Similarities and differences of body control during professional, externally forced fall to the side performed by men aged 24 and 65 years

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B Data Collection
C Statistical Analysis
D Manuscript Preparation
E Funds Collection

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Abstract

Background & Study Aim: Cognition of kinematics of body movement during balance loss, fall and collision with the ground in various circumstances is a basic condition of both expanding our knowledge of these phenomena and optimizing effective prevention of falls and collisions with the ground and vertical obstacles. The aim of the study is to determine whether a substantial difference in age of men training combat sports results in differentiation of body balance during professional, externally forced fall to the side.

Material & Methods: Two men have been subjected to the study: 65-years-old scientist (A), who has been training judo and other combat sports for over than fifty years and is professionally involved in teaching people how to fall down safely; 24-years-old physiotherapist (B), who trains judo as an amateur, have completed specialist course on safe falling and used those exercises in his kinesitherapy practice (including patients with psychological disorders). The analysis of kinematics of body movement during forced fall has been performed by an assistant. Tested person was trotting in place on the hard ground and each ankle joint was wrapped with a separate judo belt *(obi)*. The assistant was knocking each joint out of balance by pulling one of the belts. Tested person was not aware in which direction (right or left side) he would be knocked out by the force causing the fall. The analysis included four falls to the left side. Measurements have been performed with the use of MVN Biomech system (XSENS) based on inertial sensors equipped with accelerometer, gyroscope and magnetic field sensor.

Results: Most falls of both subjects are similar in terms of duration and trajectory angle of the mass centre. The beginning of lowering mass centre occurs later in person B. At the end of the performance of the fall person A causes a slight flattening of the trajectory of the mass centre which may indicate that such preparation of the body and movement of its parts is to slightly decrease the vertical speed of mass centre before contact with the ground. Person B finishes the fall with setting the torso angle of around zero degrees relative to the ground (therefore, directly after collision with the ground it is relatively motionless). After reaching zero degrees, the torso angle of person A passes to negative values (–25°), indicating performance of rolling the trunk. Such behaviour allows for additional dispersal of energy reducing thereby the force of body impact on the ground.

Conclusions: The retirement age does not necessarily involve a deterioration of ability to control the body during unintended fall and collision with the ground. On the contrary, suitable training results in the fact that such person can optimally protect his body in such circumstances and function more effectively in comparison with considerably younger people. Obtained results are, moreover, an empirical proof of methodological correctness of safe falls modelled on techniques used in judo (ukemi waza).

Key words: biomechanics analyses · injury prevention · ukemi waza

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Human body strain energy (its value and distribution) – has an dominating influence on occurrence of injuries during falls. Jaskólski and Nowacki [13] explain this phenomenon in a theoretical way and assume that the surface of a human body is homogenous and flexible. Total strain energy is a sum of **strain energy of distortion** and **strain energy of volume change**. They assume strain energy per volume unit as an essential indicator, the value of which exerts an important impact on creation of injuries:

$e = m^2 \cdot dV^2 / 2E \cdot F^2 \cdot t^2$

where: *dV* – difference in speed before and after the fall (in practical terms equal to the speed component immediately before collision perpendicular to the base); *E* –Yung's module; *F* – surface of force interaction; *t* – time of braking at collision [13]

CFR – symbol to general distinction of fall hazard circumstances [16]

Degree [*shortening:* deg] – usually denoted by ° (the degree symbol), is a measurement of planeangle, representing $^1/_{360}$ of a full rotation. It is not an SI unit, as the SI unit for angles is radian, but it is mentioned in the SI brochure as unaccepted [38]

Non-apparatus test – that motoric test (exercise endurance test) of the required reliability (accurate and reliable), which use does not require even the simplest instruments [40]

Quasi-apparatus test – can be conducted with simple instruments (a stopwatch, a ruler, a measuring tape, etc.) [40]

Posture – *noun* the position in which a body is arranged, or the way a person usually holds his or her body when standing [39]

Position – *noun* 1. the place where a player is standing or playing 2. the way in which a person's body is arranged [39]

Perceptual sentence – in the methodological meaning is constative utterance the result of some observation (result of the measurement).

Introduction

Approximately 90% of all injuries involving the pelvic girdle and the femur is caused by a fall usually resulting from a fall to the side [1]. Femur fractures are so bothersome both to the injured person and those from immediate environment that they result in lowering the quality of life. An injured person loses permanently or for the long time his independence, whereas a significant social impact involves high expenditure on health care [2].

Femur fractures are a public health problem of a global range. It has been estimated that in 2050 the number of such fractures will amount to 6.3 million [3]. Due to fracture and required hospitalization the risk of death is tripled during the six months after the injury and increased during the next six years after the occurrence of the fracture [4]. In general, falls (regardless of which body part is colliding with the ground) are one of the main causes of mortality among the elderly. The number of registered falls increases by approximately 30% in people aged over 65 [5-7].

Approximately 30 % of the elderly fall in their homes during a year while performing daily activities, half of which cannot raise oneself [8, 9]. Falls in domestic environment can be characterized with lower acceleration and lower impact forces on the ground. It is associated with furnishings and possibility to partially absorb the shock from the collision with the ground by beforehand leaning on an arm on the chair, bed, etc. Such falls usually do not end with fractures. Approximately 40 % of falls occur while walking. Circa 5 % of them end with a fracture, while 5-10 % with serious injury requiring medical care. Falls lead to approximately 12% of deaths and are the sixth leading cause of death among the elderly [10]. Weakening of muscle strength and coordination occurring with age is reflected by slower movement. Gait with short phase of moving the limb as well as the fact that it is raised too low cause the risk of tripping. Weakened muscle strength results also in lack of control over the phase of straining a limb after a step. Too strong and uncontrolled heel impact against the ground in case of uneven or slippery ground also increases the risk of fall. Fall to the hip may result in femur fractures mainly due to collision of greater trochanter with the ground or fracture to the femoral neck [11].

One possible factor contributing to smaller number of femoral fractures in young people in comparison with the elderly is the biomechanics of the fall itself (even though it is not fully professional). The number of falls to the side among the elderly is six time higher compared to a fall forwards or backwards and 30 times higher if the hip collides with the ground. Lower number of falls to the side among adolescents may be associated with the transfer of the momentum of the fall to upper limbs or knees, i.e. using entire muscle strength to change the trajectory of the fall by the rotation. At the same time, adolescents are reported to sustain more wrist injuries caused by a fall [12]. Even if a young person falls to the side, it is the sufficient muscle strength and generally higher control over the body in comparison with the elderly that allow to start the collision with the ground from gluteal muscle and afterwards with other body parts (colliding side of the body), what in turn initiates dispersion of the impact force. This manoeuvre protects pelvic girdle and the femur. However, lack of professional preparation and experience in terms of safe fall cause more common injuries to the wrist and knees. Unprepared people usually precede the attempt to amortise the fall with either leaning on one's arm (arms) or colliding with the knee (knees) or at the same time with an arm and knee (arms and knees).

Unfortunately, safe falls theory is not commonly known. In brief – a falling individual may decrease the unit deformation energy by: (a) increasing body area in contact with the base during fall; (b) increasing time of braking or braking distance during collision itself; (c) the muscles are appropriate amortisation means for shocks that a human body is submitted to (during a fall the muscles tend to play the amortising role best if the joint system over which they run is set at the most convenient angle) [13].

Important empirical evidence proves that understanding the safe falls theory greatly increases the effects of teaching safe falls to adolescents and elderly [14, 15]. Cognition of kinematics of body movement during balance loss, fall and collision with the ground in various circumstances is a basic condition of both expanding our knowledge of these phenomena and optimizing effective prevention of falls and collisions with the ground and vertical obstacles.

The aim of the study is to determine whether a substantial difference in age of men training combat sports results in differentiation of body balance during professional, eternally forced fall to the side.

Material and Methods

Participants
Two men have been subjected to the study: 65-years-old scientist, body height 181 cm, body weight 84 kg (A), who has been training judo and other combat sports for over than fifty years and is professionally involved in teaching people how to fall down safely; 24-years-old physiotherapist, body height 183 cm, body weight 77 kg (B), who trains judo as an amateur, have completed specialist course on safe falling and used those exercises in his kinesitherapy practice (including patients with psychological disorders). Both participants signed an informed consent for research.

Research procedure
The analysis of kinematics of body movement during forced fall has been performed by an assistant (see *ArchBudo Academy*: "Forced fall to the side"). Tested person was trotting in place on the hard ground and each ankle joint was wrapped with a separate judo belt (*obi*). The assistant was knocking each joint out of balance by pulling one of the belts. Tested person was not aware in which direction (right or left side) he would be knocked out by the force causing the fall. The analysis included four falls to the left side. Measurements have been performed with the use of MVN *Biomech* system (XSENS) based on inertial sensors equipped with accelerometer, gyroscope and magnetic field sensor.

The measurement of movement kinematics allows for determination of the movement trajectory of individual body parts and determination of their speed and acceleration.

In this paper the 'Results' part has been written in different manner than in a standard original paper. Part 'Results' comprises not only a set of perceptual sentence but also contains interpretations.

Statistical Analysis
Means and standard deviations are given as descriptive statistics. In order to determine the significance of the differences between the two means (results man A and man B), at test for independent samples was used.

Results (and interpretation)

The analysis of displacement and speed of the movement of body mass centre
In the majority of duration of safe (controlled) fall to the side an estimated angle of movement trajectory of the body mass centre is similar in both men (Figure 1). Differences involve details on controlling various body parts prepared for safe collision with the ground.

Man A at the end of the fall slightly flattens the movement trajectory of the body mass centre (this may indicate that such preparation and movement of entire body to safe fall results in slight reduction of vertical speed of the mass centre just before contact between body and the ground). This relationship is also discernible in the graph presenting the speed of body mass centre (Figure 2).

The beginning of lowering the mass centre during controlled fall occurs later in man B (what may indicate slightly longer time required to prepare the entire body to perform safe collision with the ground).

The analysis of changes to the angle between the torso and the ground
During the safe fall performed by man A the torso angle after reaching zero degrees passes to negative values of approximately –25° (indicating that rolling the trunk more to the back was performed in the final phase of the collision with the ground – Figure 3/Photograph 1; such behaviour allows for additional dispersal of energy reducing thereby the force of body impact on the ground).

Safe fall of man B ends with setting the torso angle of around zero degrees (indicating that after the fall this person lies relatively motionless on the ground – Figure 3/Photograph 2).

Analysis of the trajectory of the arm movement performing absorbing impact during collision with the ground
Man A after making an impact against the ground with an arm (i.e. performing a significant activity to amortize the impact of the collision of the body with the ground) immediately lifts arms up and does not place them back on the ground (Figure 4/Photograph 3). Men B, on the other hand, directly after making an impact against the ground with an arm slightly lifts them up and immediately lowers them towards the ground. Afterwards, he keeps them in the same position until the end of the movement (Figure 4/Photograph 4 and 5).

Technique – *noun* a way of performing an action [39]

Safe fall technique – a method to control the body while it is losing the balance to provide effective shock absorption during collision with the ground or maximal minimization of potential injuries

STBIDF – the susceptibility test to the body injuries during the fall [28]

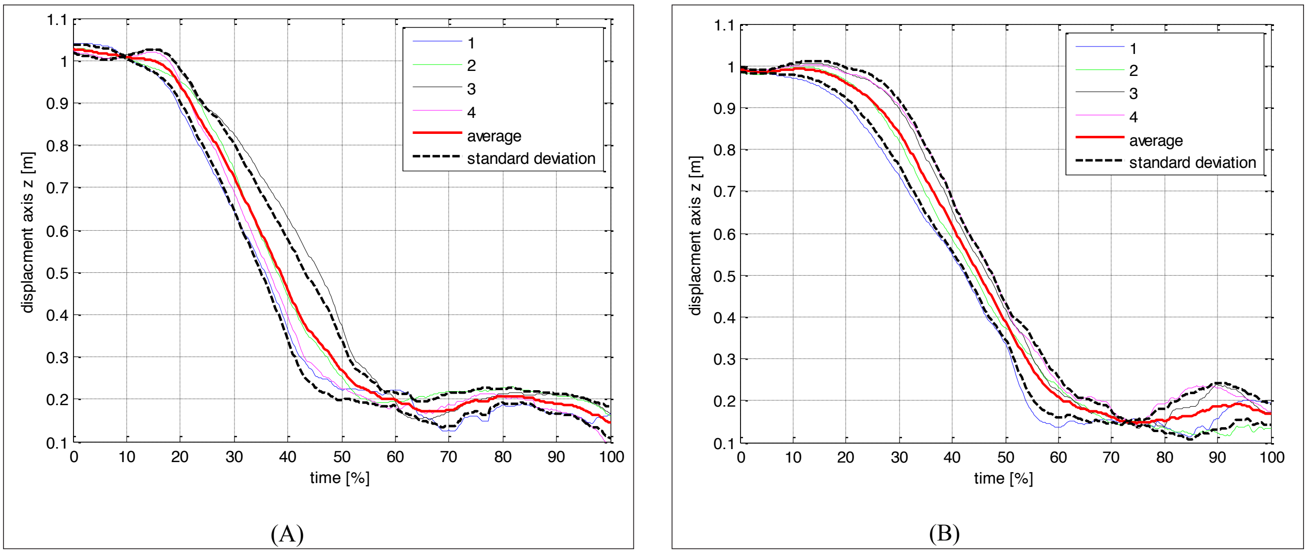


Figure 1. The displacement of the mass centre along the Z-axis: (A) 65-years-old man; (B) 24-years-old man

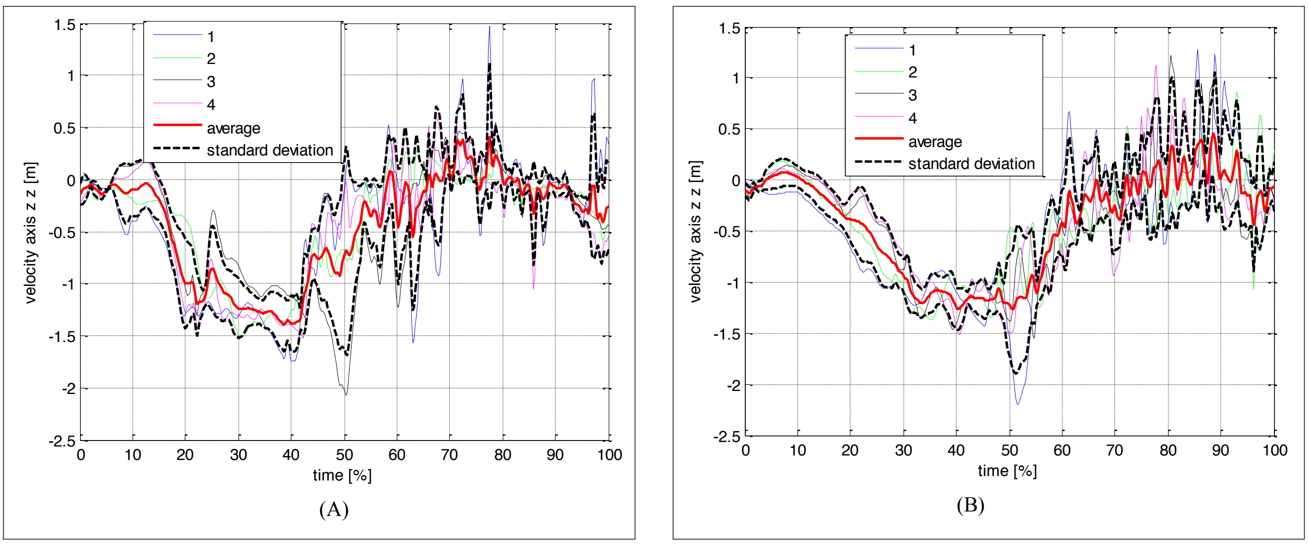


Figure 2. The speed of mass centre along the Z-axis: (A) 65-years-old man; (B) 24-years-old man

Table 1. Biomechanical characteristics of professional falls to the left performed by two men on the hard ground (each one performed four times)

Variable	Min torso angle [deg]		Max angle of the glenohumeral after the fall [deg]		Angle in the knee joint at the moment balance loss [deg]		Maximum displacement of the center of the left hand after the fall [m]		Speed of the body mass centre during the fall [m/s]	
	$\bar{x}$	±	$\bar{x}$	±	$\bar{x}$	±	$\bar{x}$	±	$\bar{x}$	±
Man A 65 years old	15.29	7.15	121.90	28.35	34.05	19.25	0.44	0.15	1.70	0.26
Man B 24 years old	3.25	0.93	72.74	3.83	14.02	5,45	0.063	0.009	1.64	0.38
Difference	12.04		49.16		20.03		0.377		0.06	
p	<0.02		<0.02		<0.10		<0.01		-	

The differences in the trajectory of arm movement arise directly from the manner of how the movement was performed with entire upper limb in glenohumeral joint (Figure 5). Man A after absorbing impact quickly bends the arm in glenohumeral joint to the angle of circa 130° (such movement of the limb allows for rolling the entire body more onto the back enabling additional, fluid dispersion of the energy of the fall and collision with the ground – Figure 5/Photograph 6). Man B, on the other hand, leaves upper limb straightened and abducted (thus, preventing from rolling onto the back and therefore, more energy from the collision with the ground must be dispersed in various body parts during direct collision with the ground – Figure 5/Photograph 6).

The analysis of bend angle in elbow joint of the arm performing absorbing impact during the collision with the ground

Another difference in movement of the upper limb in both man can be seen in the course of bend angle in the elbow joint (Figure 6). Man A starts his straightening movement before making an impact of the arm against the ground from an angle of circa 70° (Figure 6/Photograph 8), while in case of man B the angle varies between 30°-60° (Figure 6/Photograph 9).

The analysis of the movement of lower (supporting) limb before and after the fall

Trot on bent legs before the fall itself in case of man A (see *ArchBudo Academy*: "Forced fall to the side") indicates that he consciously expects balance loss and fall as well as that he is properly prepared for such events (probably bending a leg in knee joint to the greater angle will result in smoother changes of the speed of the mass centre of the entire body and thus the shock resulting from a fall and collision with the ground will be absorbed more effectively – Figure 7/Photograph 10 and 11).

The overall analysis of controlled fall to the side

Empirical data prompt the conclusion that main elements of effective body control during the fall to the side used by man A comprise losing the energy in the final phase of the collision with the ground by rolling the torso more onto the back and relaxing the entire body after the fall (it can be noticed on the graph showing the torso angle in relation to the ground, angle in glenohumeral joint as well as arm trajectory).

At the time of a fall and collision with the ground almost entire body of man B is stiffened (it may result in creation of large forces in joints, while lack of rolling onto the back in the final phase of the collision causes more forces originating from the contact with the ground).

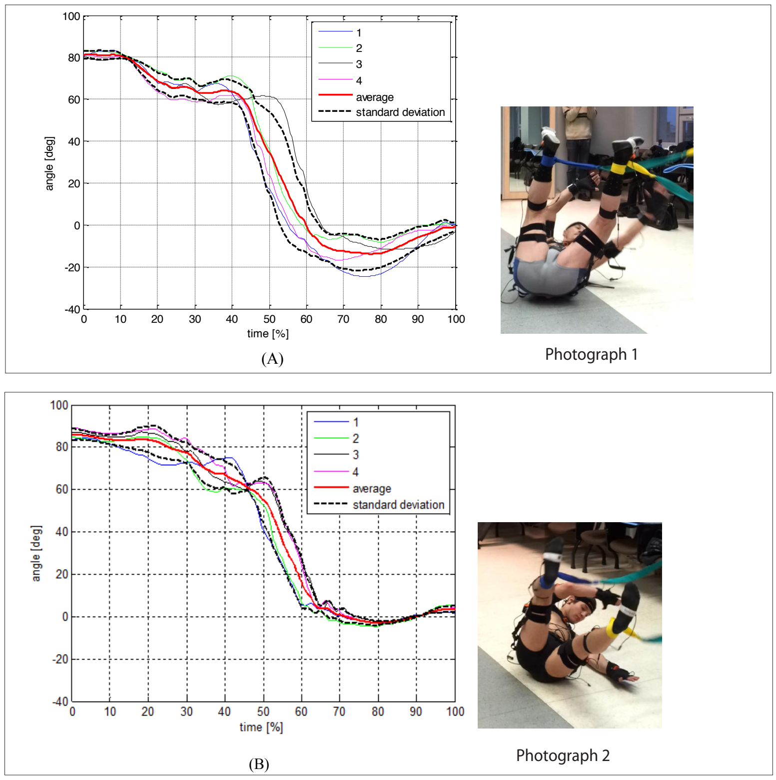


Figure 3. The torso angle relative to the ground (horizontal plane): (A) 65-years-old man; (B) 24-years-old man

The analysis of the duration of various phases of safe fall to the side on the hard ground (expressed in %) indicates two types of differentiation of studied man. Each of five factors differs in both arithmetic mean from four falls and in variation expressed by standard deviation (Figure 8). This differentiation is even more highlighted by biomechanical characteristics listed in Table 1. The only similarity is in the speed of the body mass centre during the fall (it proves that both men fall with similar speed, while details influence the type of body control and amortization of the collision with the ground, which can be reasonably interpreted in terms of quality of motor adaptation to each case of balance loss and inevitable fall to the side).

Discussion

Regardless of the cognitive value of empirical data analysed in this paper the experiment has provided some obvious evidence that a person is able to safely collide with a hard ground under the condition that he will be properly trained. Moreover, biomechanical analysis of repeated falls, although performed

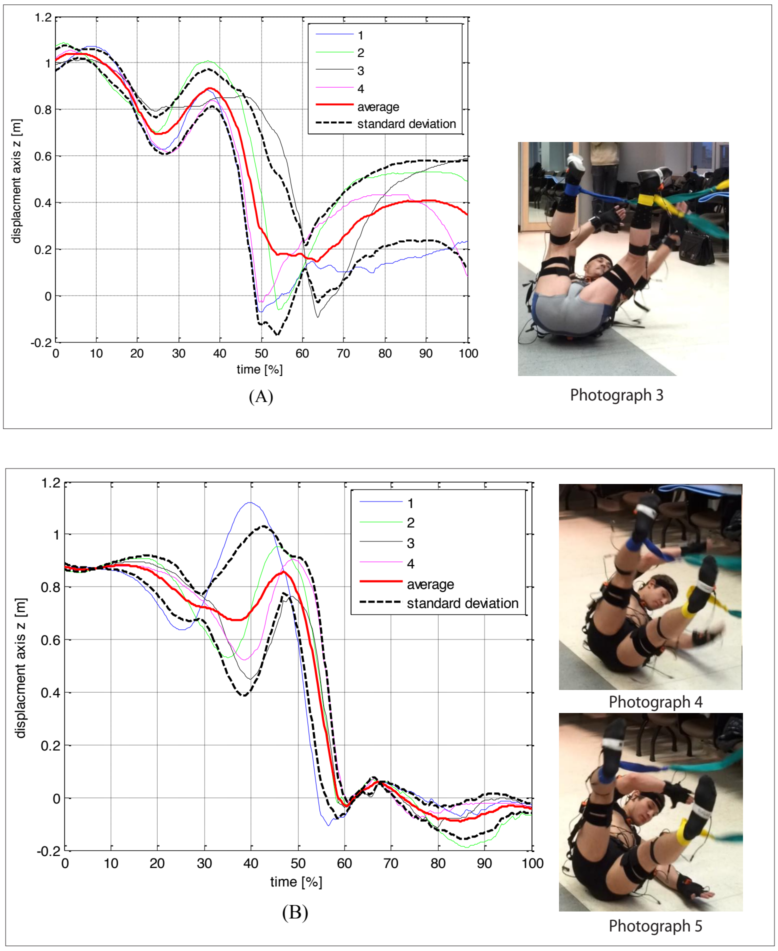


Figure 4. The displacement of the middle of left palm along the Z-axis: (A) 65-years-old man; (B) 24-years-old man

in laboratory conditions, reveals that in contrary to numerous sports techniques (based on closed movement habits) a significant part of effective body control during sudden balance loss and afterwards appropriate amortisation of the collision with the ground is the ability to adapt motorically to certain circumstances.

In this experiment balance loss of a person, who was trotting in place simulating elementary movement activity – walking, was caused by an assistant. He was pulling by judo belt wrapped around each ankle joint (left and right leg were wrapped separately) in any moment and caused a fall of a tested man either to the right or left side. The assistant made the decisions independently. Thereby, the conditions of the experiment reflected the circumstances of a balance loss categorized to CFR 3 category, which *includes the cumulative effects of any external force(s) and internal factors concerning a person performing an action; subgroup (a) fall hazard when even a simple motor activity is hindered by external conditions (e.g. walking on slippery surfaces)* [16]. It is such circumstance, when the ability of motor adaptation is a fundamental matter.

There are numerous specific circumstances in which fall can occur. Kangas et al. [17] have studied in laboratory conditions the acceleration data during experimental falls of 20 middle-aged volunteer subjects (mean age 48.4 ±6.8 years), who performed six different fall types: syncope; tripping; sitting on empty air, like when missing a chair while sitting down; slipping; lateral fall; rolling out of bed. Falls were completed on a soft mattress in a laboratory environment. The results of this study have been used by Kangas et al. [18] as the frame of reference for observation of real-life accidental falls in older people (15 females, 3 males, age above 65 years. The study showed similarities between real-life falls and experimental falls. However, Kangas et al. emphasize that some fall phases detected from experimental falls were not detectable in acceleration signals from heterogeneous real-life falls.

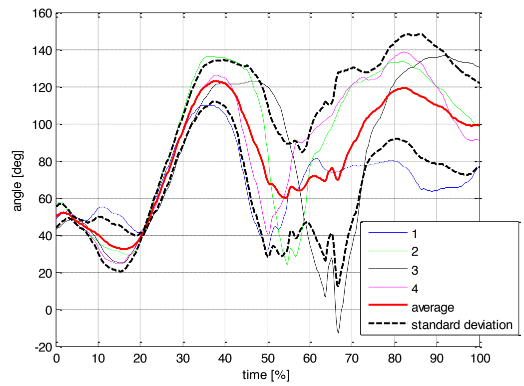
The common element that connects the study results of Kangas et al. [17, 18] with our observations is a rather obvious remarks that both in laboratory conditions and real-life the gravitational force acts on a falling body. It is, therefore, no surprise that the speed of the body mass centre is similar during the fall performed by men, whose age difference is 41 years (it is the only indicator that is not statistically significant for tested men). However, a fundamental element that differentiates the study performed by Kangas et al. and our study is a reference to fall prevention. Kangas et al. [18] explain in the discussion part that in this study, subjects performing experimental falls were instructed not to try to use their hands or knees to soften the major impact at the torso and not to take recovery steps to prevent the fall. Our underlying argument is the perspective of effective protection of a body during the fall and collision with the ground, thus the necessity to perform absorbing impacts using the upper limbs. It is, however, obvious that each healthy, physically active person will fall at least once in a lifetime and will not be able to predict the circumstances in advance. Therefore, even the most careful fall prevention would not eliminate such events from our daily activity.

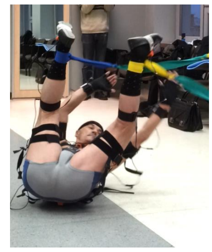
The results of our experiment induce far-reaching optimism. Trained ability of safe fall is the most effective prevention of body injuries caused by sudden balance loss, fall and collision with the ground or vertical obstacle (unfortunately, scholars do not devote much attention to the latter one). A perfect model should combine prevention based on safe falling exercises with fall prevention, which would considerably limit the probability of balance loss and fall or collision with vertical obstacle.

There are numerous scientific publications and statistical studies on the epidemiology of body injuries caused by a fall and treatment cost. Last year's report of the Institute For Health Metrics and Evaluation, University of Washington [19] reveals that within 20 years (1990-2010) a fall rose in a global scale high in the rankings comprising causes of years lived with disability as well as years lost to premature death. Among 25 causes of those negative phenomena the fall is ranked tenth. The scale of the phenomenon in economic terms can be, however, illustrated by the following prognosis: for the US health care, costs due to falls were estimated to be about $5.7 billion in 2002 and are predicted to reach $43.7 billion in 2020 [20].

Apart from commonly accepted educational and methodological solutions the results of biomechanical studies combined with methodology (methodics) of safe fall form the basis for the development of effective methods of body injuries prevention caused by a fall. A fall to the side is the most common cause of pelvic and femoral fractures [1]. Therefore and due to the subject of our paper, the overview of publications on biomechanics of fall and methods (methodics) of safe fall is particularly interesting.

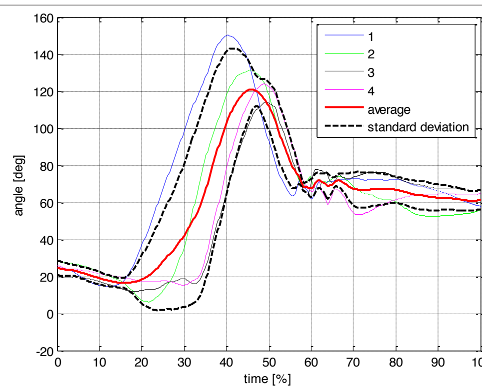
Groen at al. [21] verified the hypothesis that healthy older individuals could learn martial arts (MA) fall techniques during the training and that better fall skills would result in a reduction of hip impact force during a sideways fall. They have tested healthy six males and 19 females aged between 60-81 years. Just after five weekly sessions MA fall techniques (each of 45 min) they have found out positive adaptative effects: fall performance from a kneeling position was improved by a mean increase of 1.6 on a ten-point scale ($p<0.001$); hip impact force was reduced by a mean of 8% (0.20 N/N, $p=0.016$); fear of falling was reduced by 0.88 on a visual analog scale ($p=0.005$). However, a fall to the side from a kneeling position does not reflect real-life falls. This is a simplification specific to training conditions. Moreover, the participants wore soft-shell hip protectors. Although such protection raises ethical standards, it at the same time undermines the credibility of the assessment of fear of falling in such empirical system in relation to real-life falls.

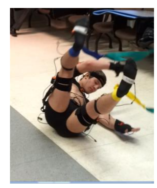




Photograph 6

(A)





Photograph 7

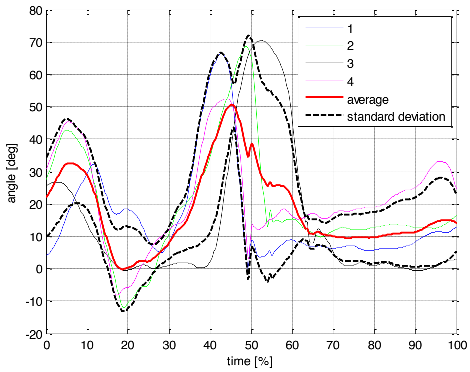
(B)

Figure 5. The bend angle of the left glenohumeral joint: (A) 65-years-old man; (B) 24-years-old man

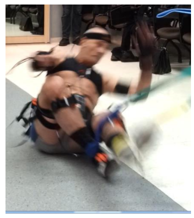
Undoubtedly, Groen et al. [21] were inspired by previous observations (expressed in the justification of their own studies) stating that MA fall techniques indeed reduced hip impact forces by 12–27% compared to other types of falls, including a natural fall [22, 23]. They quote the result of the study performed by Weerdesteyn et al. [24], who claim that even 30-minutes of MA fall techniques training will result in a 17% reduction of hip impact force in young adults.

In our opinion, fall performance based on experts' assessments is the most valuable indicator among three ones used to assess the adaptative effects (fall performance; hip impact force; fear of falling) and indirectly the effectiveness of training programs (Groen at al. [21] used in their study a ten-point scale). Other indicators are also important but in this hierarchy they function as supplementary information.

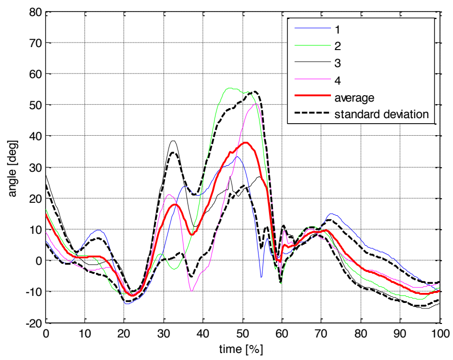
Any experienced teacher of MA fall techniques knows that the most difficult issue is to eliminate



(A)



Photograph 8



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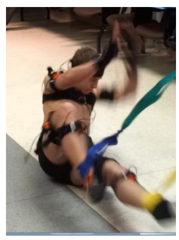

Photograph 9

Figure 6. The bend angle of the left elbow joint: (A) 65-years-old man; (B) 24-years-old man

leaning on ones palm, forearm or knees before the torso collides with the ground during the fall (speaking about observations in the gym, letting alone the falls in real-life). The scale of body injuries in judo, especially during training [25], is an empirical proof speaking for this argumentation. Judo novices are, on principle, taught the safe fall techniques and how to protect falling body of a partner during training and of a competitor during the fight (training or tournament). However, the issue of body injuries is serious in this area of physical activity as revealed by Japanese experts [26, 27].

Formulation of assessments on adaptation to safe collisions with the ground on the basis of the assessment of safe fall techniques in laboratory conditions may be misleading in the sense of repeating established motor pattern – tests or easy simulations (see [14] and *ArchBudo Academy*: „Safe Falls Academy", „Collision with wall"). A habit to lean on ones arms during the fall is so strong that even two courses of safe falling adapted to activities in real-life (not martial arts) does not eliminate those unreasonable motor response in young women (n = 68) [28]. Before these two courses during subsequent three tasks of STBIDF-test errors in arms control were made by 45.5%, 80.9% and 89.7% women. The errors in head control were respectively committed by: 17.6% (72), 4.4% (82.6), 14.7% (92.6) (results before courses is given in the brackets).

Sterkowicz-Przybycień and Oleksy [29] assessing the effectiveness of 12 sessions of semester course on „judo and combat sports" (90 minutes per week) attended by 46 young men have used only the general indicator STBIDF (from 0 to 14 points). They have revealed over double reduction of injury risk during a fall (the result of the test before the training amounted to 7.98-, whereas after training to 3.50 points). Moreover, they have also found out, that a significant shift of students to groups bearing lower risk has occurred, whereas the number of people, who initially showed very high susceptibility to an injury during a fall, has significantly decreased (from 21 to 2). After the course only one person performed STBIDF-test with some errors. Therefore, it may be indirectly concluded that the trends to reduce errors of controlling various body parts during a fall in men specially trained for such circumstances is similar to the effects of training in young women.

Boguszewski et al. [30-32] have used STBIDF-test in comparative studies. They have found out that people training judo (n = 46; for at least 4 years) less likely sustained body injuries during a fall and the effects of those events were less serious in comparison to people who do not train (n = 75). The correlation between the STBIDF indicator and the number of sustained body injuries during a fall amounted to 0.25 for judokas and 0.57 for non-training people. However, in the context of this discussion the attention should be drawn to other result from the study performed by Boguszewski et al. [30]. It cannot be denied that people who train judo for at least 4 years have sufficient ability of safe fall. However, the results of STBIDF-test of both women (n = 13) and men (n = 33) indicate that in laboratory conditions they have performed errors in controlling all observed body parts (lower limbs, hips, upper limbs, head) in similar proportions. The highest indicator of errors relates to upper limbs. Similar result of STBIDF-test was obtained by blind children [31] and children with visual impairment [32]. Both groups of disabled children show similar characteristics of localization of body injuries caused by fall. Girls more frequently suffer from upper limbs injuries, whereas boys from upper limbs injuries.

Correlation of the results of specific motor tests or other expert observations assessing safe fall techniques with age, hip impact force etc. may not always be justified. In fact, the longer period of education, the larger assimilations of demonstrated safe fall techniques with adopted motoric model. In another words, the more people obtain maximal score according to adopted evaluation scale [14]. This is proven not only by motor similarity of a fall to the side performed by men aged 24 and 65 years in our experiment, but also by the fact that both men did not subjectively feel the negative effects of numerous collisions with hard ground. Yet, the biomechanical characteristic of each controlled falls provided empirical proofs that the older man is more effective in losing the energy in the final phase of the collision with the ground.

Therefore, studies on body control during the fall and collision with the ground (regardless of the direction of balance loss and the sequence of collision with the ground of particular body parts) in relation to spinal curvature, spinal mobility, and back extensor strength etc. [33], comparison of acceleration signals of simulated and real-world falls [34] the use of depth data for fall detection [35] are very valuable in cognitive and applicative sense.

Conclusion

The use of modern measuring equipment and original research methods means that our knowledge

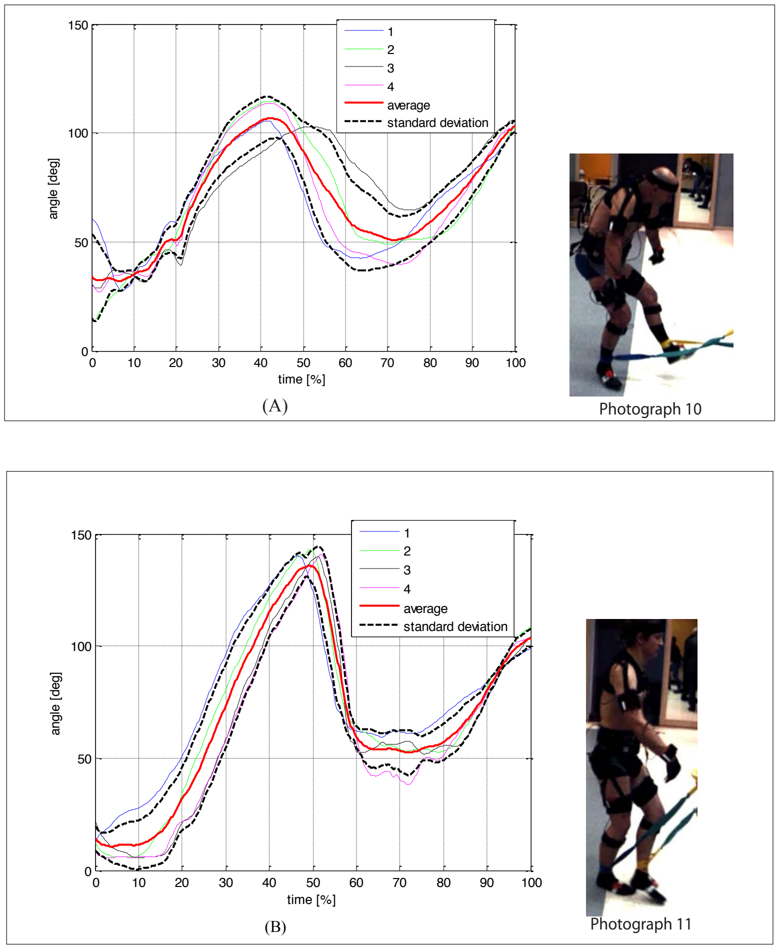

Figure 7. The bend angle of the knee joint of the supporting (right) limb: (A) 65-years-old man; (B) 24-years-old man

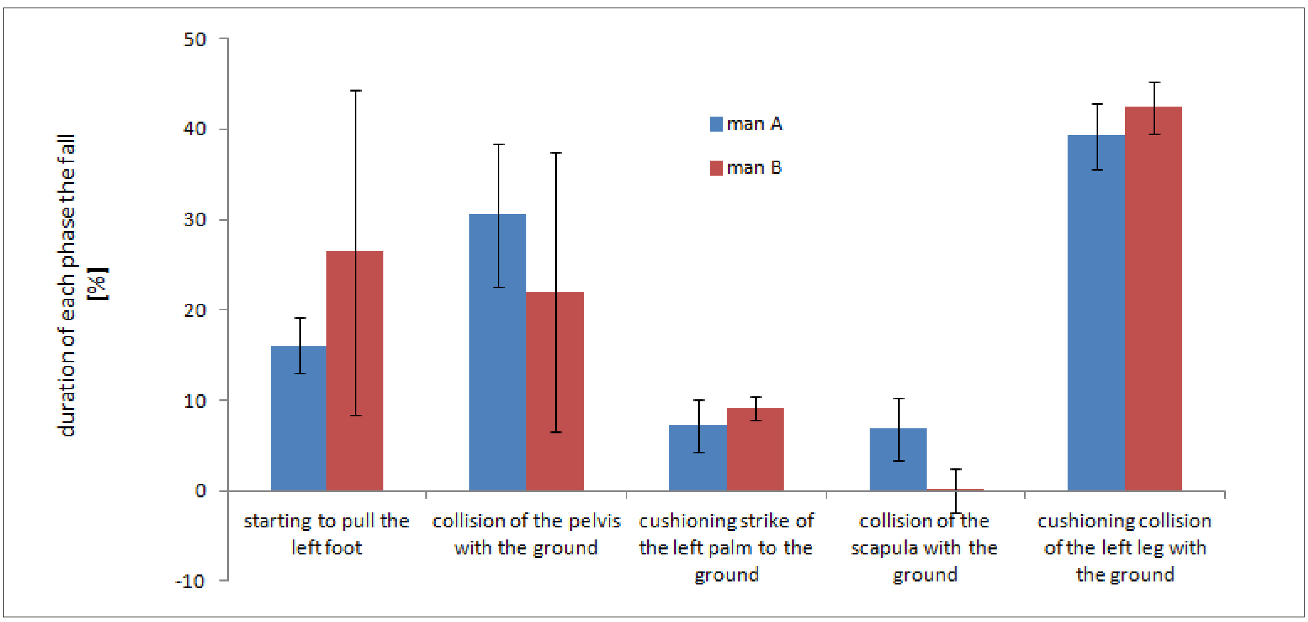

Figure 8. Duration of each movement phases

about specific issues of unintended or intended fall is becoming more detailed. Empirical data depict various aspects of backward or forward falls and falls to the side [35, 36] and are relevant in scientific sense. Non-apparatus tests or quasi-apparatus tests falling into three categories: (a) for an initial evaluation of susceptibility to injuries during the fall and observation of this phenomenon during the training and after it ends [28]; (b) providing elementary knowledge about motor capability of a particular person to learn safe fall techniques [37]; (c) used to evaluate the effects of learning safe fall techniques [14] are of particular importance for educating people on safe falling.

The results of our experiment and the results obtained by other scientists discussed in this paper entitle us to make the more general conclusion that the retirement age does not necessarily involve a deterioration of ability to control the body during unintended fall and collision with the ground. On the contrary, suitable training results in the fact that such person can optimally protect his body in such circumstances and function more effectively in comparison with considerably younger people. Obtained results are, moreover, an empirical proof of methodological correctness of safe falls modelled on techniques used in judo (*ukemi waza*).

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Conflict of interest

Authors declares that there are no conflict of interests.

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