ERROR IN STOP WATCH TIMING

by

RAYMOND JOHN MCMILLIN

B. S., Kansas State College
of Agriculture and Applied Science, 1932

A THESIS

submitted in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1932

TABLE OF CONTENTS

INTRODUCTION

Interest in reaction time as a scientific problem dates from 1895 when the royal astronomer, Maskelyne of the Greenwich Observatory, discharged one of his assistants because of his slow reaction time in indicating the instant a planet or star appeared in the exact center of the telescope.

Since that time experiments with reaction time have been carried on extensively to determine its relation to mental ability, age, motor ability, and many other factors.

Rumberger (1) carried out an experiment several years ago to show the error present in stop watch timing on the athletic field. In this experiment, seven skilled and four unskilled timers measured the time between two flashes of light with a stop watch while the actual time was measured mechanically. A warning signal was given before the first light was flashed but no warning was given before the light was flashed the second time. As a result, this experiment fails to show the true error in stop watch timing on the athletic field (track), because the warning to get ready to stop the watch, which timers get at the end of a race when they see the runner approach the finish line, is not con-

---

(1) Rumberger, E. K. The Accuracy of Timing with a Stop Watch. Journal of Experimental Psychology 10: 60. 1927.

sidered. This does not mean that timers watch the runner approach the finish line but that they cannot help seeing the runner as he comes into their field of vision while they are focusing their eyes and concentrating on the finish line.

As a conclusion to one of his studies in reaction time, Miles (2) said that reaction time experiments should be arranged to resemble as closely as possible the particular skill or motor task to be measured. With Miles' statement in mind an experiment to locate the error in stop watch time of running races was carried out with the experimental conditions arranged as closely as possible to actual track conditions.

METHOD

Two experiments were carried out: the first to measure the lapse of time between the firing of a starter's gun and the starting of a stop watch by a timer at the beginning of a race; and the second to measure the lapse of time between the touching of the finish line by a runner and the stopping of a watch by a timer at the finish of a race.

Twelve timers who have had experience in timing intramural, interscholastic, and intercollegiate track and

---

(2) Miles, W. R. Studies in Physical Exertion: II. Individual and Group Reaction Time in Football Charging. Research Quarterly 2: (No. 3) 5. October 1931.

swimming meets at the college; and twelve timers who had never before used a stop watch were used as subjects in this experiment. Twenty trials were given each timer in starting a stop watch at the beginning of a race and in stopping a watch at the finish of a race.

A Dunlap chronoscope, which measures accurately to one-five hundredth of a second was used to measure the lag in starting and in stopping a watch. The chronoscope was kept at a constant speed by the use of an electrically maintained tuning fork of fifty double vibrations per second.

First Experiment -- Starting a Stop Watch

In measuring the lag between the fire of a gun and the starting of a stop watch, at the beginning of a race, a reaction circuit was set up in connection with the chronoscope so that the experimenter could start the hand on the dial of the chronoscope simultaneously with the flash of a red light, by pressing a stimulus key. On the athletic field, a timer responds to the flash and smoke of the gun in starting his stop watch rather than to the report of the gun because of the time it takes the noise to travel from the starting to the finishing point of a race. In this experiment a flash of light was substituted for the flash of a gun as a stimulus for the timer to start his watch in order to eliminate the report of the gun. In the gymnasium, where this experi-

ment was carried out, the gun could not be as far removed from the timer as it is on the athletic field, and the proximity of the report of the gun would influence the reaction time of the timers. Simple reaction time (3) to light varies from .15 to .225 second while simple reaction time to sound varies from .082 to .195 second. Had the gun been used the reaction time of the timers would have been reduced from .068 to .143 second.

A warning signal, "Guns up", was given the timer varying from one to three seconds before the experimenter flashed the light. This warning signal is comparable to the warning received by timers of a track event when they see the runners assume their "Get set" position.

The reaction circuit also included an electrial connection to the timer's stop watch as shown on Plate I. The stop watch was enclosed in a wooden case and an attachment to the crown of the watch pushed a spring wire from its point of contact when the timer "punched" his watch. The breaking of this electrical contact stopped the hand on the dial of the chronoscope, thereby indicating the lapse of time between the flash of light and the starting of the stop watch by the timer at the beginning of a race.

---

(3) International Critical Tables of Numerical Data I: 94-95. 1926.

Plate I

Plate I

Electrical connection of stop watch to chronoscope.

A. Wooden case enclosing stop watch

B. Crown of watch

C. Lead cover over crown of watch

D. Fibre rod

E. Stop watch

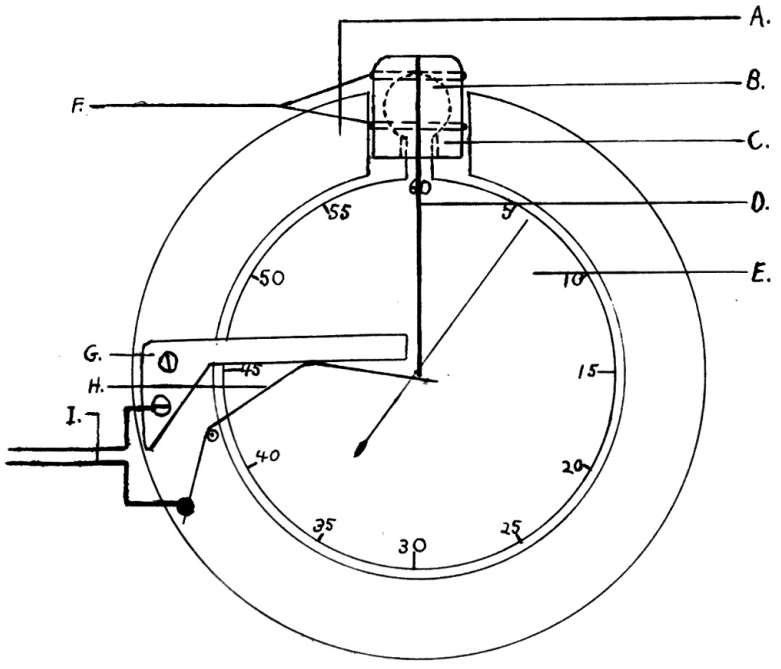
F. Bolts attaching lead cover and fibre rod to crown

G. Contact plate (also holds watch in wooden case)

H. Spring wire

I. Electrical connection to chronoscope

PLATE I



Second Experiment -- Stopping a Stop Watch

In measuring the lapse of time between the touching of the finish line by a runner and the stopping of the stop watch by a timer, at the finish of a race, the reaction circuit was set up in connection with the chronoscope so that the hand on the dial of the chronoscope was started by a runner touching the finish line, thereby breaking an electrical contact, as shown on Plate II. This reaction circuit also included the same electrical connection to the timer's stop watch as used in the first experiment.

Each timer was instructed to stop his watch as soon as he saw the chest of the runner touch the finish line just as they are instructed in timing actual races. Stopping the watch broke the electrical contact and stopped the hand on the dial of the chronoscope, thereby indicating the lapse of time between the touching of the finish line by a runner and the stopping of a stop watch by a timer at the finish of a race.

All results are expressed in sigmas, a sigma being one-one thousandth of a second. The lag for each timer in starting a stop watch at the beginning of a race is shown in table 1. The reliability of these results is apparent by

Plate II

Plate II

Electrical connection of finish line to chronoscope.

A. Finish line posts

B. Electrical connections to chronoscope

C. Wire finish line

D. Metal contact to finish line

E. String finish line (extension of wire finish line)

F. Runner approaching finish line

PLATE II

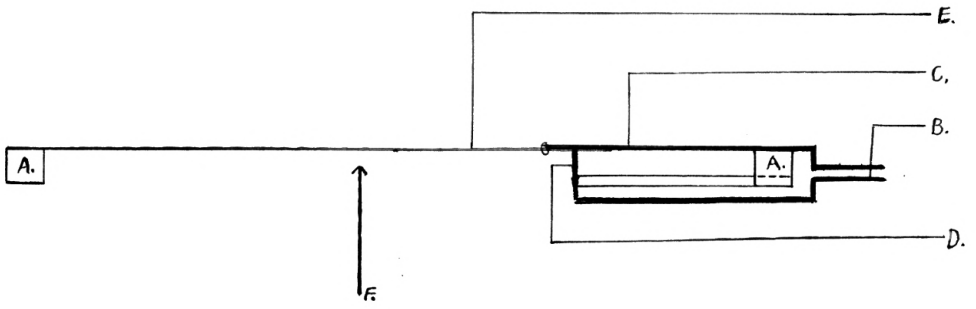


Table 1. Lag in Starting a Stop Watch*

	Timer	Trial 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Mean	SD**	AD***	Amount of range
Experienced Timers	A	224	170	160	144	166	156	148	192	172	172	178	166	166	174	174	174	228	176	172	150	173±3	20±2	14	80
	B	162	252	134	132	148	166	150	216	136	128	162	172	140	146	142	154	164	164	242	142	163±5	34±4	24	124
	C	160	204	222	260	194	176	186	170	192	202	248	116	198	140	140	148	136	150	178	152	179±6	37±4	30	132
	D	184	130	146	202	120	136	138	176	136	138	190	200	178	150	148	124	150	172	152	178	157±4	25±3	22	82
	E	202	194	202	216	226	214	192	224	250	256	266	218	200	260	224	266	224	180	206	238	223±4	25±3	21	86
	F	180	162	180	128	116	170	174	174	132	162	156	180	150	166	184	224	124	184	168	138	163±4	25±3	20	108
	G	282	276	208	250	294	178	256	178	178	214	342	164	142	126	174	196	308	150	158	204	214±9	60±6	51	216
	H	184	140	200	204	164	180	168	110	184	164	144	160	176	210	154	184	152	124	180	182	168±4	25±3	20	100
	I	150	164	148	152	132	112	124	126	180	206	144	152	148	156	168	146	166	150	162	170	153±3	20±2	15	94
	J	176	182	160	194	188	182	268	142	184	288	280	188	164	220	180	168	136	140	162	200	190±6	42±4	31	152
	K	186	154	182	190	172	190	198	214	246	184	192	176	152	262	274	164	202	230	214	230	201±5	33±3	28	122
	L	158	168	130	152	114	148	150	164	158	142	140	146	146	176	148	180	226	134	212	148	157±4	26±3	19	112
Inexperienced Timers	o	168	156	156	158	148	196	136	224	142	190	192	168	136	176	138	162	164	134	148	178	164±3	23±2	18	90
	p	152	246	178	156	184	170	202	144	146	134	150	156	164	158	146	180	172	138	132	156	163±4	26±3	19	114
	q	184	150	154	144	152	122	172	208	202	168	262	246	178	138	136	144	182	122	210	184	173±6	37±4	30	140
	r	126	226	114	148	158	138	172	164	126	140	150	154	142	188	148	130	164	170	174	170	155±4	24±3	19	112
	s	300	274	286	208	180	296	232	254	248	224	214	266	282	204	270	226	248	274	232	220	247±5	33±3	28	120
	t	186	168	148	146	200	180	220	184	176	158	196	132	138	172	186	232	164	194	156	156	175±4	26±3	21	88
	u	128	124	128	110	120	130	100	136	120	116	136	150	140	130	122	122	120	116	116	130	125±2	11±1	9	50
	v	132	200	142	140	216	138	164	144	190	170	142	136	120	182	156	132	136	136	116	128	151±4	27±3	22	100
	w	134	136	116	98	170	186	160	126	152	136	120	138	124	120	140	200	148	118	222	120	143±5	30±3	24	124
	x	256	172	166	150	184	170	234	240	216	186	234	152	180	188	236	248	260	202	246	264	209±6	37±4	34	114
	y	134	174	136	120	136	152	152	130	202	148	134	174	134	170	140	148	140	162	154	184	151±3	20±2	16	82
	z	160	164	140	120	146	158	138	114	218	176	142	142	252	222	126	136	156	156	138	208	161±5	38±4	27	138

*Expressed in sigmas

**Standard deviation

***Average deviation

the low probable errors of the means and standard deviations, the standard deviations being over eight times as great as their probable error. The mean or constant error for the twenty-four timers in starting a stop watch varies from 125 ± 2 sigma for timer "u" to 214 ± 9 sigma for timer "G". With the exception of timer "G" who has an average deviation of 51 sigma, a low degree of variability is present in the timing as the average deviations for the other twenty-three timers vary from 9 to 34 sigma. The amount of variation for each timer varies from 50 sigma for timer "u" to 216 sigma for timer "G" as shown by the range for each timer.

Table 2 shows the average lag in starting a stop watch for each group as a whole. The average lag in starting the watch is 178 ± 4 sigma for the experienced group and 168 ± 6 sigma for the inexperienced group. On the average, the two groups correspond closely in speed of starting a stop watch at the beginning of a race, and although the inexperienced group has a smaller mean lag, the average deviation of their means, 22 sigma, is greater than the average deviation of the means of the experienced group, 21 sigma. This shows that there is a greater variation among the inexperienced timers than among the experienced timers in speed of starting a stop watch.

Table 2. Lag in Starting a Stop Watch for Each Group*

Group	Mean average	Standard Deviation of means	Average Deviation of means
Experienced	178 ± 4	21 ± 3	21
Inexperienced	168 ± 6	31 ± 4	22

*Expressed in sigmas

The lag for each timer in stopping a stop watch after a runner touches the finish line is shown in table 3. These results are also reliable as shown by the low probable errors of the standard deviations. The mean or constant error for the timers in stopping a watch varies from 26 ± 2 sigma for timer "E" to 95 ± 6 sigma for timer "w". With the exception of timer "L" who has an average deviation of 51 sigma, a low degree of variability is present in timing as the average deviations for the other timers vary from 9 to 36 sigma. The average deviations for sixteen of the twenty-four timers are from 2 to 32 sigma greater in stopping a watch than their average deviation in starting a watch while the deviations of the other eight are from 2 to 17 sigma less. The average deviations for the timers are on an average 2 sigma greater in stopping a watch than the average deviations in starting a watch, showing that there is a

Table 3. Lag in Stopping a Stop Watch*

	Timer	Trial 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Mean	SD**	AD***	Amount of range
Experienced Timers	A	24	42	56	8	84	58	44	62	56	76	90	56	78	2	56	42	70	68	70	68	56±3	23±2	17	88
	B	80	78	58	102	30	38	70	80	8	30	86	122	60	32	30	126	72	100	26	94	66±5	33±3	29	118
	C	2	62	84	44	56	6	28	2	20	18	28	74	26	36	38	2	62	40	2	18	32±4	24±3	20	82
	D	60	130	112	60	120	38	2	40	56	70	50	36	28	26	28	64	42	36	44	2	52±5	34±4	25	128
	E	46	28	38	8	2	28	2	30	22	28	20	28	20	20	32	38	24	46	30	34	26±2	12±1	9	44
	F	118	40	104	36	128	98	42	120	108	40	98	44	94	104	102	84	76	42	80	38	80±5	31±3	28	92
	G	52	42	48	60	64	18	40	128	100	122	12	140	80	2	96	104	112	70	62	128	74±6	40±4	34	138
	H	56	106	86	90	96	128	84	102	86	32	34	88	8	46	26	38	38	78	42	52	66±5	32±3	29	120
	I	50	64	94	62	66	110	74	42	114	126	114	42	18	34	112	100	34	126	50	90	76±5	33±4	30	108
	J	32	126	138	114	42	104	120	64	44	32	34	38	92	12	46	84	38	66	116	126	73±6	39±4	36	116
	K	86	70	82	2	100	84	58	94	96	46	84	2	90	44	116	28	68	116	6	38	66±5	35±4	30	114
	L	58	60	38	98	4	2	56	180	142	2	36	168	116	38	4	84	168	48	62	158	76±9	58±6	51	178
Inexperienced Timers	o	102	30	56	32	26	64	6	34	68	36	108	54	100	38	52	62	58	74	42	46	54±4	26±3	20	102
	p	48	56	34	76	32	48	48	78	80	90	36	56	54	44	60	18	44	30	36	36	50±3	18±2	15	72
	q	44	54	34	70	56	2	70	54	22	8	92	70	46	40	24	26	48	38	50	40	44±3	21±2	17	90
	r	22	30	46	52	64	18	72	20	54	20	26	2	46	36	68	42	86	126	18	36	44±4	28±3	22	124
	s	2	106	100	94	110	70	22	66	96	66	64	100	78	32	72	24	60	70	72	72	69±4	29±3	21	108
	t	80	130	40	94	92	22	90	136	36	42	92	116	50	116	92	96	132	110	94	98	88±5	32±3	26	114
	u	28	36	60	54	82	46	34	36	50	24	28	78	8	78	24	68	14	48	28	56	44±3	21±2	18	74
	v	100	84	104	148	20	80	58	56	40	36	2	42	92	44	44	66	58	60	70	42	62±5	32±3	25	146
	w	124	88	124	70	102	186	72	68	112	76	104	112	122	24	58	92	132	26	152	56	95±6	39±4	32	162
	x	2	96	96	74	14	8	60	90	26	82	128	46	70	24	26	58	62	108	38	80	59±5	35±4	29	126
	y	60	58	110	30	2	24	30	42	42	42	54	60	24	2	40	16	40	102	64	82	46±4	28±3	22	108
	z	66	2	46	66	40	24	76	100	92	50	96	46	78	20	50	36	22	82	94	78	58±5	31±3	25	98

*Expressed in sigmas

**Standard deviation

***Average deviation

greater variable error in the lag in stopping a watch than there is in the lag in starting a watch. A computation of the coefficient of variation for the two groups shows that the relative amount of variability in stopping a watch is almost twice as great as the variability in starting a watch. The amount of variation for each timer varies from 44 sigma for timer "E" to 178 sigma for timer "L" as shown by the range for each timer. Every timer has a smaller average lag in starting a watch because they could anticipate the runner touching the finish line but could not anticipate the flash of light. This same condition is true in timing actual races on the athletic field.

Table 4 shows the average lag in stopping a stop watch for each group as a whole. The average lag in stopping the watch is 62 $\pm$ 3 sigma for the experienced group and 60 $\pm$ 3 sigma for the inexperienced. On the average, the two groups correspond more closely in speed of stopping a watch than they did in speed of starting a watch.

Table 4. Lag in Stopping a Stop Watch for Each Group*

Group	Mean average	Standard deviation of means	Average deviation of means
Experienced	62 $\pm$ 3	17 $\pm$ 2	14
Inexperienced	60 $\pm$ 3	16 $\pm$ 2	13

*Expressed in sigmas

Considering the fact that the experienced timers started their watches on an average 178 $\pm$ 4 sigma after the light was flashed and only 62 $\pm$ 3 sigma after the runner touched the finish line, it is evident that in timing an entire race the timers would "clock" a runner in less than the actual time.

Table 5 shows the average error for each timer in timing an entire race. This error was determined for each timer by subtracting his average lag in stopping a watch from his average lag in starting a watch. It will be noticed that sixteen of the twenty-four timers have an average error over 100 sigma or one-tenth of a second and that timer "E" has an average error of 197 sigma, almost one-fifth of a second.

Table 5 also includes the greatest possible error that could be made by each timer in timing an entire race. This error was determined by subtracting the smallest lag made by each timer in stopping a watch from his greatest lag in starting a watch. The greatest possible errors vary from 142 sigma for timer "u" to 340 sigma, over three-tenths of a second, by timer "G".

The least possible error that could be made by each timer is also listed in table 5. This error was determined by subtracting the greatest lag made by each timer in stopping a watch from his smallest lag in starting a watch. In

Table 5. Error in Timing an Entire Race

	Timer	Average error	Greatest lag in starting watch	Smallest lag in stopping watch	Greatest possible error	Smallest lag in starting watch	Greatest lag in stopping watch	Least possible error	Range of possible error
Experienced Timers	A	117	228	2	226	148	90	58	168
	B	97	252	8	244	128	126	2	242
	C	147	248	2	246	116	84	32	214
	D	105	202	2	200	130*	130	0	200
	E	197	266	2	264	180	46	134	130
	F	83	224	36	188	116	92	24	164
	G	140	342	2	340	142*	140	2	338
	H	102	210	8	202	110	106**	4	198
	I	77	206	18	188	126*	126	0	188
	J	117	288	12	276	140*	138	2	274
	K	135	274	2	272	152	116	36	236
	L	81	226	2	224	180*	180	0	224
Inexperienced Timers	o	110	224	6	218	134	108	26	192
	p	113	246	18	228	132	90	42	186
	q	129	262	2	260	122	92	30	230
	r	111	226	2	224	126*	126	0	224
	s	178	300	2	298	180	110	70	228
	t	87	220	22	198	132	132**	0	198
	u	81	150	8	142	100	82	18	124
	v	89	216	2	214	156*	148	8	206
	w	48	222	24	198	186*	186	0	198
	x	150	264	2	262	150	128	22	240
	y	105	202	2	200	120	110	10	190
	z	103	252	2	250	114	100	14	236

*not the smallest lag)
**not the greatest lag) used in order to show the least possible error

some cases the greatest or smallest lag was not used because it would not show the least possible error that could be made by the timer. The least possible errors vary from no error for six timers to 134 sigma for timer "E".

The range of possible error is also listed for each timer. This range was determined by subtracting the least possible error made by each timer from his greatest possible error. These ranges of possible error which vary from 124 sigma for timer "u" to 338 sigma for timer "G" give some indication of the amount of variability in timing among timers.

Table 6 shows the average error in timing the 240 races for each group as a whole. The average error for the experienced group is 116 $\pm$ 6 sigma and 108 $\pm$ 6 sigma for the inexperienced. The average error of the experienced group is 8 sigma greater than that of the inexperienced group but this is due to the great lag of several experienced timers in starting the stop watch and a very small lag in stopping the watch.

Table 6 also includes the average of the greatest possible errors and the average of the ranges of possible error made by the timers in the two groups. Although the experienced timers have a greater average error in timing entire races than the inexperienced timers, the correlation between the average lag in starting a watch and the average lag in stopping a watch is .45 $\pm$ .16 for the experienced

group and .36 ± .17 for the inexperienced, showing that the experienced timers have a more uniform variation in the two kinds of lag.

Table 6. Error in Timing Entire Races for Each Group*

Group	Mean average	S D** of means	A D*** of means	Mean of greatest possible error	Average range of possible error
Experienced	116 ± 6	32 ± 4	26	239	215
Inexperienced	108 ± 6	32 ± 4	23	224	204

*Expressed in sigmas
**Standard deviation
***Average deviation

VERIFICATION

Another experiment was carried out later as a check on the results obtained as the error in timing an entire race. In this experiment not all the timers who took part in the first two experiments were available, only eight of the experienced timers being used.

In this experiment the reaction circuit was set up so that a short dash could be timed electrically to one-five hundredth of a second by the chronoscope while a timer timed the dash with a stop watch. The flash of light was again substituted for the flash of a gun and the warning signal, "Guns up", was used as in the earlier experiment. The hand

on the dial of the chronoscope started simultaneously with the flash as before and the runner started when he saw the flash. The hand of the chronoscope stopped when the runner touched the finish line and broke an electrical contact as in the earlier experiment.

The watch was always read to the following tenth of a second if the hand of the watch stopped in the interval between the divisions on the dial. The time for the dash as taken by the stop watch was subtracted from the time recorded by the chronoscope, or vice versa, to find the error in timing by the stop watch. Twenty trials were taken for each of the eight timers available.

Results

Table 7 shows the error in timing short dashes with a tenth second stop watch, for each timer and for the group as a whole. In timing the 160 dashes there were 34 overestimations ranging from 4 to 114 sigma, averaging 36 sigma; and 124 underestimations ranging from 4 to 364 sigma, averaging 95 sigma. The average error in timing by the timers varied from 47 to 117 sigma, but the average error in favor of the runner varied from -30 $\pm$ 10 sigma for timer "I" to 117 $\pm$ 10 sigma for timer "A".

These results are not a true verification of the error present in timing an entire race because of the large standard deviations and average deviations which indicate a wide dispersion of the errors. This is due to the small number

Table 7. Error in Timing with a Tenth Second Stop Watch*

Timer	Trial 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	-206	-122	-284	-128	-160	-100	-124	- 92	- 28	-100	-122	-144	-100	-146	-202	-124	- 88	- 66	- 96	- 26
B	- 50	8	36	- 34	-204	- 40	32	24	- 30	- 70	- 30	0	- 46	- 42	- 24	- 34	-130	- 90	-132	- 96
E	22	18	10	- 8	- 82	- 94	-242	- 74	- 74	6	-126	-108	-158	-130	-160	- 52	- 80	-136	-170	4
F	-120	- 68	- 66	-164	- 44	- 96	18	- 46	84	- 66	- 98	-128	- 22	36	40	- 48	- 62	- 18	- 56	-138
G	-110	10	-88	-166	- 58	-364	- 72	30	-162	- 76	-102	- 66	- 30	6	-182	-166	0	12	- 76	58
I	- 24	- 24	102	32	4	- 8	52	86	40	- 52	26	- 20	- 46	- 44	18	108	60	114	- 6	76
J	- 78	-204	- 22	- 36	- 62	- 30	- 28	-120	- 74	- 98	-198	-168	-152	- 18	- 14	- 32	24	-160	- 34	- 4
L	- 80	- 62	- 58	-124	-186	- 22	-220	-126	- 46	-108	-140	- 44	20	-100	- 72	-192	-112	- 74	- 56	78

(Table 7 cont'd)

Timer	Over-estimations	Mean of over-estimations	Greatest over-estimation	Under-estimations	Mean of under-estimations	Greatest under-estimation	Smallest error	Average error	Average error in favor of runner	Standard deviation	Average deviation	Range of error
A	0	--	--	20	117	284	-26	117	117±10	69±7	38	258
B	4	25	36	15	70	204	0	58	48± 9	58±6	44	240
E	5	12	22	15	113	242	4	88	82±11	72±8	59	264
F	4	45	84	16	78	164	±18	71	53± 9	62±7	47	248
G	5	23	58	14	122	364	0	92	80±14	94±10	64	422
I	12	60	114	8	28	52	4	47	-30±10	65±7	49	166
J	1	24	24	19	81	204	- 4	78	75±10	68±7	57	228
L	2	49	78	18	101	220	20	96	86±10	69±7	53	298
Group	34	36**	59**	124	95**	217**	9**	80**	66± 6**	37±4	12	265**

*Expressed in sigmas

**Mean

of trials given each timer. The average deviations for the timers vary from 38 sigma for timer "A" to 64 sigma for timer "G". Timer "A's" low average deviation as compared to the average deviations of the other timers is due to the absence of overestimations in his timing.

The average error in favor of the runner, made by each timer, has a correlation of .24 $\pm$ .22 with the average error in timing entire races, as determined for each timer in the earlier experiment. The average error in favor of the runner is 66 $\pm$ 6 sigma for the entire group. This error is comparable to the average error in favor of the runner, 113 sigma, determined for the eight timers in the earlier experiment. It is comparable because the average error in favor of the runner in the verification experiment is about 45 sigma less than the actual average error made by the timers. The stop watch was always read to the following tenth of a second when the hand stopped between the tenth second divisions on the watch, thereby reducing the average error in favor of the runner. If the hand just exceeded a tenth second division, it would probably be 90 sigma to the next division and the error made by the timer in timing that race would be reduced 90 sigma. Theoretically, the average reduction in error would be one-half of 90 or 45 sigma for the 160 sigma.

The amount of variation in the timing varied from 166

sigma for timer "I" to 422 sigma for timer "G" as shown by the range of error for each timer. In timing the 160 dashes, timers "B" and "G" each timed one race without error but at the other extreme there were 47 errors exceeding 100 sigma, 6 errors exceeding 200 sigma and one error exceeding 300 sigma. Over one-third of the dashes were timed with an error exceeding 100 sigma or one-tenth of a second and 125 of the dashes have an average error of 100 sigma.

In order to find if there is as much error present in timing races with a stop watch read to a fifth of a second as there is in timing with a stop watch read to a tenth of a second, the times as recorded by the tenth second stop watch for the 160 dashes were transposed to times expressed to a fifth of a second, i.e. 4 1/10 and 4 4/10 became 4 1/5 and 4 2/5. These transposed times were then subtracted from the times as recorded by the chronoscope, or vice versa, to find the error present in timing races to a fifth of a second.

Table 8 shows the error in timing 160 short dashes with a fifth second stop watch for each timer and for the group as a whole. In timing the 160 dashes there were 65 over estimations ranging from 2 to 214 sigma, averaging 81 sigma; and 91 underestimations ranging from 2 to 284 sigma, averaging 79 sigma.

Table 8. Error in Timing with a Fifth Second Stop Watch*

Timer	Trial 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	-106	- 22	-284	- 28	-160	0	- 24	8	- 28	0	-122	- 44	0	-102	- 46	- 24	- 88	34	- 96	- 26
B	- 50	108	136	66	-104	- 40	132	124	- 30	- 70	70	0	- 46	- 42	- 24	- 34	-130	- 90	-132	4
E	122	118	10	92	18	- 94	-142	- 74	76	106	-126	- 8	-158	-130	-160	- 52	20	-136	- 70	104
F	-120	- 68	- 66	- 64	- 44	- 96	118	54	184	- 66	- 98	-128	- 22	36	40	- 48	- 62	82	- 56	- 38
G	- 10	110	- 88	- 66	42	58	-264	- 72	130	-162	24	- 2	34	- 30	106	- 82	- 66	100	112	- 76
I	76	- 24	202	132	104	92	152	86	40	48	26	80	- 46	56	18	108	60	214	- 6	176
J	22	-104	78	64	38	- 30	72	-120	- 74	2	-198	-168	-152	82	- 14	- 32	124	- 60	- 34	- 4
L	20	- 62	42	-124	- 86	78	-120	- 26	- 46	-108	- 40	56	120	-100	- 72	-192	- 12	26	- 56	178

(Table 8 cont'd)

Timer	Over-estimations	Mean of over-estimations	Greatest over-estimation	Under-estimations	Mean of under-estimations	Greatest under-estimation	Smallest error	Average error	Average error in favor of runner	Standard deviation	Average deviation	Range of error
A	2	21	34	15	80	284	0	62	58±11	71±12	55	318
B	7	91	136	12	66	132	0	72	8±13	84± 9	70	268
E	9	74	122	11	105	160	-8	89	24±15	100±11	90	282
F	6	86	184	14	70	128	-22	75	23±12	80± 8	65	312
G	9	80	130	11	82	264	- 2	81	9±15	98±11	81	394
I	17	98	214	3	25	46	- 6	87	-80±20	132±14	53	260
J	8	60	124	12	83	198	2	74	25±13	88± 9	71	322
L	7	74	178	13	80	192	-12	78	26±13	89± 9	71	370
Group	65	81**	140**	91	79**	175**	6*	77**	12± 6**	37± 4	15	316**

*Expressed in sigmas

**Mean

The average error in timing by the timers varied from 62 to 89 sigma but the average error in favor of the runner varied from -80 ± 20 sigma for timer "I" to 58 ± 11 sigma for timer "A". These results like those in timing to a tenth of a second are not a true verification of the error present in timing an entire race because of the large standard and average deviations which indicate a very wide dispersion of the errors. However, these results indicate the relative accuracy and variability of stop watch timing to a fifth of a second as compared to stop watch timing to a tenth of a second.

The average deviations for the timers vary from 55 sigma for timer "A" to 90 sigma for timer "E". These average deviations are from 4 to 31 sigma greater than the average deviations for the timers in timing dashes to a tenth of a second. A computation of the coefficient of variation for the timers shows that the relative amount of variability in timing to a fifth of a second is from two to eight times as great as the variability in timing to a tenth of a second.

The average error in favor of the runner, made by each timer in timing entire races to a fifth of a second has a correlation of .33 ± .21 with their average error in timing entire races as determined in the first two experiments. This correlation is greater than the correlation between the error in timing to a tenth of a second and the error as determined in the earlier experiments.

The average error in favor of the runner is 12 $\pm$ 6 sigma for the entire group. This error is also comparable to the average error, 113 sigma, determined for the eight timers in the earlier experiment. The average error in favor of the runner has been reduced about 95 sigma because the watch was always read to the following fifth if the hand stopped between the fifth second divisions on the watch. If the hand of the watch just exceeded a fifth second division it would probably be 190 sigma to the next fifth second division and the error made by the timer in timing that dash would be reduced 190 sigma. Theoretically, the average reduction in error would be one-half of 190 or 95 sigma for the 160 dashes.

The amount of variation in the timing varied from 260 sigma for timer "I" to 394 sigma for timer "G" as shown by the range of error for each timer. With the exception of timer "G", whose range is 28 sigma less, these ranges are from 24 to 94 sigma greater than the ranges in timing to a tenth of a second and the average range of error for the group is 51 sigma greater.

In timing the 160 dashes, timer "A" timed three and timer "B" timed one dash without error but at the other extreme there were 49 errors exceeding 100 sigma and 4 exceeding 200 sigma. Although the number of errors exceeding 100 sigma have increased, the extreme errors present in timing

to a tenth of a second have been reduced from one 300 sigma and six 200 sigma errors to four 200 sigma errors in timing to a fifth of a second. One-third of the dashes were timed with an error exceeding 100 sigma and 114 of the dashes have an average error of 100 sigma or one-tenth of a second.

CONCLUSIONS

1. Error is present in timing races with a stop watch.
2. This error is in favor of the runner.
3. This error is offset to some degree by reading the stop watch to the following tenth or fifth of a second when the hand stops between the divisions on the watch.
4. Timing to a fifth of a second is more accurate than is timing to a tenth of a second--the timer's error is offset more by reading the watch to the following fifth than to the following tenth of a second when the hand stops between the divisions on the watch.
5. The average error in timing to a fifth of a second is negligible--the offset in reading a watch to the following fifth is about equal to the timer's error.
6. Each timer has a great variation in timing with a stop watch.
7. There is a great variation between timers in timing with a stop watch.

8. There is a greater variation in each timer and between timers in timing to a fifth of a second than in timing to a tenth of a second.

ACKNOWLEDGMENTS

I wish to acknowledge the helpful guidance and criticism given by Dr. V. L. Strickland in the preparation of this study, the assistance given by Dr. W. H. Andrews in the statistical treatment of data collected, and the cooperation of the members of the athletic department who acted as subjects.

REFERENCES

Bean, C. H. 1927.
Job Analyzing Athletics. Journal of Applied Psychology, 11: 369-380.

Cummins, R. A. 1914.
A Study of the Effect of Basketball Practice on Motor Reaction, Attention and Suggestibility. Psychological Review, 21: 356.

Dunlap, K. and Wells, G. R. 1910.
Reactions to Visual and Auditory Stimuli. Psychological Review, 17: 319.

Henmon, V. A. C. 1914.
Concerning Individual Differences in Reaction Time. Psychological Review, 21: 153.

Holmes, J. H. 1924.
Reaction Time to Platometrically Equal Chromatic Stimuli. American Journal of Psychology, 34: 414.

McFarland, R. A. 1930.
Experimental Study of Relationship between Speed and Mental Ability. Journal of General Psychology, 3: 67.

Miles, W. R. 1931.
Correlation of Reactions and Coordination Speed with Age in Adults. American Journal of Psychology, 43: 377.

---------- 1928.
Studies in Physical Exertion I: A Multiple Chronograph for Measuring Groups of Men. American Physical Education Review, 33: 379.

---------- 1931.
Studies in Physical Exertion II: Individual and Group Reaction Time in Football Charging. Research Quarterly of the American Physical Education Association, II: (No. 3) 5-14.

---------- and Granes, B. C. 1931.
Studies in Physical Exertion III: Effect of Signal Variation in Football Charging. Research Quarterly of the American Physical Education Association, II: (No. 3) 14-32.

National Research Council 1926.
Reaction Times. International Critical Tables of Numerical Data, 1: 94-95.

Perrin, F. A. C. 1921.
An Experimental Study of Motor Ability. Journal of Experimental Psychology, 4: 24-67.

Rumberger, E. K. 1927.
The Accuracy of Timing with the Stop Watch. Journal of Experimental Psychology, 10: 60-61.

Seashore, R. H. 1930.
Individual Differences in Motor Skills. Journal of General Psychology, 3: 38-66.