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COMPARISON OF PHOTOCELL AND OPTOJUMP MEASUREMENTS OF MAXIMUM RUNNING VELOCITY

PRIMERJAVA FOTOCELIČNIH IN OPTOJUMP MERITEV MAKSIMALNE TEKAŠKE HITROSTI

ABSTRACT

Due to additional data on stride length, contact and flight times, a combination of photocells and optojump measurements are currently in use to measure running velocity. As both systems are used to measure velocity, this research focused on ascertaining whether velocity measurement results obtained by photocells or by optojump are equally valid. The research involved 17 sprinters. Each of them performed two sprints of 20 meters, with a flying start. The velocity was simultaneously measured by the photocells and optojump. The photocells were installed at four consecutive, 5-meter long sections. The optojump was installed from the first to the last pair of photocells. In measurements with the optojump, foot contact closest to the photocells was used to determine the beginning and the end of an individual section. In measurements with photocells, the running velocity on the 10- to 15-meter section was 10% higher than the running velocity on 0- to 5-meter section. Comparison of velocities measured by photocells and optojump has shown that the velocities on the start to 5-meter section and on the 10- to15-meter section differ statistically significantly. Based on the obtained results, we have concluded that measurements of running velocity with photocells do not give the same result as measurements with optojump.

Keywords: running, velocity, photocells, optojump

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POVZETEK

V zadnjem času se zaradi dodatnih informacij o dolžini koraka ter časih faze opore in leta na meritvah hitrosti teka kombinira uporabo fotocelic in optojumpa. Ker se lahko z obema merilnima sistemoma meri hitrost, je bil namen te raziskave ugotoviti, ali pri meritvi hitrosti s fotocelicami dobimo enak rezultat kot pri meritvi hitrosti z optojumpom. V raziskavi je sodelovalo 17 sprinterjev. Vsak merjenec je izvedel dva sprinta 20 m z letečim startom. Hitrost je bila merjena hkrati s fotocelicami in optojumpom. Fotocelice so bile postavljene na štirih zaporednih odsekih dolgih po pet metrov, optojump je bil postavljena od prvega do zadnjega para fotocelic. Pri meritvi z optojumpom so bili za začetek in konec posameznega odseka uporabljeni dotiki stopala s podlago, ki so bili najbližje fotocelicam. Pri meritvah s fotocelicami je bila hitrost na odseku od 10. do 15. m za 10 % večja kot hitrost na odseku od začetka do petega metra. Primerjava izmerjenih hitrosti s fotocelicami in optojumpom je pokazala, da sta se hitrosti na odsekih od začetka do petega metra in od 10. do 15. metra statistično značilno razlikovali. Na podlagi rezultatov smo zaključili, da merjenje hitrosti s fotocelicami ne da enakega rezultata kot merjenje hitrosti z optojumpom.

Ključne besede: tek, hitrost, fotocelice, optojump

INTRODUCTION

The velocity of motion in sport is an ability that is significant for athletes, coaches and researchers, as well as being interesting for audiences. Velocity can be measured in a variety of ways, such us with sensors attached to running shoes (Foot pod, Polar, Suunto), Global Positioning System (GPS), Differential Global Positioning System (DGPS), radar, photo finish, kinematic analysis, photocells and optojump (OJ). The various ways of measuring differ in accuracy, complexity (as for time required to perform measurement and the knowledge needed to handle with the equipment) and price.

A sensor attached to running shoes and wrist-watch sized GPS devices have lately become very common in endurance running for measuring velocity. These devices are affordable and simple to use, but are low in precision. More precise than the GPS, is the DGPS system. It is far more expensive and requires the athlete to wear a relatively large piece of equipment, which interrupts the motion.

Velocity can be measured with radar – well known in road traffic speed measurements. However, radar is rarely used to measure the velocity of runners, because they achieve low velocities and because of the presence of small, even and reflective surfaces on the athlete that are required for accurate measurement. Radar measurement also requires a non-obstructed view between the runner and the measuring device. The price for precision radar is high.

Velocity measurements at track and field competitions are done with a photo finish. Measurements with a photo finish are highly precise and the system does not interrupt the athlete's motion; however, the system is not affordable for a wider audience of users. For the purpose of research, velocity measurements are often carried out with a kinematic analysis. Accuracy in measurement depends on the video capture frequency taken by the camera. However, for the purpose of measuring running velocity, kinematic analysis even at the lowest capture frequency of 25 frames per second is still very accurate. Defining the position of the center of mass at each frame in a kinematic analysis and calculating the velocity of the center of mass this way yields an extremely precise velocity measurement, but for a 20 m long section it would be enormously time-consuming. The advantage of the kinematic analysis is that we can measure the velocity of the centre of mass – which most of other methods cannot – and that the measurement does not obstruct athletes' motion.

In sport, photocells are the most commonly used technology for measuring velocity. They are used by athletes and coaches in training, and by researchers conducting experiments. Photocells are affordable and easy to use. There are a number of various models available on the market. They differ in the way they transmit the signal, in the number of beams that need to be broken in order to make the clock react, and in the way of determining when the break of beam is applicable. The disadvantages of photocell measurements are that one cannot measure the velocity of the centre of mass and that the measurement accuracy depends on the part of the athlete's body he/she breaks the beam with. If each time the athlete breaks the beam with a different part of the body, or if each time the same part of the body is in a different position, the measurement precision will decrease.

Wireless photocells are very easy to use, as they do not require the installation of any connecting cables, so the system can be set up very quickly. Wireless photocells have a disadvantage –signal transmission interference when other devices using similar frequencies are used nearby.

Interference causes incorrect signal detection and thus also triggers the measuring clock when the beam has not been broken. There is no interference with photocells using electric cables for signal transmission; however their installation is far more demanding and time-consuming

For precise photocell measurements, which part of the athlete's body breaks the photocell beam is highly important. Parts of the body with which it is possible to break the beam are determined by the vertical positioning of the photocells. If the photocell sensors are installed at chest height, the athlete can break the beam with an arm or with the torso. This way, the athlete can break the beam with the leading arm at one time and at another time with the torso, thus causing an error, since the torso can be from 20 to 30 cm behind the leading arm (Yeadon, Kato, & Kerwin, 1999). Such errors can be avoided if the beam is set at hip height. The athlete cannot break the beam with an arm. However, it may happen that the beam is broken with the leading leg. The latter occurs often if athletes are of different heights. The photocell sensors could be positioned at the head height (Dyas & Kerwin, 1995). Nevertheless, if athletes are of different heights, it would be necessary to adjust the sensor height for each individual athlete. Photocell timing errors can be decreased by considering the duration of breaking the beam. The applicable break of beam is the one that lasts longer. The error however is still not suppressed, since at the time of the break of beam, an arm or a leg can still be just ahead of the torso. There is no interval between the break of beam made by the arm or leg and the break of beam made by the torso; the photocells treat this as a single break of the beam, even though it has not been triggered by the torso. The athlete's torso may be in various positions at the time of the beam break, which causes a certain measurement error.

The problems of determining which part of the body breaks the beam can be decreased if several beams or pairs of photocells are used and mounted in different heights that are lined up vertically. The applicable break of beam moment is when all the beams are broken. An error of 0.1 m/s (Yeadon, Kato & Kerwin, 1999) occurs when using double-beam photocell velocity timing.

The OJ system has recently become commonly used in sports measurement. OJ measures the stride lengths as well as the contact and flight times. Based on the measured data, the computer software calculates the velocity of a runner. OJ consists of a series of transmitter and receiver bars, each 1 meter long. The bars are consecutively connected to one another so as to reach the length of 120 m. Photocell sensors are installed on the transmitter and receiver units. The sensors are 0.03 meters apart, causing an error of +- 0.03 meters when measuring the stride length. The measurement accuracy depends also on the vertical distance between the sensors and the running ground. By increasing the vertical distance, the error linearly increases. In linear correlation, the error can be decreased by using a correction factor (Viitasalo et al., 1997).

Like the photocell measurement system, OJ cannot measure the centre of mass velocity. OJ measures the average velocity of an athlete, represented by a part of his/her body. With the OJ system, this is the foot. The computer software can be adjusted to determine whether the heel or the toes of a foot are applicable for measurement. For accuracy, it is important that the running stride technique is consistent. If the stride is shortened or lengthened due to a change in technique, this will increase errors in the measured running velocity.

The purpose of this research is to ascertain whether velocity measurement results obtained by either single-beam photocells or by optojump are the same.

METHODS

Participants

Seventeen sprinters (11 male and 6 female) participated in this research. Their average best score in a 100 m run was 10.92 s (+-0.34), the age 20 years (+-3.4), height 1.77 m (+- 6.8), weight 69.6 kg (+-6.2) for males. For females, the average best score was 11.89 s (+-0.22), the age 19.8 years (+-3.7), height 1.69 m (+- 5.6), weight 58.4 kg (+-2.9).

Protocols

Every participant performed two sprints of 20 m, flying start. Sprinters chose their own acceleration lengths, the length never being shorter than 40 m. The breaks between two sprints lasted at least 5 min and not more than 8 min. The measurements were carried out in an indoor track and field hall, on an artificial surface. Finding the repeatability of measurements done by the photocells and the OJ both sprints was used. For further analysis, the fastest sprint of each participant, measured with the photocells was used.

Instruments

Five pairs of wireless single-beam photocells (Brower timing, USA) were installed along a 20-meter distance. Each pair was 5 meters apart. The first pair of photocells was used to start the timing system. Photocells were installed at a height of 1.14 meter. The transmitter unit was 1.8 meters apart from the receiver unit. The photocell transmitted the signal upon the first break of beam, regardless of the break length. The time was measured with a precision of one hundredth of a second.

The measuring chain optojump (Microgate, Italy) was installed along a 20-meter distance. The beginning of the chain was leveled with the beam of the first pair of photocells, and the end with the beam of the last pair. The optojump transmitter bar was 1.3 meters apart from the receiver bar. The distance between the sensor centers on each individual bar was 0.03 m. Sensors were 0.005 meters off the surface. The measurement was processed via the serial port on a portable PC, model HP XE4500, CPU 1.7 GHz.

The following variables of velocity were used to compare the photocell and optojump measurements. The velocity measured with photocells was calculated as a quotient of distance between the photocells and the time the sprinter needed to run the distance. The velocity was calculated for the first 5 meters (vf0_5), the second 5 meters (vf5_10), the third 5 meters (vf10_15), and the fourth 5 meters (vf15_20), as well as for the first 10 meters (vf0_10), for the first 15 meters (vf0_15) and for 20 meters (vf0_20).

With OJ, it was not possible to calculate velocity for the exact 5-meter sections. Therefore, the foot contact closest to the photocells was used to determine the beginning and the end of an individual section. For the measurement, the toes of the foot were applicable. The length of the section was measured by the OJ. Some sections were longer and some shorter than 5 m. The velocity of individual sections was calculated as a quotient of the measured distance on a section and the time the sprinter needed to run the distance. The labels for individual variables are as follows: velocity for the first 5 meters (vo0_5), the second 5 meters (vo5_10), the third 5 meters (vo10_15), and the fourth 5 meters (vo15_20), as well as for the first 10 meters (vo0_10), for the first 15 meters (vo0_15) and for 20 meters (vo0_20).

Procedure

All the statistical analyses were made with the SPSS software. A t-test for related samples was used to compare the variables measured by photocells and by OJ. The ANOVA test was used to test the differences among the variables that were measured with the same method. The $P < 0.05$ level was used to establish statistical significance.

RESULTS

Each sprinter was recorded for two maximum running velocities. The comparison of the two velocity measurements showed that the measurements done by the photocells and the OJ are repeatable on all sections. The velocity at individual 5-meter sections is shown in Table 1 and Figure 1. In photocell measurements, there was a great velocity oscillation. The maximum velocity measured on the 10- to 15-meter section, was on average 10% higher than the lowest velocity measured on the 0- to 5-meter section. On the 0- to 5-meter section, the measured velocity was statistically significantly lower than the velocities measured on other sections. In OJ measurements, there were no statistically significant oscillations in velocities as per individual sections. Velocities measured with photocells and OJ statistically significant differed on two sections. The velocity measured with photocells on the 0- to 5-metres section was statistically significantly lower ($P<0.000$) than the velocity measured with OJ. While on the 10- to 15-meter sections, the situation was just the opposite.

Table 1: Average velocity in different sections.

	OJ		PhotoC			OJ		PhotoC			
section	mean	SD	mean	SD	P	mean	SD	mean	SD	P	section
0 - 5 m	9.35	0.65	8.71	0.61	0.000	9.35	0.65	8.71	0.61	0.000	0 - 5 m
5 - 10 m	9.36	0.56	9.28	0.62	0.222	9.36	0.59	8.98	0.56	0.000	0 - 10 m
10 - 15 m	9.36	0.67	9.61	0.81	0.004	9.36	0.62	9.18	0.61	0.000	0 - 15 m
15 - 20 m	9.33	0.55	9.36	0.56	0.579	9.35	0.60	9.22	0.58	0.000	0 - 20 m

Legend: OJ – optojump; PhotoC – photocells; SD – standard deviation.

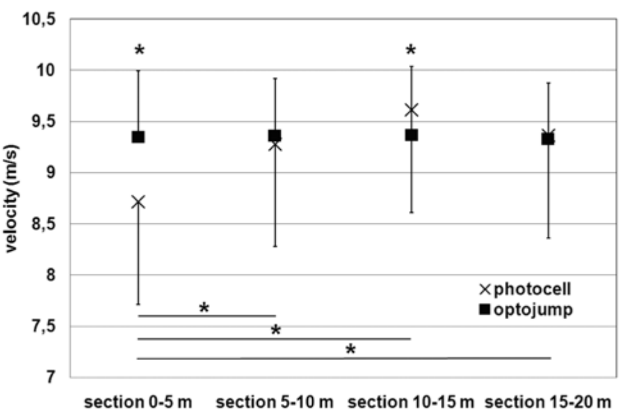

Figure 1: The velocity at individual 5-meter sections. * P<0.05

Figure 2 shows the average velocities measured with photocells and OJ on sections of different lengths. Regardless of the section length, the average speed measured with the photocells was always statistically significantly lower (P<0.000 for each section) than the average velocity measured with OJ (table 1).

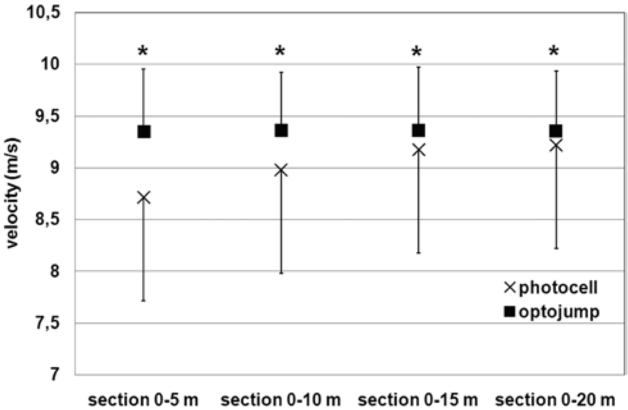

Figure 2: Average velocities on sections of different length. * P<0.05

The distance between pairs of photocells was 5 meters, while the lengths of sections with OJ are shown in Figure 3. In OJ measurements, the section from 0- to 5- meters and the section from the 15- to 20- meters are statistically significantly shorter than sections from 5- to 10- and 10- to 15- meters. The shortest section (1.99 m – one participant) was from the 0- to 5- meters, and the longest section (7.11 m – one participant) was from the 10- to 15- meters. The average lengths sum of individual sections in OJ measurements was 17.76 meters, the longest one being 19 meters and the shortest one 16.36 meters.

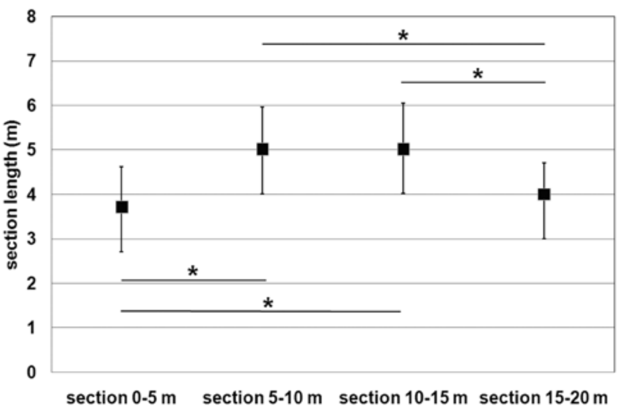

Figure 3: Sections length in optojump measurements. * P<0.05

DISCUSSION

The purpose of this research was to compare velocity measurements obtained by two timing systems – a single-beam photocell system and OJ. Despite the fact that on two sections there was no statistically significant differences in velocity measured by photocells and OJ, we can affirm that the two timing systems do not measure the same velocity values and that the systems are not equivalent.

With photocell measurements, there was a great oscillation in velocity as per individual sections. In the first section, the velocity was statistically significantly lower than in other sections. The 10- to 15- meter section also stood out. The velocity measured there was higher than in other sections, yet the differences in velocity in 5- to 10- and 15- to 20-metres sections were not statistically significant. The oscillation in the measured velocity can either be caused by the runner or an error in measurement. All runners were given instructions to run at their maximum speed. All of them started with a more than 40 meter-long acceleration run, which according to other research (Brüggemann, Koszewski, & Muller, 1999; Delecluse, 1997) means that all of the runners were in the zone of relatively constant running velocity. As the runners were in the zone of relatively constant velocity and there was no fatigue present, it can be concluded that runners did not cause the velocity measurement oscillations by changing their pace or velocity of running.

The oscillation in running velocity measured by the photocells could be caused by an error in measurement. To achieve an accurate as possible measurement, the runner would have to break a beam with the same part of the body and in the same position each time. To meet such conditions, the photocells would have to be positioned on an even number of the runner's strides. In our case, the photocells were installed on 5-metre long sections, which do not meet the even number of strides requirement; therefore, upon breaking the beam, the runner's body position was different each time. Single-beam photocells that react on the first break of beam and are installed at elbow height, react to an arm in 60% of the cases and in 40% of the cases to the athlete's torso (Yeadon et el., 1999). Since the arm can be up to 30 cm ahead of the torso, a faulty reaction of the photocells on 5-meter distance shows up to 6% higher velocity than the athlete is actually running at. Yeadon et al. (1999) calculated that the measurement error with single-beam photocells that react on first beam break and are installed at the arm height is 0.49 m*s-1. This error corresponds to the oscillation in the measured velocity with photocells in our experiment. Someone can conclude that difference between the first section and rest of the sections is not a measurement error, but instead, a real significant running speed difference. This could be true if measurements with OJ showed similar results, such measurements showed constant velocity in all sections so we can affirm that the oscillation in velocity measured by the photocells is the result of errors in measurements.

We are of the opinion that oscillations in velocity measured by the OJ are also the result of errors in measurements. With OJ measurements, the sensors are 0.03 meters apart. At a 1.99-meter section and velocity of 9 m/s, the error in measurement (due to the distance between the sensors) is 0.14 m/s. The error is greater than the difference in average velocity between the sections where sprinters velocity were maximal and minimal. The problem with both timing systems is that these devices measure the time when one part of the body crosses a certain point, based on which the velocity of the runner is calculated. The systems do not measure the centre of mass velocity. Provided that the athlete's body is in the same position each time a measurement is taken, then the velocity would be quite close to the actual velocity of the athlete's centre of mass. Since the athlete's body is not in the same position at all times, measurements with photocells produce an error of up to 0.49 m/s. In the methodology of calculating the velocity of running with OJ used in our experiment, it can happen that in the first and last sections only one stride is considered for velocity measurement (definition of a stride as per Cavanagh and Kram, 1989), as the shortest first section was 1.99 m, and the shortest last section was 2.11 m. Calculating the velocity based on one stride only, can result in error because of the asymmetry of the strides. No runner performs symmetric strides; in some runners, the difference between left and right stride lengths can be more than 10% (Belli, Lacour, Komi, Candau, & Denis, 1995). Because of possible asymmetry, it is recommended that OJ measurements are always performed on even strides, not on previously-defined section lengths.

In case of simultaneous measurements with photocells and OJ, it is recommended to install the OJ around 1.5 m before the first pair of photocells. Using a similar concept, OJ should be used at least until 1.5 m after the last pair of photocells. This increases the number of running steps measured by OJ, and reduces the measurement errors for the first and the last section.

When comparing the velocity at the 5-, 10-, 15- and 20-meter sections, we have ascertained that the difference in velocities measured with photocells and OJ decreases with longer sections. A longer section means that a runner makes more strides. Some research has shown that in order to determine average values of running or walking, 3 to 400 strides are necessary (Owings and Grabiner, 2003; Diss, 2001; Belli et al., 1995). The fewer the strides, the bigger the measurement error. In this research, from one (a 5-meter section) to nine (a 20-meter section) strides were used. The more there were strides, the smaller was the difference between average velocities measured with photocells and OJ (Figure 2); however, differences in measured velocities still remained statistically significant. It is not possible to decrease the error by lengthening the measurement section, as the runner cannot maintain his/her maximum velocity for more than 20 meters (Brüggemann et al., 1999). In practice, someone could however increase the number of sprints. This should be considered carefully so as not to cause the fatigue. The runner again would not be able to achieve his/her maximum velocity and would make average results of measurements worse.

The results of maximum velocity measurements with single-beam photocells installed 1.14 meters high are different than the results of maximum velocity measurement done by OJ in cases when the measurement sections are 5 to 20 meters long. Further research should be carried out in order to ascertain which of the timing system gives the results that would be closer to the actual centre of mass velocity.

References

Belli, A., Lacour, J.R., Komi, P.V., Candau, R., & Denis, C. (1995). Mechanical step variability during treadmill running. *European Journal of Applied Physiology* 70 (6), 510–517.

Brüggemann, G. P., Koszewski, D., & Muller, H. (Eds.). (1999). Biomechanical Research Project Athens 1997 Final Report. Oxford: *Meyer & Meyer Sport (UK) Ltd.*

Cavanagh, P.R., & Kram, R. (1989). Stride length in distance running: Velocity, body dimensions and added mass effect. *Medicine and Science in Sports and Exercise* 21 (4), 467–479.

Delecluse, C. (1997). Influence of Strength Training on Sprint Running Performance. *Sports Medicine* 24 (3), 147–156.

Diss, C.E. (2001). The reliability of kinetic and kinematic variables used to analyse normal running gait. *Gait and Posture* 14 (2), 98–103.

Dyas, J.W., & Kerwin, D.G. (1995). A photocell based timing system for studying linear kinematics of running. In J. Watkins (Ed.), *Proceedings of the Sports Biomechanics Section of the BritishAssociation of Sport and Exercise Sciences 20* (pp. 29–32). Leeds: BASES.

Owings, T.M., & Grabiner, M.D. (2003). Measuring step kinematic variability on an instrumented treadmill: how many steps are enough? *Journal of Biomechanics* 36 (8), 1215–1218.

Viitasalo, J.T., Luhtanen, P., Mononen, H.V., Norvapalo, K., Paavolainen, L. & Salonen, M. (1997). Photocell Contact Mat: A New Instrument to Measure Contact and Flight Times in Running. *Journal of Applied Biomechanics* 13 (2), 254–266.

Yeadon, M.R., Kato, T., & Kerwin, D.G. (1999). Measuring running speed using photocells. *Journal of Sports Science* 17 (3), 249–257.