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# Diagnosis of Motor Habits during Backward Fall with Usage of Rotating Training Simulator

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Additional information is available at the end of the chapter

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## Abstract

There are jobs with high risk of a fall. It seems reasonable to create a device for diagnosis and improving safe fall skills for workers. The aim of the present study was a verification of usability of a rotating training simulator for assessing motor habits during a fall caused by an external force by conducting validation procedure. Material and Methods: the participants were chosen from a group of 128 students of physical education of the University of Zielona Góra. Predictive validity was determined by comparing results of immediate fall test (IFT) to forced fall test (FFT). Repeatability was determined by conduction test/retest conditions. Reliability was also determined by comparing grades given by two observers with those given by an expert. Results: the acquired results show that there were no significant differences between results of IFT and FFT tests conditions and also no significant differences between test/retest conditions separately for IFT and FFT, alongside with moderate correlation of its results. Good and excellent reliability ICC values were obtained for observers and experts (from  $r = 0.853$  to  $1.00$ ). Summary: the obtained results show that the rotating training simulator is a valid and reliable tool for diagnosing motor habits during a fall caused by an external force.

**Keywords:** accidental falls, safety, biomechanical phenomena, validation studies, ergonomics

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## 1. Introduction

Motor safety of people is important in terms of protection of health. A person can lose his/her health as a result of hitting an object that can mechanically damage his/her body [1]. Falls are very frequent reasons of mechanical injuries to a human body from the youngest one [2] to the elderly [3]. According to the WHO definition of a fall, it is a result of a sudden loss of balance and changing a body position from vertical to horizontal [4]. The loss of balance can be a result of involvement of an external force, for example, pushing or hitting [5]. The loss of

balance by an external force, for example, a centrifugal force in a curvilinear motion, can be facilitated by a slippery surface [6]. Even trained people from special services may fall. Up to 20–30% of injuries of firefighters, around 10% of EMS employees, 20% of policeman nonfatal injuries are caused by a fall [7, 8]. A consequence of balance loss can be a fall, which does not necessarily lead to an injury. When falling, trained people can control their body activities adequately to the fall direction [9] and proper reaction of the body during a fall can be practiced, which is shown in numerous research results [10, 11]. After several training courses in safe fall techniques, which are most frequently based on martial arts methodology, human susceptibility to injuries during a fall can be improved. Thus, through an adequate training, we can increase motor safety of a person. Kalina and Barczyński defines motor safety of a person as consciousness of a person undertaking to solve a motor task or consciousness of a subject who has the right to encourage this person to do this or even enforce it, who will be able to do it without the risk of losing life, injuries, or other adverse health effects [11].

The most dangerous are falls performed backward [12]. If a person's front is moved to the direction opposite to the direction of the motion, then this person is unable to see the circumstances that cause a fall. Very often, the reason of falling backward is a slip [13]. As some authors report, slips or trips account for 50% of all falls [14].

There is a non-apparatus test measuring susceptibility to body injuries during a fall designed by RM Kalina [15]. By assessing a way to lie down, he determined probability of occurrence of an injury when falling backward. He puts scores based on committing errors while lying down, which determine which body parts are most prone to injury in real life situation. This idea was a point of reference to process of its evaluation.

### 1.1. Biomechanical aspects of backward fall

One of the first attempts of biomechanical analysis of a men's fall on the ground were presented by Jaskólski and Nowacki [16, 17]. The mechanical energy of moving man consists of kinetic energy  $E_k = mV^2/2$  and potential energy  $E_p = mgh$ . If center of gravity of a man is lowered because of a fall, it results in increase of kinetic energy due to lowering potential energy

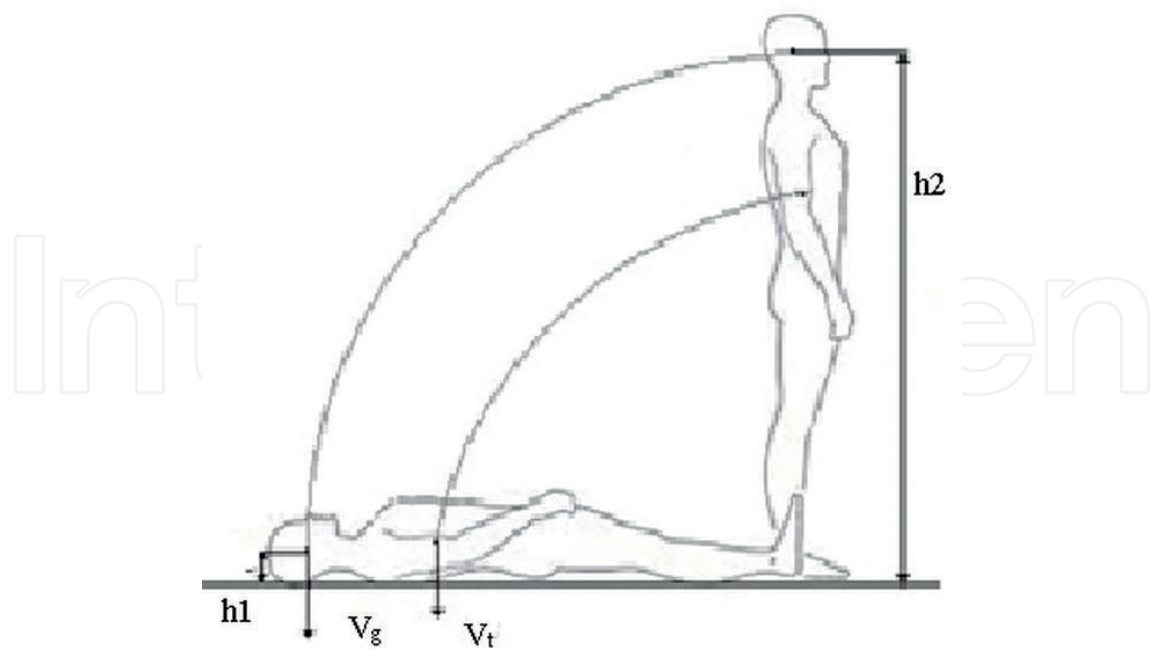
$$mgh_2 - mgh_1 = mV^2/2 \quad (1)$$

If the man has a certain velocity of  $V_0$  before a fall, then the formula for kinetic energy of the movement while hitting the ground takes form of:

$$mV^2/2 = mV_0^2/2 + mgh_2 - mgh_1 \quad (2)$$

where  $m$  is the body weight,  $h$  is the height of the man's center of gravity ( $h_2$ —before the fall,  $h_1$ —after the fall), and  $g$  is the gravitational acceleration.

From biomechanical point of view, that segment of a body part model is a velocity, which specific body segments are gaining during a fall depends on their initial height. Velocity acquired by head's center of mass  $V_g$  will be higher during a fall than for trunk's center of mass  $V_t$  (Figure 1).



**Figure 1.** Changes in velocities of body segments during a backward fall.

Jaskólski and Nowacki analyzed the deformation energy of a human body during a fall. They assume that body surface is homogenous and resilient. They assumed that all of kinetic energy of a faller comes from deformation energy. They established a formula for deformation energy per volume unit of human body.

$$e = \frac{k}{t^2 S^2} \quad (3)$$

where  $S$  is the surface affected by the force during collision with the ground,  $t$  is the time of deceleration during the collision, and  $k$  the values a man does not have any influence on during a fall.

Obtained formula (3) justified that deformation energy per the volume unit of the human body could be reduced during a fall by increasing area of contact with the ground, as well as time of this contact. Similar conclusions were formulated by Reguli and coauthors [18], pointing out necessity of distribution of the forces during a fall to the biggest possible area and suppressing a fall in possibly longest time.

Biomechanical analysis of a fall presented by Jaskólski and Nowacki does not include analysis of deformation energy of human body while performing a rotational motion on the ground.

In sport disciplines, where falls are on daily basis, this pattern of movement is very common. Biomechanical analysis of falls performed by rotational motion on the ground was conducted by Mroczkowski [17], who compares human body during rotational motion to a rolling wheel. He gets the following formula:

$$mV_0^2/2 + mg(h_2 - h_1) = mV^2/2 + I\omega^2/2 + s f_t N/R \quad (4)$$

where  $m$  is the body weight,  $h$  is the height of the man's center of gravity ( $h_2$ —before the fall,  $h_1$ —after the fall,  $g$ —gravitational accelerations,  $V$ —velocity of the center of a man's gravity ( $V_0$ —before fall,  $V$ —after fall),  $f_t$  is the sliding friction coefficient,  $N$  is the contact force,  $R$  is the radius of the circle on which the subject is moving, and  $I$  is the moment of inertia and  $w$  is angular velocity.

Analysis conducted by author (or rather its summary) results in conclusion that during such fall, deformation energy of human body per body part volume contacting with the ground may be reduced by lowering time of contacting of the body with the ground and extending area of contact of body parts with the ground. Lowering the time of contact with the ground could be achieved by increasing velocity in certain limits. Increasing circle's radius on which fall is performed is a factor, which increases a contact area with the ground. It causes lesser friction force of rolling faller, which is responsible for inelastic deformations of the body. Velocity of a faller in such manner, compared to fall without movement is lesser, which states in formula 2. It happens due to change of potential energy not only by rotational movement, but also by its progressive aspect. Adopted movement model in formula 4 assumes that person performing a fall did not fight for maintaining a balance. His movement model is similar to a ball thrown from a certain height, which is rolling on the ground afterward. But it is common for humans to defend from falling by activating muscles accordingly. In that case, formula 4 needs to be completed, by including a certain kinetic energy, which person gains before a fall. Then, we get this formula:

$$mV_0^2/2 + mg(h_2 - h_1) = mV^2/2 + Iw^2/2 + s f_t N/R + W \quad (5)$$

where  $W$  is the work done by a muscles, which suppress a fall.

## 1.2. Techniques of backward falls

Techniques of falling, thought in certain sport disciplines, could be put into two kinds:

### 1. First one: fall performed in a way similar to gymnastic backward roll (**Figure 2**)

Habit of such fall could be obtained during teaching backward roll in a program of physical education classes in a school or in gymnastic-related disciplines. In a rolling phase through the head, it is necessary to perform dynamic extension of upper limbs, which will result in elevating shoulders and trunks upward. Line of performed roll is indicated in an end phase by the head. There are forms of performing a fall, where rolling is performed by shoulder line, not by the head and extending upper limbs. This form could be seen in handball or volleyball players.

### 2. The second one: fall performed backward with side aligning of the body

Rolling is starting from more retracted leg, which is aligned to the side. This leg was bend accordingly, in a way that will form a circle with the line of contact. Body movement imitates a rolling ball. Whole line of a body contact with the ground forms a circle. From **Figure 3**, it can be seen contact begins with, e.g., left leg, then on a buttocks goes to the right shoulder

and ends up on right upper limb. Upper limb forms a bow, so line of contact of the body with the ground may remain as a circle. This method of falling is often described in martial arts [19–21].

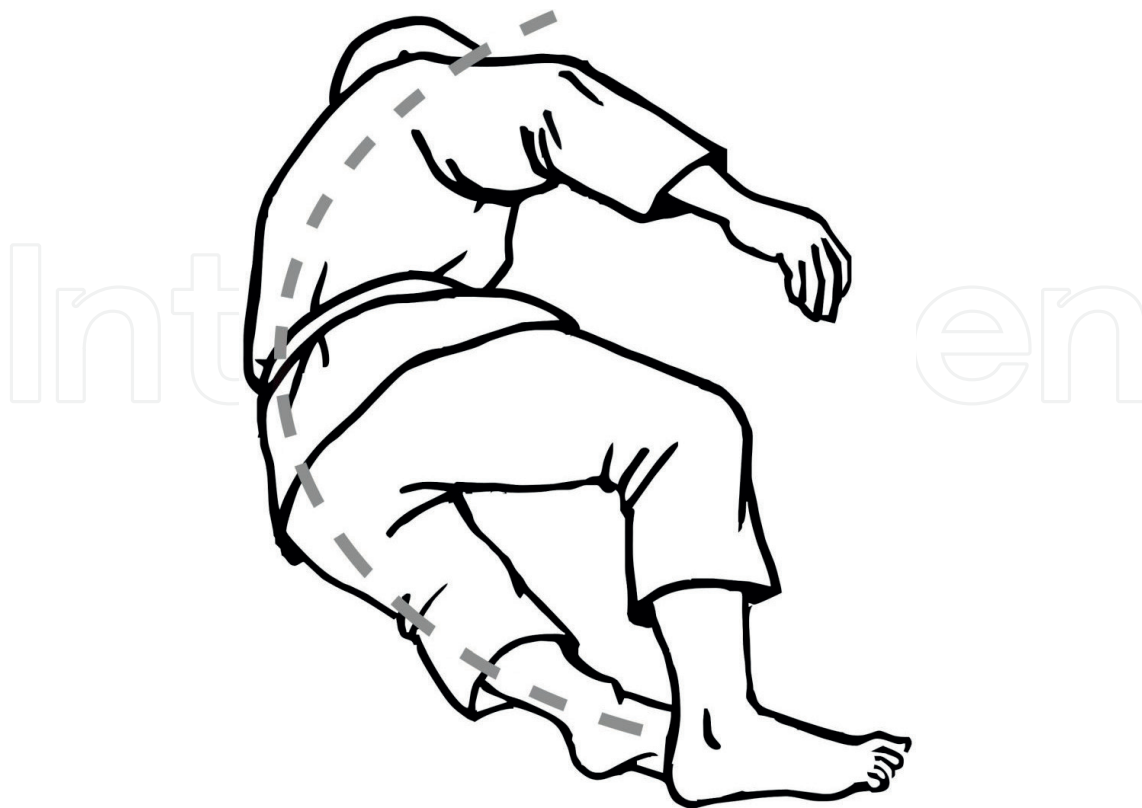
This way of performing fall is commonly used during a training of defend kind of special forces, football players, speedway riders, etc.

There is no empirical studies comparing those two methods of falling in a biomechanical aspect in terms of sustaining possible injuries of the body during a fall.



**Figure 2.** Fall backward by rolling over.





**Figure 3.** Side positioning in a backward fall.

Mroczkowski [17] highlighted importance of length of line of contact with the ground, so the first contact will not be collision at the same time. It is better to start movement in a manner, which allows falling with a bigger radius  $R$ , which explains formula 4. Going beyond the line of circle with specific body parts may result in hitting the ground and increasing strains on them. For example, hitting with the pelvis griddle at the beginning of a fall may result in occurrence of inertia forces on specific body parts. These forces are especially dangerous for the head and may result in its hyperextension.

While side falling, circle's radius  $R$  is bigger than in the other way of falling, because it starts at the feet. The bigger a radius of the circle is, the lesser is the rolling friction, as well as deformation energy per volume unit. With this kind of fall, it is required to retract one leg. In a case when this movement is delayed, it may result in a fall on the pelvis griddle causing unsymmetrical distribution of forces while hitting a ground.

For the first kind of fall, contact with the ground begins with buttocks. In a moment of contact with the ground, the pelvis griddle's strain is distributed evenly. The problem is a big knee flexion, to avoid big strain on the buttocks while hitting the ground.

While conducting biomechanical analysis, it is important to include a direction of velocity, with which foot hits a ground [17]. If part of vertical velocity is significantly bigger than horizontal one, for example during fall from height, it is important to land on both feet evenly. It follows that forces, which put strain on hip joints, need to be similar. Only after fulfilling these criteria, one can perform rolling in a circle-like movement.

This case could occur in for example falls during jumps on trampoline. In that case, it is strongly advised to apply first kind of falling technique. After landing, there is no time for additional lower limb movement.

On the other hand, when there is a big value of horizontal velocity component compared to vertical one, it is important to align body as fast as it is possible, so a contact with a ground will be proceeded by rolling over, forming a circle [17]. In such condition, there will be no harm to a pelvis griddle due to unsymmetrical load of hip joints, because vertical velocity component during a fall will not be big. We can conclude from this analysis that in such case, it is recommended to use techniques based on falling on the side, with assumption, that foots are not blocked during a movement of the body.

In both methods of falling, practitioners of martial arts or combat sports often obtain a habit of hitting a ground with hand with proper angle. Hitting a ground could reduce kinetic energy, with which human body segments hit the ground [22, 23].

But for people untrained in falling techniques, it is common to extend and arrest hands during backward fall, which is considered as error [24]. It may result in fractures or serious joint injuries in upper limbs. This reflex is especially dangerous during jumps on trampoline.

During a competition in martial arts and combat sport, it is not always possible to roll over in a circle movement back to vertical position. During fight between two judo competitors, they try to restrict opponent movements, which is a reason why during a fall, they try to disperse collision energy by hitting the ground. During backward falls (koho-ukemi) and side falls (yoko-ukemi) [22, 23] taught in judo, it is crucial of proper performance, to contact the ground with the biggest possible area alongside with properly hitting the ground with a hand to reduce collision energy.

Competitors in martial arts hit the ground with their hand automatically, even if there was possibility to make full rolling over movement, to reduce collision energy. They cannot be certain if opponent allows them to perform full rolling movement and regain vertical stance, because they might be for example held. However, it is important to notice, that fights and hits are performed on mattress, and not, e.g., on concentrate floor. Theoretical considerations described above require empirical verification.

### **1.3. Rotating simulator as an device for training of rotational motion**

For practicing of falls for experiment participants, rotating training simulator was applied (patented) [25]. The rotating training simulator includes an induction three-phase motor driving simulator base in rotational movement. Replaceable additional platforms and vertical bars could be installed to simulator base. Rotating simulator allows to improve motor habits connected with performing rotational techniques. While performing rotational techniques, it is important to adopt sense of balance to changes in angular velocity during rotational movement and acceleration affecting the body alongside that. Rotating training simulator could be a tool for improving sense of balance of a competitor, who is preparing to apply techniques, which involves greater physical abilities [26].

Rotating training simulator can teach how changes in body position may affect acquisition of different angular velocity during rotational movement of a man. It could indicate moment of



inertia for determined positions while performing rotational techniques. This way of experimental explanation of laws of rotational movement mechanics might result not only in faster understanding in physics education, but also enhanced process learning process of motor actions qualified as rotational techniques. These assumptions were made while teaching specific rotational techniques of aikido [27, 28]. Rotating training simulator is a device that can be used for training of falls by creating centrifugal force.

Mroczkowski states [17] that one of the important factors increasing forces that may cause a fall is that which causes sudden change in direction of movement. Transfer from a rectilinear movement into a curvilinear movement increases the effects of external forces that are responsible for a fall. At the moment of changing a movement direction, a force of inertia occurs.

The person in such a movement is affected by a centrifugal force, with which a small friction force of a surface can result in slipping. Besides that, while being in curvilinear movement of body segments, especially during rotational movement, inertia forces affect internal organs. Angular accelerations affect sense of balance, forcing men to certain reactions. Slowing these reactions for sudden changes in rotational movements—for example in sports—could lead to a fall.

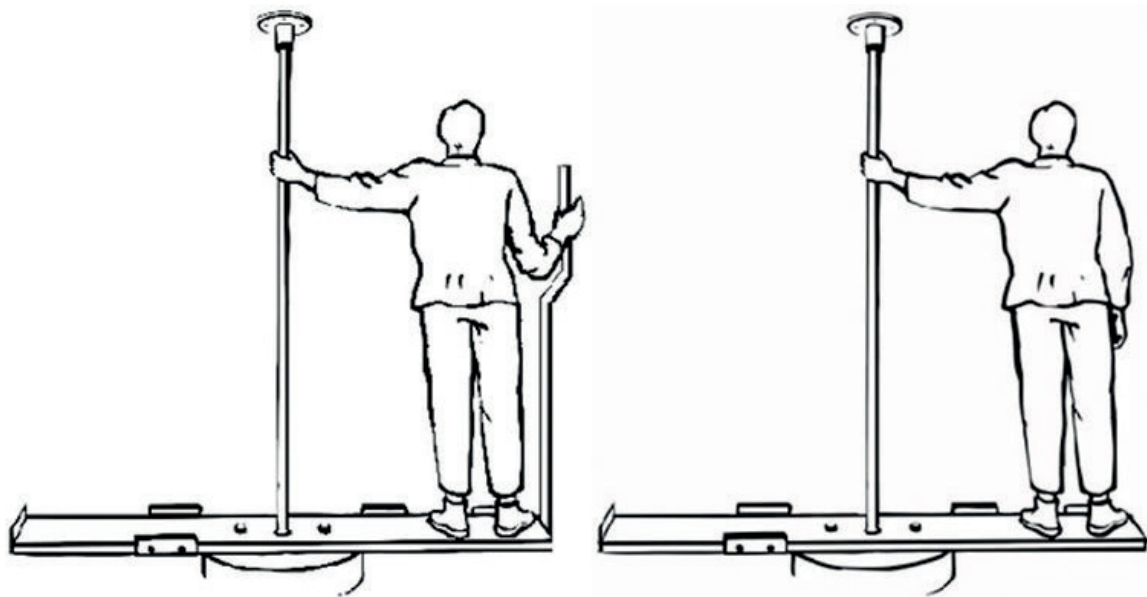
Rotating training simulator could be used to scientifically observe ways of controlling the body during loss of balance and fall of a man, who stays in relative immobility. These simulations did not only refer to situation when person is sitting in a stopped car and someone hits it with another car, but also bus passenger who stays during ride and bus hits something. In certain simplification of reasoning, falls from rotating training simulator could be simulation external forces, which cause a fall of anybody (being hit by running animal or person, sudden landslide, etc.). Rotating training simulator, applied in training of safe falling, could intensify effects of learning and lead to improving of motor safety of training people.

This device could greatly contribute in expanding our knowledge about phenomena of rotational movements of the human body and adaptations to motor action with frequent occurrence of certain situations. Probability of being in such situation unwillingly concerns especially soldiers, policemen, firemen, etc. That is why rotating training simulator could find its application value as a device enhancing a training of employees of such services.

#### 1.4. Description of rotating training simulator during fall exercises

**Figure 4** presents application of the simulator for the needs of the author's experiment. The rotating disc has a board fixed to it, which is at least 2 m long. The rotating disc can be accelerated to a chosen rotational frequency.

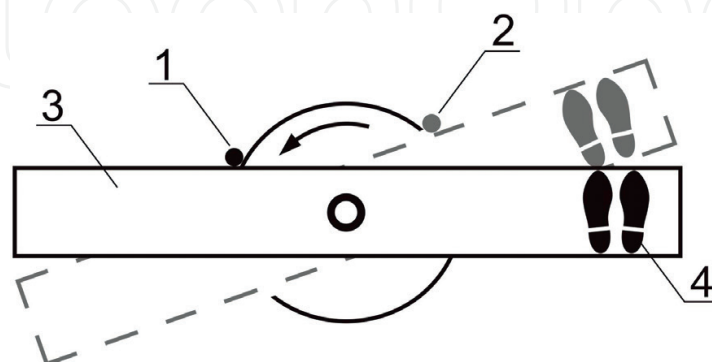
Near the rotating disc, there were two locks placed (**Figure 4**). After switching the drive off and displacing the end of the board on which a subject was standing, a locking pin was released, sticking upward. The board is also provided with rubber bumpers into which the sticking out pin bumps when the board is in move. The first pin causes an abrupt stop of the board motion, whereas the other limits its motion in the opposite direction after it hits the bumper (**Figure 5**). A braking switch is on the control panel.



**Figure 4.** Method of setting the position by a student at the moment the board bumps into the first pin (version with and without the additional pipe).

Its activation causes transfer of voltage onto the motor, which stops the rotary motion of the disc with the board. This switch played an important role in the experiment, especially when participants lost their balance and jumped down when the disc was being driven into the desired frequency. The switch stops the board. The additional factor causing a fall was the fact that after the board bumped into the first pin, it moved in the opposite direction to the person's fall (**Figure 5**). The electrical system applied with an encoder made it possible to measure the frequency of rotations and the angle of the platform rotation on the control panel as well as to record data on a PC [26].

To provide safety of the students exercising on the platform, mats were placed around the apparatus. The subjects fell off the board on two layers of the mats. The bottom layer was composed of 7 cm thick hard mats, whereas the upper layer consisted of softer mats, 10 cm thick.



**Figure 5.** Method of stopping the board as a result of bumping into the pins. Key: 1—first pin, 2—second pin, 3—board, and 4—place where subject's feet are put.

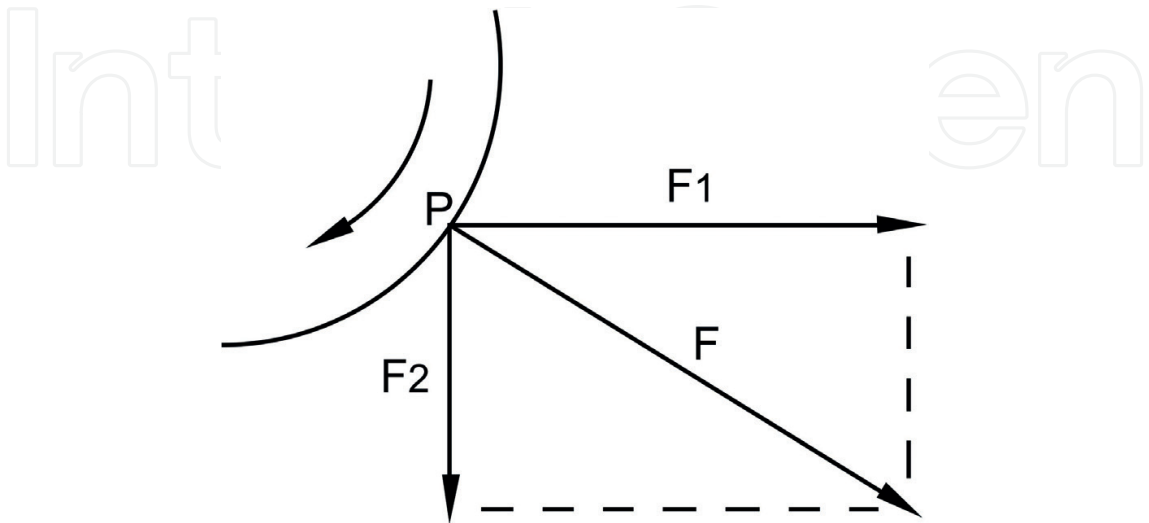
Participants exercising on rotating training simulator were wearing protective headgear similar to that used in combat sports. Additionally, in the first tests on the rotating simulator, the participants were wearing shin protection gear. If the expert supervising the test concluded that the subjects' behavior did not involve any risk, they were allowed to use shin protectors if they wished. Maintaining balance by a subject while on the rotating disc was simplified by constant and relatively low acceleration of the disc. The value of acceleration was selected in a way that would not cause any balance disruptions or eventually its loss.

While the board was being accelerated, the participants were allowed to hold on to two pipes (**Figure 4**). Using the second pipe was not necessary, as shown in the "relative immobility" movie attached to the article, which explained the mechanism of the rotary trainer [26]. If the balance of a person was uncertain, the second pipe was attached upon the subject's request. The participants signed a formal consent for participating in the tests of this experiment.

A subject assumed the position as shown in **Figure 4**. After reaching the required rotational frequency and after the first pin acted, the subject let go of the pipe. There was a sound signal to release the pipe at the moment the first pin was activated. During the first pin activation, the inertial force worked on the tested person. At the same time, the board moved away in the opposite direction to the direction the person was moving until it bumped into the second pin (**Figure 5**). This caused additional balance disturbances of the tested person. As a result of the collision, the angle of the board displacement depended on the place where the second lock was fastened to the surface. The outside leg (**Figure 5**) moved approximately 40 cm away. Such a board move can be a good simulation of a foot slipping when walking on a slippery surface.

1.5. Analysis of the force causing a fall

When the board with a person exercising on it stops abruptly, there acts a resultant of the inertial force, as presented in **Figure 6**.



**Figure 6.** Distribution of forces causing a fall of a person exercising on the rotating training simulator.

Inertial force  $F_1$  is a centrifugal force acting on the tested person and it is calculated with the formula:

$$F_1 = \frac{mV^2}{r} \quad (6)$$

The force  $F_2$  resulting from the sudden decrease in the linear velocity value  $V$  of the tested person due to the board bumping into the first pin is calculated following the formula:

$$F_2 = -ma \text{ or } F_2 = -\frac{m\Delta V}{\Delta t} \quad (7)$$

The resultant force  $F$  is calculated as follows:

$$F = \sqrt{\left(\frac{mV^2}{r}\right)^2 + (ma)^2} \quad (8)$$

The bigger change resulting from changes in the frequency of rotations is brought about rather by the force  $F_1$  than  $F_2$ , because after the formula transformation, we find that its value depends on the rotational frequency  $f$  squared

$$F_1 = m\omega^2 r \text{ or } F_1 = m4\pi^2 f^2 r \quad (9)$$

Thus, the resultant force  $F$  acting on the tested person increases significantly as a result of an increase in the rotational frequency. The total inertial force that acts on the person making a fall is difficult to calculate because human body is not a uniform rigid body. A change of the human body's linear velocity depends on various factors. However, it is easier to analyze an increase in the centrifugal force value along with an increase in the rotational frequency. The formula referred to herein (9) shows that with an increase in the rotational frequency as presented in the experiment, namely from 0.2 to 0.26 Hz, this force increased by 70%, whereas with an increase to 0.3 its value rose by 125%.

The present chapter shows a validation procedure of the rotating simulator as a tool for testing motor habits of a man during a fall, as well as balance maintenance after a fall. Preliminary results of the validation procedure were presented at the first World Congress on Health and Martial Arts in Interdisciplinary Approach, HMA 2015 [29]. In the study, the authors expanded experimental methods by including simulations of falls that are similar to those occurring in real life situations. The purpose of this study is to show its usability by presenting validation procedure of rotating training simulator device.

## 2. Material and methods

### 2.1. Participants

The participants were chosen from a group of 128 students of physical education of the University of Zielona Góra. Participants were divided into two groups. First group of 96 students were

randomly selected for test conducted in 2014 and 2015. Second group was composed of 32 participants, selected for conducting studies in 2016 and 2017. Due to criteria of validation procedure, two students performed task correctly, but in different manner regarding determining angles in knee joint. This factor excluded them from the overall analysis due to impossibility of comparison conditions. The students were physically active, often practicing a particular sport discipline with the mean age of 25.4.

In the first group, among all participants, 59 students agreed to participate in forced simulation fall test. Second group included those students, who fall in the first attempt for all applied circumstances, so they were qualified for test-retest circumstances.

There was a formal consent granted by the Bioethical Committee of the Regional Medical Council in Zielona Góra for conducting this research under the number 4/55/2014. The experiment was conducted in 2014 to 2017.

## 2.2. Assessment procedure

Falls were performed with certain frequencies;  $f_1 = 0.2$  Hz,  $f_2 = 0.23$  Hz,  $f_3 = 0.26$  Hz, and  $f_4 = 0.3$  Hz. In the experiment, the selected frequencies correspond to an average line velocity of a subject's center of gravity:  $V_1 = 1.0$  m/s,  $V_2 = 1.15$  m/s,  $V_3 = 1.3$  m/s, and  $V_4 = 1.5$  m/s, acquired after application of the following equation:

$$V = 2\pi f r \quad (10)$$

The velocity was determined basing on the reports of other authors, who tried to define peak slip velocity which would definitely result in a fall. Strandberg and Lanshammar suggested that a slip over a distance of 10 cm with peak slip velocity above 0.5 m/s could result in a fall [30]. Other authors report that a fall will occur at a peak slip velocity above 1 m/s [31] and even 1.44 m/s for young people [32]. That is why a board run on a longer distance can be compared to loss of balance on, for example, ice or oil spill.

For a subject to have an inertial force act on him properly, it was necessary to assume, after releasing the grip, the posture as shown in **Figure 1**. It was forbidden neither to move feet on the board before it hit the pin nor to lean the body forward. Otherwise, the trial was repeated. All the falls performed by the trainees were recorded by cameras. The positions of the cameras made it possible to view the motor activities both from the left as well as from the right. The way a particular fall was made was assessed by analyzing successive frames.

First task in immediate fall test (IFT) test begin with command "fall immediately." This condition is applied to situations in some sports. For example, football players may decide to fall immediately after action of external force, without fight to maintain balance. This strategy may lower the risk of injury. After tested person perform this task, three body parts were assessed. Errors performed by "head" (hitting a ground), "hands" (supporting while landing), and "hips" (correct is to bend the knee in a value higher than 90°). The same criteria of assessment were applied for IFT and FFT tests. Assessment of knee flexion was performed with commonly used manner in physiotherapy standards [33]. Each body parts were given



scores: 1 point for “hip” or “head” error and 2 points for “hands” error, depending supporting on one or both hands. When performing a fall from the rotating training simulator, the participants first jumped off on one foot. Jumping off with both feet was impossible because of a sudden disc movement in the opposite direction after it bounced from the first pin. That is why for assessing body control during a fall, the criteria from the first STBIDF task were taken, counting from the moment when after landing a subject started to lose balance while trying to stand on one leg.

In the same way as in STBIDF test, tested person always entered room of testing separately, to avoid seeing each other during performing exercises on rotary trainer. Experiment was divided into two phases. Firstly, IFT test was performed. Tested person, executed command “fall immediately” directly after desk was stopped and they lose balance due to action of external force. If tested person committed serious “head” and “hips” errors on the lower velocities, they were not permitted to perform on higher velocities because of safety reasons. That is the reason why number of tested subjects decreases alongside with the increased velocity. Secondly, tested persons performed forced fall test (FFT). Same exclusion criteria as in IFT were applied. If tested person maintains balance after landing, such result was not included for specific velocity. After a week, there was retest for the same individuals with the same conditions (test (t1)–retest(t2)) validation procedure.

In order to compare the test results, subjects must perform a fall backward in such a way as to make the positioning of particular body parts properly visible on a freeze frame on XY plane, both from the left as well as from the right. This analysis is possible when the position of the body is similar to the one in a gymnast’s back flip (**Figure 3**). It was possible for 98% of the experiment participants. However, some people can perform a fall backward with a lateral body position (**Figure 4**). Such a fall method is used in some combat sports, e.g., aikido, which was presented by Mroczkowski in the film “relative immobility” [26]. Comparing results of tests performed with the above-mentioned body position would be difficult, especially in terms of defining the knee joint angle during a fall.

### 2.3. Validation procedure

Construct validity is determined by test conditions itself. During the test, tested person falls as a result of losing balance due to action of external force, which is the same reason why people fall in real life situation. People can fall in a different manner, revealing their own motor habits during loss of balance and contact of the body with the ground. For fulfilling predictive validity, two possible responses of tested people were considered. In a first option (IFT), in a moment of balance loss, tested person immediately started to control body movements to eventually lie down safely. In the second option (FFT), tested person falls only if they cannot maintain balance. In a real life situation, people mostly are trying not to fall and they decided to do so in last resort. In those two different options, occurrence of similar motor habit is expected. Readiness to fall immediately or fighting for maintaining balance should not affect a way, how someone is controlling his body movement during collision with the ground. Fall is understood as unintentional balance loss; however, lack of difference between decisions of tested persons regarding undertaken strategy will allow to determine predictive



validity. For that purpose, T Student for dependent samples was computed for results of IFT and FFT. Because conditions of FFT did not require, that person have to fall if he can maintain balance, there should be an increase in number of tested persons alongside with the increase of force that causes fall. Increase of fallers alongside with increase in velocity will additionally confirm validity, which simulates real life situation, where forces causing falls are different, and probability of fall is increased when causing force is bigger.

Validation procedure requires confirmation, if test conducted on the device is reliable, so if there is repeatability of results. Comparison of results in a procedure of test/retest condition in a 1 week period was performed, to avoid significant changes in tested persons behavior and experiences. Comparison was performed separately for IFT and FFT. Each of four applied velocities were compared separately. For determining reliability of tests, T Student for dependent samples was applied because of pointing criteria applied in tests. For head and hips errors, there are only 0 or 1 point, where lack of differences between results needs to be done to determine repeatability of results. Additionally, for both test, correlation between results of both test in test-retest conditions were conducted.

For confirming reliability of tests on the device, it was resolved if applied assessment criteria is repeatable by independent observers. Two students of physical educations conducted independent assessment of tested subjects and then, it was compared with an expert evaluation. For revealing such correlation of assessment, intraclass correlation coefficient was computed.

Moreover, presenting a proportion of quantity of participants who falls, to all who participate during FFT, will indicate probability of fall after application of specific force. Participants, who fall at lower velocities, are more likely to fall than people who maintain balance even at higher velocities. Differences in number of fallers will confirm that testing on rotating simulator can not only diagnose motor habits during a fall, but also ability to maintain balance in a moment of its loss during action of external forces.

## 2.4. Ethical considerations

Ethical points including conduct and reporting of the research, contributions, authorship as well as declaration of Helsinki on ethical principles for medical research involving human subjects were considered.

## 3. Results

### 3.1. Predictive validity

For all applied variables for specific velocities, there were no significant differences between points acquired by tested people in IFT and FFT (for first assessment). Alongside with the increase in velocity, there is increase of fallers from 23 people for lowest velocity (v1) to 43 for highest (v4). There is a slight difference between v3 and v4. The lowest difference was revealed for hand errors, while the highest was for hip errors (**Table 1**).

Velocity	Variable	N	Difference	Standard deviation difference	t	Degrees of freedom	p-value	Confidence -95%	Confidence +95%
v1	Hands	23	0.00	—	—	22	—	—	—
	Head	23	-0.087	0.417	-1.000	22.000	0.328	-0.267	0.093
	Hips	23	0.130	0.344	1.817	22.000	0.083	-0.018	0.279
	Sum	23	0.043	0.562	0.371	22.000	0.714	-0.200	0.287
v2	Hands	34	-0.029	0.171	-1.000	33.000	0.325	-0.089	0.030
	Head	34	-0.029	0.171	-1.000	33.000	0.325	-0.089	0.030
	Hips	34	0.029	0.171	1.000	33.000	0.325	-0.030	0.089
	Sum	34	-0.029	0.300	-0.572	33.000	0.571	-0.134	0.075
v3	Hands	42	0.024	0.563	0.274	41.000	0.785	-0.152	0.199
	Head	42	-0.071	0.463	-1.000	41.000	0.323	-0.216	0.073
	Hips	42	0.119	0.395	1.952	41.000	0.058	-0.004	0.242
	Sum	42	0.071	0.973	0.476	41.000	0.637	-0.232	0.375
v4	Hands	43	0.000	0.488	0.000	42.000	1.000	-0.150	0.150
	Head	43	0.023	0.556	0.274	42.000	0.785	-0.148	0.194
	Hips	43	0.093	0.426	1.431	42.000	0.160	-0.038	0.224
	Sum	43	0.116	0.956	0.797	42.000	0.430	-0.178	0.411

**Table 1.** Test T for dependent samples between IFT and FFT for each variable and all velocities ( $p < 0.005$ ).

### 3.2. Repeatability

In test-retest conditions in IFT, tested persons did not reveal significant changes between results of repeated assessment. For v3 velocity, number of tested person decreased. The lowest difference was for hand errors. Tested people did not reveal any difference between sum of points for v4 velocity (**Table 2**).

For specific errors of body control, tested people did not reveal significant changes between results of repeated assessments. However, for most of situations (v1,v2,v4), sum of point was statistically significant. For two velocities (v1 and v4), there were no differences between committed hip errors. Revealed difference for hand errors was higher than in IFT. Firstly, at the beginning of increase in velocity, number of qualified person increased, but at velocity v3, it stabilized (**Table 3**).

For sum of all velocities (v1-v4) for both test, all correlations were statistically significant. In IFT, highest correlation was revealed for hip errors ( $r = 0.818$ ). Correlation for IFT had moderate level for hand and head errors ( $r = 0.651$  and  $r = 0.652$ , respectively) and high for hips errors. That is why there is high correlation between sum of point acquired by tested

Velocity	Variable	N	Difference	Standard deviation difference	t	Degrees of freedom	p-value	Confidence -95%	Confidence +95%
v1	Hands	94	0.021	0.206	1.000	93.000	0.320	-0.021	0.064
	Head	94	0.064	0.353	1.751	93.000	0.083	-0.009	0.136
	Hips	94	-0.011	0.274	-0.376	93.000	0.708	-0.067	0.046
	Sum	94	0.074	0.513	1.407	93.000	0.163	-0.031	0.180
v2	Hands	94	0.000	0.388	0.000	93.000	1.000	-0.079	0.079
	Head	94	-0.043	0.357	-1.157	93.000	0.250	-0.116	0.030
	Hips	94	-0.032	0.177	-1.751	93.000	0.083	-0.068	0.004
	Sum	94	-0.074	0.553	-1.305	93.000	0.195	-0.188	0.039
v3	Hands	85	0.012	0.244	0.445	84.000	0.657	-0.041	0.064
	Head	85	-0.012	0.393	-0.276	84.000	0.783	-0.097	0.073
	Hips	85	-0.024	0.308	-0.705	84.000	0.483	-0.090	0.043
	Sum	85	-0.024	0.654	-0.332	84.000	0.741	-0.165	0.118
v4	Hands	83	0.000	0.312	0.000	82.000	1.000	-0.068	0.068
	Head	83	0.012	0.247	0.445	82.000	0.657	-0.042	0.066
	Hips	83	-0.012	0.247	-0.445	82.000	0.657	-0.066	0.042
	Sum	83	0.000	0.584	0.000	82.000	1.000	-0.128	0.128

**Table 2.** Results of IFT for test(t1) to retest (t2) using T Student for dependent samples.

persons ( $r = 0.711$ ). For FFT test, tested person revealed very high correlation for hand errors ( $r = 0.843$ ), but low correlation for hips and head errors ( $r = 0.373$  and  $r = 0.218$ , respectively). Still, sum of points acquired for both assessment is strongly correlated ( $r = 0.774$ ) (**Table 4**).

Values of intraclass correlation coefficients between two student observers (ob1, ob2) and between them and an expert for different circumstances were at good or excellent level. It is a proof of a very high reliability of the test (**Table 5**).

T1, T2–test and retest attempts in IFT; N–number of participants; ob1,ob2—student observers.

While performing first attempt of FFT, for velocities v1 and v2, there were more participants who maintain balance after precipitation. For velocities v3 and v4, there were more fallers than those who maintain balance. There was slight difference between fallers for velocities v3 and v4 (**Figure 7**).

Velocity	variable	N	difference	standard deviation difference	t	degrees of freedom	p-value	confidence -95%	confidence +95%
v1	Hands	14	0.214	0.426	1.883	13.000	0.082	-0.460	0.032
	Head	14	0.071	0.267	1.000	13.000	0.336	-0.226	0.083
	Hips	14	0.000	0.392	0.000	13.000	1.000	-0.226	0.226
	Sum	14	0.286	0.469	2.280	13.000	0.040	-0.556	-0.015
v2	Hands	25	0.200	0.577	1.732	24.000	0.096	-0.438	0.038
	Head	25	0.080	0.277	1.445	24.000	0.161	-0.194	0.034
	Hips	25	-0.040	0.351	-0.569	24.000	0.574	-0.105	0.185
	Sum	25	0.240	0.663	1.809	24.000	0.083	-0.514	0.034
v3	Hands	30	0.133	0.434	1.682	29.000	0.103	-0.295	0.029
	Head	30	0.100	0.403	1.361	29.000	0.184	-0.250	0.050
	Hips	30	0.033	0.183	1.000	29.000	0.326	-0.102	0.035
	Sum	30	0.267	0.521	2.804	29.000	0.009	-0.461	-0.072
v4	Hands	29	0.172	0.468	1.983	28.000	0.057	-0.351	0.006
	Head	30	0.067	0.450	0.812	29.000	0.423	-0.235	0.101
	Hips	30	0.000	-	-	29.000	-	-	-
	Sum	30	0.233	0.568	2.249	29.000	0.032	-0.446	-0.021

**Table 3.** Results of FFT for test (t1) to retest (t2) using T Student for dependent samples ( $p < 0.005$  marked as red).

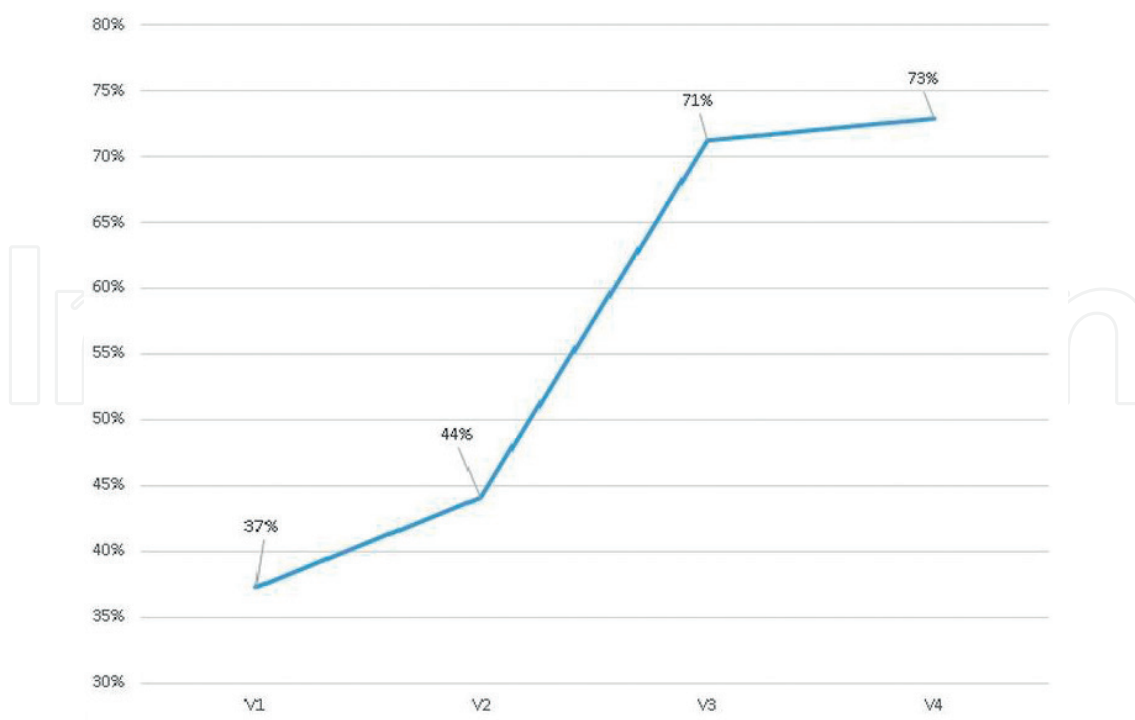
variable	IFT (n=356)	FFT (n=99)
hands	0.651	0.843
hips	0.818	0.218
head	0.652	0.373
sum	0.711	0.774

**Table 4.** R Spearman correlation results for sum of velocities (v1–4) for results of test-retest of both IFT and FFT ( $p < 0.005$  marked as red).

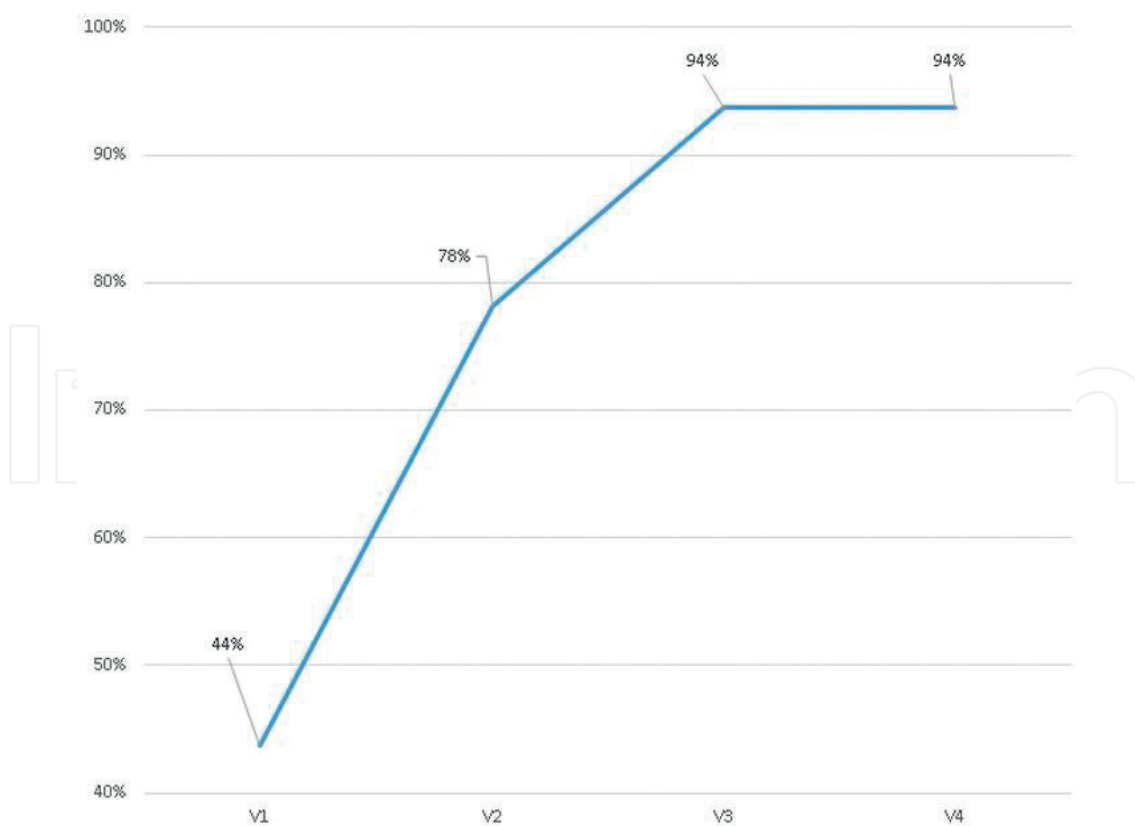
V1						
	T1			T2		
	ob1-ob2	ob1-expert	ob2-expert	ob1-ob2	ob1-expert	ob2-expert
	N = 94	N = 94	N = 94	N = 94	N = 94	N = 94
Hands	0.951	1.0	0.951	1.0	1.0	1.0
Hips	0.941	0.941	0.882	0.934	0.931	0.939
Head	1.0	1.0	1.0	0.934	0.966	0.967
V2						
	T1			T2		
	ob1-ob2	ob1-expert	ob2-expert	ob1-ob2	ob1-expert	ob2-expert
	N = 94	N = 94	N = 94	N = 94	N = 94	N = 94
Hands	0.853	0.853	1.0	0.827	0.827	1.0
Hips	1.0	0.934	0.937	0.965	0.962	0.925
Head	1.0	0.968	0.968	0.943	0.972	0.972
V3						
	T1			T2		
	ob1-ob2	ob1-expert	ob2-expert	ob1-ob2	ob1-expert	ob2-expert
	N = 80	N = 80	N = 80	N = 83	N = 83	N = 83
Hands	1.0	1.0	1.0	1.0	1.0	1.0
Hips	1.0	1.0	1.0	1.0	1.0	1.0
Head	1.0	0.958	0.958	0.919	0.96	0.96
V4						
	T1			T2		
	ob1-ob2	ob1-expert	ob2-expert	ob1-ob2	ob1-expert	ob2-expert
	N = 78	N = 78	N = 78	N = 78	N = 78	N = 78
Hands	1.0	1.0	1.0	1.0	1.0	1.0
Hips	1.0	0.962	0.960	1.0	0.963	0.963
Head	1.0	1.0	1.0	1.0	1.0	1.0

**Table 5.** Intraclass correlation coefficients between scores given by students (ob1, ob2) and those given by an expert for different tested circumstances in first attempt of IFT. All correlations are significant ( $p < 0.05$ ).

In test-retest conditions, number of participants were lower ( $n = 32$  instead of  $n = 59$ ). For velocity v1, more than half of participants managed to maintain balance. Between v1 and v2, there was significant increase in number of fallers. For velocities v3 and v4, almost all participants fall, with no difference in number of fallers (**Figure 8**).



**Figure 7.** Proportion of fallers to all participants during first attempt of FFT (t1) (n = 59).



**Figure 8.** Proportion of fallers to all participants in FFT for test-retest conditions (t1/t2) (n = 32).



## 4. Summary

Data presented in **Figure 6** confirm that alongside with increase in velocity on which fall occur, there was increase in number of fallers. In formula 8, it states that alongside increase in linear velocity, there is increase in inertia force affecting practitioner and causing a fall. Therefore, increase in a force causing a fall is connected with bigger probability of fall, which is confirmed by obtained results. At the same time, among randomly chosen group of 59 people, which participate in FFT, 73% fell for highest velocity (43 participants). Therefore, 27% of tested people have sufficient balance skills, which allows them to maintain balance after action of external forces during experiment. For the lower velocities, there were more participants who maintain balance. This phenomena confirm construct validity of tests on this device, as this device is creating proper circumstances accordingly to definition of a fall.

Entry studies of authors indicate that there is correlation between probability of fall occurrence in FFT and level of coordination in rotational motion by nonapparatus tests.

For FFT in test/retest conditions, only those participants who fell for all velocities during first attempt were included. The retest results indicate improvement in maintain balance for some individuals (**Figure 8**). Some of participants did not fell for specific velocities, and there were more of nonfallers for lower velocities, when precipitating force is lower.

This process indicates that there was improvement because of acquired motor experience. We can conclude that rotating simulator could be used as a tool for improving balance after its loss during action of external forces as in circumstances created in FFT.

Immediately, there appears a suggestion for a coach, who trains athletes in a specific sports discipline where a risk of a fall is high, to apply a safety fall diagnostics in his work. The diagnosis should be done before the contestants are allowed to compete at a level, where the risk of injury is raised for players without proper abilities of body control during a fall or collision [34].

Application of the apparatus of that kind would be of special importance to people, who in their work may encounter forces responsible for a fall. Such people may, for example, include firemen, soldiers, policemen, stuntmen, or athletes of various sports disciplines. Simulated falls, for example, in full equipment might expose unconsidered disturbances in motor control because of carried equipment or specific uniform. Proper defensive mechanism during extreme situation will work only if trained persons had met similar situations in the past. Acting accordingly during a duty is more like trained habits. The same situation is when someone is exposed to fall, especially in critical situation, like firefight. Moreover, because most of nonfatal injuries caused by falls occur when worker is tired due to prolonged action [8]. Therefore, rotating training simulator would be perfect during their training as supplementary element of training course to improve their competence.

In comparison of IFT and FFT, there were no significant differences between test results (**Table 1**) for errors during control of specific body parts as well as there were no significant differences between conditions of test/retests for both applied tests (**Tables 2 and 3**). Obtained

results may justify suggestion, that motor actions of a man during a fall are not random. For tested students, we can conclude that during a fall, there is a motor habit. Improving that habit could lead to reduction of body injuries during a fall. It is right to say that “sustaining injury” is not an unavoidable consequence of fall [24]. Performing certain movements during a fall is possible in certain limits of precipitating forces values [17].

Formula 4 explains that for fall performing during IFT test, that energy during a fall changes into kinetic energy of the motion and rotation and energy connected with rolling friction. For FFT analysis, formula 5 should be applied. While performing FFT, a participant tries to protect himself from falling by proper muscle contractions. As a result, mechanic energy during a moment of a fall is reduced because of work „W” done by muscles, which inhibit a fall. By this work, there is deceleration of fall. This could result in different numbers in “head” errors, as in some cases, kinetic energy of movement may be insufficient to fully roll the body over a head. Although, results of IFT and FFT did not reveal significant differences between committed errors, there is a clear difference in strength of correlation between IFT and FFT for both “hips” and “head” errors (**Table 4**). Because each time value of “W” could be different, as work performed by muscles differs as person fights to maintain balance. From the moment of balance loss due to a slip, a human has around 200 ms to start motor operations leading to an effective control of the body during a fall [35]. A variety of body motor control abilities and changes in reaction speed due to a changing spatial body orientation lead to taking various actions and strategies in order to prevent the body from an injury. An untrained person, in a real life situation, would try to maintain balance at all costs, that is why precipitated, and he would try to regain balance as long as he can [36]. An untrained person would fall if the force applied would be too strong for him to maintain balance [37].

The obtained results (**Tables 2 and 3**) demonstrated, that the rotating training simulator is a reliable assessment tool used for diagnosing susceptibility to injuries during a fall caused by external forces, showing repeatability of the acquired scores. The results demonstrated in **Table 5** show a big application value of the test. Scores given by observers having been instructed about assessment criteria are sufficient to make a reliable judgment about susceptibility of certain body part injuries during a fall of a tested person. A possibility to verify the trainees’ performance assessment on the recorded footage and presenting their mistakes to them plus the possibility to rate people’s motor control progress both in a point scale and in a visual manner makes rotating training simulator applications corresponding to the idea of complementary health-related training [11].

The presented method of evaluating susceptibility of body injuries during a fall by using the rotating stimulator could be upgraded and expanded by applying proper biomechanics motion capture devices. That kind of gear could allow to measure acceleration of specific body parts during a fall or to analyze changes of angles between joints in a specific moment. Using a mattress during tests reduces accelerations, which occur when the body contacts the ground. Reducing the size (thickness) of mattress might improve accuracy of measurements. But on the other hand, it might be dangerous for inexperienced participants or those with bad motor habits. An advantage of using adequate sensors, like XSENS system [38], would be a possibility to measure accelerations and angles

among particular body segments in XYZ dimension. Further analysis will allow to gather knowledge about other body configurations during a fall and check, which is the best for minimizing potential injuries.

In the methodology of a safe fall, it is said that a fall should not take longer than 1/3 of all training session time [39]. Application of rotating training simulator during a training session and elaborating a proper training methodology will be a goal of future studies. We need to take into account the fact that using apparatus assessment tools requires more funds and a special training ground. Advantage of rotating training simulator is the fact that none of the tested people was injured and that the test was carried out by a qualified person who applied the right rotating frequency causing that external forces were not too strong for subjects to cope with and that might result in an injury. Further studies might involve accepting different types of body configuration during a fall, such as the mentioned side configuration (**Figure 3**). This might require changing the assessment criteria of susceptibility to injuries during a fall. Teaching safe falls is given little attention in physical education curricula or treating them as supplementary exercises in sport. Authorities ignore this injury factor for young population and pay no attention to developing practical motor competences that can increase people's safety. It is proved that even children from 10 to 12 years old have a high level of injury risk [40]. Therefore, it seems advisable to take a proper action to teach kids proper motor habits, which will reduce risk of injuries, rather than taking care of them in hospital after accidents.

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