BASIC LANDING CHARACTERISTICS AND THEIR APPLICATION IN ARTISTIC GYMNASTICS

Miha Marinšek

University of Maribor, Faculty of Education, Slovenia

Review article

Abstract

Landings are extremely important in gymnastics to improve athlete performances as well as to reduce injuries. Studies on landings therefore provide an interesting field of research in which numerous studies have been conducted. This article gives an overview of the results from these studies that can be used by coaches to improve teaching on landing techniques. The biomechanical characteristics and motor control of landings is reviewed.

Keywords: *gymnastics, landings, kinematics, dynamics, motor control.*

INTRODUCTION

Landing is the final phase in aerial routines (take off phase, flight phase, and landing). Landing is important for success in gymnastics and is therefore of interest to researchers and coaches who want to improve landing performances.

Landing success depends on the physical fitness (preparation) and motor control of the gymnast. Physical preparation refers to the gymnast's ability to cope with the load to which they are exposed during the landing. Motor control refers to the control the gymnast has over the skill they perform. Both of these factors enable successful and safe landings.

Results from various studies show a low success rate of landings in competition (McNitt Gray, Requejo, Costa, and Mathiyakom, 2001; Prassas and Gianikellis, 2002). During the Olympic games 1996 in Atlanta McNitt Gray et. al. (1998) investigated landings from the high bar and parallel bars. Competitors performed twenty landings. Only one was performed without a mistake. At the European Championships in 2004, of all the saltos performed on the floor, 30 % were performed without error and 70 % were performed with errors (Marinšek, 2009).

KINEMATIC AND DYNAMIC CHARACTERISTICS OF LANDING

Landings in gymnastics are performed with first contact of the lateral part of the foot followed by the medial part (25 ms to 32 ms). The heel touches the ground between 27 ms and 52 ms later than the toes (Janshen, 1998). The ankle joint angle change (25^0 to 30^0) during the landing is less than that of the knee joint (79^0 to 89^0). Depending on the angle of the knee joint, landings are categorised as either stiff or soft. Landings where the knee angle is smaller than 63^0 are classed as stiff landings, and those where the knee angle is greater than 63^0 are classed as soft landings (Devita and Skelly, 1992). For soft landings there must be a contraction of at least 117^0 at the knee joint.

Depending on the height and type of landing, different force magnitudes are developed. A higher flight phase results in a higher vertical ground reaction force. Vertical ground reaction force represents external force which the gymnasts have to overcome with their muscle force and has an impact on the gymnast's linear and angular momentum. A variable that also affects linear and angular momentum is the time that the landing takes to perform. Impulse of force is the product of force and time; this is represented by the area below the curve in Figure 1. The impulse of the force is a consequence of the gymnast's weight and velocity, so its quantity cannot be changed at landing. The goal of landing is to change the shape of the area below the curve. Gymnasts can alter the shape of the area by increasing the time taken to perform the landing. Gymnasts can achieve this by increasing hip, knee, and ankle amplitude.

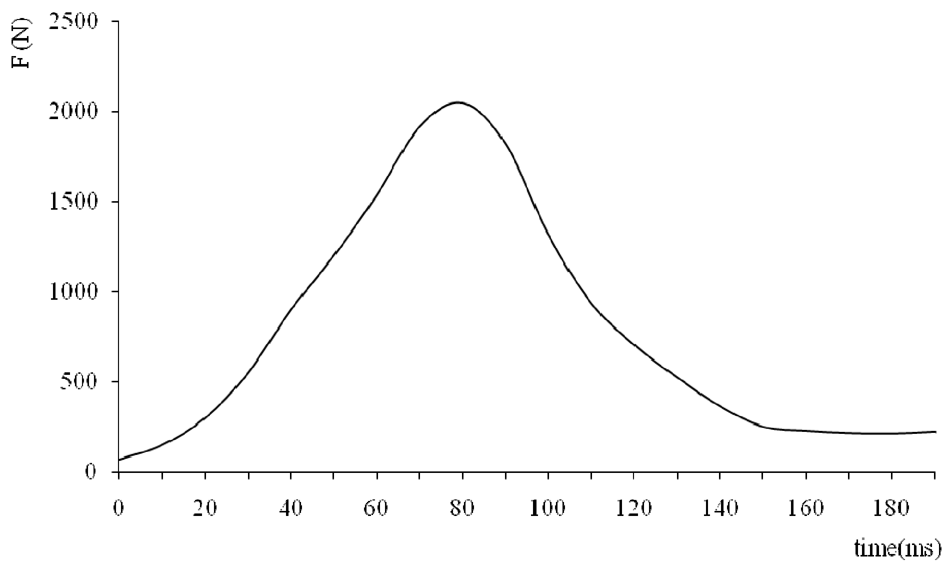

Figure 1. *Landing shown as the force – time relationship.*

As the height from which a landing is performed increases, muscles are required to respond more quickly, however, bodily movements maintain the same course (Devita and Skelly, 1992; Arampatzis, Brügemann and Klapsing, 2002; Arampatzis, Morey Klapsing and Brügemann, 2003). With the increase of height the amplitude in ankles, knees and hips rises. During stiff landings the ankles and knees are the most loaded joints and during soft landings hips are the most loaded joints (Zhang, Bates and Dufek, 2000).

Top level gymnasts use different landing techniques compared to recreational gymnasts (McNitt Gray, 1993). Recreational gymnasts use a higher range of motion in the knees and hips compared to top level gymnasts. Top level gymnasts use less motion in the knees and hips. One of the reasons for higher forces at landings of top level gymnasts is higher pre-activation of muscles (Metral and Cassar, 1981; Devita and Skelly, 1992; McNitt Gray, 1993; Janshen, 1998, 2000). Higher pre-activation is the activation of the muscles prior to touchdown and enables gymnasts to actively absorb energy and lower the loading on the heel (Nigg and Herzog, 1998). This results in improved stability of the ankle during the support phase (Janshen and Brüggemann, 2001).

Drop landings differentiate between gymnasts and non-gymnasts. It has been shown that drop landings performed by female collegiate gymnasts result in higher vertical ground reaction forces than drop landings performed by non-gymnasts (Sabick, Goetz, Pfeiffer, Debeliso and Shea, 2006). Collegiate gymnasts display greater symmetry in peak vertical force distribution in landings compared to non-gymnasts. The improved symmetry in gymnasts is, according to researchers, an adaptation to the large ground reaction forces experienced during landings in their sport.

Forces experienced during take-offs and landings in artistic gymnastics can be very high. Forces measured at landings can range from 3.9 to 14.4 times the gymnast's body weight (Panzer, 1987; McNitt Gray, 1993). The highest forces measured when performing double back somersaults ranged from 8.8 to 14.4 times the gymnast's body weight. This was 6.7 times more body weight compared to back somersault. Karacsony and Cuk (2005) found that forces at take off at different somersaults can be up to 13.9 times the participant's body weight.

At landing, two peaks of vertical ground reaction force are formed. The first peak indicates toe contact and the second peak the contact of the sole of the foot with the surface. The first peak is usually small and is seen as a declination in curve (Figure 1). The second peak is normally greater than the first one and represents the maximal force.

Foot position is an important aspect of gymnastics landings. Different techniques show significant differences in several kinematic and dynamic parameters (Cortes et al., 2006; Kovacs et al., 1999). The 'heels first' technique results in higher vertical ground reaction force, smaller contraction in knees and knee valgus compared to the “toes first” technique. When landing with higher forces, knee valgus forces tend to transmit to the knees and spine which may cause serious injuries. Increased forces on the knee valgus during landings has been identified as a risk factor for anterior cruicate ligament injury (Chappell, Creighton, Giuliani, Yu and Garrett, 2007; Sell et al., 2007; Withrow, Huston, Wojtys, and Ashton Miller, 2006; Blackburn and Padua, 2008). The most loaded joints during landing with the heels first are the knees and hips. When a heel first landing is performed, the shape of the force-time curve changes significantly (Figure 2). The maximal force is achieved more quickly and is also greater in magnitude. When a toes first landing is performed, the highest forces are developed in the achilles tendon (Self and Paine, 2001). Higher activation of ankle muscles enables gymnasts to lower the loading on the heel (Nigg and Herzog, 1998). Cadaver study (Self and Paine, 2001) showed that sportsmen don't use all of their potential to actively absorb forces at landings. In light of these findings gymnasts should try to land using the toes first technique. This is highly connected to the take-off phase in the sense of gaining adequate momentum to allow sufficient time to prepare for contact with the landing surface.

Different researchers (Tant, Wilkerson and Browder, 1989; McNair and Prapavessis, 1999; Prapavessis and McNair, 1999; Onate, Guskiewicz and Sullivan, 2001; Zivcic Markovic and Omrcen, 2009) found that systematical teaching of landings decreases the loadings at landings. Proper landing techniques can help prevent injuries.

To perform safe landings gymnasts must be physically prepared to overcome the loadings at landings. During training it is important to develop upper leg and lower leg strength. Treatment with only isometric contraction of the upper leg results in increased activation of the upper leg muscles and decreased activation of the lower leg muscles. This results in a more rapid heel-ground contact with increased force (Janshen, 1998). Treatment with isometric contraction of the calf muscles results in increased foot stabilization via dorsal extension and pronation leading to reduced ground reaction force under the heel.

When planning conditioning, coaches must consider the development of upper body strength. Aerial skills that involve twisting around gymnast's longitudinal axis tend to load not only the legs but also the spine at landings. Leg joints and spine are especially loaded when gymnasts use contact twist technique. When using the contact twist technique the gymnast will be twisting during the landing, which can result in spine and leg injuries (Yeadon, 1999). Therefore it is important for gymnasts to improve their core stability.

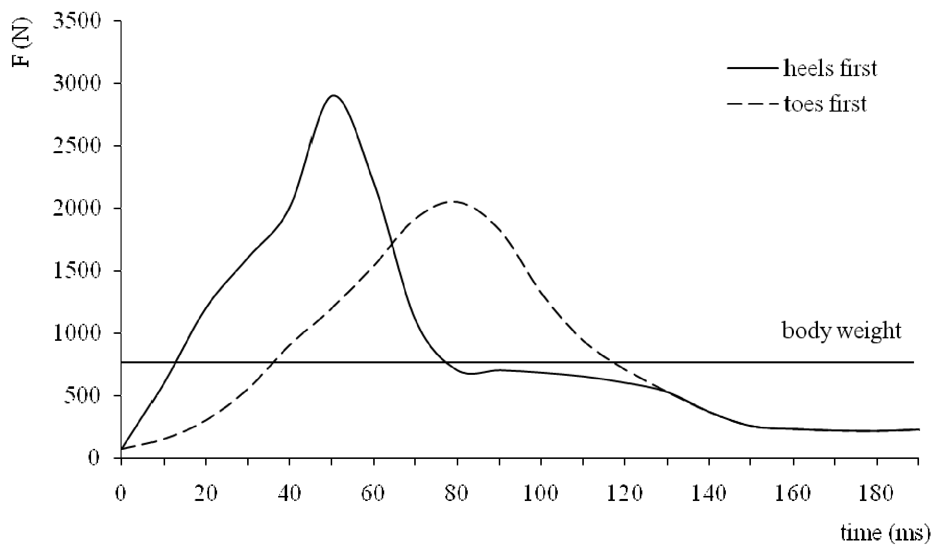

Figure 2. *Two differente type of landings.*

HOW DO GYMNASTS CONTROL LANDINGS?

Magnitude of impact forces during landings tend to increase not only with the increase of falling height, and therefore increase in impact velocity, but also with the skill complexity (Panzer, 1987; McNitt Gray, Munkasy, Welch and Heino, 1994; Karacsony and Čuk, 2005; Marinšek and Čuk, 2007; Marinšek, 2009).

Gymnasts begin to prepare for landing during the flight phase. In order to increase stability during contact with the landing surface they have to distribute momentum among body segments and prepare muscles for loading.

Gymnasts can distribute momentum among body segments through flexion/extension in different joints. The aim of these movements is to achieve conditions at contact consistant with those of a successful landing. The movements depend on aerial skill characteristics and momentum acquired at the take off phase (Marinšek and Čuk, 2007). Modifications of one subsystem may be sufficient to achieve the task objectives of landing (Requejo, McNitt Grey and Flashner, 2002; Requejo, McNitt Grey and Flashner, 2004). Modifications in the trunk-arm subsystem may be an effective mechanism for controlling total body movement of inertia, and enables gymnasts to maintain lower extremity kinematics after contact. Gymnasts should try to put their arms in an upward position before the landing, as the fewest number of errors was found during landings when gymnasts had their arms in an upward position (Marinšek and Čuk, 2008). Gymnasts can also use their arms to control the landing after the contact. They can circle their arms in the same or the opposite direction to the direction of movement. Modifications with hands help them to preserve and transfer total body movement of inertia (Prassas and Gianikellis, 2002).

The landing and take off phase of aerial skills are programmed independently (McKinley in Pedotti, 1992). The goal of take-off movements is to produce as much energy as possible at the end of the take-off. On the other hand the goal of landing is to absorb energy. Take off movements are normaly eccentric – concentric contractions and landings eccentric contractions (concentric contraction exists but can not be connected to eccentric in the sense of muscle control). For this reason it is important to distinguish these two movements in teaching methods. During landing a special mechanism must make it possible to contract the muscles and at the same time keep the muscle stiffness low (Dyhre-Poulsen, Simonsen and Voigt, 1991).

Motor programme for landing is always pre-programmed (Dyhre Poulsen, Simonsen and Voigt, 1991). Preparation of muscles on loading starts from 150 to 170 ms before first contact and is seen as electrical activity in muscles. Motor control system predicts fall time and initiates muscle activity at a time appropriate to expected impact (Duncan and McDonagh, 2000). The pattern of motor programme for landings is always the same and does not change with the falling height. What changes is muscle activity that adapts to the height of the flight phase (Dyhre-Poulsen, Simonsen and Voigt, 1991). As falling height increases, muscle activity (and therefore muscle stiffness) of the lower limbs increases during the pre-activation phase, and during the landing itself (Arampatzis, Morey Klapsing and Brügemann, 2003). In order to regulate reaction forces during landings, feedforward and feedback control is being used by the nervous system (Munaretti, J., McNitt Gray and Flashner, 2006). The feedforward system defines muscle excitability, and the feedback system controls the movement. For landings it is important that excitability of α motor neurons is low, and the gymnast receives as much internal and external information during the landing phase as possible.

One of the most important pieces of information that contributes to landing success is visual information. Visual guidance during falls in which environmental cues are known is not necessary in order to adopt a softer landing strategy (Liebermann and Goodman, 1991) but does improve precision of control (Lee, Young and Rewt, 1992). Visual control helps gymnasts to distribute momentum among body segments (e.g. moving their arms) at the right moment and create the best position for landing.

When performing back tuck somersaults visual feedback enhances landing stability and yields better landing scores (Luis and Tremblay, 2008). Optimal feedback occurs when the retina is stable. Different visual conditions affect some of the execution parameters. Narrowing peripheral vision does not affect the kinematic characteristics of landing and landing balance. However, the absence of vision causes less stable landings compared to the full and narrowed vision field (Davlin, Sands and Shultz, 2001a). Gymnasts are more stable at landing under conditions that allow vision during either the entire somersault or the last half of the somersault. However, different vision conditions do not affect trunk and lower body kinematics (Davlin, Sands and Shultz, 2001b).

When gymnasts perform a more difficult skill (double back somersault), and when visual feedback during the performance is possible, they slow their heads prior to touchdown in time to process optical flow information and prepare for landing (Hondzinski and Darling, 2001). There is not always enough time to process vision associated with object identification and prepare for touchdown. Therefore it can be concluded that gymnasts do not need to identify objects for their best double back somersault performance.

In view of the research findings, gymnasts should try to gain visual information during the entire aerial skill, and in the last half of the aerial skill stabilize their head in order to get the best quality visual information.

DO SURFACE CHARACTERISTICS AFFECT LANDING?

When talking about landings, it is also important to consider the stiffness of the surface gymnasts are landing on. Surfaces vibrate and deform when exposed to loads. Vibration of the surface depends on the magnitude and direction of the force applied, and the stiffness of the surface. Stiffer surfaces tend to vibrate with higher frequency and smaller amplitude compared to compliant surfaces (Figure 3).

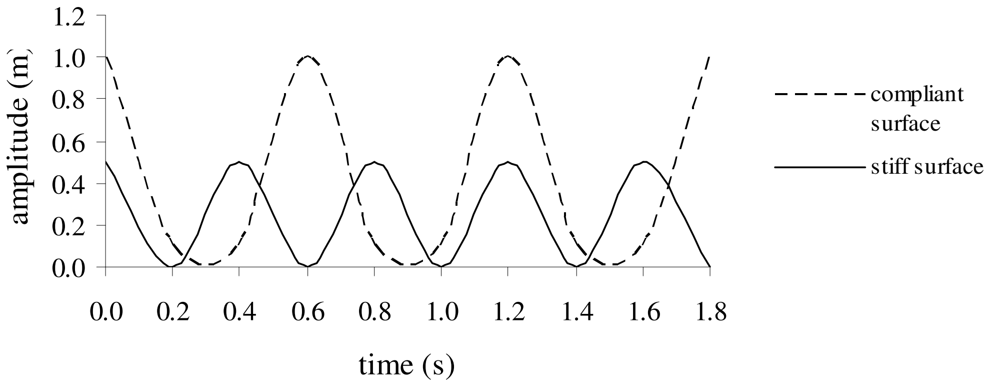

Figure 3. *Amplitudes and frequencies of surfaces of different stiffnesses.*

The aim of landing is to dampen the vibrations of the surface. The surface deforms because of the impulse of the force that is produced by the gymnast's falling body. To dampen the vibrations it is important to harmonize muscle activity with the surface vibrations i.e. modulate body stiffness in response to changes in surface conditions.

Different surface conditions affect landing strategies. If landing on a mat, peak vertical forces are lower, landing phase times are longer, and knee and hip flexions are greater compared to landing without a mat (McNitt Gray, Takashi and Millward, 1994). When comparing landings on stiff or soft mat, knee flexion and peak knee flexion velocities tend to be greater for landings on the stiff mat than on the soft mat. Gymnasts modulate total body stiffness in response to different landing conditions. Mat landings tend to be softer than landings without a mat. However, the presence of a mat may reduce the need for joint flexion and may alter the vertical impulse characteristics experienced during landing. Therefore coaches should pay attention to landing executions during training regardless of the surface conditions gymnasts are landing on.

One of the factors that influences landings is the construction of the mat. Coaches should ensure that they obtain good quality mats. Mat construction influences the motion of the foot. The mechanical advantages of a soft mat (higher energy absorption) include a decrease in foot stability (Arampatzis, Brüggemann and Klapsing, 2002). The eversion at the calcaneocuboid joint increases with the height (Arampatzis, Morey Klapsing and Brügemann, 2003). On the other hand the falling height does not show any influence on the tibiotalar and talonavicular joints during landing. With the special stabilising interface inserted in the mat it is possible to reduce the influence of the mat deformation on the maximal eversion between forefoot and rearfoot (Arampatzis, Morey Klapsing and Brügemann, 2005).

CONCLUSION

Landings in gymnastics, because of their importance in competitive gymnastics and number of injuries that result from them, are a very interesting area of research. Injuries sustained during landings result in time lost in training and competitions. Therefore coaches should ensure correct landing techniques are being taught. Coaches must be aware that when gymnasts land they use special mechanisms to control their movement. In this sense landings are different from other gymnastics movements, and need to be practiced thoroghly. Mechanisms used to absorb the external loading at landings are modified according to the stiffness of the landing surface. When soft mats are used the absorption of energy is increased, but also leads to a decrease in foot stability. In some cases the presence of the mat may even reduce the need for joint flexion and result in higher forces. It is therefore important to practice landing on different surfaces during training sessions. Coaches also have to be aware of the high loadings their gymnasts are exposed to during landings. Repeated landings, and the forces experienced during these landings contribute to the serious injuries experienced by many gymnasts. For these reasons emphasis must be placed on learning and practicing correct landing techniques.

REFERENCES

Arampatzis, A., Brügemann, G. P. and Klapsing, G. (2002). A three – dimensional shank – foot model to determine the foot motion during landings. *Medicine and Science in Sports and Exercise*, 34(1), 130-138.

Arampatzis, A., Morey – Klapsing, G. and Brüggemann, G. P. (2003). The effect of falling height on muscle activity and foot motion during landings. *Journal of Electromyography and Kinesiology,* 13(6), 533 – 544.

Arampatzis, A., Morey – Klapsing, G. and Brüggemann, G. P. (2005). Orthotic effect of a stabilising mechanism in the surface of gymnastic mats on foot motion during landings. *Journal of Electromyography and Kinesiology,* 15(5), 507 – 515.

Blackburn, J.T. and Padua, D.A. (2008). Influence of trunk flexion on hip and knee joint kinematics during a controlled drop landing. *Clin Biomech (Bristol, Avon)*, 23(3), 313 – 319.

Chappell, J.D., Creighton, R.A., Giuliani, C., Yu, B. and Garrett, W.E. (2007). Kinematics and electromyography of landing preparation in vertical stop-jump: risk for noncontact anterior cruciate ligament injury. *The American Journal of Sports Medicine*, 35(2), 235 – 241.

Cortes, N., Onate, J., Abrantes, J., Gagen, L., Van Lunen, B., Dowling, E. and Swain, D. (2006). Kinematic analysis of jump – landing technique during various foot – landing styles. *Medicine and Science in Sports and Exercise*. 38(5) Supplement: S392.

Davlin, C.D., Sands, W.A. and Shultz, B.B. (2001a). Peripherial vision and back tuck somersaults. *Percept Mot Skills,* 93 (2), 465 - 471.

Davlin, C.D., Sands, W.A. and Shultz, B.B. (2001b). The role of vision in control of orientation in a back tuck somersault. *Motor Control,* 5 (4), 337 - 346.

Devita, P. and Skelly, W. A. (1992). Effect of landing stiffness on joint kinetics and energetics in the lower extremity. *Medicine and science in sports and exercise*, 24(1), 108 – 115.

Duncan, A. and McDounagh, M.J.N. (2000). Stretch reflex distinguished from pre-programmed muscle activations following landing impacts in man. *Journal of physiology* 526 (2), 457 – 468.

Dyhre-Poulsen, P., Simonsen, E.B. and Voigt, M. (1991). Dynamic control of muscle stiffness and H reflex modulation during hopping and jumping in man. *Journal of physiology* 437, 287 – 304.

Hondzinski, J.M. in Darling, W.G. (2001). Aerial somersault performance under three visual conditions. *Motor Control*, 5 (3), 281 - 300.

Janshen, L. (1998). Neuromuscular control during gymnastic landings. V Arsenault, B., McKinley, P. in McFadyen, B. (Ed.): *Proceedings of the Twelfth Congress of the International Society of Electromyography and Kinesiology (ISEK)* (str. 136 – 137). Montreal, Kanada.

Janshen, L. (2000). Neuromuscular control during gymnastic landings II. In: Hong, Y. and Johns, D.P. (Ed.): Proceedings of XVIII International Symposium on Biomechanics in Sports. Hong Kong, China.

Janshen, L. and Brüggemann, G.P. (2001). Neuromuscular control during expected and unexpected landings. In Gerber, H. in Müller, R. (Ed.). *Proceedings of the XVIIIth Congress of the International Society of Biomechanics.* Zurich, Switzerland

Karacsony, I. and Cuk, I. (2005). *Floor exercises – Methods, Ideas, Curiosities, History.* Ljubljana: STD Sangvincki.

Kovacs, I., Tihanyi, J., Devita, P., Racz, L., Barrier, J. and Hortobagyi, T. (1999). Foot placement modifies kinematics and kinetics during drop jumping. *Medicine and Science in Sports and Exercise,* 31(5), 708 – 716.

Lee, D.N., Young, D.S. and Rewt, D. (1992). How do somersaulters land on their feet? *Journal of Exp Psychology: Human Perception and Performance,* 18 (4), 1195 - 1202.

Liebermann, D.G. and Goodman, D. (1991). Effects of visual guidance on the reduction of impacts during landings. *Ergonomics*, 34(11), 1399 – 1406.

Luis, M. in Tremblay, L. (2008). Visula feedback use during a back tuck somersault: evidence for optimal visual feedback utilization. *Motor Control,* 12 (3), 210 - 218.

Marinšek, M. (2009). Landing characteristics in men's floor exercise on European Championship 2004. *Science of Gymnastics Journal,* 1(1), 31 – 39.

Marinšek, M. and Čuk, I. (2007). Theoretical model for the evaluation of salto landings in floor exercise. In N. Smajlovic (Eds.), *International Symposium New Technologies in the sport* (p. 63-68). Sarajevo: Univerzitet, Fakultet sporta i tjelesnog odgoja.

Marinšek, M. and Čuk, I. (2008). Landing errors in men's floor exercise. *Acta Univ. Palacki. Olomuc., Gymn.*, 38(3), 29 – 36.

McKinley, P. and Pedotti, A. (1992). Motor strategies in landing from a jump: the role of skill in task execution. *Experimental brain research* 90 (2), 427 – 440.

McNair, P.J. and Prapavessis H. (1999). Normative data of vertical ground reaction forces during landing from a jump. Journal of science and medicine in sport / Sports Medicine Australia, 2(1), 86 – 88.

McNitt – Grey, J. (1993). Kinetics of the lower extremities during drop landings from three heights. *Journal of Biomechanics*, 26(9), 1037 – 1046.

McNitt Gray, J. L., Munkasy, B. A., Welch, M. and Heino, J. (1994). External reaction forces experienced by the lower extremities during the take-off and landing of tumbling skills. *Technique,* 14, 10 – 16.

McNitt Gray, J. L, Munkasy, B. A., Costa, K., Mathiyakom, D., Eagle, J., and Ryan, M. M. (1998). Invariant features o multijoint control strategies used by gymnasts during landings performed in Olympic competition. In North American Congress of Biomechanic (p. 441-442). Canada – Ontario: University of Waterloo.

McNitt Gray, J. L., Requejo, P., Costa, K. and Mathiyakom W. (2001). *Gender Differences in Vault LandingLocation During the Artistic Gymnastics Competition of the 2000 Olympic Games: Implications for Improved Gymnast/Mat Interaction.* Retrieved 28.6.2006, from http://coachesinfo.com/category/gymnastics/74/

McNitt Gray, J., Takashi Y., and Millward, C. (1994). Landing strategies used by gymnasts on different surfaces. *Journal of Applied Biomechanics*, 10, 237 – 252.

Metral, S. and Cassar, G. (1981). Relationship between force and integrated EMG activity during voluntary isometric anisotonic contaraction. *European Journal of Applied Physiology*, 41(2), 185 – 198.

Munaretti, J., McNitt Gray, J.L. and Flashner, H. (2006). Modeling control and dynamics of activities involving impact. Annual ASB meeting. Virginia Tech, VA. Retrieved 18.2.2008, from www.asbweb.org/conferences/2006/2006.html

Nigg, B.M. and Herzog, W. (1998). *Biomechanics of the musculo – skeletal system.* Second Edition. Wiley, Chichester.

Onate, J.A., Guskiewicz, K.M. and Sullivan, R.J. (2001). Augmented feedback reduces jump landing forces. *J Orthop Sports Phys Ther*., 31(9), 511 – 517.

Panzer, V. P. (1987). *Lower Extremity Loads in Landings of Elite*

Gymnasts. Doctoral dissertation, Oregon: University of Oregon.

Prapavessis, H. and McNair, P.J. (1999). Effects of instruction in jumping technique and experience jumping on ground reaction forces. The Journal of orthopaedic and sports *physical therapy,* 29(6), 352 – 556.

Prassas, S. and Gianikellis, K. (2002). Vaulting Mechanics. In *Applied Proceedings of the XX International Symposimu on Biomechanics in Sport – Gymnastics*. Caceres, Spain: University of Extremadura, Department of Sport Science.

Requejo, P.S., McNitt – Grey, J.L. and Flashner, H. (2002). Flight phase joint control required for successful gymnastics landings. *Medicine and Science in Sport and Exercise,* 34(5), Supplement 1, 99.

Requejo, P.S., McNitt – Grey, J.L. and Flashner, H. (2004). Modification of landing conditions at contact via flight. *Biological Cybernetics,* 90(5), 327 – 336.

Sabick, M. B., Goetz, R. K., Pfeiffer, R. P., Debeliso, M. and Shea, K.G. (2006). Symmetry in ground reaction forces during landing in gymnasts and non – gymnasts. *Medicine and Science in Sports and Exercise,* 38(5) Supplement: S23.

Self, B. P. and Paine, D. (2001). Ankle biomechanics during four landing techniques. Medicine and Science in Sport and Exercise, 33(8), 1338 – 1344.

Sell, T.C., Ferris, C.M., Abt, J.P., Tsai, Y.S., Myers, J.B., Fu, F.H. and Lephart, S.M. (2007). Predictors of proximal tibia anterior shear force during a vertical stop-jump. *J Orthop Res*, 25(2), 1589 – 1597.

Tant, C.L., Wilkerson, J.D. and Browder, K.D. (1989). Technique comparisons between hard and soft landings of young female gymnasts. In: Gregor RJ, Zernicke RF, Whiting WC, editors. *Proceedings of the XIIth International Congress of Biomechanics.* Los Angeles, CA: Pergamon Press.

Withrow, T.J., Huston, L.J., Wojtys, E.M. and Ashton – Miller, J.A. (2006). The effect of an impulsive knee valgus moment on in vitro relative ACL strain during a simulated jump landing. *Clin Biomech (Bristol, Avon)*, 21(9), 977 – 983.

Yeadon, M.R. (1999). "Learning how to twist fast." In Sanders, R. H. and Gibb, B. J. (Ed.) *Applied Proceedings of the XVII International Symposium on Biomechanics in Sports – Acrobatics* (p. 37 – 47). Perth, Western Australia: School of Biomedical and Sport Sciences, Edith Cowan University.

Zivcic Markovic, K. and Omrcen, D. (2009). The analysis of the influence of teaching methods on the acquisition of the landing phase in forward handspring. *Science of Gymnastics Journal,* 1(1), 21 - 30.