have entered more largely into other methods in a way to account for the previous results, seems to require further study.

I regret that other duties prevent me from continuing the investigation, and I now publish my results, not with the intention of denying outright the correctness of previous conclusions, but with the hope that they will act as an incentive to others to proceed with the work, so as to obtain definite information of the possibly existing factors that are capable of so completely perverting the operations of our time-sense.

Before concluding, I have to thank Profs. G. Stanley Hall and Henry P. Bowditch for their advice and assistance; and also the other gentlemen who have kindly acted as subjects for experiment, or have otherwise assisted me.

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(2) Mach: Wundt's *Physiol. Psychol.* (1te Aufl.), s. 785.
(3) Kollert: *Philosophische Studien*, Bd. i., Heft. 1, s. 88.
(4) Estel: „ „ Bd. ii., Heft. 1, s. 37.
(5) Mehner: „ „ Bd. ii., Heft. 4, s. 546.

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