

Validation Report

30 Metre Standing Sprint

The product has been validated using Umeå University and Bosön - Test facility for the National Football Federation of Sweden

November 24, 2023

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Version history

Version	Date	Comment
v1	April 26, 2022	
v2	November 24, 2023	Note in section 2.4 and Appendix B added on triggering of Photogates using Photon Sports vests

1 Introduction

Photon Sports have developed an easy to use and reliable measurement system in order to measure and give feedback to athletes during performance tests. The system consists of a 3D camera that captures images with depth information at 60 Hz, and a host computer that processes these images in real time and extracts the 3D positions of a reflective vest that an athlete wears during a test. These 3D positions are combined with algorithms to automatically extract a number of parameters (KPIs - "Key Performance Indicators") from each test/exercise. For a standing sprint test these KPIs include the maximum speed during the sprint, and any split time between two distances.This document is produced internally and will be complemented by analysis/conclusions from the ongoing validation work done at Bosön, the national development centre of the Swedish Sports Confederation.

1.1 Goal

The goal of this document is to present the strengths and weaknesses in the measurement technique, how it differs from other commonly used techniques as well as give an estimate of the measurement performance for measurements of 30 m standing sprints with the Photon Sports system.

2 Background

2.1 Start definition

Photon Sports uses the velocity in the horizontal plane to define when a run has been initiated. The last time during a sprint that the athlete goes above a velocity of 0.2 m/s gets assigned as the start time and start position of the sprint. The system has a measurement frequency of 60 Hz, and linear interpolation is used to get a more precise definition of the start time and position. Figure 1 shows an example of how the start is detected.

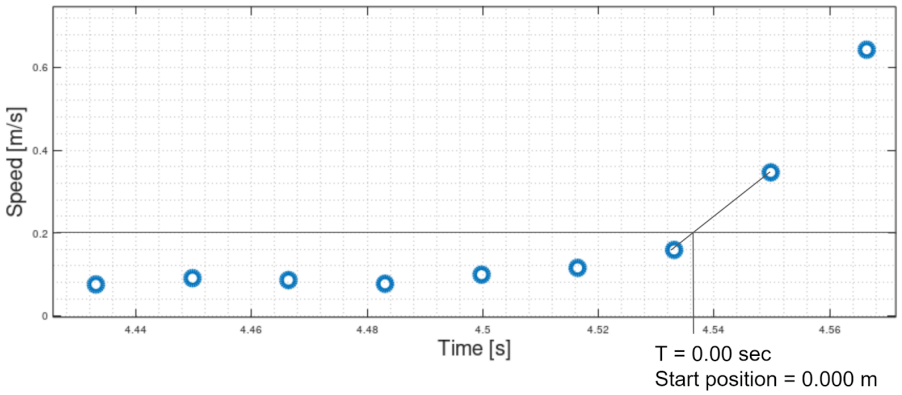


Figure 1 – The definition of the start time is the time at which the athlete reaches the velocity 0.2 m/s (i.e. same speed as used by 1080Sprint

One of the main sources of difference between timing gates, LiDAR, Photon Sports, and wire-based systems such as 1080Sprint or DynaSpeed, is the way the start is triggered. Many potential protocols are used for timing gates; e.g. start 0.3, or 0.5 m behind the first gate[1][2], in-beam start (which ideally should be adjusted to each individual to be triggered by the same amount of movement which might be difficult in practice), additional sensors (e.g. ultrasonic, pressure, or contact sensitive sensors). For most options, a safety margin is needed in order to not trigger false starts. This means that the first part of the movement is not included in the measurement. It also increases the headroom to cheat. For all systems, a clear start in a single fluid movement is crucial to minimise start discrepancies between individual runs.

Start triggering is, thus, crucial for acquiring quality data. A discussion on this can be found in [3]. There, the authors state: "Using photocell timing, the athlete must start a certain distance back from the initial timing gate to avoid premature triggering caused by a typical starting posture with a forward lean of the upper body. Thus, the athlete is already travelling at a certain speed as he/she passes the starting line, the so-called flying start. Recorded sprint time decreases as a function of flying start distance up to a certain point as a typical sprint velocity curve follows a hyperbolic relationship. Haugen et al. showed that the time saving magnitudes are significantly influenced by starting distance behind the initial timing gate, sprint distance and athlete performance level.". Thus, no matter what timing technology is used, clear instructions concerning starting posture as well as movement must be given to improve measurement accuracy of the start timing. This approach will also enhance comparisons between athletes.

2.2 What is measured?

Photon Sports uses a 3D camera and a reflective vest in order to measure the 3D position of the reflective vest - more accurately, in the 3D image that is captured, the vest shows up as an object or "blob". The centroid - or geometric centre of this blob is what defines the x and y coordinate of the athlete, while the average depth of this blob is what defines the z coordinate of the athlete. This centroid is positioned about 15-20 cm above the centre of mass (CoM) of a person.

Each camera is carefully distance calibrated from 1-34 m by Photon Sports. Each individual camera is also factory calibrated for the scaling factor to achieve X and Y from pixel and depth data.

2.3 Forward lean

The forward lean of the upper body varies during a sprint. During a start, the athlete leans forward in order to be able to accelerate. As the athlete reaches their max speed, the upper body becomes more and more upright. This somewhat affects the position that is measured by Photon Sports. If you were to compare the position of the hip of an athlete and the centroid of the back at (see section 2.2) at the start of a sprint and 20 m into a sprint: you'd see that the difference in position is different for the two reference points. When the hip bone has travelled exactly 20 m, the athlete is probably more upright than at the start. Thus, the centroid of the back has travelled a shorter distance. So depending on the athlete's height, starting position, body lean, and when and how the athlete moves to a more upright position, the deviation (20-40 cm approximately) between the hip bone and centroid can be seen as a bias. For a more forward leaning start and longer athletes this bias is likely to be more pronounced. The rate and range of distances for when the transfer from the forward-leaning start stance to the most common more upright high-speed body lean effects when this bias is seen when comparing different technologies measuring at the hip compared to back centroid.

2.4 Timing gate accuracy

As a reference, two different types of timing gates will be used for validation; SmartSpeed by Vald, and WittyGate by MicroGate (henceforth referred to as "Witty"). Both of these timing gates were chosen due to their performance being validated.[4][5] Note: Vald reproduced a graph on typical error of about 0.02 s at 5 m, 0.03 s at 10 and 20 m and 0.04 s at 30 m. Another paper[6] states the start measurement error (ME) at 0.102 ± 0.092 s and 0.019 ± 0.022 s at 5 m, and 0.009 ± 0.019 s at 10 m.

In summary, compared to a high speed camera as reference, studies using SmartSpeed show a ME and/or typical error of measurement (excluding the start measurement error that is much larger) of 0.02 to 0.04 s and a bias of about 0.02 s. It is noteworthy that this is a significant inaccuracy and of the same order of magnitude as what we want to validate. The fact that the timing gates measure at a set height and Photon Sports the movement of the centroid of the back in combination with the limited accuracy of the timing gates will most likely affect the result negatively, meaning that it is likely that Photon Sports perform better than what a straight comparison to Smartspeed shows[1].

Note: When using a Photon Sports retro reflective vest while simultaneously measuring sprint split times with timing gates it is vital to cover the front and the side of the vest facing the timing gate emitter/receiver unit with non-reflective material. Failing to do so will most likely lead to significant errors when an arm or leg passes through a gate before or after the torso. In our experience, some timing gates will not even be triggered by the trunk when using a Photon Sports vest with retro reflective material on all sides (back, front, left and right side) of the vest. See Appendix B for more details on this.

2.5 LiDAR accuracy

Studies[7] have been performed using the LAVEG Sport laser speed gun developed by Jenoptik (Jena, Germany). This technology, which is similar to the Dimetix DPE-10-500, but older, has been used to obtain sprint velocity curves of world-class sprinters since the 1997 IAAF World Championships in Athens. According to Buchheit et. al.[8], the error of the LAVEG laser in determining the distance travelled has been estimated to 0.1 ± 0.06 m when compared to 50 Hz video measurements. This roughly translates to a bias of about 0.01 s and a time uncertainty of less than 0.01 s at max speed.

2.6 Other sources of error

In the study by Altmann et. al.[6], a few false triggers of the timing gates were observed and were not corrected by the system. In that specific study, these false triggers occurred at the start timing light, with highest ME being 0.263 s (hip) and 0.134 s (upper body). In that study the data

[1] Indications to this can be found in the comparison to LiDAR, section 3.2 and 4.2.

collection was limited to 5 and 10 m sprints. In other studies both the thigh (high knee lift) and head (pronounced forward lean) have been found to falsely trigger the timing gates. This means that the technology used by SmartSpeed and Witty can provide split times that deviate more than anticipated, creating "hard-to-analyse outliers".

Using timing gates, Altmann et. al. also found that overall, ME was larger for the hip and at start than for the upper body and at 5 m and 10 m, respectively. This indicates that the height of the timing gates relative to the athlete's height may affect the ME.

In the test setup here covering 30 m with timing gates, the athletes were not instructed to run with the same amount of effort on each trial. Not doing this most likely affects the initial start movement as well as the amount of forward lean at the start and when the transition to more upright is made.

The temperature during all tests has been at room temperature, about 18 °C. The camera's depth engine is temperature compensated, however tests at low, < 10 °C, and high, > 30 °C, temperatures have not yet been verified.

3 Test setup

3.1 Timing gate data over 30 m using Smart Speed timing gates

The tests were performed in the indoor football arena Vinnarhallen at Bosön's facilities in Stockholm, Sweden using their equipment and SmartSpeed measurements were conducted by a test leader from Bosön.

Ten pairs of SmartSpeed timing gates were placed as shown in figure 2 in order to capture the split times of sprints at the distances, 2.5, 5, 7.5, 10, 15, 20, 25, 27.5 and 30 metres. These timing gates consist of a laser emitter and detector in one unit as well as a separate reflector. The normal state for the gate is that the laser is emitted, hits the reflector, and then gets reflected back into the detector. Whenever the laser beam is blocked, the timing gate registers that as someone passing by the gate.

The timing gate at the start of the sprint was configured as an in-beam start, meaning that it was placed slightly before the start line (that the other gates were measured from) in order for that gate's laser beam to hit the athlete at around their hip when they stood in a start position. The start time was then triggered whenever the athlete left the beam. The following gates was set at a height of approximately 120 cm.

42 30 m standing sprints were performed by 3 different athletes in order to get a spread in performance. The athletes were encouraged to give different amounts of effort during their different sprints in order to capture a range of performances, with the possible negative impact that their start stance and transition from forward lean to upright varies more as compared to running at maximum effort on every attempt. Their split times were captured with the timing gates, and at the same time their data was recorded with the Photon Sports system in order to compare the two.

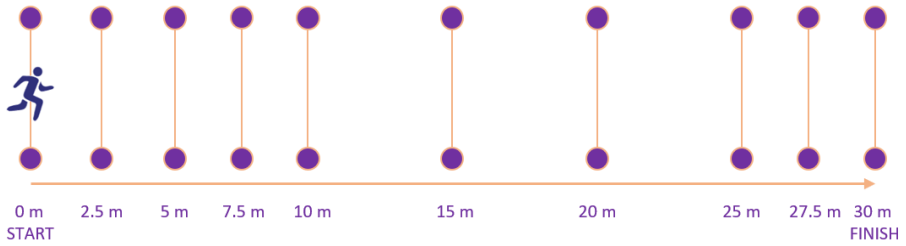


Figure 2 – Positions of the timing gates for data recording at Bosön. The height of the gate at 0 m was chosen as the average of the hip bones of the three athletes.

3.2 LiDAR

In an internal test, the performance of the Photon Sports system was compared against a LiDAR based system. The LiDAR system used was a Dimetix DPE-10-500 capable of a measurement accuracy of ± 1 mm over a 500 m range at 250 Hz. This method of measurement was selected as it closely mimics the way that Photon Sports measures the position of an athlete in that both measure the position of the back. Note that this demands a careful aiming of the laser beam to hit the athlete's back during the whole sprint. It also demands that the athlete does not drift sideways from the laser beam. The laser beam will also hit different positions of the back during the up and down movement. This affects the measurements a few centimetres during running.

The test was set up in such a way that both the Photon Sports camera and the LiDAR were placed 2 m behind the starting line. The visible laser in the LiDAR was aligned along a line on the floor and to the height of the running athlete at 30 m away. One athlete was present and performed 19 sprints.

Data was recorded simultaneously with both the LiDAR system and Photon Sports system. The raw distance data from LiDAR and the 3D positions from Photon Sports were collected and run through the same algorithms to calculate the velocity, start time, and every 2.5 m split time.

3.3 5 m sprints using Witty Gate for comparison

A separate session focusing on the first 0-5 metres was conducted using Photon Sports and the timing gate system WittyGate provided by sports medicine at Umeå University. The timing gates were positioned at 0, 2.5 and 5 m at a height of 1.2, 1.25 and 1.3 m to roughly hit the mid torso of the two athletes at each position. Figure 3 shows this setup. Two athletes ran a total of 50 5 m sprints. Athlete 1 performed 30 runs and was instructed to carefully position himself behind the start beam and avoid excessive arm swing action. Athlete 2 performed 20 runs and was not specifically instructed to be careful.



(a) **(b)**

Figure 3 – Data for a 5 m standing sprint with split timing gates at 0, 2.5 and 5.0 m.

This specific setup was done in order to gather more data from a standing 5 m sprint with the athletes starting a short distance, about 10 cm behind the start gate. In practice this distance varies between runs and thus the travelled distance as well as speed of the torso at the breaking of the start beam varies. 30 runs were performed by athlete 1, who is 182 cm tall, and 20 by athlete 2, who is 176 cm tall.

4 Result

4.1 Timing gate data 30 m

Split time data from both the SmartSpeed and Photon Sports systems were collected and aligned between the two systems. To evaluate the performance of the Photon Sports system, the measured split times of the two systems were compared. The results are presented in a box plot in figure 4. The median difference at each split distance is shown in orange, the boxes cover the second and third quartile of the data, and the whiskers extend to the last split time difference within 1.5 times the box distance. Outliers beyond the whiskers are shown as circles. Also plotted is the zero level shown in dashed red.

The split time for a certain distance is here defined as the total time of the sprint at this distance/gate minus the total time at the previous distance/gate. Thus, the split times at 2.5, 5, 7.5, 10, 27.5, and 30 m were all for a 2.5 m sprint, while the splits at 15, 20, and 25 m from a 5 m sprint. Since the same distance is compared between the two systems, it is still fully comparable.

It is clear that the first split time is a large outlier compared to the rest of the split times. Most of this can be explained by the fact that the systems do not trigger the start in the same way; Photon Sports going off of the velocity of the upper body, while SmartSpeed goes by the instant that the lower body leaves the laser beam aligned to the lower body. This is also when the effect of the upper body lean has the largest impact. However, it was also noted how a lot of the times the athletes would “creep” (i.e. slow movement before pushing away) during the start, thus triggering a start for the Photon Sports system but not for the SmartSpeed system. This becomes apparent when looking at the velocity curves at around the start time presented in figure 5. Some sprints had reached 0.6 m/s within two tenths of a second, while others had barely reached 0.4 m/s after three tenths of a second. Of course some of this variation can be explained by the fact that there are differences between the athletes. As can be seen in figure 4, a creeping start can add as much as 0.3-0.4 s over a small distance of 0.1-0.15 m.

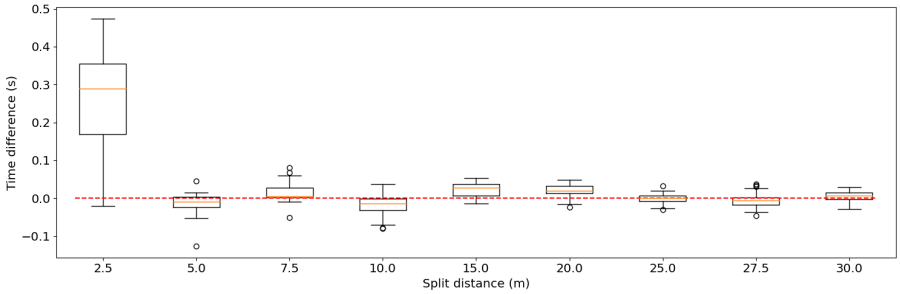


Figure 4 – Box plot of the time difference of all 42 laps between SmartSpeed and Photon Sports. Median difference is marked in orange, and the zero level is marked in red.

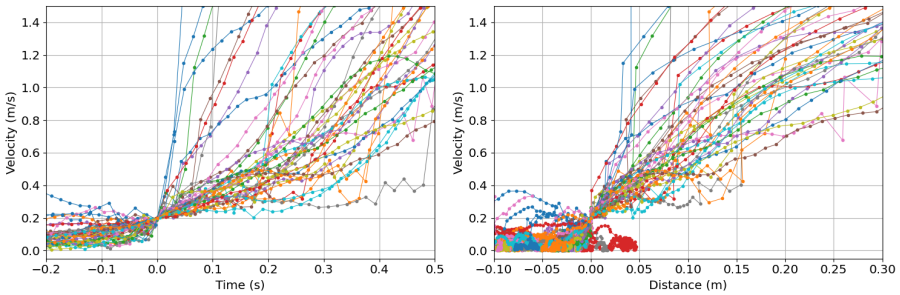


Figure 5 – Plot of the start of each of the 42 sprints. Left: velocity over time. Right: Distance over time. Note how some starts get triggered when the athlete ”creeps” away. This can also be seen in video footage of some of the starts.

Due to limitations in the SmartSpeed software, the same position for the start gate was used for all three athletes. This resulted in that the travel needed to trigger a start of the timing gate system varied between the athletes and as was seen on some video footage also between individual runs for an athlete. Screenshots from these videos can be seen in figure 10 in appendix B. This limits the usability of the first split time, 0-2.5 m.

Not taking the first split distance into account, the rest of the boxes' extremas (meaning that 50% of the values) are within 0.04 s from the zero line.

The variance in time difference at the 5, 7.5, and 10 m split distances appears to be larger than the variance in those further away. One reason for this could be that it was observed that it is somewhere around here that the athletes were done transitioning into a more upright stance. Thus, moving the average depth that is measured on the back by Photon Sports compared to the height at which the timing gates are positioned.

Any difference in variation between the splits that covered 5 m and those that only covered 2.5 is not apparent. This hints that most of the difference between the system is constant and caused by the difference in measurement technique, and not in any drift in the measurement accuracy of the Photon Sports system.

4.2 LiDAR data

In order to make the analysis comparable, the analysis between the LiDAR and Photon Sports has been conducted in the same manner as with the SmartSpeed timing gates. But since both systems measure the position of the athlete in a more continuous manner, any number of split distances could have been chosen. Here, every 2.5 m has been chosen, again, to make it more comparable to the analysis performed with the SmartSpeed timing gates.

Figure 6 presents box plots of the time difference between the LiDAR and Photon Sports systems at the chosen split distances. See section 4.1 for an explanation of what is shown in the box plot. As can be seen here, the absolute median difference between the two systems is within 0.01 s, and the boxes stay within ± 0.02 s over every split distance, including the first one which was a clear outlier for the timing gate comparison.

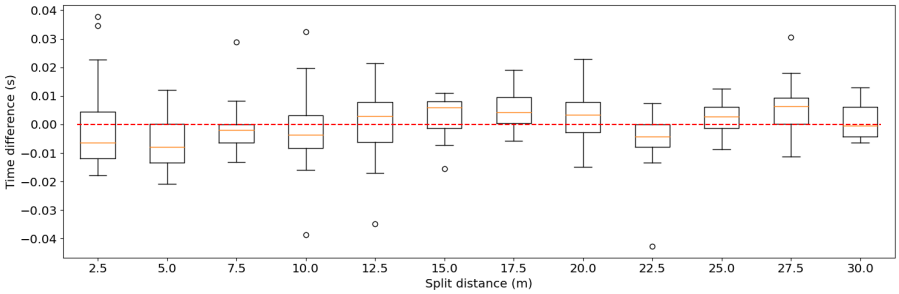


Figure 6 – Box plot of the time difference of all 19 laps between the LiDAR and Photon Sports. Median difference is marked in orange, and the zero level is marked in red.

A Bland–Altman plot (difference plot) is a method of data plotting used in analysing the agreement between two different methods. In figure 7, the difference between Photon Sports and LiDAR-based 0-30 m total time is plotted vs. total time. In the same graph the average deviation, about 0.006 s, between the two is plotted as well as the upper and lower standard deviations and upper and lower 1.96 standard deviations of the difference. Statistically the ± 1.96 standard deviations include 95% of the data points. Note that the two outliers at T≈5.1 and 6.25 s can be seen in figure 6 at the 0-2.5 m split time at about 0.033 and 0.037 s.

4.3 Witty data 5 m

The start condition in this test differed from the Smartgate test in the way that this used the start beam about 5-15 cm in front of the athlete while the latter used an in-beam start. The result using the WittyGate system and this alternative start method, presented in figure 8, shows a smaller bias and a smaller deviation between the timing gate measured split times and Photon Sports. In figure 9, it can also be seen that the data for athlete 1 shows slightly smaller bias and deviations compared to athlete 2. Athlete 1 was instructed to be careful to not start differently or use exaggerated arm swing.

Note that the timing gate beam was deliberately positioned at mid torso height of the athletes to try to trigger the gates at a position that mimics the Photon Sports centroid albeit measured at the back vs. front of the athlete. The bias between WittyGate split times and Photon Sports,

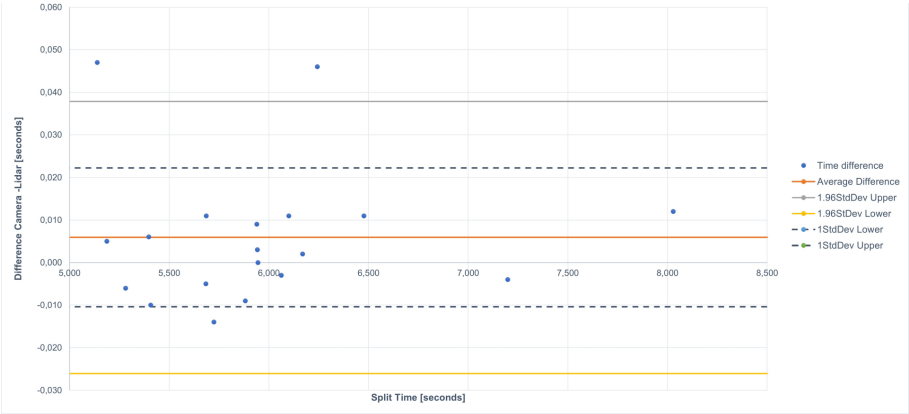


Figure 7 – Bland-Altmann plot of the difference between Photon Sports data and LiDAR data vs. average between the both.

figure 8, is about 0.12 s for 0-5 m and 0-2.5 m. The bias for the split time 2.5-5 m, i.e. excluding the first 2.5 metres, between WittyGate and Photon Sports is less than 0.01 s.

The second and third quartile of the data in figure 8 for 0-2.5 and 0-5 m lies well within the start measurement error (ME) estimated between timing gates and high speed cameras at ± 0.092 s as found in Altmann et. al.[6].

The bias of about 0.12 s lies close to the ME of the same study, 0.102 s. This slight difference can of course be influenced by the position of the gates relative to the start position, start criteria for the high speed camera detection, the height of the gates relative to the athletes height etc...

Looking at the 2.5-5 m split time difference, i.e. excluding the first 0-2.5 m, between the WittyGate and Photon Sports, there is a very good agreement between the two systems. The bias for the split time 2.5-5 m between WittyGate and Photon Sports is less than 0.01 s. The third quartile of the data lies within about ± 0.012 s.

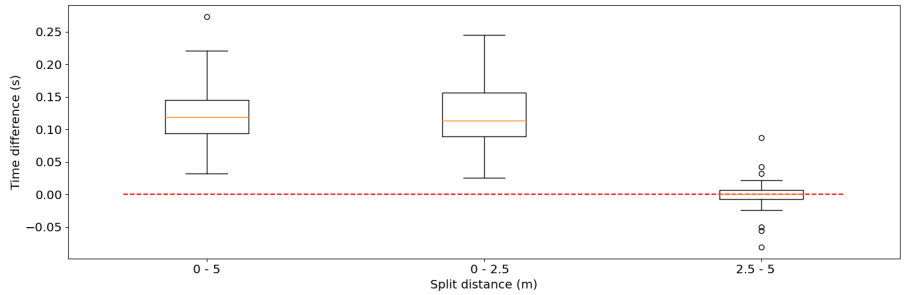


Figure 8 – Data from 50 5 m standing sprints.

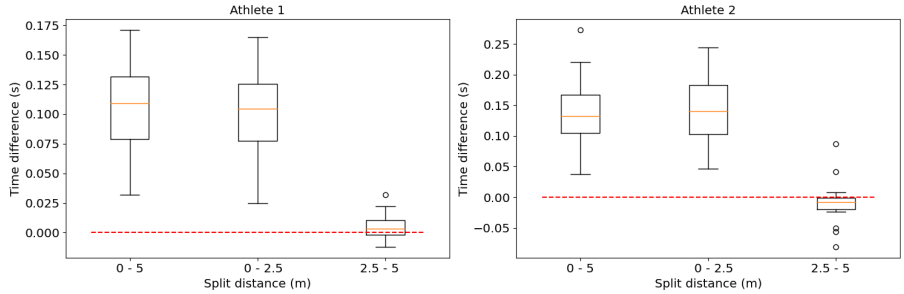


Figure 9 – Same data as in figure 8 but separated for the two athletes. The bias is slightly different as well as the time difference being smaller for athlete 1.

5 Conclusion

5.1 SmartSpeed as reference

Data from Bosön and their validated timing gate system for 42 runs and three athletes shows a good agreement with Photon Sports measured data.

Comparing split times between the two systems over 0-30 m, not taking the first split distance into account, shows that the rest of the split times are typically within 0.04 s from the zero line.

The timing gates do not exactly measure the same thing as Photon Sports so an estimated 0.2-0.4 m bias from start to finish is expected for a 30 m run. This is due to forward lean at the start and the transition to a more upright posture along the run. This differs between athletes, effort, initial lean, and height of both the athlete and the timing gates and typically translates to 0.03-0.05 s longer sprint times when measured by Photon Sports.

Triggering the start is a well known challenge for timing systems for sports. It can be argued that triggering the start of the timing on the actual movement initialising the run will give a better and more stable result.

5.2 High precision LiDAR as reference

Internal tests using a precision narrow beam laser distance sensor show extremely good agreement with Photon Sports data. The LiDAR was aimed roughly at the mid back of the runner at 30 m. This mimics the way Photon Sports measures the position, i.e. as the average of the back's position as viewed by the 3D camera. The difference between the two systems in split times as well as 0-30 m total time typically lies within 0.01 s.

5.3 Start timing study 0-5 m using Wittygates

Comparing the results of the two athletes during the 50 5 m standing sprints shows the importance of a clean start without creeping or varying the distance between where the start is initiated and the timing gate position.

5.4 Conclusion

Overall, there is great agreement between Photon Sports and the validated reference systems, and the agreement with the accurate LiDAR system also shows the validity of the Photon Sports system. There is some bias between every tested system, but maybe more importantly, the standard deviation of the measurements is low, on the order of a few hundredths of a second. Meaning that the Photon Sports system gives accurate results for the measurements of split times, and that measurements separated in time can be used to evaluate the performance and development of athletes.

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A Start setup



Figure 10 – Example of the start position and the amount of movement needed to trigger the Smart-Speed system.



(a) **(b)**

Figure 11 – Example of a more upright stance a few metres into the sprint compared to the start.



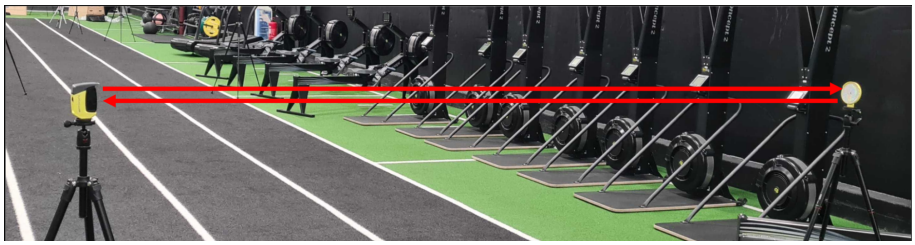
Figure 12 – Full view of the timing gate setup. Tripod from the Photon Sports system can be seen on the left in the image.

B How to compare to timing gates

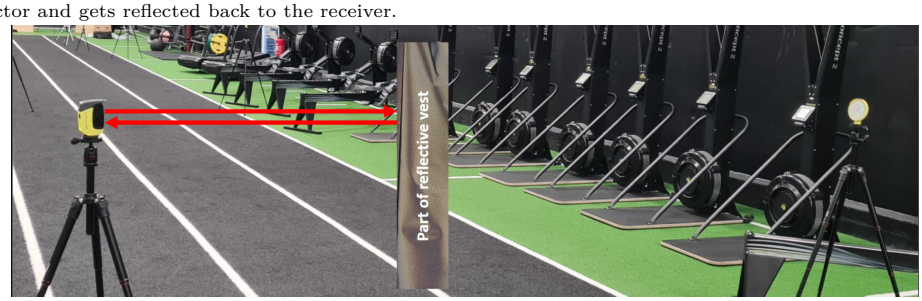
In this appendix we try to give instructions on how to use traditional timing gates while the athletes wear a Photon Sports vest.

Most photo gates use one unit containing both emitter and receiver and another unit consisting of a retro-reflector, see figure 13. The most common variants are Single beam, Dual beam, and Single beam with signal processing. Triggering is done by obstructing the light travelling from the emitter via the retro-reflector back to the receiver. Hence, when a runner that is wearing a retro reflective material (like the vests from Photon Sports) passes between the emitter/receiver and retro reflector the light is still reflected back to the receiver.

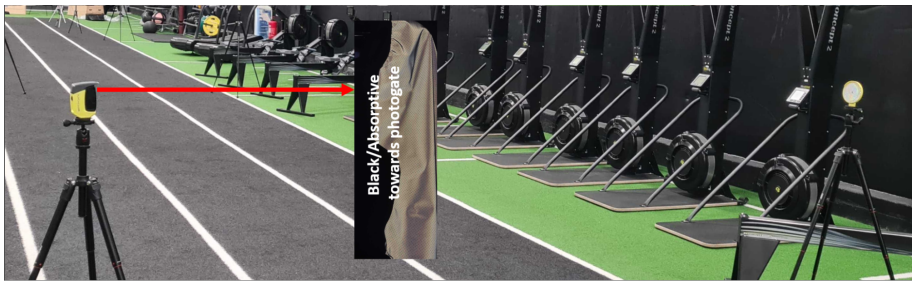
Single beam systems without signal processing may contain significant errors when an arm or leg passes through a gate before or after the torso. Dual-photocell (DP) and signal processing systems have been developed to overcome these issues and does so to a certain degree. However, if the athlete wears a retro reflective vest, depending on the technology used, there is a high risk that either the timing gate is not triggered by the trunk or that the longest trigger is from the arm, hand or leg passing by the gate, not the trunk of the athlete. Hence, it is important to use vests with black or non reflective fabric on the sides facing the timing gates to minimize the risk of no or false trigger of the gates.



(a) Emitter and receiver to the left, retro reflector to the right. Light travels from the emitter towards the reflector and gets reflected back to the receiver.



(b) A runner wearing a retro reflective fabric towards the emitter/receiver side does not necessarily stop the light from getting reflected back to the receiver.



(c) A non retro reflective material facing the emitter/receiver side absorbs and/or scatter the light so to trigger a timing event on the timing gate.

Figure 13