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USING THE DIRECTION OF THE SHOULDER'S ROTATION ANGLE AS AN ABSCISSA AXIS IN COMPARATIVE SHOT PUT ANALYSIS

UPORABA SMERNEGA KOTA RAMENSKE OSI ZA ABSCISO PRI PRIMERJALNIH ANALIZAH META KROGLE

ABSTRACT

As a rule, independent and comparative analyses of shot put data either use time-series data or generate time-dependent data. Thus, a direct time-dependent comparison of two or more competitors can only be made in a limited period of time due to differences in the shot put technique and execution. We hereby propose a method in which the direction of the shoulder's rotation angle is used as an abscissa axis as a useful tool, since experts and athletes find this method easier to conceive and apply in their field work. To demonstrate the practicability of this 'new' abscissa, we measured the 3-D kinematics of two morphologically different elite shot putters. We demonstrated a monotonic increase in the direction of the shoulder's rotation angle in a rotational technique, which serves as a basis for the application. Furthermore, the following major parameters are representatively shown: shot height, angular velocity in the elbow of the release arm, the direction of the ankles' rotation angle and absolute shot velocity. To allow a comparison, all the parameters are presented in a time- and angle-dependent manner. It was established that the new data analysis method not only brings additional benefits of data harmonisation and an easier mental conception, but also reveals new information that remains obscured in a temporal harmonisation.

Key words: analysing methodology, shot put, direction of the shoulder's rotation angle, 3-D kinematics, comparative analysis

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POVZETEK

Navadno se pri samostojnih in primerjalnih analizah podatkov suvanja krogle uporablja časovno zaporedje podatkov oz. prikaz podatkov v odvisnosti od časa. Na tak način je neposredna primerjava dveh ali več tekmovalcev v časovni odvisnosti omejena na kratko območje zaradi razlik v tehniki in izvedbi. V pomoč predlagamo uporabo uskladitve podatkov glede na smerni kot ramenske osi, ki je za strokovnjake in atlete bolj predstavljiva in lažje uporabljiva na terenu. Za prikaz uporabnosti »nove« abscise smo naredili meritve 3D kinematike dveh morfološko različnih vrhunskih metalcev krogle. Pokazali smo monotonost naraščanja smernega kota ramenske osi pri rotacijski tehniki, kar je osnova za uporabnost. Poleg tega reprezentativno prikazujemo še naslednje pomembne parametre: višina krogle, kotna hitrost v komolcu izmetne roke, smerni kot gležnjev in absolutna hitrost krogle. Vsi parametri so za primerjavo prikazani tako v časovni kot kotni odvisnosti. Izkaže se, da ima nova metoda analiziranja podatkov ne le prednosti pri usklajevanju podatkov in predstavljivosti, temveč tudi nosi nove informacije, ki v časovni usklajenosti ostanejo skrite.

Ključne besede: metodologija analiziranja, met krogle, smerni kot ramenske osi, 3D kinematika, primerjalna analiza

INTRODUCTION

Evaluating a shot put performance is very simple as the distance thrown is the only result that counts. The distance thrown is defined primarily by the path on which force is applied to the shot, which is manifested in the release velocity, the angle of release and the height of release (Stepanek, 1989; Palm, 1990; Gemer, 1990; Bartonietz, 1994; Oesterreich, Bartonietz, & Goldmann, 1997; Luhtanen, Blomqvist & Vanttinen, 1997; Lanka, 2000; Hubbard, Neville & Scott, 2001; Linthorne, 2001; Rasmussen, 2005).

However analysing a shot put technique is completely different and can be very challenging given that (even though it is relatively limited in the available space and time) shot put consists of a complex 3-D motion. This complexity of movement that produces force on the shot and the limited space and time are the factors that make an analysis a laborious task for coaches, experts and scientists. In particular, a comparison of competitors (as one of the most commonly applied analysis methods) is also hindered, especially when it is difficult to set up a precise implementation model. An identical situation occurs with shot put since large differences in the movement action can be produced solely by morphological and anthropometrical differences between the competitors. For example, the relative shot mass in relation to an athlete's mass can be a highly influential factor from the mechanical point of view and, accordingly, also from the technique point of view (Bartonietz, 1994; Bartlett, 2000). Similar effects can be produced by body height (Bartlett, 2000; Linthorne, 2001) and so on. These are the reasons for frequently applying comparative analyses to identify athletes' strengths and weaknesses.

The problem of comparative analyses is in harmonising data concerning individual throws. Most often the harmonisation method is based on a time axis; however, this is not the optimal solution. A slight difference in the initial phase, especially when the movement is slow, can delay the situation and thus jeopardise the objectivity of comparison. For example, at the moment one athlete is still completing the first double-support phase; the other has already started the single-support phase (Luhtanen et al., 1997). For this reason, some prefer to use the harmonisation of the time axis in relation to the point of release; i.e. the time the shot is released from the palm (Palm, 1990; Goss-Sampson & Chapman, 2003). The reason for this mainly lies in the fact that the final release phase is considered to be more important. Nevertheless, some phases are still poorly synchronised due to differences in the movement action.

Owing to this problem of harmonising data on the time axis it is reasonable to consider spatial harmonisation. Unfortunately, the throwing action is performed within a relatively limited space making it almost impossible for the analysis or interpretation to rely on the place of action, even though the shot movement trajectory is one of the main parameters (Linthorne, 2001).

An even more awkward situation occurs when experts' or scientists' information or advice to athletes relies on the place or time of an event. Therefore, in both practice and science, either a different notional concept or a division into phases is used, e.g. the first double-support phase, the single-support phase, the flight phase etc. (Luhtanen et al., 1997). A problem arises when the time scale that is used in science needs to be co-ordinated with the terminology used by professionals. Hence, we believe that a new axis should be introduced on which both professionals and scientists can rely.

One way we propose to resolve this problem is to introduce a polar angle of the body's rotation as the harmonisation axis, as the body's rotation can be easily conceived of by athletes and coaches/professionals and is at the same time a scientifically- and uniquely-defined parameter. How the new method is used will be demonstrated by measuring the 3-D kinematics of two elite shot putters.

METHODS

Procedures

The introduction of a new data analysis method for comparative analyses is based on a directional vector of the shoulder axis of the body and its inclination from the direction of the field sector. The following vectors are required to calculate it:

n – normal of the plane of ground i.e. the throwing circle (r = 2.135 m);

***s*r** – spatial vector of the right shoulder;

***s*l** – spatial vector of the left shoulder; and

f – vector pointing towards the direction of the throw along the middle of the field sector.

The vector multiplication of ***n*** and (***s*r**-***s*l**) results in a vector parallel to the plane of the throwing circle and pointing in the direction of the body's rotation. The angle of the rotation is a result of the dot product of the vectors ***n*** × (***s*r**-***s*l**) and ***f***. The result is an equation for the direction of the body's rotation angle:

$$\boldsymbol{fi} = \arccos\left((\boldsymbol{n} \times (\boldsymbol{s}_r - \boldsymbol{s}_l)) \cdot \boldsymbol{f} / (|\boldsymbol{n}| \cdot | \boldsymbol{s}_r - \boldsymbol{s}_l |) \right). \qquad (1)$$

Given that a shot putter makes more than one turn, a short programme is required to establish when the angle passes over from one quadrant to another so as to prevent the angle shifting from 180° to -180°. Zero is set at a point rotated towards the direction of the throwing field in the last turn at the release point.

Once an appropriate parameter of the body's rotation is obtained, all other calculated parameters can be presented in relation to the angle of rotation and not only in relation to the time axis. The application will be exemplified by the following selection of parameters: absolute shot velocity, shot height, angular velocity in the elbow of the release arm and the direction of the ankles' rotation angle, which is calculated by analogy to the direction of the body's rotation angle.

To calculate the parameters, independent routines were programmed by Matlab software and, where appropriate, they were smoothed with adequate cut-off frequencies and the orders of the Butterworth filter. The parameters were always calculated from raw data, while some of them were filtered subsequently. In all cases, both versions of the parameters are presented – those calculated from the raw data and the filtered ones. As the parameters are always presented in a comparative context, the zero time point was set at the shot release while the zero point of the direction of the body's rotation angle was set at the moment the athlete's shoulder axis is rotated towards the direction of the sector.

Participants

To demonstrate the application of the newly proposed abscissa in analysis, we used data acquired from measuring two elite shot putters (M.V. – age 28, height 1.95 m, mass 168.5 kg, BMI (body mass index) = 44.5; personal record 20.76 m; H.A. – age 26, height 1.85 m, mass 120.2 kg, BMI = 35.1, personal record 20.02 m) in May, 2005 at an international athletic meeting held in Slovenska Bistrica, Slovenia.

Instruments

Recordings were made with two fixed and synchronised camcorders (SONY DVCAM DSR-300 PK), where the angle between the optical axes of the two camcorders was about 90°. The camcorder frequency was 50 Hz and the resolution 720 x 576 pixels. The analysed area of the circle was calibrated with a 1 m x 1 m x 2 m reference scaling frame and the calibration was based on eight reference corners. The length of the analysed movement was defined by the 'x' axis, the height by the 'y' axis and the depth by the 'z' axis.

The APAS 3-D software (Ariel Dynamics Inc., San Diego, Ca.) was applied to determine the points on the digital video recordings and transform the 2x 2-D data into 3-D data. The 15-segment model of the shot putter's body was digitised and defined by 18 reference points. The eighteenth point was defined by the centre of the shot. The segments of the model represented parts of the body, linked with point-like joints. The masses and centres of gravity of the segments as well as the centre of gravity of the body were calculated by the anthropometric system (Dempster, 1955).

The competitors used their right arm to put the shot. Six attempts of each competitor were recorded and only the best throw was included in the final analysis, 20.30 m and 19.06 m for M.V. and H.A., respectively.

RESULTS

The basis of an effective application of the direction of the shoulder's rotation angle as an abscissa axis is its time-dependant monotonic increase. As the shot putter starts from an extreme position and is repeatedly turning in the same direction until the moment of releasing the shot, the parameter fulfils the basic condition, as shown in Figure 1. It is obvious that the increase is not regular but is slower at the beginning because the athletes turn more slowly. Towards the final phase, from the time of -0.4 s on, they turn more quickly.

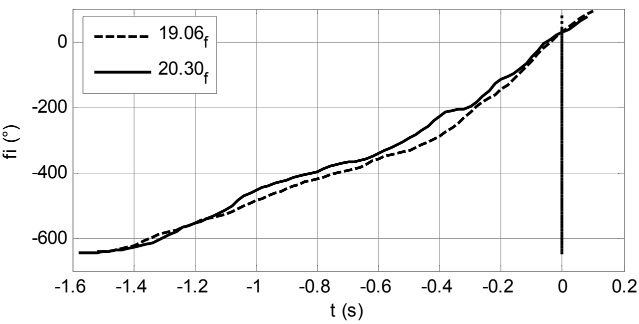

Figure 1: The time-dependent direction of the shoulder's rotation angle for two shot puts. The vertical line shows the point of release

At first glance, Figure 1 shows no major differences between the athletes, which could imply that the introduction of the new abscissa will yield no new information in terms of a comparison of athletes. In truth, this only occurs at the beginning and at the end of the diagram, which is also seen in the video frames in Figure 2 (the upper two and bottom two frames). Nevertheless, the differences in the mid section are relatively large, ranging from -1.1 s to -0.1 s, i.e. from about -500° to -100°, representing the major part of preparation for the release. For example, at the time of -0.4 s (Figures 1 and 2) the difference in rotation equals almost 60°, i.e. one-sixth of a full turn. All of the above already shows the added value of the introduced new abscissa in the comparative context, bearing in mind that a temporal harmonisation would allow the observation of parameters in a completely different execution phase.

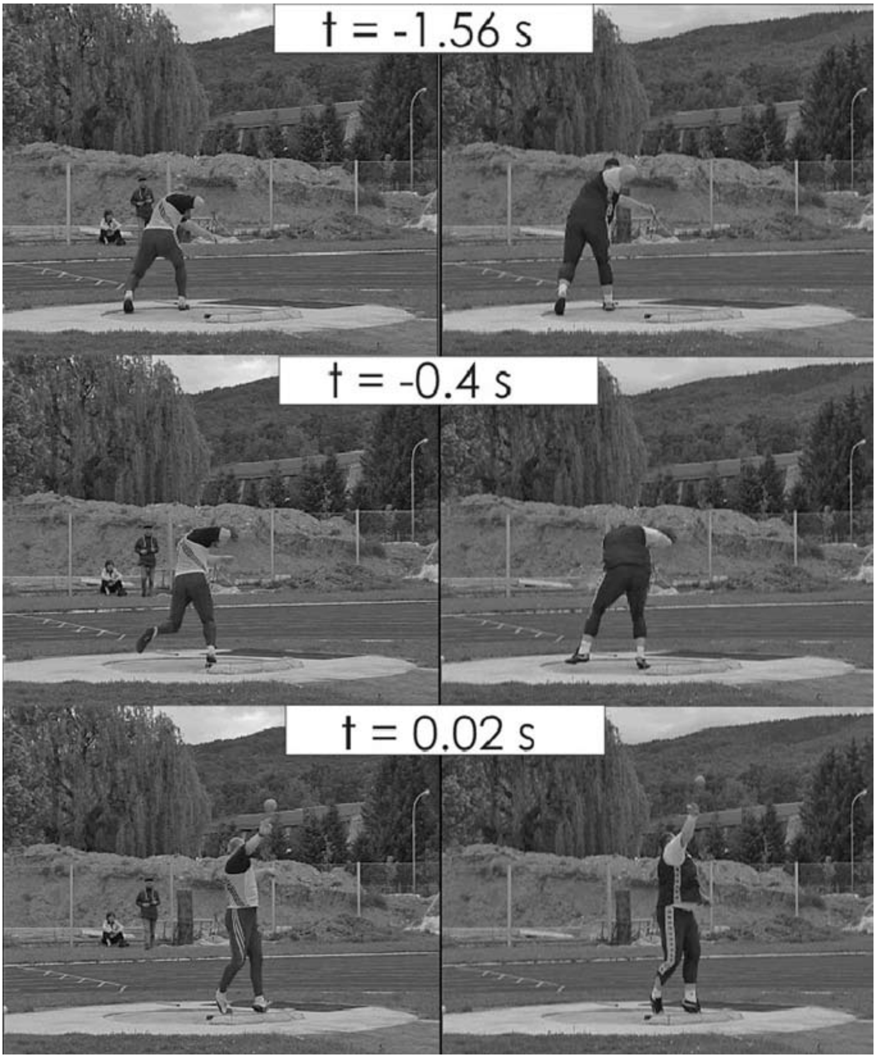

Figure 2: Video frames at three selected times for the two shot putters: left H.A. (result: 19.06 m), right M.V. (result: 20.30 m)

To start with, a simple parameter of shot height as shown in Figure 3 reveals a clear-cut difference between the time-dependent and angle-dependent data presentations. As the sample of subjects consists of two morphologically quite different athletes, the diagrams are much more interesting. We can see that the difference between the taller and the shorter athletes in terms of shot height is considerable but, 0.5 of a second before the release, both shot heights are within a range of a few centimetres. The upper diagram reveals that this happened at approximately 330° before the athletes rotated towards the direction of the field sector. The difference again started to show at about one-quarter of the turn before the zero angle. A more detailed observation reveals that the difference started to increase even more quickly from the zero angle onward; namely, in the very final phase of the release.

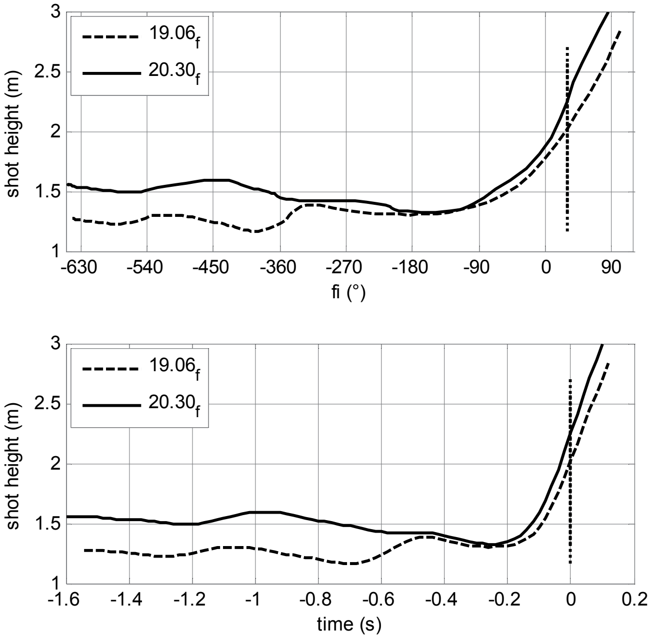

Figure 3: Shot height depending on the direction of the shoulder's rotation angle (above) and on time (below) for the two shot puts. The vertical dashed line shows the point of release

Even more interesting is the observation of differences in the angular velocity in the elbow of the right release arm used by both shot putters (Figure 4). The time-dependent diagram, i.e. the lower diagram of Figure 4, shows the delay in the angular velocity of both competitors. However, it is established that both athletes extended their elbows almost at almost the same speed in relation to the body's rotation (the direction of the shoulder's rotation angle) as the curves are relatively well compatible from -135° to 45° (Figure 4, the upper diagram).

The division of the throwing action into phases (e.g. the first double-support phase, the single-support phase, the flight phase etc.) is clearly manifested in the direction of the ankles' rotation angle (Figure 5). Each time both legs are in contact with the ground, the angle remains more or less the same. If the two athletes are compared in terms of temporal harmonisation, the phases follow each other in a very similar way. The rotation in the double-support phase and the first single-support phase of H.A. (result: 19.06 m) in the time period from zero to -0.6 s is 15° to 55° more than with M.V. (result: 20.30 m). Other phases are very similar and only exceptionally slightly exceed a difference of 20°. A comparison of the body's position in relation to phases and an angle-dependent presentation of the direction of the ankles' rotation angle reveal even larger differences, ranging from about -450° to -110° (Figure 5, below). The largest difference is seen between the angles of about -310° and -180°, indicating the considerably different technical implementation of this segment.

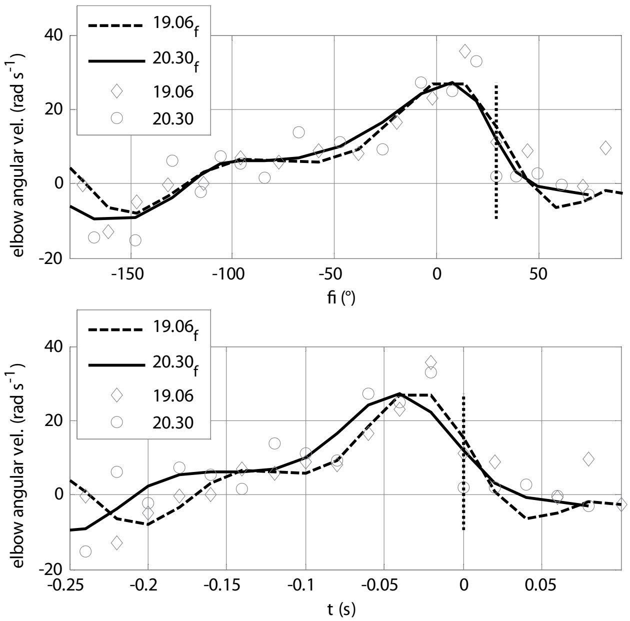

Figure 4: Angular velocity in the elbow of the right release arm for the two shot puts, depending on the direction of the shoulder's rotation angle (above) and on time (below). The full and dashed lines show the filtered data, while the circles and diamonds show the unfiltered data. The vertical dashed line shows the point of release.

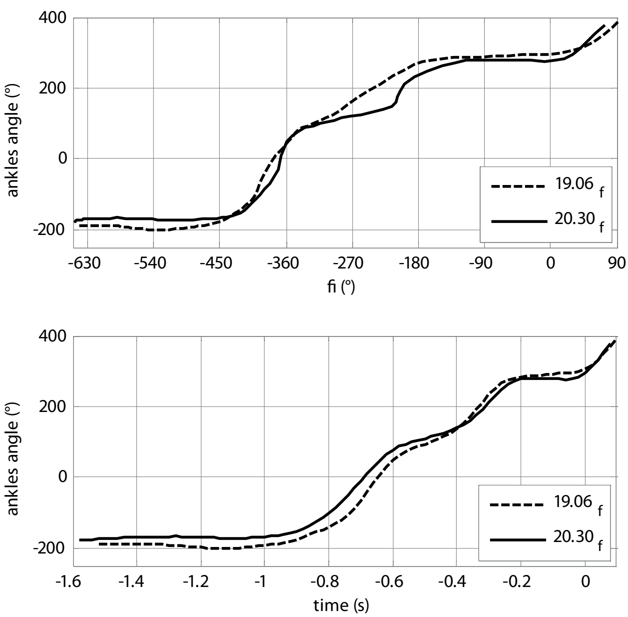

Figure 5: The direction of the ankles' rotation angle for the two shot puts depending on the direction of the shoulder's rotation angle (above) and on time (below)

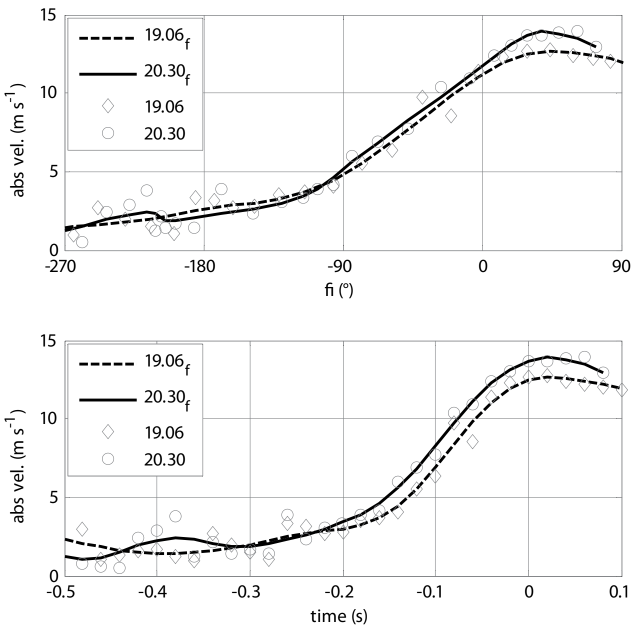

Figure 6: The absolute shot velocity in the two shot puts depending on the direction of the shoulder's rotation angle (above) and on time (below). The full and dashed lines show the filtered data, while the circles and diamonds show the unfiltered data.

The difference in the presentation can also be seen in the selected parameter: absolute shot velocity (Figure 6). A closer observation of the time-dependent diagram (the one below) shows that the curves split at the time of -0.22 s and never join again. According to this diagram, the greatest advantage of shot putter M.V. (result: 20.30 m) is the fact that he started increasing the shot velocity 0.04 s earlier than A.H. (result: 19.06 m). However, the upper diagram of Figure 6 provides different information: the first important difference occurs between the angles of -110° and -90° and the second in the very final phase of the release, between the angle of 10° and the point of release.

DISCUSSION

It has been demonstrated that the direction of the shoulder's rotation angle as a new element of shot put analyses provides a very useful tool. The basic idea was to relate the angle to the body's centre of gravity; however, the latter is only a point and has no direction whatsoever. Consequently, in the first research phase, the vector linking the point of the body's centre of gravity and the shot was investigated. It was established that the direction of this vector was not relevant. Moreover, the points can even position themselves one above the other, resulting in unwanted singularities and serious errors. The second option was either the direction of the shoulder's rotation angle or the direction of the hip's rotation angle. We chose the former, even though at first glance the hip axis appears to be a better choice because its behaviour is more similar to that of the body's centre of gravity. This choice was made for the following reasons:

for coaches, the shoulder axis is more visible and easier to conceive. In contrast, the hip axis is generally burdened by larger errors because in the most frequently used 3-D kinematic methods, where a camera system is applied, the determination of the hip joint is made difficult by the thickness of the tissue covering it.

As already mentioned in the results, the direction of the shoulder's rotation angle shows a monotonic increase caused by the specific nature of the shot put. Thus, in mathematical terms it is a suitable parameter (Figure 1). However, the non-proportionate increase in the angle or rotation of the athlete shows that the transformation from temporal to spatial dimensions is harder to imagine for experts, thus bringing value added to the angle-based approach. Although this is not explicitly seen in Figure 1, it is very important that temporal harmonisation causes a great delay in the body's rotation (Figure 2). This hinders a detailed comparison of the shot put technique, even though it provides the information that the duration of an individual action differs from athlete to athlete.

The examples in Figures 3 to 6 confirm that the introduction of the direction of the shoulder's rotation angle as an abscissa axis is highly valuable. In data analysis, it can be helpful in many ways. It improves one's conception of the phase during which the action took place and this is clearly demonstrated in the example of shot height (Figure 3). In addition, harmonisation in comparative analyses is different because new information can be used. It was thus established that the angular velocity in the hip joint of both study subjects was very similar with regard to their body position, despite the fact that it was delayed. This new approach allows us to observe differences in the execution of technique in some parameters, even though this cannot be seen on a time scale, e.g. the position of the ankles in the diagrams of Figure 5. Last but not least, with the new functionality we can better define the fractions of the throwing action in which the major differences occur and determine why one athlete is more successful than the other, as is also shown by the diagrams in Figure 6.

It can be asserted that the observation of time-dependent parameters is important due to the definition of physical parameters. It is also true that people, including experts, athletes and scientists, are used to dealing with parameters from the temporal perspective. Therefore, temporal harmonisation will remain a major element of analyses. In spite of the above, it can be argued that in practical field work it is easier to observe the technique and simpler to imagine concepts if they are supported by spatial co-ordinates or, in our case, the rotation of the body. Moreover, this method of presenting parameters in a comparative analysis yields many new and important pieces of information.

Even though the new data analysis method has not yet been tested on the linear shot put technique (Stepanek, 1989), we anticipate that this new approach is also applicable there. Furthermore, the last half of the turn can probably be efficiently harmonised, allowing for a consideration of hypothetical differences between the linear and the rotational techniques. This further increases the applicability of the new insight into data emerging from comparative analyses, as these two techniques are difficult to harmonise in time.

In fact, when applying the new method, we have to shift our observation focus to the rotation of the shoulder axis. Theoretically, the only drawback of the new method is the limited accuracy of the measurement of the shoulder axis rotation. However, in view of the development of technology, we claim that this factor is becoming less important every day.

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