Review of body balance research methods
Przegląd metod badania równowagi ciała

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Key words
body balance, methods of body balance assessment

Abstract
A man’s physical fitness largely depends on the ability to maintain body balance. This ability is examined by using various methods and tests, still searching for the best way of its evaluation. Body balance is discussed from different aspects and in relation to various developmental periods. Usually, static and dynamic balance are distinguished. Commonly used computer techniques and different kinds of tests of balance evaluation are still not satisfactory and they constitute a topic for discussion over the value of these measurements. Balance system of the body require the interaction of many mechanisms, which undoubtedly, impedes the construction of the measuring device used for its accurate and reliable assessment, both in static and dynamic conditions. The conducted research on linking body balance with other manifestations of a man’s motor skills, for example the impact of body composition and gender on the level of this feature, is very helpful in the accurate assessment of this feature among the youth and children. The differences, resulting from the interaction between environmental and genetic factors, in somatic potential that are manifested in different body size and body proportions, may be decisive of a children’s motor skills and predispositions. It has been proved that the influence of specific exercises can effectively influence the level of children’s balance. The purpose of the report is to review different methods of body balance examination. The PubMed and Scopus databases have been searched. The following keywords were used in the search: balance, postural balance, coordination diagnostics.

Słowa kluczowe
równowaga ciała, metody oceny równowagi ciała

Streszczenie
Sprawność fizyczna człowieka w dużej mierze zależy od zdolności utrzymywania równowagi ciała. Zdolność tę bada się używając różnych metod i testów, wciąż szukając najlepszego sposobu jej oceny. Równowagą ciała omawia się w różnych aspektach i w odniesieniu do różnych okresów rozwojowych. Zwykle rozróżnia się równowagę statyczną i dynamiczną. Powszechnie stosowane techniki komputerowe oraz różnych rodzaju testy oceny równowagi wciąż nie są satysfakcjonujące i stanowią temat do dyskusji na podstawie wyniku pomiarów. Układ równowagi ciała wymaga współdziałania wielu mechanizmów, co niewątpliwie utrudnia skonstruowanie przyrządu pomiarowego służącego do jego trafnej i rzetelnej oceny, zarówno w warunkach statycznych jak i dynamicznych. Prowadzone badania nad powiązaniem równowagi ciała z innymi przejawami motoryczności człowieka, np. wpływem budowy ciała i płci na poziom danej cechy są bardzo pomocne w rzetelnej ocenie równowagi wśród młodzieży i dzieci. Wynikające ze współdziałania czynników środowiskowych różne potencjał potencjalnego wyrażonego m.in. wysokością, masą i proporcjami ciała, mogą decydować o odmiennych predispozycjach i zdolnościach motorycznych dzieci i młodzieży. Dowiedzono, że wpływ określonych ćwiczeń może efektywnie wpływać na poziom równowagi dzieci. Celem doniesienia jest dokonanie przeglądu różnych metod badania równowagi ciała. Przeszkakało bazy danych PubMed i Scopus. Słowa kluczowe użyte w wyszukiwaniu: balance, postural balance, coordination diagnostics.

Article received: 22.03.2017; Accepted: 04.06.2018
Internet version (original): www.rehmed.pl

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The individual division of this paper was as follows: a – research work project; B – data collection; C – statistical analysis; D – data interpretation; E – manuscript compilation; F – publication search
INTRODUCTION

The comprehensive influence of physical activity, especially that with a significant coordination component, has been known for a long time – hence, the commonly known maxim: “healthy body, healthy mind”. Training the body activates and nourishes the brain by supporting and strengthening neuronal connections, as well as by improving the chemical and hormonal aspects of brain functioning. Many researchers have said that intense movement induces nerve cells to create dense networks of nerve connections, making the brain work more efficiently and faster, so an active body is the key to a strong and active mind[1]. Depending on the goals of physical activity, physical fitness is distinguished in the area of health, i.e. Health-Related Fitness (H-RF) and in the area of motor performance, i.e. Motor-Performance-Related Fitness (M-FP)[2]. Balance (the basic component of coordination capacity, an element of our fitness level) is the oldest sensory system that has probably been around for 600 million years. The task of balance is to facilitate orientation and behaviour associated with maintaining equilibrium[3,4].

BALANCE

Balance is the ability to use the body in the field of action of gravitational forces and to determine its own position in space. Knowledge about its location in space provides an original reference point from which it is possible to make all other spatial displacements, as well as to assess the state and adaptation to new, existing situations. The sense of balance (vestibular system) is unique, because it does not have any of its own sensations. We are not aware of balance if it functions properly, it is a key factor in the effective functioning of many other processes on which proper perception depends. It is not acquired automatically, it is something that is achieved by dynamic action[1]. The level of displaying the ability to maintain body balance in static and dynamic conditions determines the efficiency of the functioning of the organ of vision, the vestibular organ of the inner ear, the skeletal muscles and proprioceptive sensation.[3,4]

The balance organ receptors in the inner ear respond to changes in position and movement of the body. They transmit nerve impulses to the vestibular nuclei in the dorsal part of the bridge. These testicles connect with the nervous pathways of the motor nuclei of the eye muscles in the brain and the skeletal muscles in the anterior vertebrae of the spinal cord. Thanks to these connections, vestibulo-ocular and vestibulo-spinal reflexes occur. Examination of these reflexes is an important method in diagnostics of the balance system. In normal conditions, vestibular organs located in both labyrinths send impulses of equal intensity to the circuit. Receptors of the balance system, reacting to changes in position of the head and the whole body, change the intensity of these impulses, which, via the oculomotor muscles and the muscles of the trunk and limbs, leads to correction of the eyeballs and the entire body. Thanks to this, the field of vision is always maintained, regardless of head movements and the vertical position of the body under various circumstances. Strong unilateral agitation or paralysis of the balance system receptors leads to dysfunction of this system. These disorders manifest themselves subjectively in dizziness, while objectively, on the path of the vestibular and ophthalmic reflexes, rhythmic, spontaneous, associated ocular movements referred to as nystagmus appear, and regarding the vestibulo-spinal reflexes, body deviation or falling during rest and in motion can occur[5]. Under the influence of repeated stimuli acting on the balance system, there may be changes in the excitationability of this system. This phenomenon, which he called labyrinth habilitation, was observed by Abels[6] in 1906. Habilitation of the labyrinth occurs under the influence of exercises applied in the case of aviators and astronauts[7], and may also appear in sportspersons[8,9]. Szopa, comparing balance with other coordination predispositions, states that in ontogeny, balance reaches its maximum potential at the earliest time and is characterized by the smallest dimorphism and slower pace of the involution process[9,10].

The authors of numerous studies sought to link body balance with other manifestations of human motor ability in the aspect of gender differences and the influence of body structure on the aptitude to maintain balance. According to the authors of these tests, based on the results of their research – sex is not a factor differentiating the level of the ability to maintain balance, but there is a direct relationship between balance and body height and mass in boys. This dependence indicates that with increasing body size, i.e. mass and height, body balance deteriorates[11]. In every human physical activity, when the centre of balance and sensory centres cooperating with it are stimulated, the movement performed may disturb the efficiency of the balance system or stimulate it. This dependence is conditioned, to a large extent, by functional maturity of organs and senses as well as acquired motor experiences. Functional maturity and physical experiences form the foundation of movement learning[12].

The first scientific study on maintaining balance in humans was led by Romberg among people with central nervous system disorders. He quantitatively studied body deflections when standing with closed eyes[13]. Kochanowicz and Kucharska in 2004-2005 in their research on children aged 11-13, using statokinesiometric tests, indicate that the ability to maintain body balance for 32 seconds of the test may depend not only on the functional status of the labyrinth and sensorimotor mechanisms, but also psychological factors, concentration of attention and impatience with the examination (lasting 32 seconds) and the need to maintain a fixed body position during the test[14,15]. Lack of information on the reliability of measurements carried out with the use of various tools reduces the possibility of making comparisons of test results obtained by different authors and makes it diffi-
cult to use statokinesiology in the general human motor control system. The low repeatability of body balance measurements in the stabilographic test lasting 32 seconds was also shown by Kochanowicz, et al. In their research, the presented results allowed the authors to draw conclusions that the ability to maintain a stable body position in 7-12-year-old children under conditions of statokinetic tests is genetically determined and, alike most psychomotor abilities, is subject to wide variations. The repeatability of results obtained by different authors at various laboratories turns out to be low. Therefore, Romberg’s attempt with the use of the stabilographic method should be directed at stimulating the function of the labyrinth and somatomotor systems through specific exercises used in the educational process of children and youth. The balance of a human changes with development, hence, the fact that body balance constantly, dynamically develops up to the age of 10, is very important. From the age of 11, the above feature starts to be stabilized.

Computer techniques are commonly used in body balance testing. Statokinetic and stabilographic parameters are a graphical record of changes in the reaction force of the surface, based on new technical solutions—this is a short-term method and does not burden the subject. The test is based on the registration of changes in the position of the point of application and the size of the reaction force of the surface, which corresponds to the force of pressing the feet to the ground. The posturographic method has already been applied, among others, in studies including patients with damage to the central nervous system, in clinical otonuero logical tests and in the diagnosis of the balance organ. These methods are also used in the study of athletes from various disciplines and in research on the speed of motor learning. Research was also carried out on the value of the measurement obtained by using this method. Among others, it has been established that the highest reproducibility of the measurement is characterized by the position of standing on one leg - the so-called “flamingo position” and posturographic parameters did not show significant relationships with the “flamingo balance” test. Therefore, it cannot be said that the popular Eurofit test of body balance measurements brings the same information as the parameters obtained thanks to the use of the computerized posturographic system.

The issue of researching and determining physical fitness in the process of physical education constitut ed and still constitutes a subject of interest for practitioners of physical education as well as scientists dealing with these issues from a theoretical point of view. In Poland, for many years, there have been various concepts and specific attempts to scientifically solve the issue of assessing the physical fitness of school youth. In 1928, the first Polish attempt to assess this fitness was published in the work by Szczęsny Polomski titled “Body exercises for school children along with relative assessment” [Ćwiczenia cielesne dla młodzieży szkolnej wraz z oceną względną]. This work, however, did not bring much hype. In the 1930s, the concept of the physical fitness metre, emerging within the framework of the Physical Education Council’s initiative, was based on Jan Mydlarski’s measurement method, and new, more recent concepts and methods are still being created to date.

The main objective of physical education in schools is to increase the level of comprehensive physical fitness using physical exercises via rational teaching and educational methods. It requires a teacher’s conscious attitude towards the effects of his/her work and a certain amount of knowledge on the subject. Physical fitness should be checked not only by the teacher, but mainly by students interested in physical fitness, sport and strength training. In schools where motor fitness tests are used, there is an increase in the interest of young people in shaping their fitness, parents’ interest in its development, the physical fitness and health of their children rises, and the authority of a physical education teacher in the school environment also increases.

Physical fitness can be evaluated in an objective manner only with a set of (batteries) of tests, the reliability and validity of which have been examined.

**MOTOR EFFICIENCY TEST**

The European Motor Fitness Test (Eurofit), developed in 1988 after an experimental test battery, during which more than 50,000 from 15 countries were tested, is the most commonly used and recommended motor fitness test. Its tests include all basic motor skills, containing balance, which is also tested in laboratory conditions. The authors of the tests based their concept on both (M-FP) achievements and health (H-RF). “Eurofit” tests are simple, practical, and at the same time, accurate, reliable and verifiable. They provide standardized data and can be used over a longer period to track existing status, changes and trends. Everyone involved in sport and physical education is interested in studying physical fitness and knowledge about the level of fitness of children and youth. The Eurofit balance test consists in standing on one (chosen) leg, on a beam (length 50 cm, width 3 cm, height 4 cm) for a minimum of 60 seconds (Figure 1). With one hand, the subject grabs the free leg from behind the foot (“flamingo posture”), and the other hand can be supported on the investigator’s arm. The test begins when the subject is standing independently, and is interrupted if, in less than a minute, any part of the subject’s body touches the ground on which the beam is laid. After each loss of balance, the test is repeated until the subject can withstand the desired position for 60 seconds. If the subject loses balance 15 times in the first 30 seconds, the trial ends with the score of 0.

In the first test instructions issued by the Council of Europe, the test was to be performed barefoot, however, subsequent research experience convinced the employees of the Department of Theory of Physical Education that compliance with this condition negatively affects the diagnos-
tic accuracy of the test. It is then, in many cases, more a test of resisting discomfort and pain than an attempt to measure balance.

Balance assessment can also be found in other tests such as:
- Relative test of motor ability by Żak from 1991, based on “Eurofit”.
- “Eurofit” for adults (1995) created on initiative of the Council of Europe in Strasbourg to unify the methods of measuring physical fitness among adults (above the age of 20).
- A set of tests for boys aged 7-11, including a one-leg position with closed eyes and 5 backwards jumps and one knee kneel, with arms to one side, lifting one leg from the ground and maintaining position for 5 seconds.
- A set of tests for girls aged 7-11, including one-leg standing position with closed eyes, 5 backwards jumps and standing one-leg jump with 360-degree rotation to the right. Landing at place of rebound.

Examination of vestibulo-spinal reflexes is carried out using various methods:
- The Sensitized Romberg test, during which a subject stands with one foot in front of the other in a straight line. The inability to carry out this test, however, does not indicate disturbances in balance system function.
- Gait test, during which the subject walks forward with closed eyes. It is observed whether there is deviation from the direction of walking.
- Railwalking test, described in 1942 by Heath, and later by Goetzinger et al. This test consists of walking barefoot on wooden rails of different widths, while touching the heel to one’s toes. The distance covered by the participant maintaining on the rail is evaluated.
- Stepping test. This test was first described in 1938 by Unterberger, under the German name "der Tretversuch". In 1959, Fukuda modified this test by calling it "the stepping test" in English. Further modification of the above-mentioned test was done in 1963 by Zilstorff-Pedersen and Peitersen. It consists in the tested person standing in the middle of a circle drawn on the floor and with closed eyes, s/he walks at a moderate walking pace for 1 minute, bending the knees at a 90 degree angle. After a minute, the participant stops, and the movement as assessment of the body displacement in relation to the starting position takes place. Three displacement directions are evaluated: rotation around the vertical axis of the body, displacement towards the forward-backward direction and lateral displacement. The test is repeated three times, calculating the average from individual results.
- Henriksson assessed differences in the pressure of the lower limbs of the subject, standing on two scales.
- Posturography – an objective method of assessing the movement of the centre of gravity of the examined person during the Romberg test. The tests are carried out in a standing position. They can be performed with different foot configurations. The subject stands on the platform recording the pressure of the feet on the ground, the sensors placed in the corners of the platform register the movement of the centre of gravity in the sagittal and transverse axes. As a result, an image of the projection of the centre of gravity on the base plane is obtained, i.e. statokinesiogram.
- NASTYGMUS computer system, evaluating vestibulo-oculomotor and vestibulo-spinal reflexes. Examination of the vestibulo-ophthalmic reflexes is based on the observation of nystagmus, which may occur spontaneously as a symptom of inherent disorders or disease processes occurring within the balance system. In healthy people, nystagmus can be induced by artificially stimulating receptors of the balance organ by rotary, calor-ic or electric stimulus. Nystagmus can be observed visually - with the naked eye or through special glasses. Nystagmus can also be registered graphically, using the method known as electronystagmography.

The access to posturographic methods, limited in common clinical practice, makes simple clinical tests assessing body balance disorders play a very important role in assessing a patient’s balance. Thanks to their...
simplicity and form, they allow to reveal disturbances in situations similar to everyday life conditions of the patient. Most tests do not require the use of specialized equipment, so they can be carried out in an office or hospital ward. In addition, the repeatability of these tests allows to monitor the patient's functional status, assess progression of the disease or evaluate the effects of rehabilitation. Clinical tests evaluating balance can be divided not only into tests used to assess static and dynamic balance, but also providing qualitative and quantitative results.

Qualitative tests may include, for example, such tests as: the Romberg test, the Unterberger test, the tandem test, the Fukuda stepping test. They provide a general, inaccurate, subjective result which does not show the degree of severity of balance disturbance. However, quantitative tests offer measurable diagnostic results, they are characterized by repeatability and better reflect the functional status of a patient. The most well-known quantitative tests used in orthopaedics and geriatrics include:

- The Berg Balance Scale. The scale assesses static and dynamic balance after the tested person performs 14 types of movements in a standing and seated position. Each of the subsequent elements of the test is evaluated on a 4-point scale.
- The Fullerton Advanced Balance (FAB) Scale. Elements of the scale are 10 movement tasks to assess static and dynamic balance, including standing on one leg, 360 degree body rotation around the axis of the body or walking with the head turned. Each of the subsequent elements of the test is evaluated on a 4-point scale.
- Posture Grid Test. The test consists of assessing deviations in balance of the subject's body, facing a special map (type of geographical grid). As a result, body deviations assessed in the form of degrees of deviation or deviation distance from vertical position are visible on the map.
- Hinsdale Stylus Test. Assessment of balance is carried out in a standing position by means of a special element placed on the patient's head, which like a marker, denotes deviation from the vertical position on a special map/grid behind the patient. The assessment is done by measuring the distance of the patient's deviations from vertical position.
- Timed Up & Go test. Assessment of dynamic balance is carried out after a certain sequence of movements consisting of getting up from a chair, marching to a specific spot and returning to starting position. The end result is the total time that has elapsed from the beginning to completion of the correctly performed task (without loss of body balance).
- Step test. The test is carried out in a standing, straddle position. The examined person performs ascent and descent movements without losing balance on the elements placed in front of the tested person's feet (about 5 cm in height). The result of the test is the number of steps up and steps down.
- Timed Balance Test. The test consists in assessing balance when presenting specific motor tasks, including maintaining balance of the body with closed eyes and joined feet or standing on one leg with closed eyes. The result of the test is the time the maintaining body balance measured in seconds.

The tasks in these tests are usually based on actions reminiscent of everyday activities, such as getting up from a chair, transferring, standing on one leg or climbing a step. As a result, they show the real functional problems of patients, and analysis of results allows the implementation of appropriate exercises to prevent falls. There are also tests in literature assessing many aspects of motor coordination (including the ability to maintain body balance), tests assessing overall motor fitness of selected age groups with elements of balance tests. These tests are useful for diagnosis in various age groups, although those most frequently used in groups of children, adolescents and the elderly are:

- Movement Assessment Battery for Children (M-ABC). The test consists of 8 movement tasks divided into 3 categories: 3 balance tests (static and dynamic), 3 dexterity tests and 2 testing the skill of manipulating a ball. Thanks to the M-ABC, various motor skills of children are examined in 4 age groups (4-12 years of age). The performed movements are rated on a 5-point scale.
- Expanded Disability Status Scale (EDSS) – extended scale of physical failure. The test consists in performing tasks resulting from the 8th Functional Test Scale (FS), among which there is assessment of balance system function. The test assesses the severity of the disease in patients suffering from multiple sclerosis, and many aspects of the disease are taken into account.
- Charlop-Atwell Scale of Motor Coordination. The test consists in the execution of 6 movement tasks, including "tip-toe balance" to assess static balance. During testing, many coordination skills of children aged 4-6 are evaluated. The accuracy and quality of the performed movement task is taken into account for final evaluation.
- Brief Assessment of Motor Function. The test consists of 10 movement tasks and was created to quickly identify the level of development of motor skills in children. Evaluation regards, inter alia, the ability to maintain balance in a seated position without support or the ability to maintain a standing position without losing balance.
- Bruininks-Oseretsky Test of Motor Proficiency. The test consists in the execution of 8 movement tasks, assessed, among others, in terms of the ability to maintain balance of the body while walking on toes/heels in a straight line. The test examines the development of motor functions in a pediatric group of individuals within the age range of approximately 4-14.
- Peabody Developmental Motor Scale. The test consists in performing motor tasks subjected to assessment in terms of global and local motor coordination. Among the tasks of global coordination,
there are also those demonstrating the ability to maintain body balance. The subjects are children with developmental disorders. The process of maintaining balance as well as the issue of the most adequate methods for its evaluation has been repeatedly tackled in literature. The methods used can be divided into: static balance assessment methods (e.g. the flamingo test) and dynamic balance assessment methods (e.g. rotation in place, march on a rosette, body balancing on an unstable surface). All of these methods are easy to carry out in non-laboratory settings. Laboratory methods have undergone long evolution. The first tests were carried out on so-called barometers. Currently, measurements are conducted on stabi- lographs with a non-stable or stable base. The development of school physical education - usually refers to the development of the body in a broad sense. However, the main objective of physical education is to increase ver- satile physical fitness through physical exercises using rational teaching methods. The development of school youth should be studied, and the re- sults of the research should be used to assess whether the applied meth- ods are justified and proper.

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CONCLUSIONS
Balance is a coordination capacity with high individual variability. It is also known that balance understood as coordination capacity anal- ogous to other motor skills is influ- enced by targeted physical exercises and other environmental factors (e.g. noise, vibration, hypoxia). Scientific reports on the methodological the- ory of technically complex sports disci- plines (e.g. figure-skating, acrobat- ic and artistic sports - gymnastics, diving) discuss the significant influ- ence of balance function on results, while stressing that body balance pro- grammes often bear signs of randomness. Research on the impact of spec- ific exercises on the level of balance among children is the subject of many studies. The problem addressed by many authors regards coordinating stabilization abilities, which are an important element of proper human motor control. In the research by Ko- chanowicz and Kucharska, the analy- sis of data suggests the following con- clusion that specialized physical exer- cises used in physical education les- sons have significant impact on devel- oping balance. The term - phys- ical education - usually refers to the development of the body in a broad sense. However, the main objective of physical education is to increase ver- satile physical fitness through physical exercises using rational teaching methods. The development of school youth should be studied, and the re- sults of the research should be used to assess whether the applied meth- ods are justified and proper.


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