BALANCING IN HANDSTAND ON THE FLOOR

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Review article

Abstract

The contribution is a review study dealing with a handstand as one of the basic movement structures in artistic gymnastics. Balancing in this inverse position is a complex process based on physiological and physical principles. From physiological point of view the important results are from research dealing with function of vestibular apparatus, visual system, proprioception, central nervous system and motor units and their participation in balance maintaining. Another important question is a relationship between the strength of particular muscle groups and a level of balancing ability. Based on stabilometric measurements and 3D kinematic analysis of correcting movements equalizing the perturbations during a handstand we can distinguish several strategies of maintaining balance. Other important factors influencing the holding time in handstand position in gymnastics, mainly in tool disciplines, are a visual control and position of head.

Keywords: *gymnastics, balance, physiology, biomechanics.*

INTRODUCTION

Historically, artistic gymnastics in its basis derives from acrobatics for which positions and movements headfirst are typical. Handstand is one of the basic elements in both man and woman acrobatic gymnastics. Handstand in its static form is the initial and final position of many movement structures and in its dynamic form is either the basis of motion or its component. For this reason the movement structure is drilled with a great attention from the very beginning of a gymnastic life. As the exercise technique was developing, the handstand technique and balancing strategies in this position were changing as well. The handstand technique plays an important role as an initial and final position of some of the gymnastics elements mainly in artistic gymnastic of men, where the stabilized handstand determines a referees' recognition/ non-recognition of a movement structure. This is typical for acrobatics, rings and parallel bars. The stabilized handstand is not only important for balance beam, it is far more important for uneven bars in female gymnastics. Dynamic movement structures (circles, giant circles with twisting) performed without penalization must end in a handstand without follow-up persistence. Here the technical perfection of a handstand is important since the final position of one movement structure becomes an initial position of another one. The correct balancing strategy is an important part of methodology; therefore we focused on an in-depth analysis of this issue.

We can have a look at the principle of balancing from biological and physical points of view (Hudson, 1996). Both systems work in cooperation to create conditions for balance. Whether we talk about either static or dynamic balance, "owing to perturbations unsteadiness effects and bifurcations occur in a system resulting in the system becoming discontinuous, diffused. Balance at its basis, a characteristic of a quality of a system, is simultaneously a process of the system" (Brtníková & Baláž, 2007).

While it may be claimed that there is no absolute balance, every position or movement is a permanent process of balance creation by means of correcting movements. That is why we do not consider these movements disturbing. However, the tendency is to minimalize these correcting movements. By means of these movements we are able to eliminate the range and transfer of disturbing movements to different body parts, particularly the centre of gravity. Therefore a quick reaction to the stimulus informing brain about balance disruption is necessary.

Physiological principle of balancing

From physiological point of view, balancing consists of a number of phases: The first phase is a detection of a specific situation via sensory systems. When maintaining an upright position, a man uses a combination of information from vestibular apparatus, visual and proprioceptive information (Fransson, Kristinsdottir & Hafström, 2004, Vuillerme, Pinsault & Vaillant, 2005).

The function of vestibular apparatus may be limited by an uncommon head position, e.g. head bending backwards, or during handstand or fast head movements (Strešková, 2003, Asseman & Gahéry, 2005). The function of vestibular apparatus may be improved by physical exercise. Simultaneously, there is a direct relation between the functional status of vestibular apparatus and a quality of formation of some movement routines (Strešková, 2003).

Visual system provides very important information about where the body is located with respect to the environment in which it moves; eventually it provides information about the speed of the movement (Nasher, 1997, Shumway-Cook & Woollacott, 2007). The quality if visual system, mainly visual acuity and stereoscopic vision, in other words the depth of vision may influence the quality of performance of a balancing element. The influence of a visual control over the balance was investigated by more authors who generally came to the same conclusion, and it is that when the visual control is limited, the correcting movements are of greater extent. Vuillereme at al. (Vuillerme, Teasdale & Nougier, 2001, Vuillerme et al., 2001) broadly explored the role of visual stimuli in postural control of ballet-dancers and female gymnasts. He concluded that repeating of specific movements during a training improved postural regulations. A close relationship was discovered between the level of a sport training and postural abilities and a fact that limitation of visual control considerably disrupted postural performance.

Proprioception is based on a function of mechanoreceptors in skin, muscles and connective tissue and provides information about relative configuration and position of body segments, thus proprioception is essential for coordinated functioning of muscles (Nasher, 1997, Latash, 1998, Goldstein 1999, Zemková & Hamar, 2005, Shumway-Cook & Woollacott, 2007, Míková, 2007). Proprioception may as well influence the velocity and type, i.e. strategy of muscle response on balance disturbing perturbations. The function of proprioceptors may be improved by training. However, certain stimuli, e.g. joint injury, could result in incorrect movement perception of corresponding body segments (Barrett, Cobb & Bentley, 1991, Ashton-Miller, Woijtys, Huston & Fry-Welch, 2001). The experimental works of Lephart et al. (Lephart, Giraldo, Borsa & Fu, 1996) prove that artistic gymnasts have better proprioceptive perception. He investigated proprioceptive perception in knee joint in women gymnasts. He came to same results as Ramsay and Riddoch (2001) when he found out that gymnasts have better proprioceptive sensibility of a knee joint than untrained individuals. Results of both these studies imply that sportsmen who during the training process put the accent on precise movement control show proprioceptive perception of a higher level on both upper and lower extremities.

Various authors have different opinions on how much the different components – vestibular, visual and proprioceptive – contribute to balancing. Astrand et al. (Astrand, Rodahl, Dahl & Stromme, 2003) and Vařeka (2002), based on an experiment, came to a conclusion that proprioceptive organs play the most important role in maintaining a stable position. Mysliveček and Trojan (2004) and others think that the most important component is vestibular system. Sometimes, a certain sense conflict may appear when an important part is the ability to choose which information acquired by visual, somatosensoric and vestibular systems are reliable and which are not (Shumway-Cook & Horak, 1986).

The received information is then analyzed by central nervous system, where cerebellum and its functional circuits play an unsubstitutable role. From CNS (central nervous system) the information is taken via efferent pathways to muscle groups as stimuli to their activation. There, a contractive muscle force is generated which results, based on leverage of joints, in movement or stabilization of certain muscle segments, in terms of balancing we call these correcting movements.

In their works several authors have already dealt with question of the third phase of balancing process. They were investing a relationship between balancing ability and amount of muscle strength of a corresponding muscle group into which an impulse from CNS is delivered in order to maintain the balance position of body. Most previous studies focused on analysis of influence of muscle strength on static and dynamic balance in people with a significant increase in muscle flaccidity (Carter, Khan & Mallimson, 2002, Lord, Murray, Chapman, Munro & Tiedemann, 2002).

Several studies have shown that strength training improve balance (Pintsaar, Brynhildsen & Tropp, 1996, Blackburn, Guskiewicz, Petscgauer & Prentice, 2000, Hideyuki, Taketzo, Satoshi, Miho & Ukitoshi, 2000, Heitkamp, Horstmann, Mayer & Weller, 2001, Carter, Khan & Mallimson, 2002, Binda, Culham & Brouwer, 2003, Kalapotharikos, Michalopoulou, Tokmakidis, Godolias, Strimpakos, & Karteroliotis, 2004, McCurdy & Langford, 2006). Balckburn et al. (Blackburn, Guskiewicz, Petscgauer & Prentice, 2000) state that an activated muscle with its strength helps neuromuscular control in the way that during contraction it increases the sensitivity of proprioceptors detecting the muscle extension and owing to this the duration of electromechanical reflex of muscle contraction decreases. Other studies found out that, reversely, the balance training improves strength (Heitkamp, Horstmann, Mayer & Weller, 2001, Heitkamp, Mayer, Fleck & Horstmann, 2002). In contrast to these results, Wolfson et al. (Wolfson, Whipple, Judge, Amerman, Derby & King, 1993) and Verfaille et al. (Verfaillie, Nichols, Turkel & Hovell, 1997) did not find any changes in balancing skills after strength training. These contradictory results may be caused by different measuring methods. Insufficient relation between strength and balance may be due to differences among the muscle groups which are involved in strength and balance tests.

From different point of view Zemková (2004) dealt with a relationship between development of strength and balance. The authors state that owing to proprioceptive stimulation the neuromuscular system slightly fatigues which impairs balance of body position right after the strain. During longitudinal observation Zemková (2004) found out that strength training using the proprioceptive stimulation (combination of vibrations with active strength stimuli) resulted in reinforcement of balancing skills.

Postural control is thus a very complicated process with several phases. Postural control, whether in dynamic or static conditions, is dependent on body being able to react to sensory, inner and outer perturbations. During a balancing process it is important to observe the time characteristics of individual phases. When passing through individual phases there always is a certain time delay depending on structural and functional status of the system (Vařeka, 2002). Regarding the timing, postural control and motor reactions may proceed in two ways, depending on what kind of movement activity is done. The first option is anticipating postural corrections which are performed c. 80 – 500 ms before the acquired movement is initiated. These preliminary processes serve to creation of postural correction just before balance is disrupted by perturbations. The second option is a reverse action. As a reaction to inner perturbations, deviations in body posture occur, which are detected. As a response to these a reaction occurs, motor reaction, which regulate muscle strength in order to compensate the outer perturbations and keep the body in a steady position. These reflex reactions occur firstly in short-term responses 30 – 50 ms after the deviation to which they react. Then there are medium-term reactions approximately 100 ms after the deviation occurs, and finally long-term reactions, deliberate regulating actions, which occur up to 1 s after deviation (Nasher, 1997).

Physical principle of balancing

When analyzing the balance positions it is necessary to take into consideration that human body is not a compact matter but a set of connected items from which every deviation results in change of position of centre of gravity (Zemková & Hamar, 2005). In many works, mainly those focusing on mechanics (e.g. Adrian & Cooper, 1995, Hamill & Knutzen, 1995) the authors state that static balance is equal to a stable position. But as Kreighbaum and Barthles (1990) note, there is no absolute balance in human activity because human body constantly passes through certain changes in position. Every position or movement is a continuous process of recreating a balanced position using correcting movements. The processes taking place inside the human body, i.e. respiration, activity of blood circulation, deflect body from a given position. If we then, with a certain simplification, consider the resting positions as static, we may, from point of view of action of force, characterize them as following: Body lies in a static equilibrium if the forces acting on the body cancel out and body persists in rest. From biomechanical point of view, the body lies in equilibrium if it complies with two conditions:

The resultant of all forces acting on the body is equal to zero:

$$\boldsymbol{F} = \boldsymbol{F_1} + \boldsymbol{F_2} + \dots + \boldsymbol{F_n} = \boldsymbol{0}\,.$$

The resulting torque (with respect to any axis) acting on the body is equal to zero:

$$\boldsymbol{M} = \boldsymbol{M_1} + \boldsymbol{M_2} + \dots + \boldsymbol{M_n} = \boldsymbol{0}\,.$$

In a stationary body position the postural control is perceived as an ability of body to resist the force of gravitation and to keep the centre of gravity above a small base of support (Nasher, 1997). Hudson (1996) states that balance is disturbed more by horizontal forces than forces acting in vertical plane. A factor of balancing stability thus depends on ability of body to resist the horizontal changes of positions.

Balancing strategies

As we have already stated, keeping body in a static position is a continuous process of recreating balance by correcting movements. Therefore these movements are not considered disturbing. However, the tendency is to minimalize their extent. By means of these movements it is possible to eliminate extent and transfer of real disturbing movements to other body segments, mainly to centre of gravity. At locomotion system we may look as a system of inverse pendulum with more or less levels of freedom of movement depending on fixation of individual joints by isomeric contraction. Some authors have described the system of regulation of postural balance in an upright position as a three-level hierarchic system which begins at ankles, moves up to knees and finally to hips (Nashner & McCollum, 1985), whereas the knees are used to correct the big deviations.

Two possible strategies, two possible responds of locomotion system by which perturbations may be corrected in an upright position were in detailed described by Horak and Nashner (1986). When a body bends forward, either "ankles strategy" may be used during which ankle extensors are activated, knee flexors and hips extensors, or "hips strategy" with activation of knee extensors hip flexors. These two strategies differ in direction of rotary movement in hip joints. "Ankles strategy" is preferable for smaller perturbations, whereas "hips strategy" may be used for extensive or fast perturbations or when the area of support is small and only minimal rotations are possible in ankles (Horak & Nahner, 1986).

Míková (2007) summarizes and arranges the possible balancing strategies in an upright position (Fig. 1). Whether we talk about deviations in frontal or saggital plane, possibilities are ankle strategy, hip strategy and step strategy which extends the two previously mentioned strategies and authors mentioned above. During this strategy, in order to keep the position of centre of gravity above the base of support, movement of one lower extremity in opposite direction is used before the trunk is deviated owing to perturbations. By this movement part of body weight is moved to the opposite side as the weight of trunk and the centre of gravity, which is situated at mass body centre, remains above the area of support.

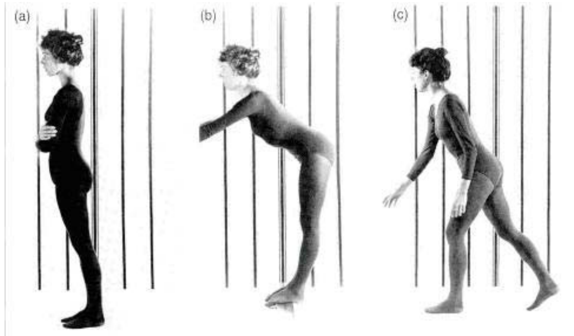

Figure 1. *Balancing strategies (Míková, 2007): a) ankles strategy, b) hips strategy, c) step strategy*

Characteristics of handstand

From the more demanding positions, handstand balancing is the one which is analyzed the most (Gauthier, Marin, Leroy & Thouvarecq, 2009, Kerwin & Trewartha, 2001, Mochizuki, Oishi, Hara, Yoshihashi & Takasu, 1997, Sobera, 2007). Handstand is a basic movement structure in the system of activities in artistic gymnastics. It is a static unstable balance position. From mechanical point of view, its specificity is determined by the height of centre of gravity, size of support area and the overall difficulty of the balance position in which we maintain stability. Last but not least, the atypical position of body (headfirst) contributes to it as well. The optimal actions of locomotion system also depend on characteristics of environment with whom it interacts. In artistic gymnastics, the balance positions are often made difficult by equipment (handstand on parallel bars, beam) whose mechanical properties and stability influences the difficultness of balancing (Croft, Zernicke, & Tscharner, 2008). The difficultness may be also increased by the fact that during these conditions already small deviation causes the centre of gravity not being over the base of support.

Balance is held by a chain of muscle actions which contribute to joint movements, manage different body configurations and control the movement of the centre of gravity (Hayes, 1988). "In order to hold balance, individual body segments have to be strengthened by means of isometric contraction of active muscle groups which fixate the spinal connections, hip and knee joints. The final position of handstand is characteristic by a flat angle between "longitudinal" body axes – arms – trunk – legs, straight head position (eyes following the hand finger tips). In order to increase the size of the area of support, fingers are slightly outstretched and placed in the area of support in the sportsman's shoulder width." (Zítko & Chrudimský, 2006). The technically correct performance involves sufficient strength of arms which carry the whole sportsman's weight, shoulder girdle and space orientation.

Balancing strategies in a handstand position

There are several ways of conducting a thorough analysis of processes contributing to balancing in a handstand position. Most often we choose the analysis of COP (centre of preasure) movement with a combination of a visual control, peripheral vision, and variants of head positions. In their researches authors start from the mechanism of balancing in an upright position. The body configuration in a handstand is similar to one in an upright position, which means that transfers occur between upper and lower extremities (Clement & Rezette, 1985). For handstand position, following differences with respect to an upright position are characteristic: The area of support is smaller, whereas the distance between the base and the centre of gravity is bigger due to a support of extended arms, which increases the instability (Slobounov & Newell, 1996). Handstand position requires an extraordinary muscle activity of upper extremities which substitute for the antigravitational task of lower extremities. Although the muscle activity of upper extremities is more precise, they succumb to fatigue.

More authors have already dealt with strategies of balancing in a handstand position; their opinions are not uniform, though. Nashner and McCollum (1985) state that the configuration of a handstand position is different from the one in an upright position because instead of three there are four joints (wrists, elbows, shoulders and hips) involved and this requires a specific postural coordination. Also Asseman et al. (Asserman, Caron & Crémieux, 2004) are of the same opinion when he states that balancing in a handstand position is more complex as it requires the presence of four joints instead of three of them.

Sobera (2007) analyzed the process of balancing in a handstand position and in a tip toe position, which comprise the basic elements in artistic and rhythmic gymnastics. The research group consisted of 10 gymnasts whose handstand position was analyzed, and 5 female modern gymnasts who were in a tip toe position. The sportsmen stood on a platform KISTLER for a period of 10 s and 20 s. COP trajectory was recorded. The measurements showed that in a handstand the deviations occurred mainly in the sagittal plane, which differed from the tip toe position where the frontal movement of COP is more important for the stability. Also Slobounov and Newell (1996) confirm bigger deviations in a sagittal plane in comparison to an upright position. Considering the strategies of balancing in a handstand position Sobera (2007) found out the most significant corrections in the wrist joints: "The control of balance in a handstand position is realized in a similar way to an upright position, i.e. via moving COP towards the fingers or the wrist joints in the sagittal plane or to right or left in the frontal plane. Holding balance in a handstand position requires maximal balancing in the wrist joints. Control of balance in this unnatural position is done mainly via increasing the pressure of fingers on the ground as a result of movement of the centre of gravity towards the fingers or the increase of pressure under the wrist joints during the movement of the centre of gravity towards the wrist."

Yedon and Trewrthe (2003) confirm the most considerable activity in wrists, where the perturbations in a sagittal plane corrected by wrist flexors and extensors with synergistically cooperating shoulder joints and hips contribute to maintaining the fixed body configuration. Rotations in wrist together with rotations in shoulders and hips generally work in the same direction as the direction of rotation in wrist.

These results are identical to the results of Kerwin and Trewarth (2001) who found out that rotations in wrists, shoulders and hips significantly correlate with the shift of the centre of gravity, and the rotation in wrist was dominant. The results of a work by Gautier et al. (Gauthier, Thouvarecq & Chollet, 2007) in which they analyzed the strategy of balancing in a handstand position in gymnasts show considerable movement in shoulders (5.56°) and wrists (12.39°), elbows almost did not move (1.21°), but reached a maximal deviations, and hips hardly moved (0.88°).

A different technique involving a flexion in an elbow joint described Slobounov and Newell (1996). According to Yedon and Trewarh (2003) the flexion is probably used just after the failure of balancing using the “wrist strategy”. Gautier et al. (Gauthier, Thouvarecq & Chollet, 2007) explain that flexion in elbow joints enable gymnasts to lessen the centre of gravity in case of extreme misbalance, as do knees in an upright position. The result is a bigger tolerance of fluctuations and possible rebalancing. The configuration in a handstand position is therefore similar to the one in an upright position with the wrist functions being similar to the ankle functions, elbows are similar to knees and shoulders are analogous to hips.

Visual control in a handstand position

Postural balance is controlled by a system of sensors including vestibular, proprioceptive and visual systems. Understanding the function of visual perception during postural regulation contributes to a better understanding of how a man moves in environment. Perception is the prime condition for a postural regulation. It enables us to record and control a direction of our movement (Stoffregen, 1985, Warren & Hannon, 1988, Li & Warren, 2000, 2002). Visual control may also compensate a lack of postural control resulting from muscle fatigue (Vuillerme et al., 2001).

The consequence of visual control during balance regulation was investigated by Gautier et al. (Gauthier, Thouvarecq & Chollet, 2007). The aim of this study was to deepen the knowledge about the postural regulations in a handstand position. Authors evaluated the influence of peripheral and central vision on balance in a handstand position in gymnasts. COP shift, angles between body segments and gymnasts’ height was analyzed during this movement task. The similarities appeared between the ways of postural regulation in a handstand position and in an upright position. In both positions the COP oscillation increases when eyes closed, which confirms the influence of visual control on balance (Clement & Rezette, 1985).

Lee and Lishman (1975) showed that the closer the visual target, the smaller the sagittal oscillations. In a handstand position owing to a lowered head position the visual surrounding is closer than in an upright position. From this point of view it should be easier to visually control the handstand position rather than an upright position. Clement et al. (1988) found out that the viewpoint is placed app. 5 cm in front of the wrist in the centre of the area between arms. They continue that gymnasts unite this point with an optimal vertical projection of the centre of gravity.

Gautier et al. (Gauthier, Thouvarecq & Chollet, 2007) analyzed the handstand performance in ten gymnasts aged 18 – 25 years. The sportsmen performed the handstand on a stabilometric platform equipped with meters which recorded COP changes in mm in sagittal (Y) and frontal (X) plane. Simultaneously a video was recorded from which the angles, dimensions and angular velocity were evaluated. The characteristics of handstand were compared during following conditions: eyes open, eyes closed, central darkness, peripheral darkness. The results showed that in gymnasts there are no significant differences among these four conditions regarding the COP shifts. The biggest oscillations were recorded in a sagittal plane – 42.6 mm, saying that the oscillations were mainly towards the fingers.

Asseman and Gahéry (2005) analyzed the influence of the head position on balancing in gymnasts who were asked to perform handstand with different head positions and with eyes open and closed. The professional gymnasts had no problem with balance in a handstand position with their eyes closed. However it was found out that it was much more difficult for them to balance when their neck was in flexion, probably because of the change of orientation of head together with vestibular apparatus. It shows main influence of had position on the postural regulation in handstand.

CONCLUSION

We support the notion that in a handstand position the body is in an upside down position and the equivalents of ankles and hips in an upright position are wrists and shoulders. The new trends in the technique of performance deal with three segmental strategies of balance correcting in a handstand position. An effort is to achieve a perfect body strengthening by isomeric contraction of abdominal, gluteal and back muscles, resulting in connection of segments legs – trunk and correction is done at a level wrist – shoulder.

As the gymnast's aim is to minimalize the correcting movements, we assume that the "wrist strategy" will be used when the whole body stays fixed in a vertical position. On the other hand, when the area of support is small, the "shoulder strategy" may necessarily be used. If the oscillations are so big that the gymnast's shoulder girdle is not strong enough to correct them with help of wrist and shoulders, then hips and elbows follow.

As we mentioned above, the position of head influences the stability on a handstand position, the handstand technique itself and it has its development. Formerly, when the exercise difficulty was not the crucial variable in artistic gymnastics competitions, the flexion of head was not considered a mistake, moreover it was the other way round. Head was in most movements the leading force. In recent periods, however, in exercise techniques we moved towards the head positioned as a continuation of neck. This technique can be used by some coaches. We agree with the opinion that head should not be fixed in any extreme position (bending forward, backward). For a gymnast the visual contact with the ground without extreme head bending is necessary.

Some authors focused only on 3D analysis or a stabilometry, however in future we want to focus on a complex analysis of balancing strategy, i.e. 3D synchronization of a kinematic analysis and a stabilometry complemented with EMG. We want to find a difference between the balancing strategies in boys and girls, juniors and seniors. We wonder if the the level of strength abilities of arms and trunk muscles and balance abilities of a gymnast influences the quality of performance the handstand and if it affects the choise of a segmental strategy of balance correcting in this static movement structure. We think that a complex perspective may reveal the little nuances applicable in a handstand drill and may make the drill more effective.

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