Reliability of interval time measurement method using video images in short distance sprint for STEAM physical education

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Abstract

The demand for STEAM in school physical education is increasing. Measuring a 50 m sprint time has been used for a long time as a teaching material to promote scientific and mathematical thinking, but the problem is that the stopwatch has a large error margin. The standard frame rate for video recording in schools is 30 or 60 frames per second, which is significantly less accurate than the 1,000 frames per second used in official track and field records. Based on this background, this study examined the magnitude of error when 50 m sprint interval times were measured using video images with standard frame rates. Four university students enrolled in a health and physical education course participated in this study. A photoelectric sensor, 59.94 fps video image, 29.97 fps video image, and a stopwatch were used for measurement instruments, and a person with a stopwatch and another person operating video cameras were set 15 m and 30 m from the goal line. The measurement error of interval times (each ten meter) was analyzed using 40 total runs, assuming the measurement by the photoelectric sensor as the true value. As the result, the following were revealed.

1) Errors were smaller with the stopwatch, 29.97 fps video images, and 59.94 fps video images, in that order. However, the difference between 29.97 fps and 59.94 fps was less than 1/100th of a second. 2) The error was smaller at 30 m than at 15 m between the video camera and goal line. 3) At the 10 m interval and further, the average error of stopwatch was 0.048 seconds, and the largest error was 0.230 seconds. On the other hand, the measurement error of the 59.94 fps video image was 0.018 seconds on average and 0.064 seconds at the largest.

These results suggest that by placing video cameras as far away from the finish line as possible and using high frame rate video shooting, the measurement of interval times can be used as a teaching material for STEAM in physical education.

Keywords：Physical education class, short distance sprint, interval time, video image, measurement reliability

I. Introduction

In recent years, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) has focused on promoting science, technology, engineering, art (liberal arts), and mathematics (STEAM) education (David & Thomas, 2013). STEAM is an educational policy that aims to promote free and creative thinking among students by encouraging learning across these fields. In physical education classes, scientific findings, such as physics and physiology, are utilized to improve motor skills and physical fitness, and engineering, such as biomechanics, supports experiments in physical exercise. In addition, mathematical thinking was required for physical education class using sports analytics which has become popular in recent years, as a teaching material (Jo, 2022). Given these facts, developing STEAM

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in physical education classes is important.

To develop STEAM in physical education classes, the use of ICT is necessary. This is because playing sports alone is not enough to learn physical education as an academic discipline but measuring and analyzing the phenomena that occur in physical exercise and games, will develop deep learning and encourage students' creative thinking.

According to MEXT (2022), ICT is often used for watching sample videos, teacher presentations, reviewing lessons and inputting learning assignments, distributing videos and assignments that can be studied at any time, and sharing results in physical education classes, with minimal use of measuring and analyzing physical movements and performance. In addition, repeated filming and viewing, has the advantage of allowing students to view physical movements and games from an outside the perspective. However, the thought process of students is subjective and qualitative; it is difficult to promote scientific and mathematical thinking that is at the core of STEAM education.

On the other hand, very few practical studies have been reported that used ICT to measure and analyze movement and performance; Watanabe & Katoh (2006) used video shooting with 60 fps (frames per second) to measure interval times in a unit on short distance sprint in track and field events and asked students to think about where problems exist. Interval time is suitable for STEAM materials because it is quantitatively measured information and can be analyzed mathematically. However, it is not clear how accurate a 60 fps video image is for the measurement of interval time.

The most accurate measurement of short distance running times is the photographic determination system used in track and field's official record (1,000 fps). The next most accurate measurement method is using a photoelectric sensor. However, since 1,000 fps high-speed cameras and photoelectric sensors are expensive, it would be practically impossible to use them at school sites. With such limitations, video recording using ordinary video cameras and tablet terminals are the most promising candidates for implementing time measurement with the highest possible accuracy. However, these devices are standardized for 30 fps or 60 fps, and it is unclear how accurate the measurement is. If it is possible to measure interval times with high accuracy using standard frame rate video recording, they could also be used as teaching materials for implementing STEAM education in track and field classes.

The purpose of this study was to determine how accurately video recording using common video cameras or tablet terminals could measure the 50 m sprint interval time, which can be replicated at school sites.

II. Method

1. Definition of intervals

The intervals were divided into five intervals for every ten meters of 0-10 m, 10-20 m, 20-30 m, 30-40 m, and 40-50 m.

2. Measurement method

Interval times were measured by applying Ito's (1991) method, in which one person measures the interval time at a single location by using video images and a stopwatch. The photoelectric sensors were placed at each interval (five locations), and the video cameras and a stopwatch holder were placed at the same location (laterally away from the finish line). The measurement of 15 m position conducted after finishing 30 m. A pole was placed between the center point of interval and line connecting the stopwatch holder or video cameras (Figures 1 and 2). This pole is to see that the runner passed each interval.

A wooden start signaling equipment was made so that the stopwatch holder, who stood over 50 m away from the starter and video viewer after shooting, could visually determine that a sound had been made. The moment that the start signal equipment closed was considered the start (Figure 3). To measure the interval time, a stopwatch was pressed at the moment when the pole and center of the runner's chest overlapped. Regarding the video image, it was replayed after shooting, and the number of frames when the pole and the runner's chest center overlapped were recorded (Figure 4). The finish line was measured when the goal line and runner's chest overlapped in common with normal short distance sprint.

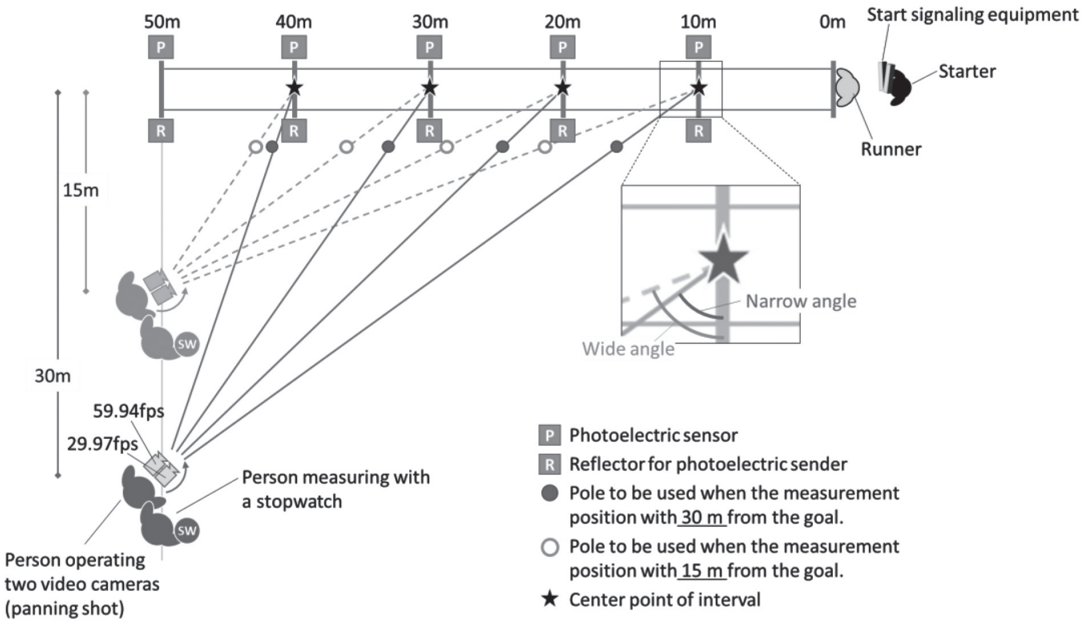


Figure 1. Overhead view of the measurement placement. In this figure, the stopwatch holder and the camera operator appear to be far apart, but in reality, the stopwatch holder's line of sight is positioned almost directly above the camera.

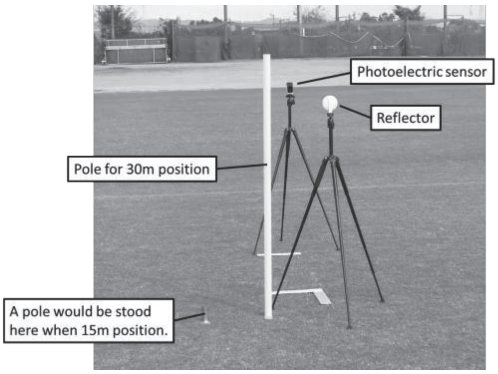


Figure 2 How to set a pole and a photoelectric sensor at each 10 m interval

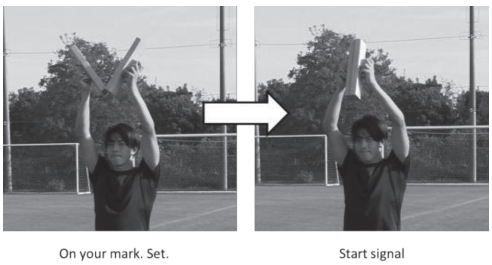


Figure 3 Starter's operation. The stopwatch holder starts the stopwatch, and the video image viewer records the number of frames at this time.

The photoelectric sensor did not measure the 0-10 m interval because it cannot pick up sound. Video images and a stopwatch measured all intervals.

3. Instruments and location of measurement

For this study, a photoelectric sensor (Microgate, Witty), video cameras (Canon, XA30), and a stopwatch (Rhythm, Citizen RC058) were used as measurement instruments. Two identical video cameras were used to simultaneously shoot video images at 59.94 fps and 29.97 fps (Figure 5). The two video cameras and stopwatch holder were positioned 15 m or 30 m from the finish line. This is because if the distance between the two video cameras and stopwatch holder were closer to goal line, the shooting angle was narrower. If the stopwatch holder was positioned far from goal line, the shooting angle was wider (see "narrow angle" and "wide angle" in Figure 1). The wider angle is thought to make it easier to identify the overlap between the pole and center of runner's chest.

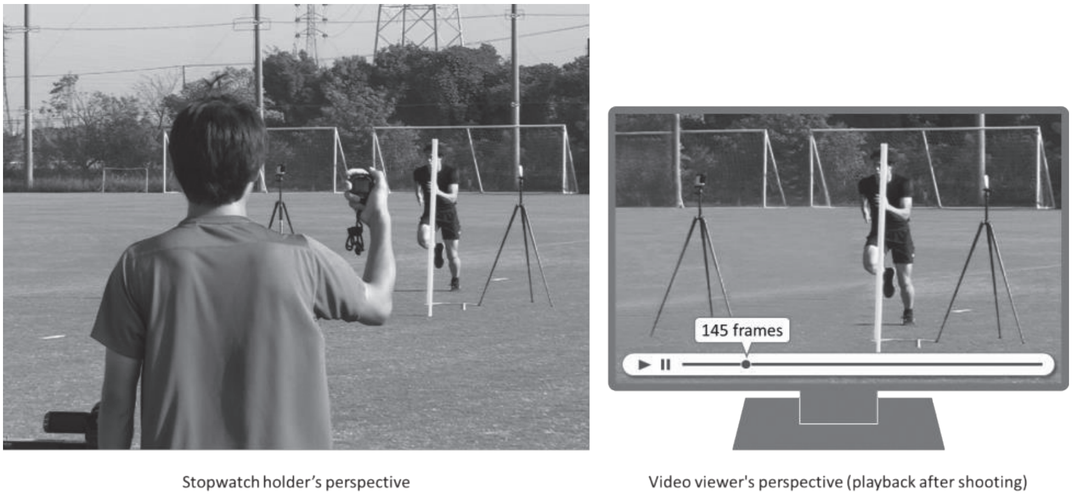


Figure 4 The stopwatch holder measured the interval time (lap time) when the center of the runner's chest overlaps with the pole (left). The video viewer (playback after shooting) measured number of frames from video image with same running (right).

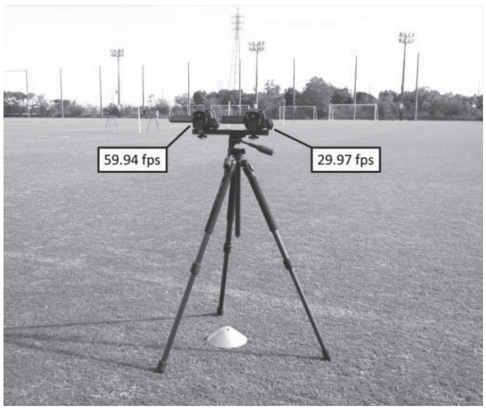


Figure 5 Two cameras (59.94 fps and 29.97 fps) were placed on the same tripod.

4. Preparation for measurement

A person with nine years' experience as a health and physical education teacher created a 50 m lane and set up all the equipment. In doing so, the distance from the starting point was accurately measured with a metal tape measure, and great care was taken to ensure that the ten m intervals and the installation of the measuring equipment were as accurate as possible. It took 50 minutes to complete all preparations.

5. Target of analysis

Four university students enrolled in a health and physical education course participated in this study. The students took turns being the runner, stopwatch holder, and video camera operator. Eight segments were measured from combinations of four different measuring instruments (photoelectric sensor, 59.94 fps video image, 29.97 fps video image, and stopwatch) and two different placement locations (15 m and 30 m). Segment 2 was measured by moving locations after Segment 1. Participants ran five times each at the 15 m and 30 m placement locations (10 runs total per participant), and a total of 40 interval times were measured by four participants (Table 1). This study was designed for STEAM in health and physical education at junior high schools and as the participants' 50 m sprint times were faster than the average time for junior high school students, they were instructed to run at 80%-90% relative to their full sprinting speed.

Table 1 Segment of measurement

Segment	Distance (*)	Instruments	Number of runs
1a	30m	Photoelectric sensor	
1b	30m	59.94 fps video image	5 per
1c	30m	29.97 fps video image	person
1d	30m	Stopwatch	
2a	15m	Photoelectric sensor	
2b	15m	59.94 fps video	5 per
2c	15m	29.97 fps video	person
2d	15m	Stopwatch	

* It means the distance from the finish line to the stopwatch holder and the video cameras.

6. How to measure interval time from video image

The number of frames when the interval have passed and frame rate of video can be used to calculate the section time (Formula 1).

$$t_i = (1/FPS)f_i - (1/FPS)f_{i-1} \cdots Formla\ 1$$

Where ti is the interval time ($t1$ is the 0-10 m interval, $t5$ is the 40-50 m interval); FPS is the frame rate of the video; fi is the number of frames at the passage of the interval ($f0$ is at the start, $f1$ is at the 10 m interval, $f5$ is at the goal). For example, if a video is shot at 29.97 fps and the number of frames at the passage of 10 m is 160 and the number of frames at the passage of 20 m is 200, the 10-20 m interval time would be (1/29.97)*200 - (1/29.97)*160 ≒ 1.3347.

7. Method to analyze measurement error

In the 10-20 m, 20-30 m, 30-40 m, and 40-50 m intervals, the difference between the photoelectric sensor and 59.94 fps video image, 29.97 fps video image, or stopwatch was calculated to be the measurement error of the interval time, and the mean, standard deviation, and ranges (maximum value - minimum value) were calculated. A two-way analysis of variance (ANOVA) with no correspondence between the distance factor (distance from the finish line of the video cameras and a stopwatch holder) and measurement instrument factor was used for statistical hypothesis test to confirm interactions. If no interaction was found, the main effect of each factor was tested. If significant differences of main effects were found, a multiple comparison test with

Tukey's HSD was performed. For the 0-10 m interval, which could not be measured with the photoelectric sensor, we compared the 59.94 fps video image, which were considered the next most accurate, and stopwatch to examine the error of manual measurement in this interval. All analyses were performed at a significance level of 5%. R 4.0.1 and R studio 2022.07.2+576 were used for statistical application.

8. Ethical Considerations

The purpose, method, and photograph publication were explained to the research participants, and the research was conducted after consent was obtained. In addition, this study was conducted with the approval of the Research Ethics Committee at the Department of Sports Sciences, Shizuoka Sangyo University (Approval No.:S22003).

III. Result

1. Interval times by photoelectric sensor

The basic statistics of the interval times measured by the photoelectric sensor were shown in Table 2. Intervals of 0-10 m could not be measured because the photoelectric sensor is not able to respond to sound.

Table 2 Interval time (second) measured by photoelectric sensor

	Distance	n	0-10m	10-20m	20-30m	30-40m	40-50m
Mean	30m	20	—	1.431	1.324	1.319	1.390
	15m	20	—	1.480	1.404	1.406	1.481
S.D.	30m	20	—	0.079	0.077	0.101	0.127
	15m	20	—	0.074	0.084	0.121	0.143
Max.	30m	20	—	1.590	1.460	1.520	1.670
	15m	20	—	1.620	1.570	1.650	1.770
Med.	30m	20	—	1.435	1.325	1.330	1.380
	15m	20	—	1.470	1.400	1.400	1.475
Min.	30m	20	—	1.310	1.190	1.120	1.220
	15m	20	—	1.320	1.280	1.230	1.280

* Interval 0-10m could not be measured because photoelectric sensor is not able to respond to sound.

2. Measurement error

Assuming the measurement by the photoelectric sensor as the true value, the difference between the 59.94 fps video image, 29.97 fps video image, or stopwatch was calculated (Figure 6). The stopwatch measurement at 15 m from the finish line had the largest error (0.054~0.085 sec). The next were stopwatch measurements at 30 m (0.045~0.053 sec), 29.97 fps video image at 15 m (0.031~0.050 sec), 29.97 fps video image at 30 m (0.020~0.031 sec), and 59.94 fps video image at 15 m (0.028~0.043 sec). The smallest error was 59.94 fps video image at 30 m (0.015~0.022 sec).

The standard deviation of the size of error was the largest for stopwatch at 15 m (0.041~0.066) and was the smallest for 59.94 fps video image at 30 m (0.011~0.017) (Figure 7). The range of the size of error (maximum - minimum) was also at the maximum for stopwatch at 15 m (0.180~0.250) and at the minimum for 59.94 fps video image at 30 m (0.042~0.064) (Figure 8).

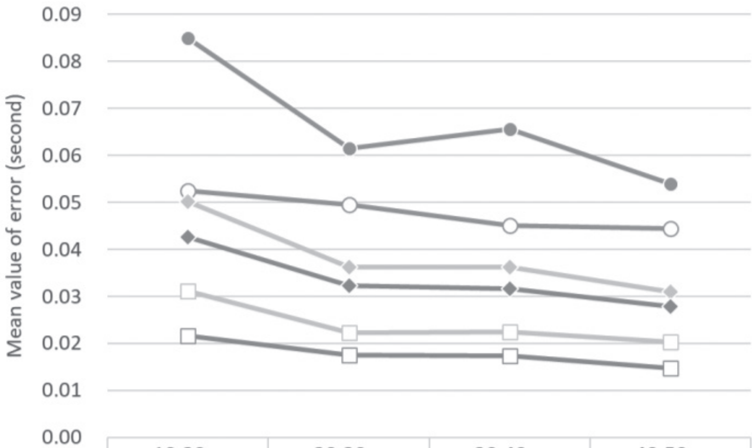
3. Results of statistical tests

The two-way ANOVA showed no interaction effects in all intervals. The main effects of the distance factor were observed in the 10-20 m, 20-30 m, and 30-40 m intervals, with medium effect sizes in the 10-20 m and 20-30 m intervals. The main effect of the instrument factor was observed in all intervals, with the large effect size in the 20-30 m interval and medium effect size in the other intervals (Table 3).

The results of the multiple comparison tests for each measurement instrument are shown in Table 4. The 59.94 fps video image and 29.97 fps video image had no significant difference in all intervals, and the effect sizes were almost none. The stopwatch and 29.97 fps video image had a significant difference in all intervals, and the effect sizes were small to medium. The stopwatch and 59.94 fps video image had a significant difference in all intervals, with all effect sizes ranging from small to medium.

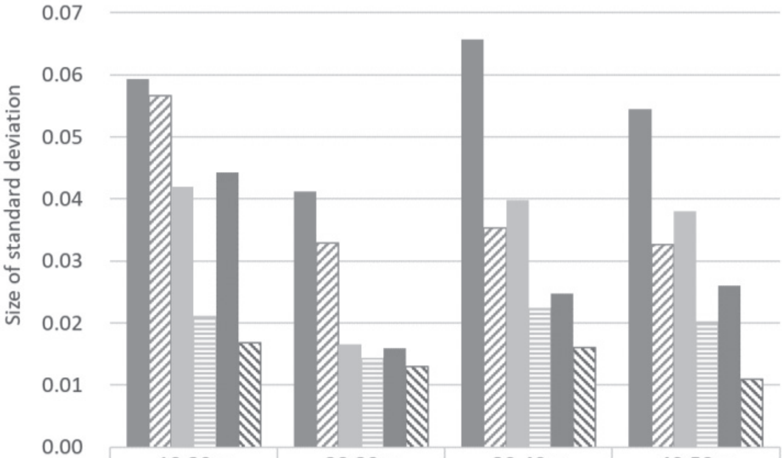
4. Measurement error in the 0-10 m interval

The difference between the 59.94 fps video image, which has the next highest measurement accuracy after the photoelectric sensor, and the manually measured stopwatch error average was determined to be 0.205 second (15 m distance) to 0.216 second (30 m distance) in the 0-10 m interval (Figure 9).



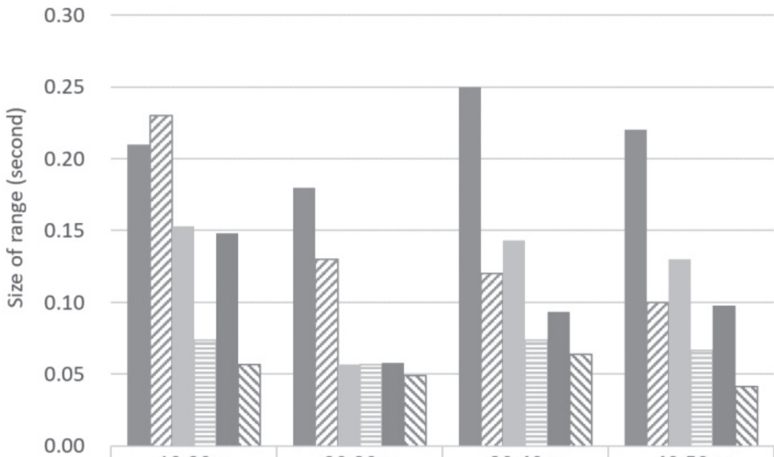
	10-20m	20-30m	30-40m	40-50m
15m・Stopwatch	0.085	0.062	0.066	0.054
30m・Stopwatch	0.053	0.050	0.045	0.045
15m・29.97fps video	0.050	0.036	0.036	0.031
30m・29.97fps video	0.031	0.022	0.023	0.020
15m・59.94fps video	0.043	0.032	0.032	0.028
30m・59.94fps video	0.022	0.017	0.017	0.015

Figure 6 Mean value of error between photoelectric sensor and video images or stopwatch.



	10-20m	20-30m	30-40m	40-50m
15m・Stopwatch	0.059	0.041	0.066	0.054
30m・Stopwatch	0.057	0.033	0.035	0.033
15m・29.97fps video	0.042	0.017	0.040	0.038
30m・29.97fps video	0.021	0.014	0.022	0.020
15m・59.94fps video	0.044	0.016	0.025	0.026
30m・59.94fps video	0.017	0.013	0.016	0.011

Figure 7 Standard deviation of error between photoelectric sensor and video images or stopwatch.



	10-20m	20-30m	30-40m	40-50m
15m・Stopwatch	0.210	0.180	0.250	0.220
30m・Stopwatch	0.230	0.130	0.120	0.100
15m・29.97fps video	0.153	0.056	0.143	0.130
30m・29.97fps video	0.074	0.057	0.074	0.066
15m・59.94fps video	0.148	0.058	0.093	0.098
30m・59.94fps video	0.057	0.049	0.064	0.042

Figure 8 Range of error between photoelectric sensor and video images or stopwatch.

Table 3 Result of main effect for distance factor and instrument factor.

Factor	Interval	Sum sq.	DF	Mean sq.	F-value	p-value	Partial η^2	Criteria of effect size
Distance	10-20m	0.017	1	0.017	9.408	0.003 *	0.076	Medium
	20-30m	0.006	1	0.006	9.049	0.003 *	0.074	Medium
	30-40m	0.008	1	0.008	5.541	0.020 *	0.046	Small
	40-50m	0.004	1	0.004	3.300	0.072	0.028	Small
Instrument	10-20m	0.029	2	0.015	7.911	0.001 *	0.122	Medium
	20-30m	0.022	2	0.011	17.885	0.000 *	0.239	Large
	30-40m	0.022	2	0.011	7.697	0.001 *	0.119	Medium
	40-50m	0.018	2	0.009	8.105	0.001 *	0.124	Medium

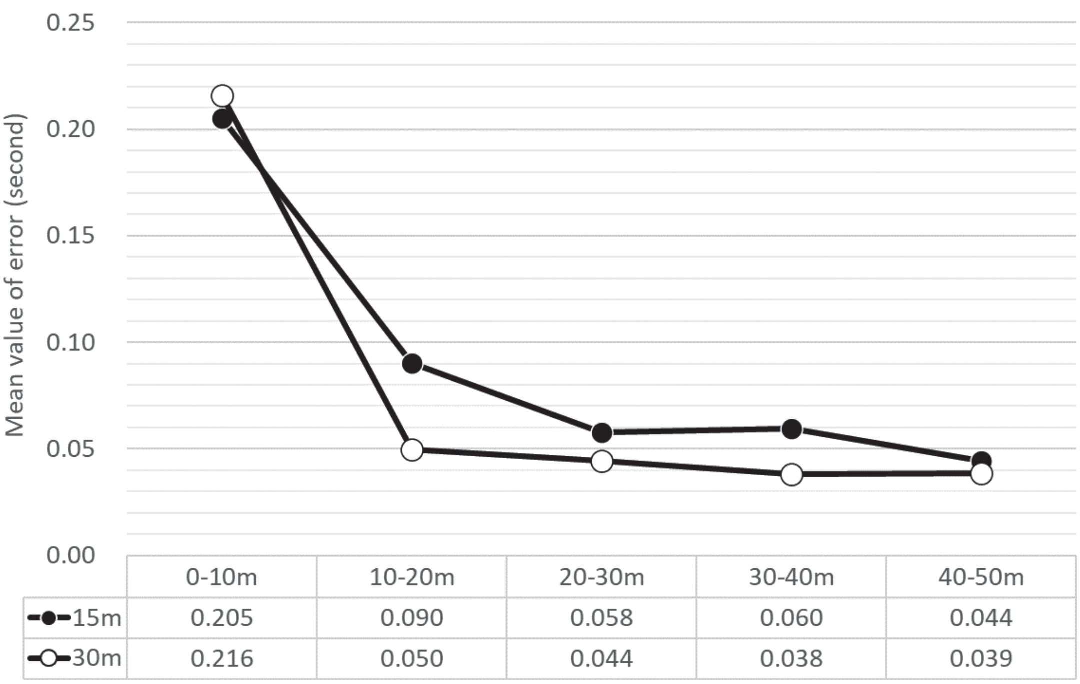


Figure 9 Mean value of error between 59.94 fps video image and stopwatch.

IV. Discussion

Although the participants in this study were instructed to run at 80%-90% of their full speed, the interval times measured by the photoelectric sensor did not vary greatly, and no runs were either too fast or too slow.

The two-way ANOVA showed no interaction effects in the intervals. However, significant differences were found in the 10-20 m and 20-30 m intervals for the distance factor with an effect size of medium, and significant differences were found in all intervals for the instrument factor with an effect size of medium or large. This means that the distance factor and instrument factor independently affect the size of measurement error. A closer distance from the finish line to the measurer tends to increase the size of error in the 10-20 m and 20-30 m intervals, suggesting that differences in measurement instruments affect the error regardless of the intervals.

According to the results of the multiple comparison test of the instrument factor,

Table 4 Result of multiple comparison between instruments.

Inte-rval	Combination of levels		Diff. of mean	Std. Error	t-value	p-value	DF	Effect size	
								r	Criteria
10-20m	59.94 fps video	29.97 fps video	-0.008	0.010	-0.854	0.670	117	0.080	Almost none
	Stopwatch	29.97 fps video	0.028	0.010	2.836	0.015 *	117	0.250	Small
	Stopwatch	59.94 fps video	0.037	0.010	3.691	0.001 *	117	0.320	Medium
20-30m	59.94 fps video	29.97 fps video	-0.004	0.006	-0.769	0.723	117	0.070	Almost none
	Stopwatch	29.97 fps video	0.026	0.006	4.621	0.000 *	117	0.390	Medium
	Stopwatch	59.94 fps video	0.031	0.006	5.390	0.000 *	117	0.450	Medium
30-40m	59.94 fps video	29.97 fps video	-0.005	0.009	-0.571	0.836	117	0.050	Almost none
	Stopwatch	29.97 fps video	0.026	0.009	3.037	0.008 *	117	0.270	Small
	Stopwatch	59.94 fps video	0.031	0.009	3.608	0.001 *	117	0.320	Medium
40-50m	59.94 fps video	29.97 fps video	-0.004	0.007	-0.580	0.831	117	0.050	Almost none
	Stopwatch	29.97 fps video	0.024	0.007	3.155	0.006 *	117	0.280	Small
	Stopwatch	59.94 fps video	0.028	0.007	3.735	0.001 *	117	0.330	Medium

59.94 fps and 29.97 fps had almost no effect size and no significant difference. Although the actual difference in error means varied slightly from interval to interval, it was extremely small (0.003~0.009 seconds), indicating that a difference in frame rate of approximately 30 fps has a small effect on the measurement error. On the other hand, the video image and stopwatch showed significant differences in all intervals, with 29.97 fps having small to medium effect sizes and 59.94 fps having all medium effect sizes. The mean difference of error in actual measurement value was 0.021-0.042 seconds, which was relatively large. The measurement errors were lower for the stopwatch, 29.97 fps video image, and 59.94 fps video image, in that order, when the photoelectric sensor readings were used as the standard. The measurement error was also lower for the distance from the finish line to the measurer at 30 m than at 15 m. The standard deviation of the error also tended to be similar, with the variation in error being lower for stopwatch, 29.97 fps, and 59.94 fps, in that order, and for 30 m than for 15 m.

The range of error between maximum and minimum when the observer was 30 m away from the goal were 0.100-0.230 seconds for the stopwatch, 0.057-0.074 seconds for the 29.97 fps video image, and 0.042-0.064 seconds for the 59.94 fps video image. This indicates that the higher frame rate video image was found to be less prone to major failures to measure interval times.

The measurement error of the stopwatch at 30 m from the finish line was 0.048 seconds on average and 0.230 seconds at its largest. On the other hand, the measurement error of the 59.94 fps video image was 0.018 seconds on average, with the largest error being 0.064 seconds. Based on these results, the measurement error from the zero to ten m interval, which could not be measured with the photoelectric sensor, was examined based on the 59.94 fps video image. The error between the 59.94 fps video image and stopwatch was 0.205 seconds at the 15 m position and 0.216 seconds at the 30 m position. Because the start signal is visually perceived as a sound, the error is likely to be particularly large for stopwatch; Todou et al. (2018) reported that the 50 m run measured by stopwatch was 0.27 seconds faster than the true time, and this study is similar to their result.

From the above, when measuring interval times in short distance sprint, it is desirable to place the video camera as far away from the finish line as possible and use a high frame rate of video image. However, the error was less than 1/100th of a second between 59.94 fps, and 29.97 fps video images.

V. Conclusion

The demand for STEAM in school physical education is increasing. The measurement of the 50 m sprint time has been used for a long time as a teaching material to promote scientific and mathematical thinking, but the problem is that the stopwatch has a large error margin. The standard frame rate for video recording in schools is 30 or 60 frames per second, which is significantly less accurate than the 1,000 frames per second used in official track and field records. Based on this background, this study examined the magnitude of error when the 50 m sprint interval times were measured using video images with standard frame rates, and the following results were revealed.

1) Errors were smaller for the stopwatch, 29.97 fps video images, and 59.94 fps video images in that order. However, the difference between 29.97 fps and 59.94 fps was less than 1/100th of a second.

2) The error was smaller at 30 m than at 15 m between the video camera and goal line.

3) At the ten m interval and beyond, the average error of stopwatch was 0.048 seconds, and the largest error was 0.230 seconds. On the other hand, the measurement error of the 59.94 fps video image was 0.018 seconds on average, and 0.064 seconds at the largest.

These results suggest that by placing video cameras as far away from the finish line as possible and using high frame rate video shooting, the measurement of interval times with high reliability can be used as a teaching material for STEAM in physical education.

VI. Acknowledgement

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