TOWARDS A SMART SPRINGBOARD (CASE STUDY)

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Original research article

Abstract

Several measurement techniques can be used to analyze vaulting in gymnastics, however, no device is specifically developed for analyzing the springboard usage. After analyzing the literature about vaulting and the types of measuring devices used for analyzing physical parameters on vault we decided to develop a dedicated apparatus for measuring springboard actions. The new device is composed of a processor unit with LCD display and is connected to accelerometer sensors that are placed under the top desk of the springboard. The acceleration of the springboard desk during the jump is measured for two axes at 1000 Hz. From measured accelerations velocities are calculated by numerical integration and several parameters such as time to maximal springboard compression and maximal velocity at take-off are determined and displayed. The data is directly transferred to a PC for further analysis through an USB connection. Matlab software was used to record, filter and analyze the measured data. Results are in good agreement with simultaneously obtained results from the force plate and laser displacement sensor measurements (similar time and vertical velocity). With developed equipment it will be possible to determine typical springboard action parameters for individual gymnast, optimal springboard parameters for a required jump, to analyze repeatability of springboard jumps, to analyze transverse movements and to optimize training and its efficiency. The developed device has good potential for use as a fast information system as well as a device for suitable science/research projects in vaulting.

Keywords: *measurement technology, accelerometer, take off velocity, vault.*

INTRODUCTION

Vaulting has very old tradition starting already from Minoan Crete culture (1800-2500 years BC). Apparatus like wooden horse was already mentioned in 4th century as soldiers preparation apparatus. The wooden springboard was introduced (mentioned in documents) by Arhangel Tuccaro in 1599 (Čuk & Karacsony 2004). Vault was an official discipline already at the first modern Olympic Games in Athens in 1896. Nowadays, vault is a gymnastic discipline for men and women by the Code of Points (COP) (FIG 2009b, FIG 2009c).

For vaulting competitions (as a discipline) an official apparatus is required comprising a runway carpet, a springboard, a table and mats (FIG, 2009a). Through the centuries the springboard was changed in design and physical characteristics and by last apparatus norms (FIG, 2009a) the main springboard dimensions are shown in Figure 4.

Vault is a complex and short (not much more than 7 seconds in average) movement (Čuk & Karacsony 2004). The problem of human interaction with a springboard is important as human has to adapt to the springboard elastic characteristics. Sands, Smith & Piacentini (2008) found each person has its own jump pattern and it is worth to study them. For this reason it is important to investigate the state of the art of the technology used to evaluate the vault and to search for new methods for improved usage of available technology. In particular, the investigation shows that many methods for analysis of the vault are available on the market but they are mostly used for research purposes and not for improvement and optimization of the gymnasts' vaulting techniques. The aim of our work was to reduce this lack and develop a device for analyzing the most important phase of the vault – the springboard actions. The device should be of low cost and easy to use so it could be used for both purposes – for research work as well as during vault training for analysis and optimization of the springboard usage.

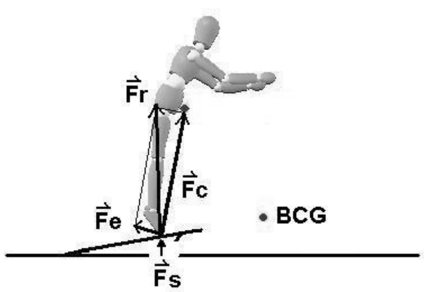
For practical reasons we divide the vault into several important phases: approach, flight to the springboard, springboard actions, 1st flight phase, support, 2nd flight phase and landing (Čuk & Karacsony 2004). The velocity of runway depends on the difficulty of a vault. In general, easier vaults require lower velocities and vice versa. According to Soviet authors Antonov (1975) and Semenov (1987) the velocity should be from 3 to 5 m/s in the last five meters of run for simple direct vaults, about 7 m/s for women doing handspring vaults and 8 m/s for more difficult vaults. For male gymnasts who have to vault over a higher horse the velocity of run should be from 7.5 to 8.5 m/s for medium difficult vaults , 8.5-9.5 m/s for difficult vaults and over 10 m/s for vaults with double salto rotation velocity. The distance of flight from run to the springboard is by Antonov (1975) and Semenov (1987) for direct vaults between 2.30 and 2.80 m. The time of flight depends from the velocity of the run and the take-off force. Generally this time is between 0.24 and 0.30s. The feet are maximum 0.35 cm above the ground; females reaching slightly lower values for all parameters. From the research done with 3D kinematic and Optojump apparatus Veličković, Petković, Petković (2010) noticed differences between the strategy of runway of the best gymnasts (in the middle of runway they decelerate for a moment) comparing to the average ones (their runway is accelerated all the time). According to Čuk and Karacsony (2004) for the vaults with a pre-element (round off) the distance of flight from run to the springboard is between 2.80 and 3.50 m, while the time is between 0.32 and 0.38 s.

Board contacts are divided into the compression phase and the take off phase. The first phase is characterized by extreme load and compression of a springboard while the second phase is characterized by the use of elastic reaction of a springboard and maximal force of take-off muscles (all hip, knee and ankle extensors, trunk extensors and shoulder abductor). In order to gain sufficient angular momentum the final take-off force is always eccentric behind the body center of gravity (BCG) (according to the direction of the jump) and in the direction of the jump (Figure 1) .

The duration of board contact is very short, about 0.12 s (Table 1), which is a very low value. As a rule, if a gymnast has a contact mainly with a front part of foot on a board, the time is shorter while in case the contact is mainly on the whole foot area the board contact time is longer (Čuk & Karacsony 2004). This is also the reason why all pre-element vaults have a longer time of board support. The position of the feet on the board should be parallel, hip width apart and BCG should be in the center of the springboard according to the z-axis (left-right position) and toes should be placed 20 cm from the front edge of the springboard. In practice (Čuk and Karacsony, 2004) measurements show quite different results (Table2).

Ferkolj (2010) after the kinematic analysis reports for handspring double salto forward tucked at the moment of the take-off velocity in x axis 5.04 m/s, velocity in y axis 4.65 m/s and velocity in z axis 6.86 m/s; similar but slightly lower velocities were found by Cormie, Sands and Smith

(2004). Using electromechanical film Keränen, Moisio and Linnamo (2007) also obtained similar results for a Roche vault. Using force plate measurements Bolkovič and Čuk (2000) report that for simple jumps (squat and split jump) 6-6.5 of body weight (BW) force is need at take-off within 0.15 second time spent on the springboard. Using force plate and load cells Greenwod and Newton (1996) showed that 10.3 BW at the take-off is needed for a handspring forward. Bradshaw et al. (2010) analyzed variability of performing vault during the day to day training with a series of photo cells and contact mats and the results show that the runway velocity (coefficient of variability (CV) = 2.4-7.8%) and the board contact time (CV 3.5%) were less variable than the first flight phase time (CV = 17.7%) and support time (CV = 20.5%). Sano et al. (2007) analyzed movement of 29 springboard points and segments with a force plate and a high speed camera. A model of only four segments produced almost the same accuracy as a 29-segment model; the simplified model is thus recommended as a more efficient method to measure board reaction force. Sands, Smith & Piacentini (2008) used magnetic sensors on a springboard to analyze the springboard dinamics during the take-off for handspring. According to the figures they showed the pattern of the curves for all sensors on the upper edge of the springboard were the same.



Legend:
Fe – eccentric force
Fc – centric force
Fs – springboard elasticity force
Fr – result force
BCG – body center of gravity

Figure 1. *Directions of forces at take off by Čuk and Karacsony (2004).*

Table 1. *Time of board support (World Championship Qualification, Debrecen (HUN), 2002)(Čuk and Karacsony, 2004).*

Board contact	Women	N	Men	N
Handspring jumps	0,12	22	0,12	27
Tsukahara jumps	0,12	12	0,12	37
Round of handspring backward jumps	0,15	18	0,14	11
Round of, 1/2 turn handspring forward jumps	0,15	13	0,16	2
Round of, 1/1 turn handspring backward jumps	0,16	9		

Table 2. *Position of feet according to springboard edge and horse edge (World Championship Qualification, Debrecen (HUN), 2002)(Čuk and Karacsony, 2004).*

Women	N	From springboard edge (m)	From horse edge (m)
Handspring jumps	22	0.41	1.12
Tsukahara jumps	12	0.44	1.24
Round of handspring Backward jumps	18	0.12	0.56
Round of, 1/2 turn handspring forward jumps	13	0.17	0.69
Round of, 1/1 turn handspring Backward jumps	9	0.15	0.81
Men			
Handspring jumps	27	0.34	1.04
Tsukahara jumps	37	0.34	1.05
Round of handspring Backward jumps	11	0.25	0.67
Round of, 1/2 turn handspring forward jumps	2	0.21	0.62

Table 3. *Advantages and disadvantages of technology used in vault researches.*

Technology	Advantages	Disadvantages
video technology	Used for fast information system, can be used on all apparatus	To obtain quantitive data it is time consuming and not appropriate in real time for training purposes
kinematic system for 2D and 3D analysis,	Very accurate data on kinematics	It is time consuming and not appropriate in real time for training purposes, high costs
force plate, load cells,	Very accurate data on dynamics	Special podium conditions are needed, hard to afford in gym, high costs
contact mats,	Very accurate data on time	Low durability
photo cells,	Very accurate data on time, low costs	Used only for runway
Optojump,	Very accurate data on time, distances, frequencies	Used only for runway, needs flat surface, high costs
electromechanical film,	Accurate data on time, forces	Not on the market
magnetic sensors	Accurate data on time, acceleration and velocity	Not on the market

Bradshaw et al. (2010), Dolenec et al. (2007), Bricelj et al. (2008) found that for optimal preparation for the competition the variability of vault parameters should be optimized and stabilize them. Furthermore, for progression of the vault it is important to know if gymnast can produce such data that enable more difficult vaults.

Most often used technologies in vault research and training processes are presented in Table 3. All these technologies have advantages and disadvantages. For instance, Optojump is a sophisticated technology that enables quite accurate position detection at several positions, but can only be used on flat surfaces (not on the springboard). Systems providing (almost) real time results are for instance video systems, photo cells and contact mats.

The quality of the vault strongly depends on appropriate usage of the springboard. Therefore we concentrated our research efforts to develop and analyze a system/device that would be capable of detecting and analyzing this extremely dynamic event. The system should be relatively low cost but sufficiently accurate and easy to use. Low cost mostly requires use of miniature electronics in conjunction with accurate but low cost sensors. Accuracy is mostly related to appropriate selection of sensors and R&D efforts for their optimal usage while ease of use is related to suitable selection of most relevant parameters that clearly determine the quality of the springboard usage. According to already mentioned research results we decided to evaluate the quality of the springboard usage through the following parameters:

- time of feet contact on the springboard,
- maximal velocity of the springboard during the take-off phase,
- time to maximal springboard velocity,
- time to maximal springboard compression (zero velocity).

In the following it will be shown that these parameters provide sufficient information on the quality of the springboard usage. In addition to the selected parameters, it would be advantageous to be able to detect and analyze also the lateral movement during the gymnast contact with a springboard as well as determine the point of toes contact on the springboard.

In order to obtain the desired parameters, two different approaches can be used. We can either use a general purpose solution as for instance use a commercial tensiometric force plate or develop a dedicated device that would be optimized for the desired application. The advantage of a general purpose solution is obvious as it is commercially available and as such received "ready for use", the repeatability and accuracy of the device is known and procedures for measurements are set. On the other hand, the interpretation of the results is left to the experience/expertise of the user. A clear advantage of developing a dedicated system for analysis of the springboard usage is in simplicity of usage, portability and price.

METHODS

In order to develop a device capable of determination of relevant parameters during springboard usage we concentrated on several possible solutions as shown in Table 4.

According to a short review of development options described in Table 4 and future trends in microelectronics we decided to develop a device based on Phillips ARM7 processor from the chip family LPC21xx. This family of chips facilitates a variety of chips which are replacable (the same software can be applied to all of them) enabling selection of a most suitable chip in the very late stage of development or even before the final production. Beside selection of a suitable chip a decision of suitable periferal units and transducers/sensors should be made. In particular, selection of appropriate transducers that would be suitable for achieving the desired operation of the device is crucial for optimal performance and the price of a system and in fact it also influences complete hardware and software development. Table 5 presents a (limited) review of possible transducers to accomplish the desired task. The MEMS based accelerometers seem to be most reasonable solution that fulfils several design criteria: low cost, portability, ease of use, accuracy (Močnik and Križaj (2008).

Table 4. *Comparison of possible development approaches.*

	Advantages	Disadvantages/deficiencies
Measurements with portable computer, general purpose Data Aquisition Systems (DAQ) and appropriate sensors	No need to develop hardware and only concentrate on software and appropriate sensor usage	Limited mobility, high cost, limited usage of suitable sensors, short battery life, …
FPGA (Field-programmable gate array) card with SPARTAN-3	Very fast operation, very flexible chip	Very complex, high cost of development
Development board with PIC18 processor	Very common, low cost, easy to use	Slow operation, high cost of professional development tools
Development board with ATMEGA16	Very common, low cost, easy to use	Slow operation, sensitive to electrostatic breakdown
Development board with ARM7	Most recent platform, simple architecture, low cost, low power consumption, availability of development tools, USB support	Slower than FPGA, relatively small amount of internal memory

Table 5. *Selection of possible transducers.*

	Advantages	Deficiencies
Non laser optical sensors	Well know operation, output as distance	Low cost, less accurate, mechanical construction needed
Laser based sensors	Could be very accurate, output as distance	High cost, mechanical construction needed
Force sensors (in particular strain gage)	Similar as used in tensiometric plates, accurate if well designed, direct force output	Not necessary low cost, well designed construction needed, temperature dependant
Electromechanical sensors	Various kinds. Could be very accurate in conjunction with optical reading, output as distance	Cost depending on required accuracy, …
Micro-electro-mechanical (in particular MEMS accelerometers)	Low cost at high accuracy, output as acceleration, very miniature, easy mounting	Velocity and distance obtained by integration, calibration required

MEMS devices are miniature chips made by microelectronic technology with addition of some technological steps enabling development of miniature mechanical systems. MEMS accelerometers are micron sized mechanical systems with a fixed and a moving mass. A variety of mechanisms are used to detect miniature movements of the moving mass relative to the fixed one. In most cases, small capacitance changes are measured. Most of modern MEMS accelerometer chips incorporate also electronic part which task is to amplify the signals and prepare them for analog or digital output. The output of a MEMS accelerometer is directly proportional to the measured acceleration. Such devices are nowadays commonly used in cars to detect crashes and fire the airbags, in computers to stop the disk in case of dropping, in mobile phones, cameras, GPS systems etc (Kavanagh and Mentz (2008), Zeng and Zhao (2011)). Due to their small size and accuracy they are also very suitable for use in sports (Križaj and Mihevc (2007)). Due to broad usage of MEMS accelerometers and microelectronic technology used for their production these devices are low cost and with good performances. We decided to develop our system on chips from ADXL family from Analog Devices. These chips are known to be very accurate, cover a variety of different acceleration ranges and are low cost.

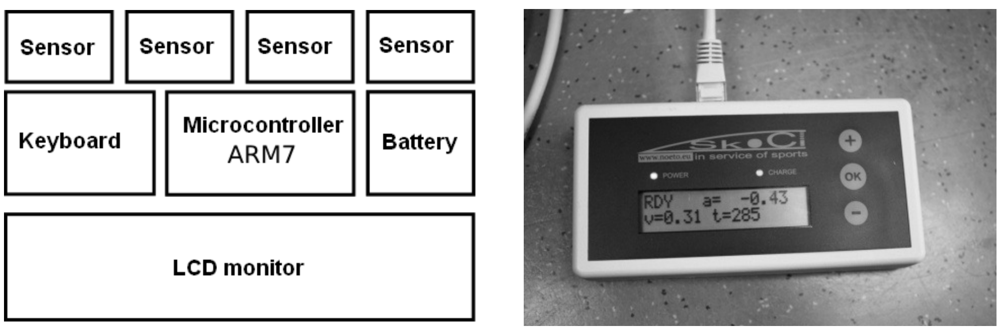


Figure 2. *Block diagram with hardware and appropriate periphery and final main board.*

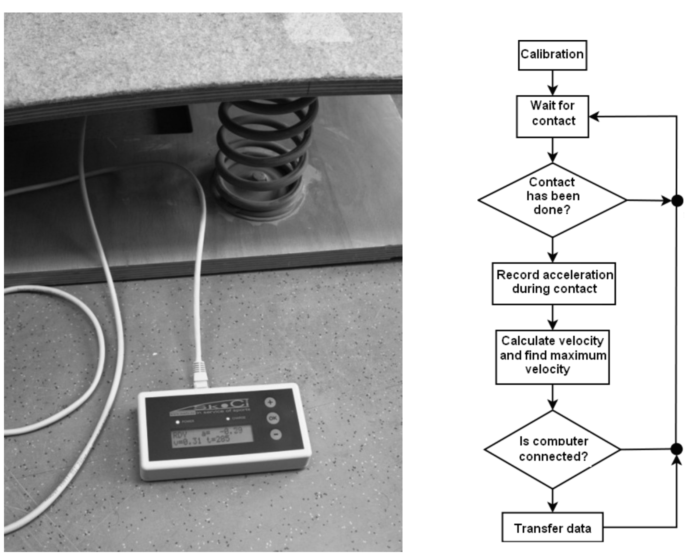


Figure 3. *Device with sensor connected under the springboard and block diagram of measuring process.*

The block diagram of the designed device and the final developed device are presented in Figure 2. The device is capable of measuring acceleration for two axes at 1000 Hz with possible extension to two additional sensors. The sensors can be either with analog or digital output; currently the device is configured/programmed for usage of analog sensors. In our investigation we used 5g to 10g sensors from Analog Devices . The device has only three buttons, currently mainly used for the calibration procedure. The calibration of the sensors before usage increases accuracy of measurements as the output values can depend on the temperature and other environmental conditions. The calibration procedure is very simple and is based on the fact that accelerometers are sensitive to the earth gravity which can be fruitfully used for the calibration purpose. The device operates most of the time in the stand-by mode that significantly prolongs the battery life. The measurements start as soon the device detects a small acceleration change indicating the start of the jump onto the springboard. After the measurement is performed the device calculates the velocity by numerical integration of acceleration values and by appropriate filtering. Complete acceleration values and velocity values are stored in internal memory and can be used for additional processing, in particular for a transfer to a personal/portable computer. As soon as the jump is finished the build-in LCD display presents most important calculated values such as maximal springboard velocity at take-off and time to maximal velocity. Other values as described in introduction can be shown as well.

The accelerometer sensor was fixed in the middle and under the springboard, 0.25 m from the front edge of the springboard (where the toes should be placed at the most efficient take off).

Several experiments were performed in order to analyze the device behavior and suitability: / - the measured results were compared to the results obtained by distance measurements using a high accuracy laser system,

- the results were compared with simultaneously measured forces by a tensiometric force-plate (AMTI , FORCE and MOTION; model BP622 600 -2K),

- different types of jumps were performed (drop jumps from 0.4 m high box, and 3 - 4 steps runway and jump from a springboard) by non gymnasts in order to evaluate the suitability of the device.

Matlab. 7.0 computer software was used to analyze the measured signals. Acceleration and velocity are related through the derivative/integral

$$a(t)=\frac{\mathrm{d}v(t)}{\mathrm{d}t} \Leftrightarrow v(t)=v(t_0)+\int_{t_0}^{t} a(t)\mathrm{d}t$$

(1).

Since the sensor measures acceleration (also gravitational) the velocity profile is obtained by integration of acceleration according to equation (1). Numerical integration requires some precautions since already small measurement errors or errors due to noise by the surroundings or electronics are significantly increased during numerical integration (Žagar, Križaj, (2005)). As a consequence raw data were additionally filtered with a moving average and a Butterworth low pass filter before numerical integration.

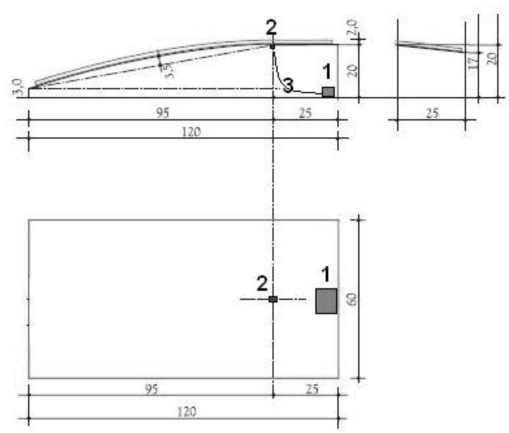


Figure 4. *Springboard by FIG norms (FIG, 2009a) and placement of 1-processor with monitor, 2-sensor, 3-wires.*

RESULTS

1. Raw acceleration measurements and calculation of velocity profile

Figure 5 presents raw measured acceleration data for a typical jump onto a springboard and calculated velocity profile according to eq. 1. The axes in the figure are inverted. This means that positive axis for acceleration points upwards while positive axis for velocity points downwards (toward earth). It can be seen that the sensors is very sensitive and detects also very small acceleration changes (2 mg, where 1 g refers to the earth gravity acceleration - approx. 9.8 m/s^2). It should be noted that maximal accelerations indicate maximal changes of velocity and not directly maximal velocities.

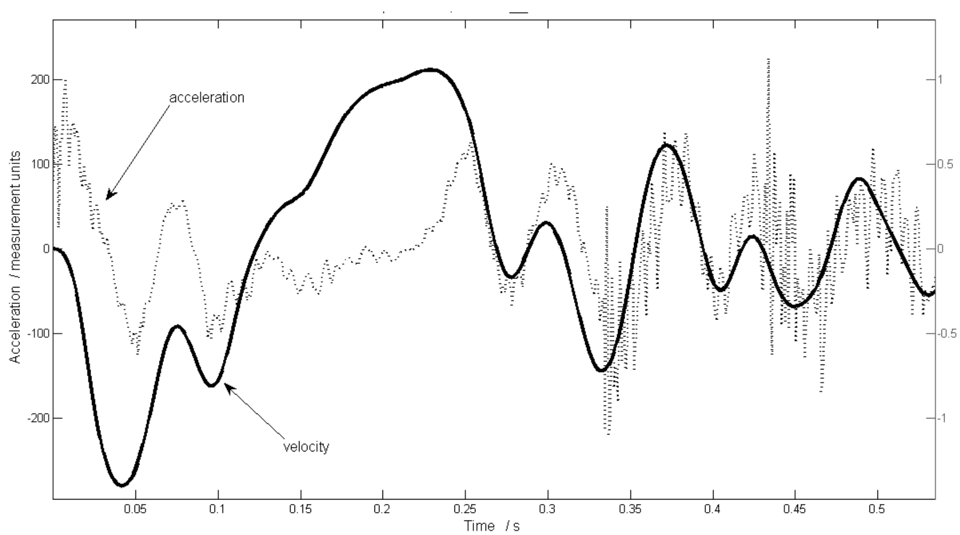


Figure 5. *Raw acceleration data and numerically calculated and filtered velocity profile for a typical jump onto the springboard.*

2. Comparison with force measurements and laser distance measurements

It can be assumed that the force (F) of spring compression (in particular in case standard solenoid springs are used – as in our case) is linearly related to the compression distance ($F = kx$), where x is the compression distance and k is the spring compression constant. Such a relation can be in particular expected in the middle range of compressions. In order to perform this comparison, the velocity curve was integrated once more according to the relation between the compression velocity and the distance

$$v(t) = \frac{\mathrm{d}x(t)}{\mathrm{d}t} \Leftrightarrow x(t) = x(t_0) + \int_{t_0}^{t} v(t)\mathrm{d}t \qquad (2)$$

Figure 6 shows a comparison of force measurement and acceleration measurement with consecutive velocity and distance determination from the measured acceleration for two consecutive jumps (the gymnast jumped onto the springboard and landed again on the springboard). The obtained curves are very similar and thus indicate that the relationship between the force measurement and the acceleration measurement can indeed be obtained. The developed device seems more sensitive to vibrations what is actually advantage in defining the proper gymnast's action. Human body has numerous wobbling masses and such disturbances for action on a springboard can be accurately detected with a developed system.

Another test has been performed using a high accuracy laser distance measurement system. From obtained vertical distances we have calculated the velocities by numerical derivation (the curve needs to be smoothed and filtered before derivation). As shown in

Figure 7 very good agreement has been obtained between velocities obtained by numerical derivation of the laser measured distances and velocities obtained by integration of measured accelerations. This confirms correct usage of the developed device.

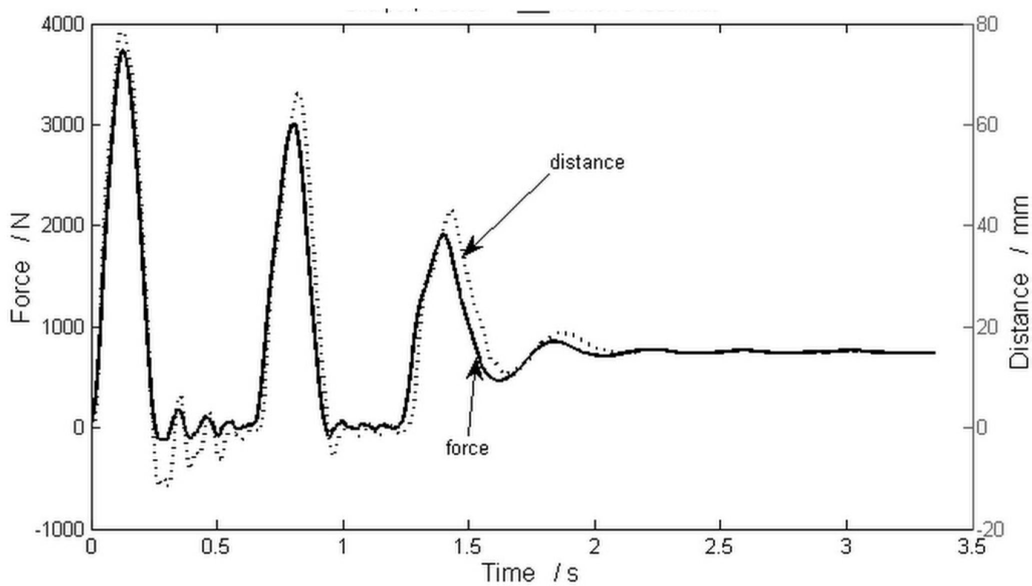


Figure 6. *Comparison of vertical force measured with a tensiometric force plate and distance calculated from vertical springboard acceleration with new device vs time.*

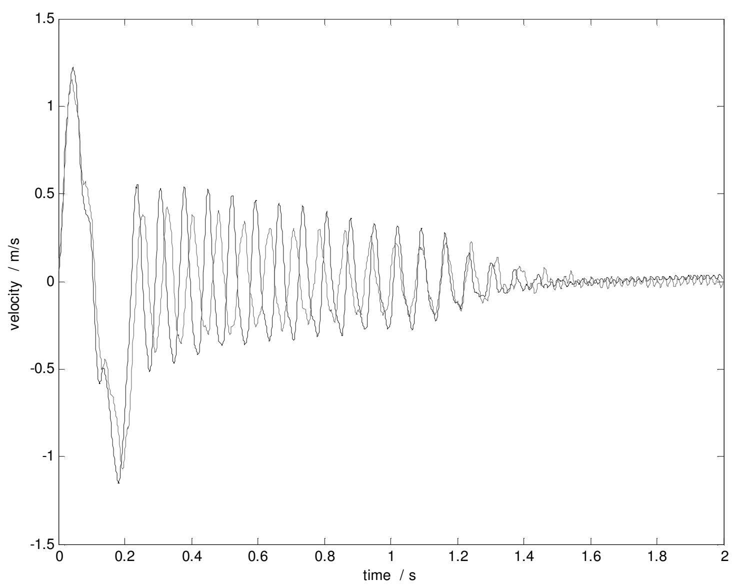


Figure 7. *A comparison of springboard velocity obtained by measuring acceleration and the velocity obtained from distance measurements with a laser distance sensor.*

3. Determination of significant points on the velocity/time curve

Several important points can be identified on the vertical velocity/time curve that can be used to analyze performance of a springboard usage (Figure 8). Before any action on the springboard its vertical velocity is zero. When a gymnast touches down the springboard it starts to move downward accelerated. Because of the counter force of the springs the velocity decelerates and in the moment of maximum compression the vertical velocity is zero again. After this point the springboard is moving upward and the vertical velocity of the springboard increases and reaches maximum just before the toes of the gymnast release from the springboard (comparing times from high speed camera and accelerometer). After this moment the velocity of the springboard reduces and damped oscillates toward zero.

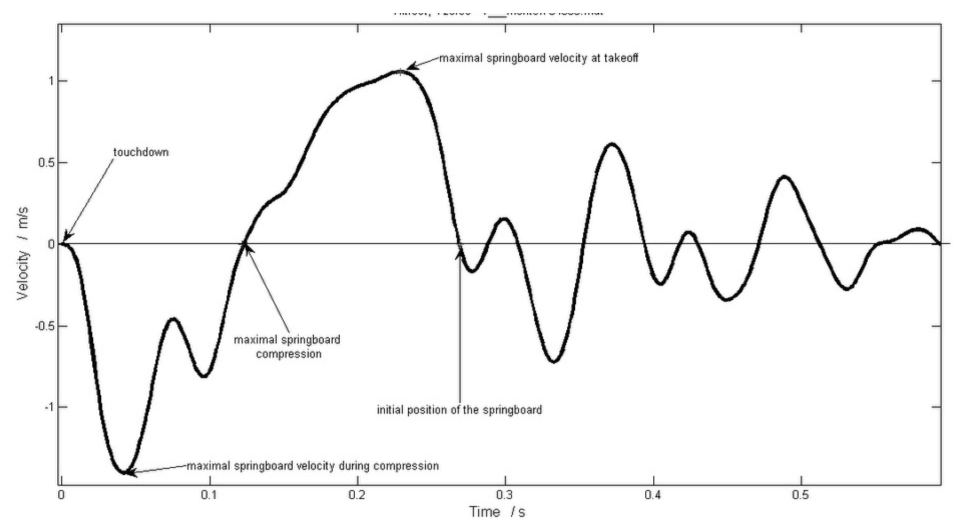


Figure 8. *Typical vertical velocity [m/s]/time[s] pattern.*

From the vertical velocity/time curve we can identify the following parameters:

- time to the first maximal negative velocity,
- maximal negative velocity
- time from the touch down to the most compressed springboard (zero velocity):
- time to maximal positive velocity
- maximal positive velocity
- time to initial position of the springboard (zero velocity)

Correct interpretation of determined parameters is not a trivial task as many parameters can influence them; in particular, the gymnasts body composition (mass, height, wobbling mass) and execution of a jump. Short times on a springboard could indicate very stiff body. Curve with only one peak in negative direction could indicate very good stiffness, take off phase with one peak indicates supose very good sinchronized muscle action. We expect that the time to the first maximal negative velocity and time to the most compressed springboard (zero velocity) demonstrate dynamics of the landing phase onto the springboard. Furthermore, calculated compression (in meters) is directly related to the compression force and thus to the potential energy that the gymnast can exploit during take-off from the springboard (compression depends on body translation momentum and muscle force; however both are affected by the body weight). The first phase of the jump starting from the touch-down to the maximal springboard compression could indicate the capability of the gymnast to store the energy mostly into the springboard (springs) and tendons. The second phase starts from the maximal springboard compression to the take-off.

The efficacy of this phase can be determined from the difference of times between the maximal positive velocity and the time to maximal springboard compression. Several peaks on the take off curve could indicate non adequate consecutive, sinchronised and rhythmic action from different extensors – e.g. gastrocnemius, quadriceps, erector spinae).

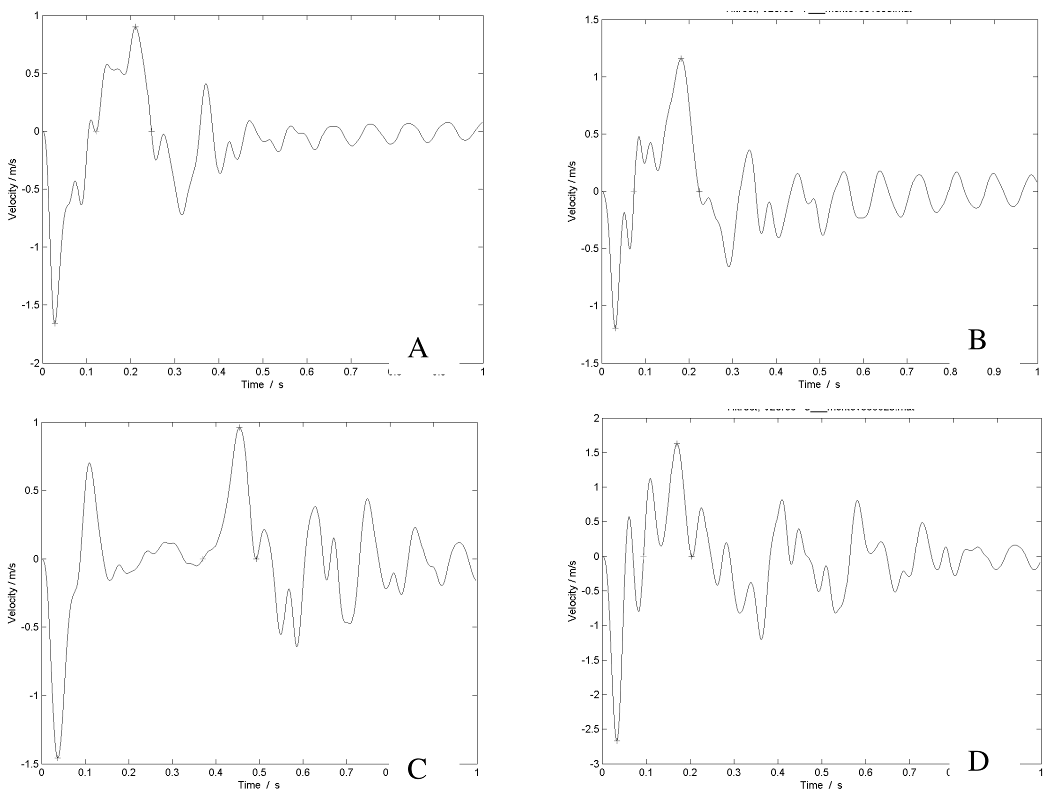


Figure 9. *Vertical velocity profiles for four different types of jumps. A –drop jump from the box with landing to springboard with full feet, and take of with toes; B – from 3-4 steps runway jump on springboard with full feet and take off with toes, C – drop jump from box on toes until the half squat position and take off with knees mostly (heel is not placed on the surface at any time), D –from 3-4 steps runway jump on springboard with toes first than heel and very energetic take off from toes.*

One particularly important feature of the developed device should be identification of different types of jumps that could serve for evaluation of performances as well as capabilities of the gymnast for a particular vault. Figure 9 presents velocity/time profiles for four different types of jumps: A – is a drop jump from a box with landing to a springboard with full feet and take- off with toes; B – is a jump onto a springboard from 3-4 steps runway with full feet and take-off with toes, C – is a drop jump from a box on the toes

is similar to those on the force plate for take-off from a squat position (curve

until the half squat position and take-off with knees mostly (heel is not placed on the surface at any time), D – is a jump onto a springboard from 3-4 steps runway with toes first than heel and very energetic take off from the toes. While A and B curves are similar in compression, they do express slight difference in the take-off phase. It seems a person who had performed the jump B had problems with the take-off action. Jump C clearly shows an amortization phase, the time for getting into a half squat position and the take-off curve with one peak only). Jump D shows the shortest time of a jump and the highest take-off velocity, however the curve pattern is similar to the jump A and B with more peaks during the take-off phase indicating non linear take-off action (slight delays, non adequate synchronization between the human and the springboard, non adequate timing of the take-off muscles action etc).

CONCLUSIONS

Correct springboard usage is crucial for performance of optimal vaults. As the event of the jump onto the springboard and the take-off is very dynamic and lasts typically less than 0.2 s it cannot be well interpreted by human eyes only. Some help of technology is desired. As a consequence we identified some possible technologies that can be used for measurement of the jump performance and analysis of usage of the springboard. In order to provide the springboard users an affordable and yet efficient technology we developed a device that is easy to use, of small dimensions and as such very portable and has low cost. The concept is based on usage of miniature acceleration sensors that are mounted below the top springboard desk. Due to miniaturization the sensor does not influence the gymnast performance and yet provides very accurate measurements. The evaluation of a jump is based on interpretation of the data obtained from measured acceleration. In particular, the velocity profile is calculated and several typical parameters are identified such as time to first negative maximal velocity, time to maximal compression, maximal springboard compression, maximal positive velocity during take-off and time to maximal positive velocity. These parameters have been related to the stiffness of the gymnast during the jump, the potential energy stored in the springboard, gymnasts take-off muscle action, etc. The performance of the developed device has been compared with other measurement techniques in particular with force plate measurements and measurements of springboard compression with a laser distance measurements. In both cases a comparison revealed similar patterns and confirmed the selected choice of technology. The developed device was currently tested only in the laboratory environment so the next phases of research would include also measurements in real environment. It is expected that with the developed equipment the user would be able to:

- determine typical springboard action parameters per gymnast,
- determine optimal springboard parameters for required jump,
- analyze repeatability of springboard jumps,
- analyze transverse movements,
- optimize training and its efficiency.

In near future we will concentrate our efforts to determine reliability as well validity of the presented approach and the developed device. The device has a potential for use as a fast information system of gymnasts' performance on the springboard as well as a device suitable for science/research projects in vaulting.

REFERENCES

Antonov, L. (1975). Preskoci za žene [Vaulting for Women]. Moskva: Fiskultura i sport.

Bolkovič, T., & Čuk, I. (2000). Differences between men and women biomechanic characteristics of take off of simple horse jumps. In: ČOH, Milan (ed.), JOŠT, Bojan (ed.). Biomechanical characteristics of technique in certain chosen sports. Ljubljana: Faculty of Sport, Institute of Kinesiology, 20-24.

Bradshaw E., Hume, P., Calton M., &Aisbett, B. (2010). Reliability and variability of day-to-day vault training measures in artistic gymnastics, Sports Biomechanics 9(2), 79-97.

Bricelj, A., Dolenec, A., Bučar Pajek, M., Jakše, B., Čuk, I., Čoh, M.(2007). Reliability of runway characteristics of vault in women artistic gymnastics. In: SMAJLOVIĆ, Nusret (ed.). *Zbornik naučnih i stručnih radova-dodatak*.

Sarajevo: Univerzitet, Fakultet sporta i tjelesnog odgoja, 32-35.

Cormie P., Sands, W.,A., & Smith, S.L. (2004). A Comparative Case Study of Roche Vaults Performed by Elite Male Gymnasts. Technique, August, 6-9.

Čuk, I. & Karacsony, I. (2004). Vault, Methods, Ideas, Curiosities, History. Ljubljana: ŠTD Sangvinčki.

Dolenec, A., Čuk, I., Karacsony, I., Bricelj, A. & Čoh, M. (2006). Runway characteristics of vault in women gymnastics. *Kalokagathia*, 44(3-4), 127-136.

Ferkolj, M. (2010). A kinematic analysis of the handspring double salto forward tucked on a new style of vaulting table. *Science of Gymnastics Journal 2*(1), 35-48.

FIG (2009a). Apparatus Norms. Loussane: FIG.

FIG (2009b). Code of Points Men Artistic Gymnastics. Loussane: FIG.

FIG (2009c). Code of Points Women Artistic Gymnastics. Loussane: FIG.

Greenwood M., & Newton, J.W. (1996). Direct force measurement of the vault take off in gymnastics. In: ISBS - Conference Proceedings Archive, 14 International Symposium on Biomechanics in Sports, 332-335, Obtained from: http://w4.ub.uni-konstanz.de/cpa/article/view/2729/2576 on 26.7.2011.

Kavanagh, J.J., & Menz, H.B. (2008). Accelerometry: A technique for quantifying movement patterns during walking, Gait & Posture *28, 1 – 15.*

Keränen, T., Moisio, T., & Linnamo, V. (2007). Artistic gymnastics vaults vertical take off velocity measured by electromechanical film. Obtained from: http://www.kihu.jyu.fi/tuotostiedostot/julkinen/2007_ker_artistic_g_10000.pdf on 26.7.2011.

Križaj, D., & Mihevc, I. (2007). Prenosni merilni sistem za merjenje pospeškov [Portable measurement system for measuring accelerations]. *Šport*, 55(4), 58-64.

Močnik, C., &Križaj, D. (2008). Načrtovanje prenosnega merilnega sistema za merjenje pospeškov [Design of portable data logger system for accelerometer sensors]. *Inf. MIDEM*, 38(2), 89-93.

Sano S, Ikegami Y, Nunome H, Apriantono, T., & Sakurai, S. (2007). The continuous measurement of the springboard reaction force in gymnastic vaulting. *Journal of Sports Sciences* 25(4), 381-391.

Semenov, L.P. (1987). Opornie prižki [Vault]. In: Gaverdovskij, J.K., et all. Gimnastičeskoe mnogobore mužskie vidi. Moskva: Fiskultura i sport.

Sands W.A., Smith, S.L., & Piacentini T. (2008). Studying Vault Board Behavior: A Preliminary Look. Obtained from: http://www.polhemus.com/?page=motion_case_studies_vault on 26.7.2011.

Veličković, S., Petković, D., & Petković, E. (2011). A case study about differences in characteristics of the run-up approach on the vault between top-class and middle-class gymnasts. *Science of Gymnastics Journal 3*(1), 25-34.

Zeng, H., & Yhao, Y. (2011). Sensing movement: Microsensors for body motion measurement. *Sensors 11*, 638-660.

Žagar, T., & Križaj, D. (2005). Validation of an accelerometer for determination of muscle belly radial displacement. Med. biol. eng. comput.. 43(1)78-84.

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