TIMING ACCURACIES FOR SWIMMING

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Abstract

Timing accuracies of seventeen swim meets, involving over 16,000 times have been carefully examined. From these results the sources of timing errors have been determined as well as the resulting accuracies of various types of timing.

The average human start delay is found as 0.18 to 0.23 seconds and the average human finish delay is 0.11 to 0.15 seconds. The resulting accuracies of various timing methods are found including human watches, three button finish with a gun start and with a manual start.

Human watches with 0.1 second reading are fast by an average of 0.04 to 0.06 seconds with a standard deviation of 0.10 seconds.

Timing conducted with three button finish, (second button stops the timer,) is fast by an average of 0.05 to 0.08 seconds when a manual start is used, and is slow by an average of 0.11 to 0.15 seconds when a gun start is used. The standard deviation of the finish timing is 0.05 seconds.

These methods of timing are compared for accuracies and recommendations are made which will substantially improve timing accuracies when humans are involved in the finish determination of the event. The use of a gun start with a fixed delay equal to the average human finish delay will achieve an accuracy double that of any other technique using human reactions. This system produces 70% of the times within ± .05 seconds of the actual electronic time versus 35% to 38% for other techniques.

Background

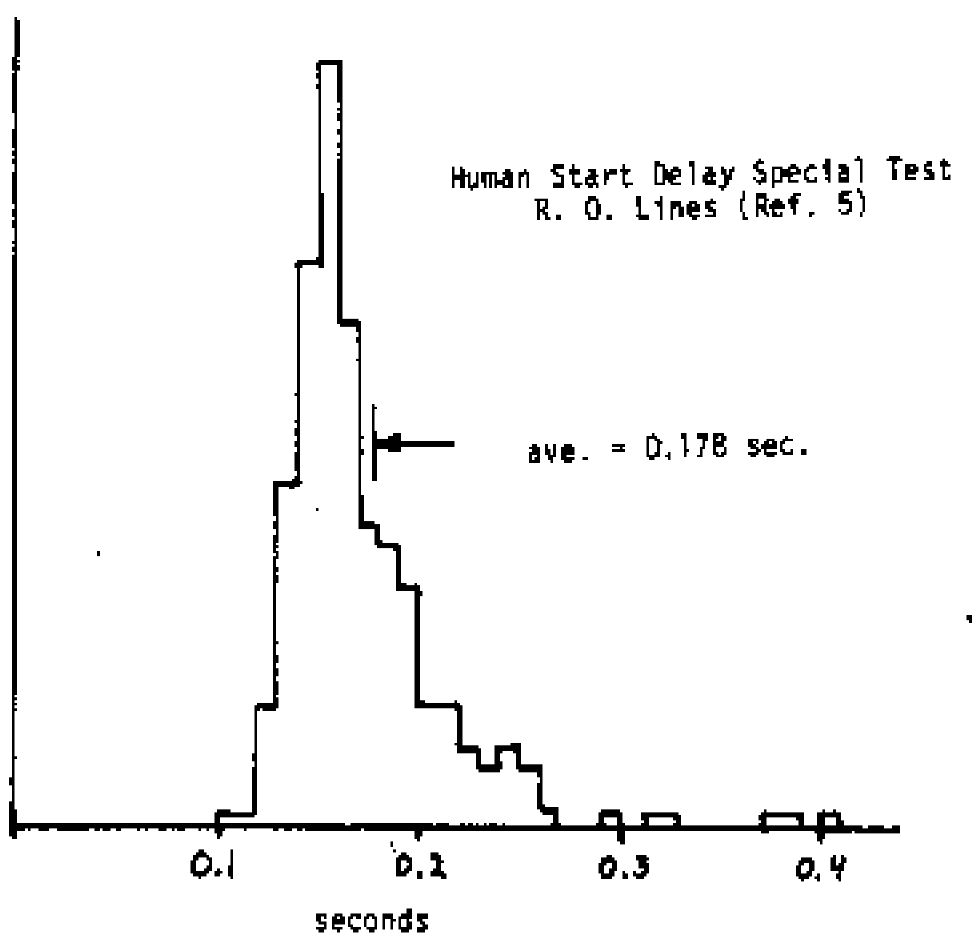
The accuracies of human timing have been investigated for many years with laboratory response times being measured as ranging from 0.15 to 0.20 seconds in response to visual stimulation.[1] The advent of electronic timing in swimming began in the 1960's and was introduced in response to the need of fairness to the swimmers. Parkinson and Stager wrote as follows on the results of the 100 meter freestyle in the 1960 Olympic Games, "Who won the race is no longer the question but the damage that was done to two fine young athletes is something that we should recognize and remedy. Neither Lance Larson or John Devitt will know for certain who really earned the Gold Medal for this ultimate of swimming races."[2]

With this concern electronic timing was developed in the '60's with the Olympic trials in the 1968 being conducted with electronic timing and watch back-up. The advent of two timing systems, one being electronic, permitted the examination of the relative accuracy of these systems. The first data understandingly reflects the concern that the electronic accuracy is being tested rather than human accuracy as the data plots were titled machine time deviations from watch timing. Through the careful work of R.O. Lines this early data was tediously examined by him starting with the 1968 Olympic trials and through the National Long Course meet in Houston, Texas in 1971.[3,4,5] These results were presented at the AAU National Convention in December, 1969 and December, 1970 and in notes completed in October, 1971. This data forms the basis for seven of the seventeen meets examined.

The general conclusion at that time was that electronic timing is slightly slower than watch timing.[3,4,5,6] It is interesting to note that the R. Lines notes of October, 1971,[3] show plots which are in terms of human times vs machine times indicating a confidence in the accuracy of electronic timing at that time.

Starting in 1970 the use of three button finish equipment was used as a back-up to full electronic timing. In the AAU National Long Course meet in August 1970 and the AAU National Short Course meet in Pullman, Washington, in April 1971 the back-up equipment was started with a gun start and a manual finish. These results showed average back-up times which were slower than the fully automatic timing. This was due to the finish reaction time delay of the human timer. This average was determined as 0.11 to 0.12 seconds.[5] Apparently in an effort to improve back-up timing, an experiment was performed at Pullman by R. Lines[5] which determined the human reaction time on starts to range from 0.11 seconds to over 0.40 with the average delay of .178 seconds, figure 1. The obvious hope was that the start delay would compensate for the finish delay thus improving timing accuracy.

In the 1971 AAU National Long Course meet at Houston, Texas, and in all subsequent National AAU meets which were examined with the single exception of the 1975 Junior Olympics, back-up timing was conducted with a manual start and a human button finish. The 1974 National NCAA meet which was examined also used a gun start 3 button finish back-up timing system. The results of this 1971 meet showed back-up timing with this technique to be fast by an average of 0.06 seconds (estimated from histo-gram plots).



Human Reaction Time To Gun Start

Figure 1

Using this 1971 data R. O. Lines came to the conclusion that the finish delay was 0.11 seconds.[5] His conclusion was that timing with manual start, manual button finish is 0.064 seconds faster than the actual event as measured by full automatic equipment.

In the National Short Course meet at Cincinnati, Ohio in April, 1973, Ken Pettigrew's analysis of that meet showed that the back-up times, which were manual start--three button finish, were fast by an average of 0.069 seconds.[6] He also noted that a primary error source was the start delay which in twenty one of over 200 heats was greater than 0.2 seconds. (In actual fact the start delay was in excess of 0.30 seconds since the finish delay of over 0.10 seconds must be considered.) This was evidenced by all back-up times in a given heat being fast by 0.2 seconds or more which can only be attributed to the start delay.

The National Long Course meet at Louisville, Kentucky, August 1973, was also conducted with a manual start, manual button finish back-up timing. This data was carefully recorded by Sally Ventres, Shirley Brown, and June Krauser. The portion of this data kept by S. Ventres was analyzed for this present work. This timing showed the average back-up times to be fast by 0.052 seconds. This data represents the least time difference between back-up and fully automatic timing in any of the meets examined. Since the raw data was available this also represents the first data in which the finish statistics could be determined. With the aid of the hand computer the standard deviation of the finish was found as 0.051 seconds. (This procedure is discussed in detail in Appendix A.)

In this past year the results of the AAU National Long Course meet in Kansas City, August 1975, the AAU National Junior Olympic meet in Ithaca, New York August, 1975, and the Minnesota AAU Long Course Championship meet have been examined in detail, touch by touch, to determine accuracies.

The Junior Olympic meet and the NCAA National meet are of particular importance since they provide raw data timing on a system with a gun start, three button finish as back-up timing to the fully automatic system. This permits direct measurement of the finish delay (found as 0.145 seconds and 0.112 for the J. O. and NCAA meets respectively) and the finish delay distribution. The standard deviation is found as 0.045 to .051 seconds for these meets. The other two of these meets, the Minnesota Long Course Championship and the National AAU Long Course meet, showed back-up times which were fast by 0.08 seconds due to the manual start delay and a finish distribution of 0.05 and 0.067 seconds respectively.

At the request of Dan Ventres, data was supplied by Fred Beisel of Yardley, Pennsylvania on several meets which he had examined. These meets are valuable since they are not National meets and include a meet with a gun start and three button finish as primary timing with a watch back-up. The difference between primary and secondary showed an average value of 0.15 seconds. The number is in excellent agreement with the start and finish delays measured by other meet data. The primary timing is expected to be 0.11 seconds slow and the back-up 0.05 second fast, thus giving an expected difference of 0.16 seconds.

Recently, a meet was conducted with primary timing consisting of a manual start - pad finish with back-up of a manual start three button finish. In an effort to reduce the start delay on the primary time, two start buttons were used in that system. The average difference of 0.079 seconds is slightly less than the expected value of 0.10 seconds. (The primary system is expected to be fast by 0.18 seconds and the back-up fast by 0.08 seconds thus an expected difference of 0.10 seconds.) The primary time was probably 0.16 seconds due to the use of two buttons with the first starting the timing system.

It is clear that with the development of electronic equipment with malfunctions of only 1% to 2% that attention must be directed to upgrading timing accuracies of back-up techniques which involve human reaction times. Through an understanding of the sources of inaccuracies, means of improving human timing can be identified and used. The use of human timing when needed should be made as accurate as possible so that the swimmer or heat receives a fair time. Further, back-up timing and procedures must be fair to the athlete receiving that back-up time and fair to the other swimmers in that or other heats which have accurate machine times which can only be accomplished thru timing which is neither faster or slower than the primary time.

The current practice of using manual start and manual finish produces fast times for back-up, in some cases as fast as 0.3 seconds. Use of these times produces unfair timing to the swimmers with machine times. Comparison of back-up times to determine place of the swimmer with a primary malfunction determines place in as accurate way as is possible with human timing. However, the time is inaccurate and produces problems when compared with swimmers in other heats etc. Since malfunctions occur in only 1-2% of the touches the use of a simple correction factor when the primary and back-up timing systems have a significant time difference in order to determine the accurate times is clearly not a burden to the meet officials. Appendix C describes this technique which virtually eliminates this error source in back-up timing.

Discussion of Data

Table 1 shows the data from these seventeen meets. The data from the several meets is shown so that the effect of different methods of timing are easily correlated. For example, watch back-up timing is fast by 0.04 to 0.065 seconds in the six meets with this type data. There are no major inconsistencies in the data.

The data from fourteen of these seventeen meets is presented in Figures 3-7. These data have been carefully plotted(and replotted from other data) to be consistent as to sign and magnitude. This permits an easy comparison of the accuracies of the back-up timing at these various meets.

The data for watch timing is presented in histogram form with the number of times having 0.1, 0.2, etc. time differences being noted. These have been replotted as follows. For the times noted as having

Table 1. Meet Data Summary

Meet	Location	Date	Primary			Secondary				Malfunctions			Average Difference of Secondary Timing from Primary Timing					Finish Standard Dev.
													Gun Start/Pad Finish			Manual Start Pad Finish	Gun Start 3 Button Finish	
			Type	Start	Finish	Type	Start	Finish	Times	Caught at Meet	(Note 1) Not Caught	(Note 2) % Malfunction	Watch	Gun Start Button Finish	Manual Start Button Finish	Manual Start Button Finish	Watch	
Womens Olympic Trials	Los Angeles, CA	Aug. 23-26, 1968	Avionic	Gun	Pad	3 Watches	Manual	Manual	466	106	13	25.5	-0.06					
Mens Olympic Trials	Long Beach, CA	Aug. 30-31, 1968 Sept. 1-2, 1968	Avionic	Gun	Pad	3 Watches	Manual	Manual	582	16	14	5.1	-0.05					
AAU National S. C.	Long Beach, CA	April 10-13, 1969	Avionic	Gun	Pad	3 Watches	Manual	Manual	1117	73	73	13.0	-0.04					
AAU National S. C.	Cincinnati, OH	April 9-12, 1970	Data Time AMPT	Gun	Pad	3 Watches	Manual	Manual	1636	5	18	1.4	-0.05					
AAU National L. C.	Los Angeles, CA	Aug. 20-23, 1970	Data Time AMPT	Gun	Pad	2 Data Time MPT	Gun	Manual	1743	41	4	2.5		+ 0.11				
AAU National S. C.	Pullman, WA	April 7-10, 1971	Data Time AMPT	Gun	Pad	MPT	Gun	Manual	1563	15	43	4.0		+ 0.12				
AAU National L. C.	Houston, Texas	1971	Data Time AMPT	Gun	Pad	MPT	Manual	Manual	1817	3	33	2.1			-0.07			
AAU National S. C.	Cincinnati, OH	1973	Data Time AMPT	Gun	Pad	Cox 3 Button	Manual	Manual	1561	Unknown					-0.069			
AAU National L. C.	Louisville, KY	Aug. 20-25, 1973	Data Time AMPT	Gun	Pad	3 MPT	Manual	Manual	349	5	9	4			-0.052			0.051
Suburban Aquatic Girls	Pennsbury, PA	February 23, 1974	Colorado Time	Gun	3 Button	Watches	Manual	Manual	282	0	2	0.7					-0.15	
Age Group TRI Meet	Pennsbury, PA	January 18, 1975	Colorado Time	Gun	Pad	Watches	Manual	Manual	148	2	8	6.7	-0.06					
Suburban Aquatic B Meet	Pennsbury, PA	February 15, 1975	Colorado Time	Gun	Pad	Watches	Manual	Manual	432	12	34	10.8	-0.065					
Minn. AAU L. C. Champ.	New Hope, Crystal Minnesota	August 1975	Colorado Time	Gun	Pad	C. T. 3 Button	Manual	Manual	465	5	3	1.7			-0.085			0.087
AAU National L. C.	Kansas City, KS	August 1975	Colorado Time	Gun	Pad	C. T. 3 Button	Manual	Manual	988	6	9	1.5			-0.080			0.050
AAU National Junior Olympic	Ithaca, NY	August 1975	Colorado Time	Gun	Pad	C. T. 3 Button	Gun	Manual	2669	27	10	1.3		+0.150				0.050
NCAA National	Long Beach, CA	1974	Omega	Gun	Pad	Omega 3 Button	Gun	Manual	331	0	2	0.6		+0.112				0.045
West Metro. Sectional U. S. Girls Meet	Hopkins, MN	November 1975	Colorado Time	Manual	Pad	Cox 3 Button	Manual	Manual	138	3	1	2.9				+ 0.079		0.063

Note 1: Malfunctions "not caught" are defined as those times in which the primary and secondary times differed by more than 0.25 sec. This value is well outside the normal timer reactions. However, it is probable that not all of these differences were due to actual malfunctions.

Note 2: The percent malfunction must be carefully examined for confidence limits, i.e., the small number of touches at the West Metro Meet gives an uncertainty of ± 2.4%. The NCAA meet data which contained only part of that meet data had only 331 touches which produces an uncertainty of ± 1.2%. The AAU Natl. J.O. Meet in 1975 contained 2269 times over 98% of the meet data. The accuracy of this data is ± 0.4%. There is no significant difference in the number of malfunctions in the last five meets.

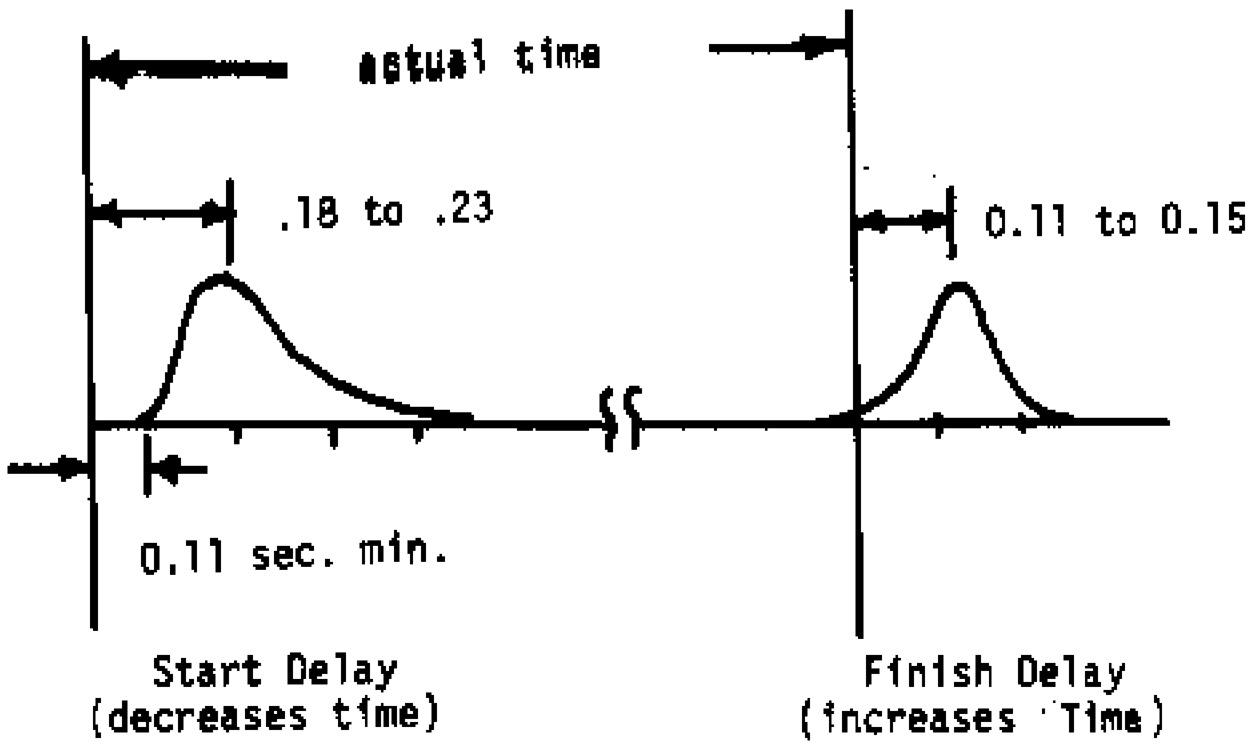
0 time differences this data is plotted as centered at -0.05 since the watch reading is faster than every machine reading in that group. (Whenever the tenths digit of the watch and machine reading are the same, the time was judged to have a zero time difference.)

For data involving back-up and primary times which are read to hundreths or less this displacement of 0.05 seconds does not exist in this data. For this data with .01 resolution or better the histograms were plotted with .01 seconds resolution.

Timing Methods

This data provides a basis for determination of the basic accuracies and sources of errors in various forms of timing. Figure 2 shows the timing which results from a start delay and finish delay. The start delay is shown as averaging 0.18 to 0.23 seconds. The data indicates that in a meet with short events and close location of the meet starter and the manual start operator that the value of 0.18 seconds average delay is achieved. However, with long meets and fatigue a value of .20 to .21 is more typical. Further watch operators located some distance from the starter have an average start delay of .21 to .23 seconds. At the finish the reaction time of finish timers is quite predictable. The average finish delay is 0.11 seconds with a tight distribution of 0.05 seconds, standard deviation. The average delay of 0.15 seconds apparently is associated with the button design of the particular equipment used in that meet. i.e. the delay is apparently predictable to ± .01 seconds even though it's magnitude is different for different button designs.

With these assumptions, Table 2 was developed showing the average timing errors for different types of timing. The assumptions are that the finish delay is 0.11 seconds and the start delay is 0.18 seconds. When manual watches are used the start delay is assumed to be 0.21 seconds as discussed above. The finish delay assumption should be changed with different button designs.



Human Start and Finish Reaction Time

Figure 2

Start Delay = 0.18 + .01 to .05 if using stiff buttons or have general fatigue or distance from start
Finish Delay = 0.11 + .04 if using stiff buttons

	Start Delay (minus)	Finish Delay (plus)	Reading Δ	Average Error
Gun Start - Pad Finish	0.0	0.0	0.0	0.0
Gun Start with Fixed Delay Equal to 0.13 ± .02 sec	-0.11	+0.11	0.00	0.0
3 Button Finish	(.15)	(.15)		
Manual Watches 0.1 sec.	-0.21	+0.11	+0.05	-0.05
Manual Start - 3 Button Finish	-0.18	+0.11	0.0	-0.07
Gun Start - 3 Button Finish	0.0	+0.11	0.0	+0.11
Watches 0.01 sec reading	-0.21	+0.11	-0.005	-0.105
Manual Start - Pad Finish	-0.18	---	---	-0.18

Timing Error Source and Results

Table 2

Watch Timing

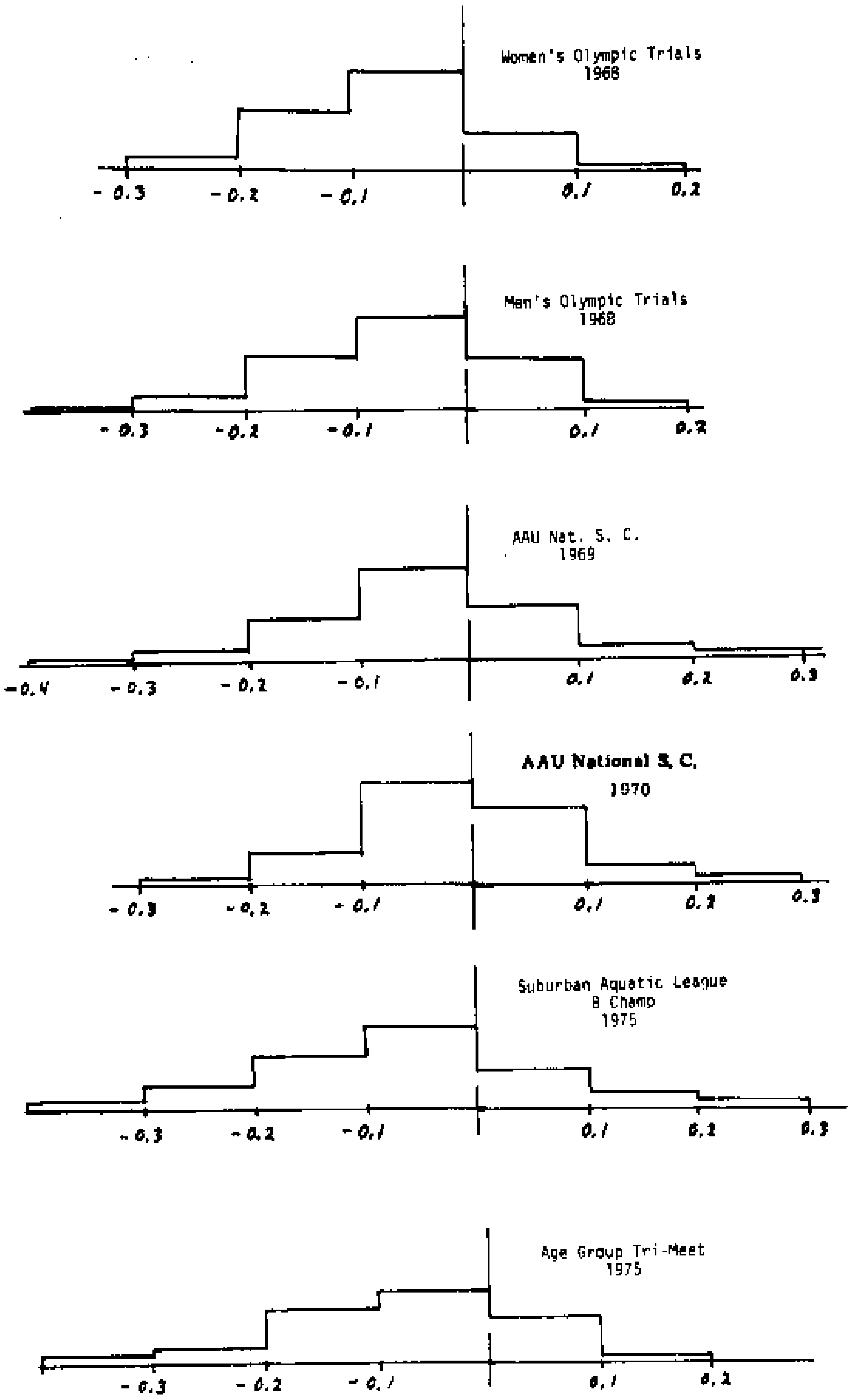
Watch timing accuracy is determined by the start delay, finish delay and method of reading the watch. The start delay was measured by R. Lines as 0.18 seconds with a special test at Pullman, Washington.It is expected that this delay would be longer than this value for timers located at various positions with respect to the gun. The probable value of average timer delay is 0.21 ± 0.03 seconds. Watch finish delay is most probably 0.11 ± 0.02 seconds. The watch reading is therefore fast by 0.10 seconds. However watch reading rules, reference 8, state that if the reading is past a tenth mark (no matter how little) that the watch reading is recorded as the following mark, a slower time. This produces an average reading correction of 0.05 seconds slower to all

0.1 second watch readings. Thus watch readings are expected to be 0.05 seconds, (0.10 - 0.05) fast. This slightly fast timing of watches has been noted for some time.[7] This data permits a clear identification of the reasons for this average fast reading. It is of interest to note that with the emergence of digital hand watches reading to hundreths of a second that the 0.05 correction produced by rounding up will be lost if the watch is read to the hundreth. The readings from these watches would be expected to be fast by 0.1 seconds. They could be read like 0.1 second watches (i.e. 51.11 is read as 51.2 and 51.19 is read as 51.2). To arbitrarilly add a full one tenth second to all readings would be the most accurate timing. However, persuading coaches, swimmers, parents, etc. of the accuracy of this procedure is beyond the scope of this effort if indeed it is possible at all. Manufacturers of these watches might consider this factor as a possible correction factor to be built into the watch, producing more accurate timing.

<u>Three Button Finish Timing</u> (With a Manual <u>Start)</u> Figure 4

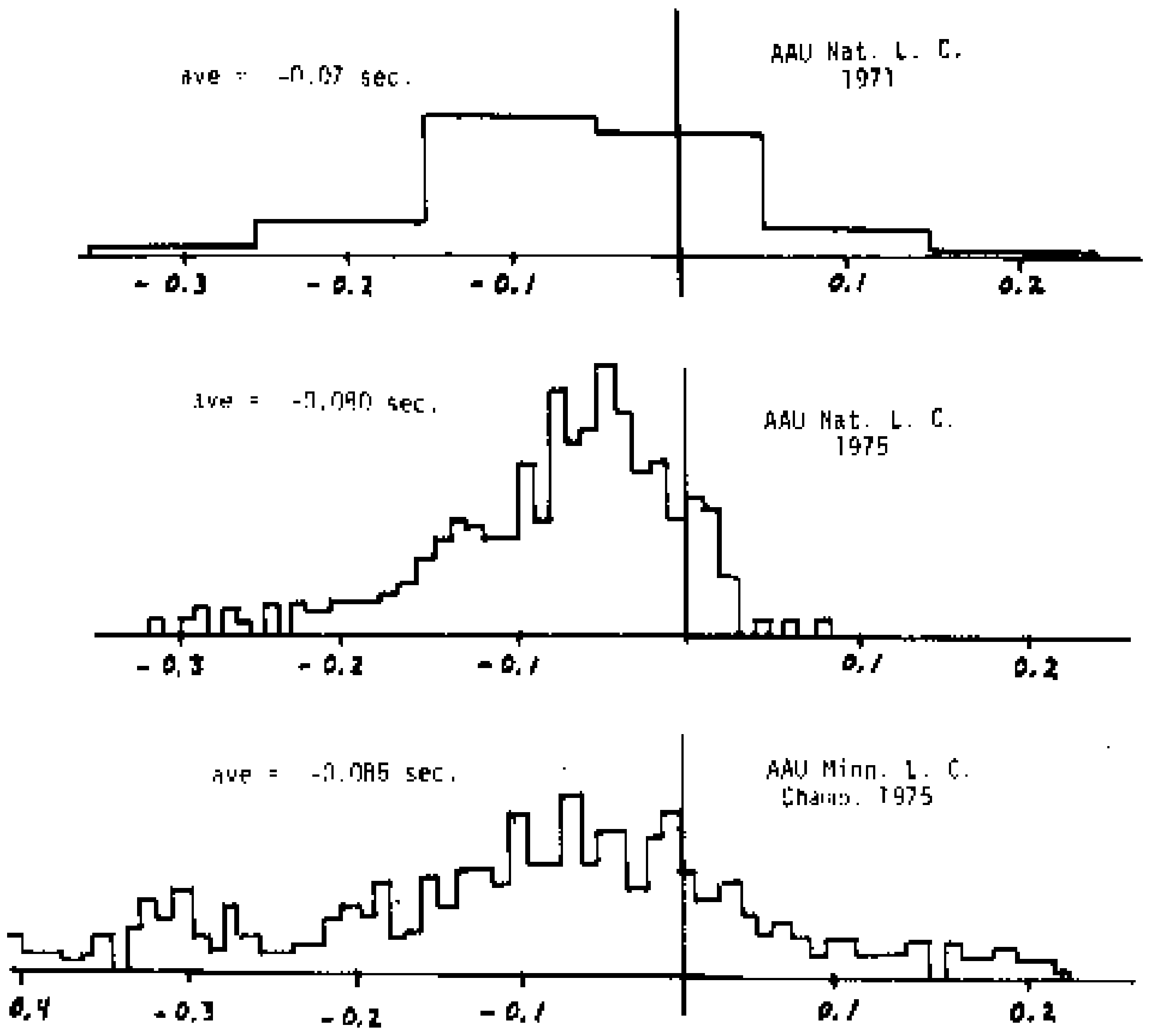
The timing of events with a second button, of three buttons, finish would be expected to be the same as watch timing if a manual start is used, (as in watch starting). This would be true if it were not for two very significant differences. First the button finish is read to hundreths or thousandths of a second and therefore the 0.05 due to rounding up is not present in the data. This data would then be expected to be about 0.08 seconds fast when compared to fully automatic timing. (The start delay is assumed to be as good as 0.20 seconds.) The meet data of 0.06 ± 0.02 seconds compares favorably with this expectation.

Second and most important the start of the three button systems is common to all lanes. This permits the best method of providing accurate timing which is the same for each swimmer in a given heat. However a late start, resulting in fast times, will be shared by all swimmers in that heat and will give those swimmers faster times than those in the other heats of the same event. (In the case of manual watch timing a late start affects only one watch of the three per lane and is rejected by **the fact that the middle time is used** whereas in electronic timing, started by hand, no such reject occurs.) Ken Pettigrew noted this late start in the 1973



Manual Watches Timing Vs. Fully Automatic

Figure 3

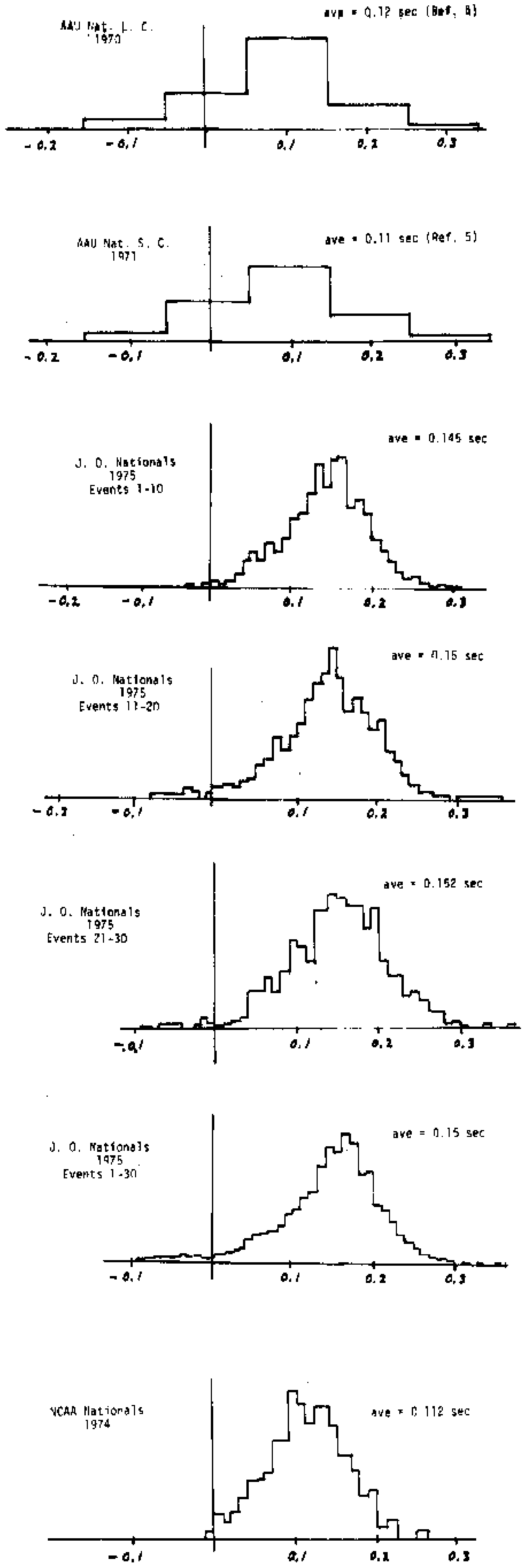


Manual Start - 3 Button Finish Vs. Fully
Automatic Timing

Figure 4

the fact that the middle time is used whereas in electronic timing, started by hand, no such reject occurs.) Ken Pettigrew[6] noted this late start in the 1973 National Short Course results, It was also evident in the National Long Course and Minnesota State Long Course meet data of August 1975. In the Minnesota meet fifteen of the seventy heats examined had time delays which were greater than the finish delay by over 0.2 seconds. Seven of those heats were slow by over 0.30 seconds. Eight other fast heats were consecutive heats obviously caused by a tired starter of the three button system.

It was also noted that severe variation in time delay occurred when the swimming event was a 50 meter event. This event started at the far end of the pool 50 meters from the back-up starter which made getting a good start difficult. It should be noted that since the speed of sound is 300 meters per second the sound is heard 0.16 seconds after the gun start. This has obvious implications for track timing which is conducted in this fashion.



Gun Start - Manual Finish
Timing Vs. Fully Automatic Timing

Figure 5

Three Button Finish Timing (With Gun Start) Figure 5

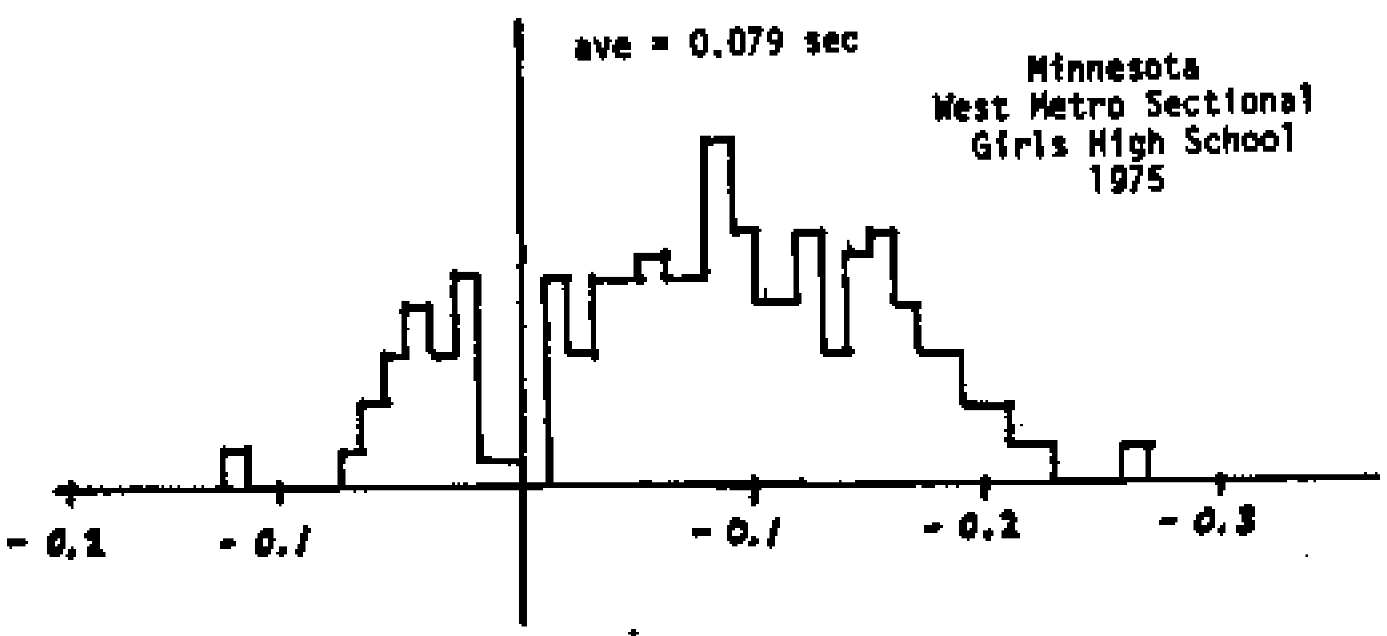
The use of a gun start does an excellent job of removing the variability of the manual start but gives slow times due to the finish delay. This makes results consistent heat to heat but produces an average time which is slow by 0.11 to 0.15 seconds. The time variation apparently depends somewhat on the button design with the stiff button producing the larger finish delays. The standard deviation of the timing, about this average delay, is 0.045 to 0.055 seconds. The individual data of the three separate days of the National J.O. meet, August 1975, shows that this time delay and distribution is quite constant. In addition the results of this study make a strong case for the dependability of the finish delay.

Three Button Finish Timing (With Gun Start and Fixed Delay)

The variable start delay caused by the human start can be eliminated with a gun start and the finish delay cancelled by the use of a fixed delay in the electronic equipment equal to the measured finish time delay. This results in three button timing with average errors of less than .01 to .02 seconds and with a very tight distribution arount the actual times.

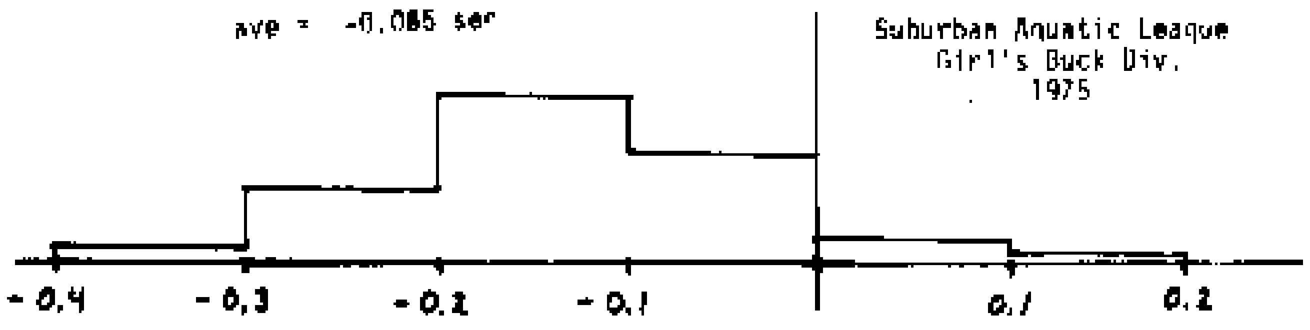
Other Timing Techniques

Figure 6 and 7 show the results of two other meets which have non-standard timing methods. The results are also consistant with the basic conclusions of this work.



Manual Start - 3 Button Finish Vs. Manual Start-Pad Finish

Figure 6



Watch Timings Vs. Gun Start - 3 Button Finish

Figure 7

Conclusions

The conclusions of this work are as follows:

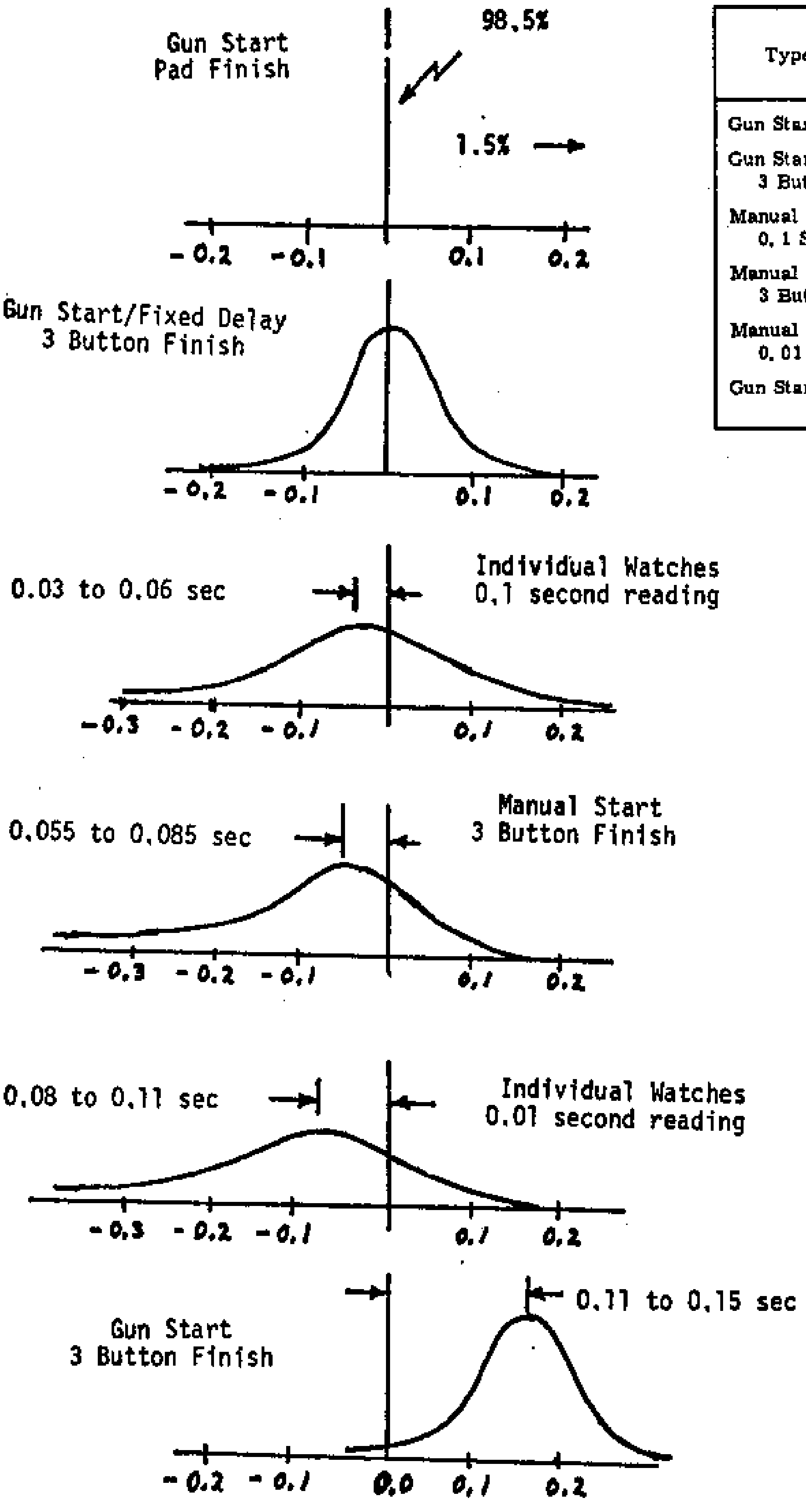
1. The average start delay caused by human reaction to the gun flash is 0.18 to 0.23 seconds. This time can be longer, up to 0.4 or 0.5 seconds, depending upon operator attention and fatigue. It is the major source of three button timing errors and is to be avoided if at all possible. Figure 1.
2. The average finish delay caused by human reaction to the finish of a race is 0.11 to 0.15 seconds. The larger time probably being associated with a stiff button system. This delay is well behaved and would be expected to be relatively constant from meet to meet. The distribution of finishes around this average delay is very close to a normal distribution with a standard deviation of 0.05 seconds. Figure 4
3. Consistent with conclusions 1 and 2 derived from these meet data, the accuracies of various forms of timing are shown in figure 8 and listed in table 3. The data of table 3 shows the accuracy of these various techniques. The accuracy is listed in two ways. The first is the % of times which are within a given accuracy of the given time, ± .05 and ± .10 seconds. In the second case the chance of having times which are greater than a given value (0.1, 0.2, 0.3 seconds) are listed. Obviously the % in the first case should be as large as possible and the chances of the second as small as possible.
4. Significant improvements in manual timing con be achieved with the use of a gun start with a fixed delay equal to the average finish delay. This results in significant improvements in timing and resulting ranking accuracies.

Table 3. Timing Accuracy vs Type of Timing

Type of Timing	% of Times Within		Chances of Having Times Worse Than		
	±0.05 sec	±0.10 sec	>0.10 sec	>0.20 sec	>0.3 sec
Gun Start - Pad Finish	98.5	98.5	1 in 60	1 in 60	1 in 60
Gun Start - Fixed Delay 3 Button Finish	68-72	95-97	1 in 20	1 in 20,000	1 in 500 x 10^6
Manual Start - Manual Stop 0.1 Second Watches	37	66	1 in 3	1 in 20	1 in 250
Manual Start - Manual Stop 3 Button Finish	28-32	55-62	1 in 2 or 3	1 in 4 or 20	1 in 10 or 30
Manual Start - Manual Stop 0.01 Second Watches	28	53	1 in 2	1 in 10	1 in 30
Gun Start - 3 Button Finish	2-4	16-20	4 in 5	1 in 5 or 6	1 in 600

Timing Accuracy Vs. Type of Timing

Table 3



Timing Distribution Vs. Type of Timing

Figure 8

5. Rules should be adopted which permit the correction of back-up times by using the average difference between primary and secondary timing. This will obtain a best measure of the actual time when secondary times must be used and substantially improves back-up accuracies.

Acknowledgment

The assistance of Dan Ventres has been invaluable in encouraging this work, providing a significant portion of the data, and contacting others to provide additional meet data. Dan's concern and dedication to rules and techniques which insure fair competition has been an important factor in this analysis.

Bill Beierwaltes of Colorado Time has been a great help in providing all of the raw data from the National J.O. meet, August, 1975.

Fred Beisel's data from three Pennsylvania meets which were not of the national attention, was invaluable in showing that the conclusions are not limited to National type meets or timing.

Alex F. Cheng of Seagull Enterprises, Inc. (Omega) has supplied raw data on part of the 1974 NCAA Finals.

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Appendix A

Analysis Procedure

The analysis of the timing accuracies is conducted in the following manner: When both primary and secondary systems use a gun start the procedure is to first calculate the difference between the primary and secondary times and then list these differences for all individual swimmers. This data is then plotted in histogram form to give a visual indication of the timing accuracy distribution. The data is then analyzed by computing the average and the standard deviation of the individual time differences.

When the two timing systems are started with different sources, the data is analyzed by computing the average and standard deviation for all individual time differences in each heat. The average measures the time difference between the two systems starts and finishes. The standard deviation measures the distribution of the human finish reaction times.

The average standard deviation of all heats is the best measure of the finish delay statistics and the average of all time differences measures the average difference in the two timing systems. (In situations such as the 1973 AAU Long Course, where the back-up timing is obtained from three back-up systems with separate starts, the standard deviation is not a direct measure of the finish delay.)

An actual example is shown below in which this procedure is illustrated. This example is from the 1975 AAU Long Course Meet and includes all seven preliminary heats of Event 26 - Men's 100 meter freestyle.

Event 26 Men's 100M Free

Heat		1	2	3	4	5	6	7	8	x	s
1	Pri			52.366	52,266	52,526				114	76
	Sec.			52.361	52.101	52,354					
	Diff.			.005	.165	,172					
2	Pri.	53.014	53.804	52.423	53.366	53.383	53.062	52.638		94	64
	Sec.	52.962	53.577	52.347	53.271	53.365	53,004	52.501			
	Diff.	,052	,227	.076	.095	.018	,058	.137			
3	Pri.	55.057	53,444	52,005	53.611	53,466	53.696	53,735	53.262	118	57
	Sec.	54.991	53,223	51.981	53.465	53.366	53.607	53.590	53.108		
	Diff.	.066	,221	,024	.146	.100	.089	.145	.154		
4	Pri.	53.217	53,246	53.576	53.060	53,277	53,038	53.522	53.195	78	56
	Sec.	53.150	53.066	53.591	52,989	53.263	52,955	53.401	53.098		
	Diff.	,067	,180	.015	.071	,014	.083	.121,	,107		
5	Pri.	53,661	53,407	52.688	53.057	52,820	51,302	52,623	53.869	107	90
	Sec.	53.538	53,250	52.763	52,879	52,733	51,236	52,418	53,722		
	Diff.	.123	,157	.105	,178	,087	.066	,205	,147		
6	Pri.	54.417	52,770	51,926	50.596	52.056	53.708	54.105	54.248	149	38
	Sec.	54,348	52,588	51.783	50.457	51,927	53.559	53.908	54,063		
	Diff.	,069	,182	.143	.139	.129	.149	.197	,185		
7	Pri.	53,698	52,085	52.945	51.262	51,607	51.794	52.992	54.998	65	66
	Sec.	53.677	52,009	52,977	51,091	51,625	51,722	52,895	54,863		
	Diff.	.021	,076	,032	.171	.018	.072	.097	.135		

Average Difference = ,103; Average Standard Deviation = ,063

Table A-1. Example of Timing Raw Data, 1975 AAU L.C.

Appendix B

Individual Timer Reactions

The results of the National J. O. Meet and the AAU Long Course Meet in 1975 includes data on the individual button finishes of the 3 button secondary timing. At the National AAU Long Course Meet in Kansas City the timers were instructed to always use the same button. The data resulting from this meet thus permits the ability of individual timers to be examined. The effort of doing this study for the whole meet was not undertaken. However, the results of Events 9 and 10, Women's and Men's 200 meter Freestyle were examined to determine individual timer behavior.

This data is shown below as time differences from pad times. Unless the time difference is circled, all back-up time differences are less than the pad time, Figures B1 and B2. (Note the apparent malfunction in Lane 5 - Heat 7 of Event 9.

These results show the average to be virtually the same for the second button average and all button averages. (The difference was less than 0.008 seconds.) The standard deviation of the finish was increased from ~.055 for the second button only to ~.080 when all times are considered.

In considering the individual timers a determination was made as to whether a given timer is fast or slow when compared to the other timers in their lane. Figure B-3 shows the result of this analysis. In some lanes a fast or slow timer is clearly identified. For example, in Lane 7 the timer on button A was the fastest timer in that lane in all 12 of the heats examined.

Since an estimate of start delay and finish delay was available for 24 times (8 lane times, 3 timers per lane) for each heat, a measure of an individual timer's accuracy when compared to the average of all 24 timers could be calculated. This was done for the data of Event 9 only and is shown in Figure B-4. Timer 7-B (Lane 7, Button B) clearly shows up as slow by 0.055 seconds whereas Timer 7-A is fast by .072 seconds. (Fast and slow are relative to the average of all 24 timers.) Lane 1 apparently has problems with a very fast timer and a very slow timer and with large variations in all three timers.

Button	Heat	Lane 1	2	3	4	5	6	7	8		Second Button
A	1			011	046	118				$\bar{x}$	012
B				003	023	053				s	040
C				026	023	123					
A	2	043	072	024	035	115	037	159		$\bar{x}$	054
B		205	120	005	094	110	073	028		s	053
C		off.	132	100	006	123	017	050			
A	3	114	005	061	016		034	054	048		
B		004	013	032	013		015	056	189	$\bar{x}$	-002
C		020	020	082	054		021	022	029	s	032
A	4	156	073	084	005	285	029	115	060	$\bar{x}$	050
B		026	085	106	024	195	023	010	010	s	069
C		033	185	070	009	182	017	033	014		
A	5	337	081	064	058	087	003	144	109	$\bar{x}$	119
B		139	188	040	117	069	092	051	037	s	075
C		254	205	077	001	035	043	083	094		
A	6	121	005	048	018	122	009	119	031	$\bar{x}$	034
B		117	112	014	012	103	025	013	050	s	056
C		089	090	098	033	023	037	112	038		
A	7	172	100	073	065	466	038	109	081	$\bar{x}$	53
B		204	030	015	043	389	042	040	017	s	039
C		093	140	090	012	428	049	006	032		

For 2nd button x average = 045   s average = 54
For all buttons x average = 037   s average = 75

Table B-1. Timing Raw Data Event 9, Women's 200M Free-Style 1975 AAU National L.C. Meet

Button	Heat	Lane 1	2	3	4	5	6	7	8		Second Button
A											
B	1	heat scratched									
C											
A	2		041	046	056	058	183	157		$\bar{x}$	29
B			055	[illegible]	081	036	033	083		s	47
C			159	071	071	065	054	001			
A	3	181	098	029	042	176	036	107	039	$\bar{x}$	25
B		091	009	013	079	047	025	096	050	s	42
C		067	075	072	024	038	029	031	055		
A	4	035	114	[illegible]	023	084	022	096	110	$\bar{x}$	10
B		072	138	[illegible]	060	036	005	139	[illegible]	s	62
C		044	254	025	133	007	027	039	[illegible]		
A	5	103	058	009	001	021	014	137	031	$\bar{x}$	-12
B		100	160	[illegible]	038	075	007	043	[illegible]	s	43
C		088	050	027	182	017	003	010	[illegible]		
A	6	074	058	042	017	047	053	121	024	$\bar{x}$	10
B		080	[illegible]	042	014	161	077	071	032	s	53
C		056	321	111	093	043	012	063	126		
A	7	131	093	022	025	074	016	167	036	$\bar{x}$	19
B		070	021	017	010	103	021	025	122	s	56
C		077	154	084	091	074	017	003	036		

For 2nd button x average = 13   s average = 56
For all buttons x average = 8   s average = 85

Table B-2, Timing Raw Data Event 10, Men's 200M Free-Style 1975 AAU National L.C, Meet

Lane	Timer	Number of Heats in which timer was: Fast	Mid.	Slow
1	A	10	1	0
	B	0	1	10
	C	1	9	1
2	A	2	5	5
	B	0	5	7
	C	10	2	0
3	A	2	9	2
	B	2	2	9
	C	10	0	2
4	A	2	8	3
	B	10	2	1
	C	1	3	9
5	A	7	5	0
	B	3	6	3
	C	2	2	8
6	A	2	3	7
	B	9	2	1
	C	1	7	4
7	A	12	0	0
	B	0	1	11
	C	0	11	1
8	A	10	0	0
	B	0	6	4
	C	0	4	6

Table B-3, Timing of 24 Timers - Events 9 & 10
AAU Long Course - August 1975

		Heat								
Lane	Timer	1	2	3	4	5	6	7	$\overline{x}$	s
1	A		005	117	088	245	103	130	113	73
	B		254	001	093	047	135	246	-113	113
	C		---	023	100	162	071	051	41	84
2	A		024	002	006	011	013	058	10	24
	B		072	015	018	096	094	073	32	61
	C		084	023	118	113	072	098	84	31
3	A	012	024	064	017	028	066	031	0	40
	B	004	043	035	039	052	032	027	-10	34
	C	027	052	085	003	015	080	048	29	31
4	A	045	013	013	062	034	036	023	-25	25
	B	027	046	021	043	025	006	001	2	28
	C	024	054	051	058	093	051	030	-51	20
5	A	119	067	---	188	005	104		94	63
	B	054	062	---	128	023	085		61	49
	C	122	075	---	115	057	005		3	85
6	A		085	081	096	095	009	004	-61	39
	B		025	018	044	000	007	000	1	22
	C		065	087	050	049	055	007	-49	28
7	A		111	057	048	052	101	067	72	24
	B		076	053	057	143	005	002	-55	58
	C		002	019	034	009	094	036	0	44
8	A			051	007	017	013	039	22	20
	B			186	057	129	068	059	-99	50
	C			026	053	002	106	074	-51	37

Table B-4. Individual Times Data - Event 9 - AAU National L.C., 1975

Appendix C

Methods of Improving Three Button Timing

When a manual start or gun start (without a fixed delay equal to the finish delay) as a back-up timing system there is a time difference between the two timing techniques due to the different starts and finishes. If a malfunction occurs the best measure of the actual time of that swimmer is his/her back-up time adjusted by the average time difference between back-up and primary times of all other swimmers in that heat. This average measures the difference in the start delay and the average finish delay of that heat. Since the distribution in the finish delay is 0.05 seconds, the accuracy of the adjusted times is 0.02 seconds even if only five times are used in the average and thus gives excellent timing accuracy.

This procedure is illustrated with an actual example from the 1975 AAU National Long Course Meet. Figure C-1 shows Event 26, Heat 6, Men's 100 meter freestyle. This was the heat in which Jim Montgomery set a pending world record time of 50.596. Shown in this figure is the adjusted secondary time that would be used by this technique assuming that the primary time had a malfunction. This process was followed for each lane assuming that the primary time had failed in only that lane. From this technique the adjusted secondary times would have a maximum error of .091 seconds and an average error of less than .001 seconds and no place changes would occur due to integration of these times.

This technique is also illustrated for the finals of this event. Figure C-2.

This procedure preserves the relative place of all swimmers with an official primary time. It accounts for any differences in the two timing systems by using all of the available data from both systems. It further adjusts the secondary time to the best measure of the swimmers actual time and thus avoids place and ranking problems resulting from the integration of non-adjusted secondary times. All ranking and place determination is then conducted by integration.

AAU National L.C. 1975 Event 26 Heat 6

Swimmer	Lane	Primary Time	Secondary Time	Diff.	Adj.factor lane mal.	Adj. Time	Diff.
Steve Austin WVAT	1	54.417	54.348	-.069	-.160	54.508	+.091
Byron Sims SCA	2	52.770	52.588	-.182	-.144	52.732	-.038
Rick Abbott MAC	3	51.926	51.783	-.143	-.150	51.933	+.007
Jim Montgomery BD	4	50.596	50.457	-.139	-.151	50.608	+.012
Joe Bottom SCSC	5	52.056	51.927	-.129	-.152	50.079	+.023
Mark Smith TAC	6	53.708	53.559	-.149	-.149	53.708	.000
Greg Jagenberg SSC	7	54.105	53.908	-.197	-.142	54.050	-.005
Steve McDonald SSC	8	54.248	54.063	-.185	-.144	54.207	-.041

Table C-1. Example of Timing Raw Data, 1975 AAU L.C.

AAU National L.C. 1975 Event 26 Finals Men's 100 M Freestyle

Swimmer	Lane	Primary Time	Secondary Time	Diff.	Adj. factor lane mal.	Adj. Time	Diff.
Joe Bottom SCSC	1	52.212	52.128	-.084	-.118	52.246	+034
Jack Babashoff LBSC	2	52.187	52.016	-.171	-.105	52.121	-066
Jonty Skinner NRYC	3	51.054	51.004	-.050	-.123	51.127	+073
Jim Montgomery BD	4	51.045	50.886	-.159	-.107	50.993	-052
Andy Coan FLST	5	51.465	51.358	-.107	-.115	51.473	+.008
Bruce Furniss LBSC	6	51.654	51.575	-.079	- .119	51.694	+.040
Rick Abbott MAC	7	52.271	52.132	-.139	-.110	52.242	-029
Bob A. Sells UTHI	8	51.874	51.751	-.123	-.112	51.863	-011

Table C-2. Adjustment of Back-up Times Assuming Malfunctions - Example 2

Appendix D

Data Summary

Table D-1 shows the detailed data from two of the meets examined. This table shows the nature and distribution of "malfunctions".

		AAU Long Course Nationals	AAU Long Course Minn. State Champ.
Number of touches in data set:		988	465
Number of "malfunctions" caught at the meet:		6	5
Number of malfunctions: (determined by time differences between pad and backup times when the average difference in each heat is removed from the data.)	.25 → .30	1	0
	.30 → .40	4	1
	.40 → .50	1	0
	.50 → .60	1	0
	.60 → up	0	2 (.76, 1.254)
	fast finishes	2 (1.28, .40)*	0
Total number of "malfunctions"		15	8
Standard deviations of back-up timing, removing the start delays:		0.050	.067**
Number of raw times different by more than 0.50 seconds:		3	3
by more than 0.25 seconds:		39****	77***

* Fast finishes are those in which the pad finish is earlier than the button finish by more than 0.25 seconds. In all of the data examined this only occured twice, apparently due to a "finish" caused by the timer stepping on the pad.

** The buttons used were in poor condition and not all operated. This was discovered late in the meet and then all of the buttons were cleaned.

*** Thirty - eight of these differences occured in six heats. The start delay was over .35 seconds in those heats.

**** Eleven of these differences occured in two heats which had slow starts in excess of 0.35 seconds. There were only eleven heats in the three days which had time differences greater than 0.35 seconds which were due to the start delays and were not probable malfunctions.