MORPHOLOGY BIOMECHANICS OF TRACK AND FIELD COMPETITORS

Wlodzimierz S. Erdmann

Sniadecki University of Physical Education and Sport, Gdansk, Poland

The paper presents description of relationship between morphological quantities of sportsperson's body build and mechanics of movement. Morphology biomechanics, i.e. structure, biomaterials, construction, geometry, inertia was described. Main groups of track and field disciplines (race walking, running, jumping, throwing) were presented and their relationship with competitor's mechanical body build.

KEY WORDS: track and field, competitors, morphology biomechanics

INTRODUCTION:

Morphology (from Greek *morphe* which means form, shape, build) is very significant taking into account human movement, especially sport movement. Within track and field several groups of disciplines, i.e. walking, running, jumping, throwing require different competitors' morphology. Even within those groups of disciplines there are different morphology of particular disciplines.

Physical anthropology differentiate body build usually according to linear dimensions, tissues' volume of which a body consists, mass of the body. Biomechanical approach to the body build is much broader. It takes into account all problems that have influence on body movement, body stability, body resistance to external loads. Thus morphology biomechanics consists of: 1) structure, 2) biomaterials, 3) construction, 4) geometry, 5) inertia (Erdmann, 1982, 1988, 1999).

STRUCTURE:

At the beginning structure takes into account modeling of the body. Structure deals with divisions of the body, full and simplified representations of the body, potential possibilities of movement in joints.

Human body consists of about 150 links. There are also simplified representations of a body. There are models which consist of few or more than ten segments. But the simplest representation of a body is a dot. We use it for example to position a body on a track. This can be a specific point on the body, e.g. a hip joint, or this can be a center of mass. Also after the run (at the finish) on the trunk's image of photo-finish device a point is marked which crosses as the first the finish line. This is used to measure the time of running.

The body can be described as a chain of links. Two adjacent links form kinematic pair. It has one, two or three possibilities of movement around principal axes. These possibilities are called degrees of freedom. The sum of degrees of freedom for particular kinematic chain, i.e. a fragment or the whole body is called mobility. Mobility of free (without girdle) upper extremity (according to scapula) and of free lower extremity (according to pelvis) equals 30 degrees of freedom. Mobility for the entire body equals 244 degrees of freedom. This shows huge amount of movement possibilities one can achieve. Thus every sportsperson, even acquiring the same technique of movement, has his or her own style of movement taking into account segments moved and used degrees of freedom. To this one needs to add different range of movement, different velocities and accelerations.

Analysis of body structure is especially important when para-sportspersons are taken into account. They are divided according to lack of particular fragment of body's kinematic chain.

BIOMATERIALS:

Biomaterials are all those materials that deal with living creatures. Human body consists of cells that are basic elements of tissues. They constitute organs and systems. Within the body there are also acquired and excreted and expelled solid and fluid (i.e. liquid and gas)

products. Biomaterials are only those materials that have steady status according to the body.
Within sport one can describe materials of which a healthy body is build. There are also materials that play a role as substitution to human tissues. They can be of natural or artificial origin. They are used to build orthoses or prostheses that help in reconstruction of patients' organs. This problem exists in sport of disabled persons.
Materials are checked according to their density. This varies for the human tissues from 0. 6 (lung) to 2.0 (hard bone) g/cm^3, but most often data are between 1.0 and 1.2 g/cm^3 (Erdmann and Gos, 1990).
Materials are investigated according to their resistance to external loads. The most often tissues of movement system, i.e. bones, ligaments, tendons, are investigated. Ligaments and tendons are extremely resistant to external loads. Their Young's modulus equals 2×10^6 N/cm^2 (Morecki *et al.*, 1971). Hard tissue, i.e. bone has different resistance to external loads. It depends on how many calcium, potassium, and magnesium it consists. Demineralization of a bone that happens when there is a lack of movement or wrong diet causes weakness of a tissue. This is one of the reasons of contusions, e.g. rapture of ligament or a break of a bone. Skin can have different surface. Sweaty skin must be covered with talcum or other powder minimizing friction force between a hand and equipment (e.g. shot put).

CONSTRUCTION:

Construction describes bones as specific technical elements, e.g., rods, tubes, girdles, tanks, cage. Joints are represented as levers of specific construction – hinges, ellipsoids, saddle. There is also specific construction of internal organs and systems. Organs are represented as pumps (heart, lungs), filters (kidneys), storage tanks (liver, marrow cavities). Systems are represented as hydraulic connections (circulatory system), tree trunk and branches (breathing system), central steering box and wire connections (neural system).
Particular construction of a body gives different body's shape This causes different drag force. Construction of human body has advantage when locomotion is concerned. Long lower extremities give possibility of walking or running with longer strides and thus with considerably bigger velocity. They also allow reaching high set objects. Human construction has also disadvantage when stability is taken into account. Feet surface that touches a ground has only about 0.05 m^2. It can be enlarged by placing feet wide apart. But during one foot support equilibrium of the body is challenged.
Another problem of body's construction is body's resistance to external loads. This is of special concern when cross country running and training conditions, especially during heavy training in fitness room, are taken into account. Spinal cord and marrow are well hidden in long cavities. Brain is protected in a scull. Upper internal organs are placed behind a rib cage. Lower internal organs are protected by pelvis. This protection takes into account mostly horizontal forces. When vertical forces are applied there is a problem in maintaining stability and a problem with maintaining vertebrae in proper place. During lifting large weights unparallel setting of vertebrae causes slipping of upper vertebra according to lower vertebra. Also intervertebral disc tends to go out of proper place backward into the direction of spinal cord. While reaching objects that are far away from the body or during leaning a trunk large moment of force appears acting around vertebral column's hinge point. This causes big involvement of muscle moment of force of back muscles. They are not always prepared to resist such a load. In this case often big pain appears. Here one needs to remember that large loads should be lifted not with trunk bent but rather by flexing lower extremities in hip and knee joints with a trunk nearly in vertical position.

GEOMETRY:

Geometry of the body can be described in: a) one dimension (linear quantities), i.e. length of segments (straight- and curve-linear), b) in two dimensions (planar quantities), i.e. area of surfaces, planar angles, and c) in three dimensions (spatial quantities), i.e. volume of solids, capacity of tanks, and spatial angles.

Length of segments is important in several human actions – gaits, throws, jumps. Straight lines connecting specific points of the body can present posture of the body. Height of the body is presented by a straight line extending between a ground and the most upper point called Vertex. It is situated at the most upper point of a head positioned in Francfort plane. This plane for measuring body's stature goes horizontally through lower edge of eye foramen and upper edge of ear external foramen. There are different approaches in measuring length of segments – absolute (between edges of a segment), anthropometric (between prominent bony landmarks easily palpated under the skin), kinematic (between axes of joints). The latter changes according to shifting of joint axes. This is a result of non-right curvatures of joint surfaces. Curve-linear dimensions are measured when shape of vertebral column or circumference of body segments are investigated. Lengths of a body are measured using anthropometric tools or using photographic or video images of the body.
Surface of the body (perpendicular to the direction of movement) is taken into account when drag force is calculated, which is a function of air's density, squared velocity of movement, surface of the body and shape coefficient. A vector of drag is attached to the center of body's surface. Also area of surface is presented when one wants to show a contact of the body with the ground to describe body's equilibrium. Surfaces of a body are obtained mostly by image methods.
Another planar quantity is a planar angle. This is important to show movement possibility in joint, i.e. a range of movement. There are three ranges: a) bony, it depends on joint surface of a bone and of a cartilage which covers bony joint surface, b) active, it depends on strength of muscles that move a segment and also on elasticity of soft tissues surrounding a joint, c) passive, it depends on external forces that act on a body. The latter can be a cause of contusion when an external force is stronger than tissues' possibility to resist this force.
Volume data are used to calculate body's density, e.g. with immersion method. A body of 100 kg with density of 1.03 g/cm^3 has volume of 97.0 dm^3. To the center of volume draught force is attached.

INERTIA:

Inertial quantities consist of resistance data which are important when state of the movement (velocity) is changed, i.e. at the start and at the finish of movement, during acceleration / deceleration of movement, and during change of direction of movement. For transversal movement this resistance data is called mass, and for rotational movement it is called moment of inertia.
Within track and field sportspersons mass of 40 – 60 kg for long distance runners and mass of over 100 kg for throwers are recorded. Mass of body parts differs according to sportsperson specialization. For example relative mean data of mass of thigh, calf and foot for adult males equals 10, 4, 2 % of the whole body, respectively. For high jumpers it equals 11, 6, 2 % (Kowalczyk 2006). Mass can be measured with a help of a scale which works as a lever system where on the one side unknown mass is put and on the other side known mass is put. When a lever shows zero, then masses are of equal value. Another approach is with a help of scale which works like dynamometer. Here weight (mass $\times$ gravity acceleration) of a body is measured. In order to achieve a mass calculation is needed taking into account a difference of gravity force of measuring place and scale's production place. Mass of body segments can be obtained also indirectly using relative data (percentages) or by multiplying volume times density.
Moment of inertia takes into account mass and its distribution according to axis of rotation. Moment of inertia can be presented in simplified way with a help of squared radius of inertia (radius of gyration) and mass, both according to axis going through center of mass (central moment of inertia) and according to axis going out of center of mass. The latter is calculated by adding to central moment of inertia a product of mass and distance between center of mass and axis of rotation. Moment of inertia for a whole body of upright position with upper extremities kept close to a trunk equals 1.0 – 1.2 kg$\times$m^2 while for the situation of a discus

thrower (but without a discus) with upper extremities abducted horizontally equals 2.0 – 2.5 kg$\times$m^2 (Hochmuth, 1974).
Another inertial quantity is radius of center of mass. It describes position of center of mass according to acquired reference system. Center of mass represents distribution of body's mass. It is only an imaginative point. It can be within a body or outside it. In dynamics this point serves as a point to which a vector of gravity force and vector of inertial force (d'Alambert force) is attached. In the case of gravity force in Earth situation center of mass is called center of gravity.
For humans in upright position center of mass is situated above half of body's length. Higher for males and lower for females. Usually it is situated between 55 and 57 % of body's length according to the ground. For sportspersons who have enlarged upper girdle, position of center of mass can be situated even 60 - 62 % of body's length (Erdmann, 1976). Mass and radii of center of mass for main human body parts, and especially for five parts of a trunk are presented in a work of Erdmann (1995).
Searching for position of a center of mass one can use several methods. There are direct and indirect approaches. Direct approach uses levers. Historically it started with two-arm lever, now one-arm lever is used. For positioning center of mass of a segment pantograph with proper setting of arms is used. Working with images of a body one can use template which has drawn positioning of center of mass for different lengths of different segments (first type, Walton's construction, 1970) or positioning of common centers of mass for compound segments (second type, Erdmann's construction, 1979). Above is used using sum of mass method for positioning center of mass of the whole body or its fragment. For sum of moments of mass method, also for positioning center of mass of the whole body, traditional or computerized approach can be used. While using a computer a cursor is moved over a proper landmark (e.g. a joint) and its position according to acquired reference system is memorized. This is done with all landmarks. Then computer program calculates a value of radius of center of mass of the whole body according to acquired reference system. One of the newest approaches in obtaining detailed inertial data is computerized tomography (Erdmann, 1995).

RACE WALKING:

Figure 1 presents relationship between length of lower extremity and length of a stride. Length of half of a stride depends on length of lower extremity and angle of flexion in hip joint: $b = c \times \sin\varphi$, where b – half stride length, c – lower extremity length, φ – angle of hip flexion. With the same angle of hip joint flexion of competitors A and B, longer extremity (link c') of competitor B according to competitor A with n % (n/100) causes elongation of stride's length with d value: $d = (c \times n/100) \times \sin\varphi$. For example: for $\varphi = 30^{O}$ and extremity's length of competitor A c = 100 cm, extremity length c' of competitor B longer 10 cm gives elongation of half stride's length d = 5 cm.

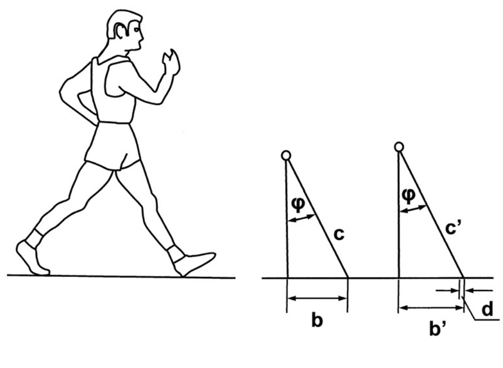

Figure 1. Race walking: longer length c' of lower extremity comparing to length c gives longer half stride b' comparing to length b with the same angle φ of hip flexion, d – difference of half stride's length (Erdmann and Grubecki, 1995).

There is an optimum length of race walker's lower extremity. Too long extremity is not advantageous. This is because moment of inertia, i.e. resistance of the extremity would be too high. Four times race walking Olympic Games winner Robert Korzeniowski is of medium

stature and his lower extremity's moment of inertia is rather small. This enables him to obtain higher frequency of movement of extremities.
Taking into account movement of pelvis its higher than usual twist gives advantage in longer stride. For example, if an athlete has a distance between hip joints h = 30 cm and he or she has higher possibility of twisting a pelvis, let say from 10^O to 11^O comparing to another athlete, a difference in a stride's length would equals d = 0.5 cm. For one stride it is small value, but multiplying by thousands of strides it is a big distance.

RUNNING:

Structure of runner's simplified body (22 links) is characterized by a needed number of possessing at least 25 degrees of freedom comparing to basic number of 50 degrees of freedom needed for normal life. Contusion can cause temporary lack of possessed degrees of freedom. A coach has to decide whether an athlete may train with decreased mobility. When disabled runners are taken into account they should be grouped according to their lack of particular degrees of freedom.
Construction of a runner has relationship with his or her shape. A shape along with velocity of running and area of surface perpendicular to velocity direction have influence on drag force. Big drag force can be minimized by covering a body with overall suit. It is especially seen within sprinting where runner wears a suit starting from the apex of a head, then tightly covering a neck, both upper and lower extremities and a trunk. Unfortunately, some runners have loose shirts or shorts and long, loose hairs (also male runners) which give bigger drag (long hairs give about 6 % bigger drag – Ernst,1992). Also sometimes a piece of fabrics with printed number on it is attached to the runner's shirt improperly, i.e. loose. In this way air goes under it and makes a drag stronger.
There is no specific one geometric (linear) model of a sprint runner at dash distances. Some of them are of a low stature thus with shorter lower extremities and with big musculature. They achieve high velocity of sprinting having high frequency of movement of their extremities. Examples are sprinters of African origin. Other sprinters have high stature thus long lower extremities. An example was Olympic multi–winner and record holder Irena Szewinska. She achieved high velocity mostly through long strides and also through considerable frequency of extremities' movement. Every long distance runner is characterized by lean and medium size body, low mass and low moments of inertia of their extremities. This allows more endure effort of their body. During running against strong wind runners should lean their bodies forward in order to diminish frontal area of body's surface, thus diminishing a drag force.
For assessment of energy output of a runner his or her position of center of mass for several strides is needed. This is investigated mostly at the laboratory using a treadmill. Vertical and horizontal oscillation of a center of mass of a runner is under investigation here.
Hurdle runners are of a high stature, but not among the highest. Here are opposite demands. For clearing an obstacle they need position of a center of mass at considerable height, thus they need long lower extremities. But during attacking a hurdle they need to achieve high angular velocity of lower leg. Also they need to make a contact with a ground as soon as possible behind a hurdle. To obtain high velocity a hurdler needs small moment of inertia of his or her lower extremity, especially of calf and foot. This can be obtained by having not so long extremities. For example one group of investigated hurdle runners were of higher stature and bigger moment of inertia of lower extremities. Comparing their results for 400 m hurdles and 400 m dash the time difference was 4.5 – 6.0 s. Other group of hurdle runners had smaller moment of inertia and some shorter extremities and achieved bigger angular velocity. They achieved the time difference of 1.5 – 3.0 s and were better in hurdle running than the previous group (Erdmann, 1976).
Hurdle runners have a big range of movement in hip joints. This allows to clear an obstacle closer to its upper edge. In objective assessment of clearing a hurdle image method using video picture can be utilized. The closer distance of center of mass to the upper edge of a hurdle the better – Figure 2.

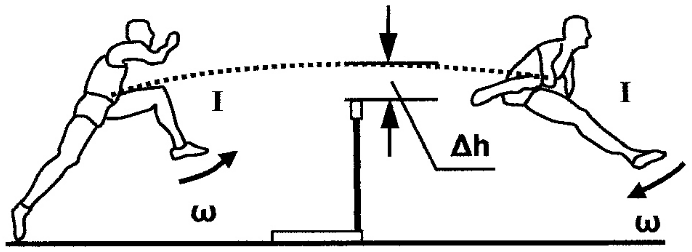

Figure 2. Clearing a hurdle. Small moment of inertia (I) of lower extremity is an advantage in obtaining bigger angular velocity (ω). Trajectory of center of body mass (dotted line) serves as an objective assessment of clearing a hurdle (Δh).

During steeplechase running clearing an obstacle may be done in two ways. The first one is similar to that for an intermediate hurdles, i.e. without touching a rail. Here center of mass moves at a flat trajectory. The second one, and it is always when the water jump is performed, is characterized by placing a foot on the rail, thus raising center of mass higher above an obstacle. By maintaining compact body position with the supporting extremity well bent and the trunk leaned forward center of mass is raised to the reasonable height.

JUMPING:

Figure 3 shows geometric (linear) dimensions which have relationship with a result in a long jump. These dimensions are: length of lower extremities (fragment d1 and d4), height h of center of mass (fragment d2), reshaping (grouping) of a body (fragment d3). Similar relationship occurs in triple jump.

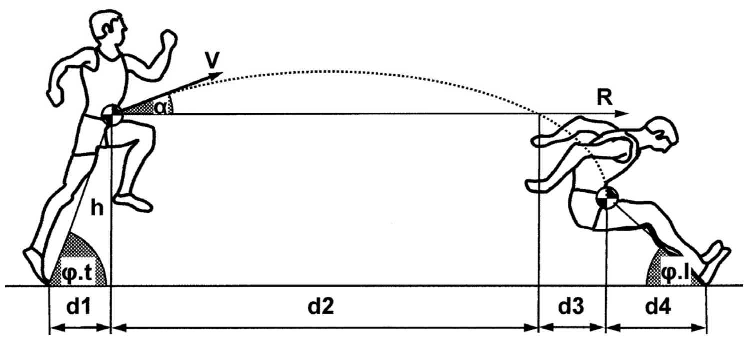

Figure 3. Distance of a long jump divided onto four fragments d. Fragments depend on body's morphology (d1-d4), strength preparation (d2) and technical accomplishment (d1, d3, d4). R – range of theoretical movement, V – velocity of take-off at angle α, h – distance of center of mass from the ground at take-off, φ – body angle of take-off (t) and of landing (l).

Ancient Greeks performed a long jump holding weights in their hands thus increasing their total mass. During a flight sequence they used to throw weights thus increasing their velocity. Here a theorem of conservation of momentum has its application.

It is obvious that longer body has advantage in a high jump. In order to calculate efficiency index EI of a jump one can use two approaches. A simplified one takes into account height H of competitor's body and height J of a jump: EI1 = J / H. In more advanced approach one needs to divide height h.j of highest raising of center of mass during a jump trough height h.s of center of mass of standing competitor's position: EI2 = h.j / h.s (see Figure 4). Usually high jumpers being over a bar keep their upper extremities along the trunk or abducted from the trunk. If upper extremities would be kept at the peak height over a head (like it is shown in Figure 4) center of mass of the whole body would be few cm lower. In this configuration of a body its center of mass would pass beneath upper edge of the bar.

In the pole vault grip height and mass of a jumper are important when type of a pole is chosen. Pole types are designated by the specifications of length and peak load with the body weight of the vaulter at a certain grip height (Schmolinsky – ed., 1978).

When a jumper puts a pole into the planting box his linear dimensions are important. There are two distances: the first one from the ground to the arm axis and the second from the arm axis to a pole kept by hands. During ascending action a vaulter swings his or her lower extremities upward and then he or she is grouping the body closer to the hands in order to diminish moment of inertia during rotational, pendulum like, movement. When a vaulter is over a bar his body being in a position with abdomen towards a bar could be even more bent than of a high jumper. Thus his center of mass could be even more beneath a bar – Figure 5.

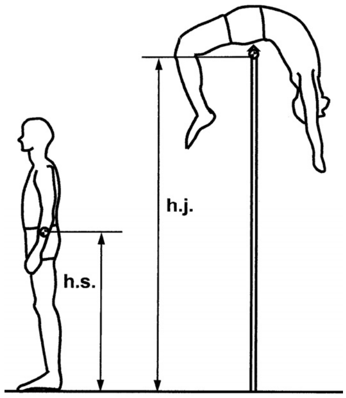

Figure 4. For calculation more advanced efficiency index of a high jump one needs to divide h.j through h.s., i.e. two distances of competitor's center of mass from the ground (Erdmann, 1997).

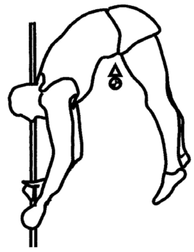

Figure 5. For a perfectly bent body of a pole vault competitor center of mass passes beneath a bar (drawing based on: Hay, 1978). .

THROWING:

Within all throws vertical linear body's dimensions are important. Throwing equipment will be released from a higher level by taller sportsperson. In addition javelin throwers need a big range of movement in shoulder joint (which is a compound joint consisting of an arm joint, movement of the scapula over the ribs, acromio-arm joint).
All throwers are characterized by a large amount of body mass. This is based on a principle of transmitting of momentum (mass × translatory movement velocity) in the translatory shot put and the javelin or angular momentum (moment of inertia × rotatory movement velocity) in the rotatory shot put, the discus, and the hammer.
In the discus throwers need long upper extremitiy in order to release a discus with higher linear velocity. This is a product of angular velocity and a radius of a turn. But longer upper extremity gives bigger moment of inertia. To overcome this difficulty during turning a body with a discus being far from a trunk a sportsperson needs to strengthen significantly his or her muscles.
During turning his or her body during discus throw a competitor holds his arms abducted from a trunk. At the end of a turn, just before release of a discus a competitor may make adduction of a free upper extremity and abducted lower extremity in order to diminish body's moment of inertia. This should give bigger angular velocity, thus bigger linear velocity of a discus. This applies also to the rotatory technique of the shot put.
In all rotatory techniques of throws to avoid stepping over after the release of equipment a thrower must increase his or her moment of inertia by abduction of extremities thus lowering angular velocity and maintaining better stability. Also lowering of the position of center of mass after the release is helping.

CATEGORIZATION:

Human population is characterized by individuals with very different body morphology. One reason of this is growing of children and youths. Another reason is genetic and surrounding influence. Unfortunately, up to now in track and field disciplines specific morphology is utilized, namely in jumps there are only tall persons, in throws there are only heavy persons. In order to attract more people to track and field disciplines categorization of persons according to body morphology should be applied. This already exists in several other disciplines, e.g. in fighting sports, in weight lifting, in rowing.

At first it could start within school competitions, where young people could be divided according to their body height in jumps and their body mass in throws. According to normal curve of data dispersion (Gaussian curve) population might be divided based on standard deviations.

FINAL REMARKS:

Body morphology within track and field disciplines is very important part of sport result. It is taken into account mostly during selection, during garment design, during technique analysis, and during direct and relative assessment of sport result. Especially the latter should be used more frequently.

Future considerations would take into account more individualized approach to competitor's body and also morphology of different disabled sportspersons.

REFERENCES:

Erdmann, W.S. (1976) Body build type according to Wanke's typology and position of center of gravity of judo competitors (in Polish). *Scientific Annales*, 6, 73-77. Warsaw – Poznan: Government Scientific Publisher (PWN).

Erdmann, W.S. (1976) *Biomechanical – morphological selection criteria of competitors for 400 m hurdle run* (in Polish). Doctoral Dissertation. Poznan: Academy of Physical Education.

Erdmann, W.S. (1979) *Template for locating compound centers of mass* (in Polish). Technical Report 1979-02, Laboratory of Biomechanics. Gdansk: Higher School of Physical Education.

Erdmann W.S. (1982) Preliminary assumptions of biomechanical – morphological model of the human body build (in Polish). *Scientific Transactions*, 6, 105-113. Academy of Physical Education in Gdansk. Warsaw – Poznan: Government Scientific Publisher (PWN).

Erdmann, W.S. (1988) Morphological biomechanics – complex view on mechanical body build (in Polish). In L.B. Dworak (ed.) *VII School on Biomechanics. Abstracts*. Poznan – Dymaczewo, 6-8 June 1988 (pp 52-53). Poznan: Academy of Physical Education.

Erdmann, W.S. (1995) *Geometric and inertial quantities of the male trunk obtained by computerized tomography method* (in Polish). Doctor of Science (Habilitation) Dissertation. Gdansk: Academy of Physical Education.

Erdmann, W.S. (1997) *Sport sciences in Poland and East Europe, biomechanics and locomotion. Based on lectures presented at Japanese universities.* Tokyo: University of Tokyo, Gdansk: May.

Erdmann, W.S. (1999) Geometry and inertia of the human body – review of research. *Acta of Bioengineering and biomechanics,* 1, 1, 23-35.

Erdmann, W.S., Gos, T. (1990) Density of trunk tissues of young and medium age people. *J. Biomechanics*, 23, 9, 945-947.

Erdmann W.S., Grubecki, K. (1995) Biomechanical, technical and informatics problems (in Polish). In Z. Mroczynski (ed.) *Athletics* (pp 189-239). Gdansk: Academy of Physical Education.

Ernst, K. (1992) *Physics of sports* (in Polish). Warsaw: Scientific Publisher PWN.

Hay, J.G. (1978) *The biomechanics of sports techniques.* Englewood Cliffs: Prentice-Hall, Inc.

Hochmuth, G. (1974) *Biomechanics of sport movement* (in German). Third edition. Sportverlag, Berlin.

Kowalczyk, R. (2006) *Individual geometric and inertial quantities of high jumpers.* Master thesis. Gdansk: Sniadecki University of Physical Education and Sport.

Morecki, A., Ekiel, J., Fidelus, K. (1971) *Bionics of movement. Bases of external steering of biomechanisms and human extremities* (in Polish). Warsaw: Government Scientific Publisher (PWN).

Walton, J. S. (1970) Template for locating segmental centers of gravity. *Research Quarterly*, American Association of Health and Physical Education, 41, 615-618.

Schmolinsky, G. (1978) *Track and Field.* Berlin: Sportverlag.