Similarities and differences of the body control during professional collision with a vertical obstacle of men aged 24 and 65

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Manuscript Preparation
E Funds Collection

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Source of support: Departmental sources

Received: 02 December 2014; **Accepted:** 26 January 2015; **Published online:** 28 February 2015

ICID: 1141642

Abstract

Background & Study Aim: Both the epidemiology of body injuries due to collision with vertical obstacles or objects in motion and the prevention of such events are very rarely discussed in the scientific literature. Understanding the kinematics of body movement during a collision with vertical obstacle may constitute a significant element used to create rational methodology for injury prevention in these circumstances. The aim of the study is to answer the question whether significant age difference of men training combat sports results in differentiation of the body control during professional collision with hard vertical obstacle forced by an external force and as a consequence whether it affects the way to protect head in particular and the amount of dissipated energy.

Material & Methods: Two men have been subjected to the study: a 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; a 24-years-old physiotherapist (B), who trains judo as an amateur, has 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 a collision with vertical obstacle was conducted. The collisions were forced by the assistant. Tested person was standing freely (with muscles relaxed) facing the front of the concrete wall at the distance of 2 metres. Assistant pushed the tested person each time towards the wall with similar force in the same way (by pressing the neck with one hand and lumbar spine with another). 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 analysis involved four registered collisions with the wall of each tested person.

Results: Since the contact of the upper limbs with the wall to the moment of stopping the body centre mass movement, both men shielded and protected the head by lifting their arms up and simultaneously flexing the arms in the elbows. This proves that the body surface in contact with the obstacle is almost identical in both men. Men A more effectively amortises the collision with the vertical obstacle. This is reflected in the average values of the head mass accelerations, which were lower by approx. 16% than in man B; the average energy absorbed by the body tissues of man A amounted to approx. 77%, whereas man B to 91% of the collision energy (man A dissipated energy more effectively). More effective amortisation of the collision with vertical obstacle by man A resulted moreover from the movements of his body segments after the collision (mainly flexing the knees, which is possible due to the relaxation of the muscles around this joint). The movement of body segments of man A in the second phase results in the increase of the mass centre movement in the direction of sagittal axis and in the increase in the body movement range.

Conclusions: Suitable training causes the person in retirement age to more effectively amortise the collision with own body with hard vertical obstacle than a young adult man with significantly shorter training experience. Completion of the specialist course on safe falling and several years of judo practice significantly increase the abilities of protecting the body of a person in the conditions, when an external force results in the collision with the hard vertical obstacle. Increased probability of the more effective prevention of body injuries or even death in such circumstances requires the inclusion of such simulations to the permanent health-related training.

Key words: biomechanics analyses · body injuries prevention· health-related training · safe fall theory

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

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 [35]

Quasi-apparatus test – can be conducted with simple instruments (a stopwatch, a ruler, a measuring tape, etc.) [35]

Kakugi – Combat sport. *Kakugi* was the term used to denote martial arts classes in the postwar junior and senior high school physical education curriculum. The term officially became "*budō*" in changes made to the national curriculum guidelines in 1989 [39]

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 [49]

INTRODUCTION

Both the epidemiology of body injuries due to collision with vertical obstacles or objects in motion and the prevention of such events are very rarely discussed in the scientific literature. There are however numerous publications concerning the epidemiology of body injuries due to balance loss and fall as well as informing about groups of higher risk of such events. The analysis performed by the Institute For Health Metrics and Evaluation University of Washington [1] has revealed that the number of people, who died or live with disability due to fall, increased in 1990-2010. This group partially comprises cases of collision with vertical obstacle. It is however highly probable that for a long time collision with vertical obstacles will not be distinguished as the cause in the epidemiology of body injuries.

Norton and Kobusingye [2] referring to the reliable sources claim that *"In 2010, there were 5.1 million deaths from injuries – almost 1 out of every 10 deaths in the world – and the total number of deaths from injuries was greater than the number of deaths from infection with the human immunodeficiency virus–acquired immune deficiency syndrome (HIV–AIDS), tuberculosis, and malaria combined (3.8 million)"* [2, p. 1723].

There is rather high awareness in numerous social circles that training some combat sports and martial arts (aikido, judo, ju-jitsu, hapkido, etc.) prepares for safe collision with the ground (but not with vertical obstacles). The nature of those combat sports and martial arts involves mutual throwing off balance the athletes who practice or fight with each other on the mats which provide partial amortisation for the body colliding with the ground. Only few methodological publications [3-5] include descriptions of techniques and exercises preparing for collision with vertical obstacles or objects in motion (see ArchBudo Academy: *Collision with wall* and *Rotational collision of body with a wall*). Vertical collisions are distinctive feature of rugby and American football. Athletes acquire skills in colliding with competitors especially during matches. Nevertheless, the collisions of rugby players are the cause of numerous injuries [6-8]. Combat sports that consist of inflicting blows on the enemy (boxing, fencing, karate, kendo, taekwondo, etc.) to some extent prepare for avoiding collisions with objects in motion.

Recently, there were several publications published based on the biomechanical analyses of the falls and collisions with the ground: backward [9-11], sideways [12, 13] and comprehensive - forward, sideways and backward falls [14]. Unfortunately, there are no publications about biomechanical aspects of collision with vertical obstacle by a human moving on his own foot. Weerdesteyn et al. studied the phenomenon of avoiding the obstacles, which could be the reason of tripping and falling [15]. There are a lot of studies analysing collisions involving cars, motorbikes or bicycles but none of them are about human movement [16-18]. Understanding the kinematics of body movement during a collision with vertical obstacle may constitute a significant element used to create rational methodology for injury prevention in these circumstances.

The aim of the study is to answer the question whether significant age difference of men training combat sports results in differentiation of the body control during professional collision with hard vertical obstacle forced by an external force and as a consequence whether it affects the way to protect head in particular and the amount of dissipated energy.

MATERIAL AND METHODS

Participants

Two men have been subjected to the study: 65-years-old scientist, bo dy 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 a collision with vertical obstacle was conducted. The collisions were forced by the assistant (see ArchBudo Academy: *Collision with the wall youths and adults*). Tested person was standing freely (with muscles relaxed) facing the front of the concrete wall at the distance of 2 metres. Assistant pushed the tested person each time towards the wall with similar force in the same way (by pressing the neck with one hand and lumbar spine with another).

Measurements have been performed with the use of MVN *Biomech* system (XSENS, The Netherlands) based on inertial sensors equipped with accelerometer, gyroscope and magnetic field sensor. The analysis involved four registered collisions with the wall of each tested person.

The measurement system consists of 17 inertial sensors placed on the body of the tested person. Each inertial sensor is equipped with accelerometer, gyroscope and magnetometer. The arrangement of sensors and the measurement data processing algorithm from the sensors allow for the determination of: linear movement of upper and lower limb joints, characteristic anthropometric points and body centre mass; angular movement of various body parts; joint angles; the derivatives of the above-mentioned values.

The following values were applied in order to assess the amortisation methods of body collision with the vertical obstacle by tested men:

- movement of the mass centre in relation to the sagittal axis and the vertical axis,
- speed of the mass centre in relation to the sagittal axis,
- flexion angle in the elbow,
- flexion angle in the knee,
- flexion angle in the hip joint,
- torso angle relative to the vertical axis.

In the analysis the movement of tested men was divided into two basic phases: the **first** one (since throwing off balance to the contact of upper limbs with the wall); the **second** one (since the contact of the upper limbs with the wall to stopping the movement of the body centre mass). The duration of individual phases calculated for tested men are analysed both in seconds and percentages (assuming 100% time to be the time from throwing off balance to stopping the body centre mass). Additionally, phase one was divided into two parts defined by the contact of the foot with the ground.

The acceleration of the head centre mass of tested men was assumed to be the measure for the amortisation effectiveness of the body collision with vertical obstacle.

The entire observed movement from being thrown off balance through hitting the wall to stop body centre mass are described according to the criteria of the principle of the conservation of mechanical energy. The energy used to throw off balance is replaced by kinetic energy EK1 and potential energy Ep1 in the first phase. Thus, the collision energy will be (approximately) equal to the maximal kinetic energy in the first phase (Ek1). The energy corresponds to the moment of gaining the maximal speed of the mass centre in the direction of the sagittal axis in the first phase. Considering the change of energy on the direction of the sagittal axis, it may be assumed that in the second phase the energy from collision will be replaced by absorbed energy (Ea) by soft tissues and hard body parts of tested men and kinetic energy of the mass centre movement (Ek2) in accordance with the relation $Ek1 = Ea + Ek2$. Thus, the value of the energy absorbed (Ea) by the human body may be determined as the difference Ek1 and Ek2 defined when the acceleration of the centre head mass reaches its maximal value ($Ea = Ek1 - Ek2$).

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. It comprises not only a set of perceptual sentence but also contains interpretations.

The analysis basic of safe fall theory

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) during a fall the muscles tend to play the amortising role best, if the joint system, which they run, is set at the most convenient angle [19].

Calculations show that only a double increasing in those two values ("a" and "b") decreases a unit deformation energy by 16 times, while its five-fold increase allows reducing the **„*e*"** value (*strain energy of volume change*) as many as 625 times. On the basis of those well justified premises, authors tend to associate the sense of preventing body injury in cases of loss of balance, fall and collision with the base with the ability of loosing falling energy or that of a foreign body in collision with the human body (e.g. when hit by a car, boxer blow, etc.). They argue in a just way that the muscles are appropriate amortisation means for shocks that a human body is submitted to [19].

Statistical Analysis

Arithmetic means of individual indices, standard deviations, distribution boundaries of the results (minimal and maximal values) were calculated. In order to determine the significance of the differences between the two means (results of biomechanical measurements man A and man B) Mann-Whitney U test was used. Statistically significant difference was assumed for p<0.05.

RESULTS (AND INTERPRETATION)

The time from throwing off balance to stopping the movement of the body centre mass of a person who is colliding with a wall

The duration of collision with vertical obstacle of both men is similar from the moment of throwing off balance to stopping the movement of body centre mass (Table 1). In both men, the first phase lasts longer. In average, it amounts slightly above 62% of the entire duration of the activity (Table 2). However, the differentiation of the extreme results of man B is lower (they do not exceed 5% in both phases).

Table 1. The duration of collision with vertical obstacle of both men, from throwing off balance to stopping the movement of body centre mass

Collision	Time of collision [s]					
	man A (65-years-old)			man B (24-years-old)		
	total	phase		total	phase	
		first	second		first	second
1	1.308	0.767	0.541	1.526	0.926	0.600
2	1.250	0.850	0.400	1.499	0.966	0.533
3	1.408	0.875	0.533	1.301	0.777	0.524
4	1.150	0.700	0,450	1.351	0.862	0.489
mean	**1.279**	**0.798**	**0.481**	**1.419**	**0.883**	**0.537**
±	*0.108*	*0.080*	*0.068*	*0.110*	*0.082*	*0.046*
min	1.150	0.700	0.400	1.301	0.777	0.489
max	1.408	0.875	0.541	1.526	0.966	0.600

Table 2. Proportion of duration of each phase of the collision with vertical obstacle (in relation to the total time from the moment of throwing off balance to stopping the movement of body centre mass) of men studied

Collision	The proportion [%] of time the individual phases of a collision			
	man A (65-years-old)		man B (24-years-old)	
	phase		phase	
	first	second	first	second
1	58.64	41.36	60.68	39.32
2	68.00	32.00	64.44	35.56
3	62.14	37.86	59.72	40.28
4	60.87	39.13	63.80	36.20
mean	**62.41**	**37.59**	**62.16**	**37.84**
±	*4.00*	*4.00*	*2.31*	*2.31*
min	58.64	32.00	59.72	35.56
max	68.00	41.36	64.44	40.28

The way of body centre mass in sagittal and vertical axis

The movement of body centre mass of man B in sagittal axis each time occurs along very similar way, whereas the distinctive features of particular collisions of man A are significantly different (Figure 1). In half of the time of movement of man A, his body centre mass in sagittal axis moved from 0.8 m to approx. 1.1 m. In the same time, this distance of man B amounted to from 0.7 m to approx. 0.85 m.

The analysis of body centre mass movement in sagittal axis (Figure 2) reveals that man A during phase one significantly raises the body centre mass (the peak falls in the middle of the activity). This results from performing a slight jump and stabilising the feet (in significantly greater straddle position than man B) before collision of the upper body with the wall (in fact, amortising strike performed with forearms) – see video *Collision with the wall youths and adults* (ArchBudo Academy). Due to this manoeuvre, part of the energy is lost for the mass centre movement relative to vertical axis. This manoeuvre is performed by man B at the end of the movement (after 60% to 80% of the time) with slight rising of COM in vertical axis.

The speed of body centre mass since the beginning of the movement to the collision of the body with the wall

Within the meaning of the average result, the peak speed of COM in relation to sagittal axis of man A falls after 40% of time since throwing him off balance and the beginning of the movement of his body towards the wall. In the case of younger man, the peak falls after 63% of the movement time. This constitutes an empirical evidence that the older man starts earlier the manoeuvre of reducing the negative effects of the collision with the wall (Figure 3).

Maximal accelerations of head and body centre mass during the collision with the wall and the collision energy

During the second phase of the collision with the wall, all values of maximal accelerations of head mass centre towards the sagittal axis of man A are lower than the one of man B (Table 3). The average result A is lower by approx. 40% ($p<0.05$). This demonstrates more effective amortisation of the collision with the vertical obstacle by older man. The effect is

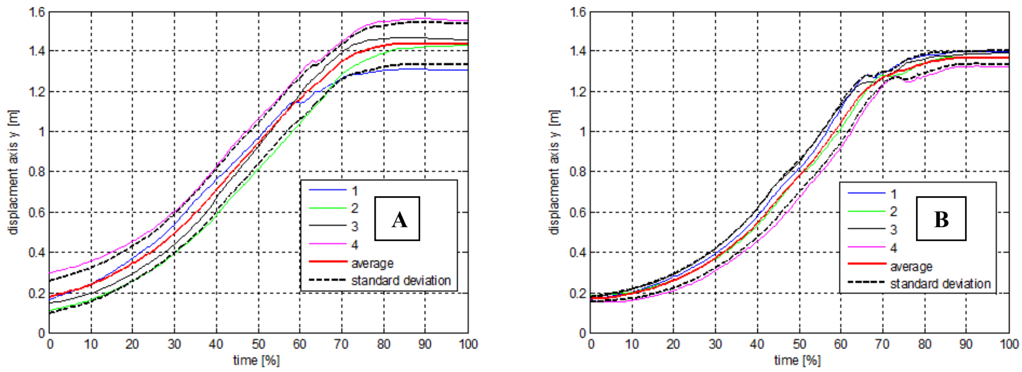

Figure 1. Movement of body centre mass in relation to sagittal axis (COM y) since the beginning of the movement to the collision of the body with the wall

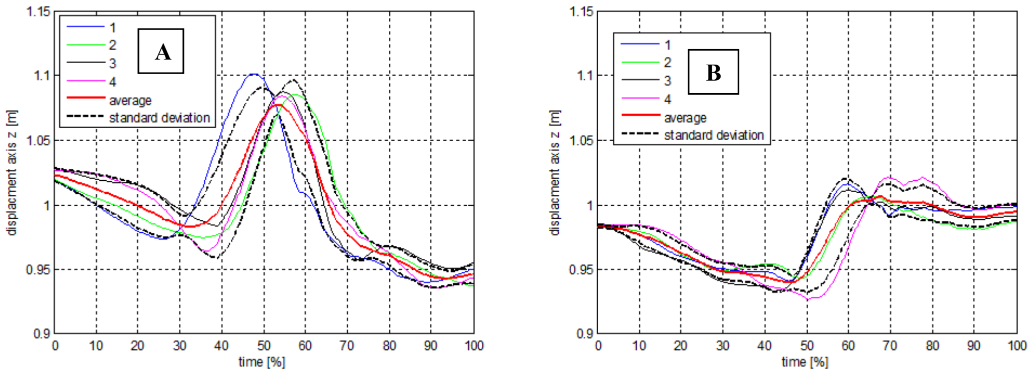

Figure 2. Movement of body centre mass in relation to vertical axis (COM z) since the beginning of the movement to the collision of the body with the wall

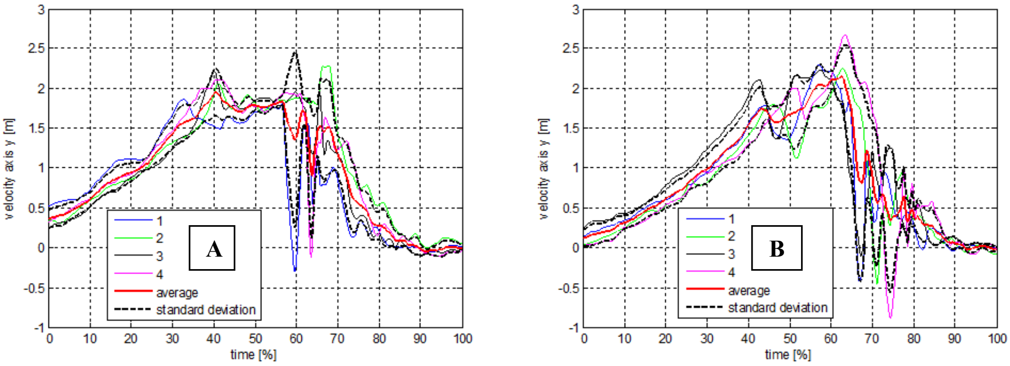

Figure 3. Movement of body centre mass in relation to sagittal axis (v COM y) since the beginning of the movement to the collision of the body with the wall

Table 3. Maximal accelerations of head mass centre in the direction of the sagittal axis in the second phase of the collision with the wall (since the contact of the upper limbs with the wall to stopping the movement of the body centre mass)

Collision	Acceleration [m/s²]			p
	Man A (65-years-old)	Man B (24-years-old)	Difference	
1	31.59	41.73	10.14	
2	29.72	37.10	7.38	
3	28.09	54.32	26.23	
4	28.54	57.01	28.47	
mean	**29.48**	**47.54**	**18.06***	**0.030384**
±	*1.56*	*9.64*		
min	28.09	37.10	9.01	
max	31.59	57.01	25.42	

*p<0.05

enhanced by appropriate tension of the neck muscles during the second phase of collision with the wall. However, man B noticeably turns his head to the side each time before collision with the wall (see video *Collision with the wall youths and adults*).

Maximal kinetic energy (relative to the body mass of both man and expressed in J/kg) in the first phase (***Ek1***), i.e. since throwing off balance to the contact of upper limbs with the wall, is in man A lower by approx. 16% than in man B. Assuming that the energy at the beginning of phase one was the same in both men, motor action of man A is the first phase resulted in reducing the collision energy. The analysis of mass centre movement in the vertical direction (Figure 2) highlights the fact that man A performs a jump in the first phase. Due to this manoeuvre, part of the energy is lost for the movement of mass centre relative to the horizontal axis.

Table 4. Maximal kinetic energy of the body centre mass in relation to the body weight of men studied [J/kg] in the first phase (Ek1)

Collision	Man A (65-years-old)	Man B (24-years-old)
1	1.72	2.63
2	2.58	2.54
3	2.44	2.49
4	2.70	3.57
mean	**2.36**	**2.81**
±	*0.44*	*0.51*
min	1.72	2.49
max	2.70	3.57

The kinetic energy of man A is greater in the second phase (***Ek2***), i.e. during maximal acceleration of head centre mass (Table 5). This results in lower differences in both values in the case of man A. This is an important empirical evidence that the value of the energy absorbed by his body during the collision is lower (Ea = Ek1 – Ek2).

Table 5. Kinetic energy of the body centre mass in relation to the body weight of men studied [J/kg] during maximal acceleration of head centre mass (Ek2)

Collision	Man A (65-years-old)	Man B (24-years-old)
1	0.45	0.45
2	0.85	0.11
3	0.58	0.42
4	0.28	0.07
mean	**0.54**	**0.26**
±	*0.24*	*0.2*
min	0.28	0.07
max	0.85	0.45

The average energy absorbed by soft and hard body tissues of older man, determined in such a way, amounts to approx. 77%, whereas the one of younger man to approx. 91% of the collision energy. Man A more effectively dispersed the energy during the second collision with the wall (only 67% was absorbed by his body) and the least effectively during the fourth collision (90%). During the second and fourth collision, body of man B absorbed 96% and 98% of collision energy respectively. These are another empirical arguments that the older man more effectively amortises collisions of his body with vertical obstacle enforced by external force.

The most effective amortisation of collision with vertical obstacle by man A results from more effective movements of his body segments after the collision with the obstacle. The movement of body segments of man B in the second phase results in the increase of the mass centre movement in the direction of the sagittal axis (Table 6) and in the significant increase in the body movement range (Table 7).

Other determinants of more effective amortisation of the collision with vertical obstacle by the older man

The movement of the torso observed in man A mainly results from bending the knees, which is possible due to relaxation of the muscles around this joint (Figure 4). A good visualisation of this relaxation is provided by sinusoidal course of man's A movement of the knees. Significant dispersion of the characteristics of various knee movements from loosing balance to collision with the wall may indicate a high motor adaptability of man A to the circumstances of each moment of throwing off balance (it cannot be assumed that the assistant used the same force causing loss of balance). Man B maintains his flexion angle in the knee at similar level in phase two (at the moment of stopping the movement, it amounts to 15°), whereas after the lapse of 25% to almost 30% of time since losing balance, the angle amounts from 12° to 14°. This is an empirical proof of his tendencies to stiffen the muscles around the knees in the first movement phase.

Table 6. Movement of the mass centre in relation to the saggital axis in the second phase

Collision	Dislocation [cm]	
	Man A (65-years-old)	Man B (24-years-old)
1	16.90	20.76
2	21.27	16.96
3	24.31	22.91
4	23.06	20.85
mean	**21.39**	**20.37**
±	*3.24*	*2.48*
min	16.90	16.96
max	24.31	22.91

Table 7. Change in the angular position of the trunk [degree] with respect to the vertical axis in the second phase

Collision	Man A (65-years-old)	Man B (24-years-old)	Difference	p
1	23.79	17.02		
2	35.74	16.25		
3	31.37	20.24		
4	34.78	20.86		
mean	**31.42**	**18.59**	**12.83***	**0.030384**
±	*5.42*	*2.30*		
min	23.79	16.25	7.54	
max	35.74	20.86	14.88	

*p<0.05

Differences in body relaxation of both men can be seen in the flexion in the hip since the initiation of the movement to collision of the body with the wall (Figure 5) and even more in the bending angle of the torso in relation to the vertical axis registered on this path of body movement (Figure 6). Both phenomena can be clearly seen in the video *Collision with the wall youths and adults.*

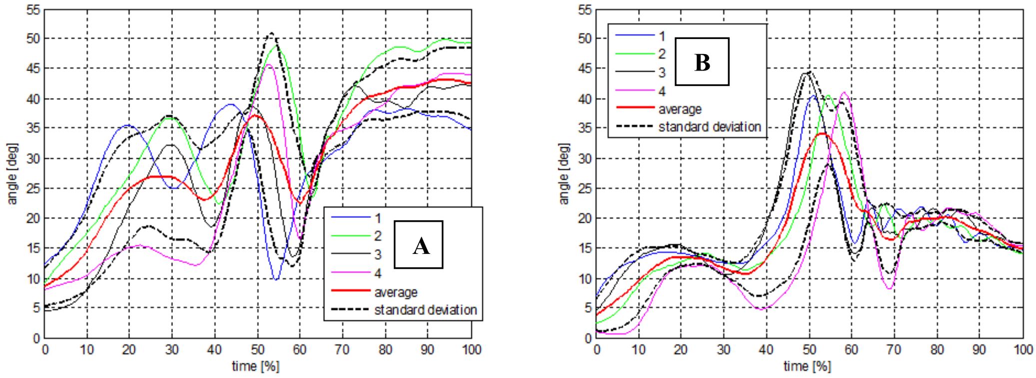

Figure 4. The flexion angle in the knee since the beginning of the movement to the collision of the body with the wall

The assistant most likely pushed with a left hand the torso of the men in the area of their loins (rather than the head with his right hand at the same time), when he initiated throwing them off balance. As a result of such throwing force, the relaxed body of man A answers with a sinusoidal movement of the hips towards the wall until the lapse of 40% of time in the range of flexion angle in the hip from –12° to approx. –28°. This means that the hips somehow anticipate the movement of the entire body. At the time of the collision, the flexion angle in the hip joint amounts from 20° to approx. 27° during the fourth collision (the accumulation occurs after the lapse of 60% to 68% of time). Man B initiates his motor response by stiffening the muscles (accumulation of the stiffening occurs after the lapse of 10% of time) and linear deepening of the hips approaching the wall (the closest values, i.e. –20° to –31°, fall after the lapse of 36% to 48% of time). The hips of both man again get closer to the wall. Man B maintains his flexion angle in the hip joint at similar level in phase two (at the moment of stopping the movement, it amounts to –15°). In the case of man A, the span of the results amounts to approx. 8 degrees and this part of phase two (from 80%-100%) lasts almost twice as long as in the case of man B (90%-100%) (Figure 5).

The negative values of the bending angle of a torso in relation to the vertical axis during the majority of performed collisions with the wall prove the high motor adaptability of man A (including correcting the motor response for similar stimuli) as well as the appropriate relaxation of the muscles according the circumstances (Figure 6). During the second collision (green), while initiating the throwing off balance by the assistant, the angle amounts to approx. –8° and after the lapse of 15% of time, it increases twice (almost –19°). This means that he has probably corrected his motor response after the first throwing off balance (blue), when he reacted with stiffening the muscles for almost identical stimuli, which caused moving away from the wall for almost 60% of the movement the body, and in the second phase (since the contact of the upper limbs with the wall to stopping the movement of the body centre mass) moving towards (after lapse of 78% of time, the angle amounted to approx. 3°, and during stopping almost 5°). The fourth collision is completed by man A with parallel position of the body in relation to the wall and during the second and third the angle was negative and amounted from –2° to –3°. The characteristics of man B constitute another empirical evidence of excessive stiffening the muscles during the collision with the vertical

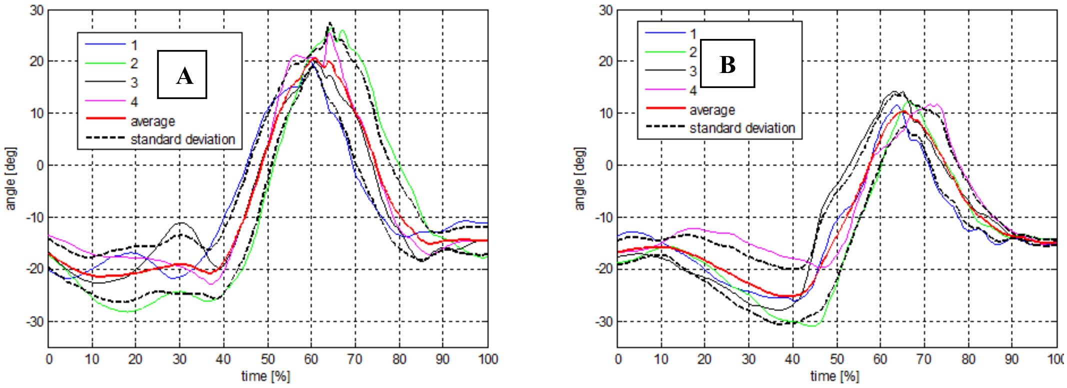

Figure 5. The flexion angle in the hip joint since the beginning of the movement to the collision of the body with the wall

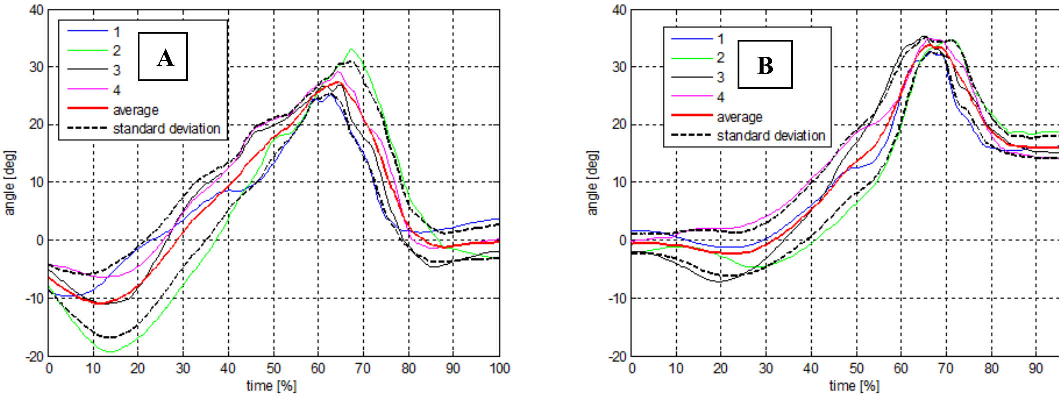

Figure 6. Bending angle of the torso in relation to vertical axis (COM z) since the beginning of the movement to the collision of the body with the wall

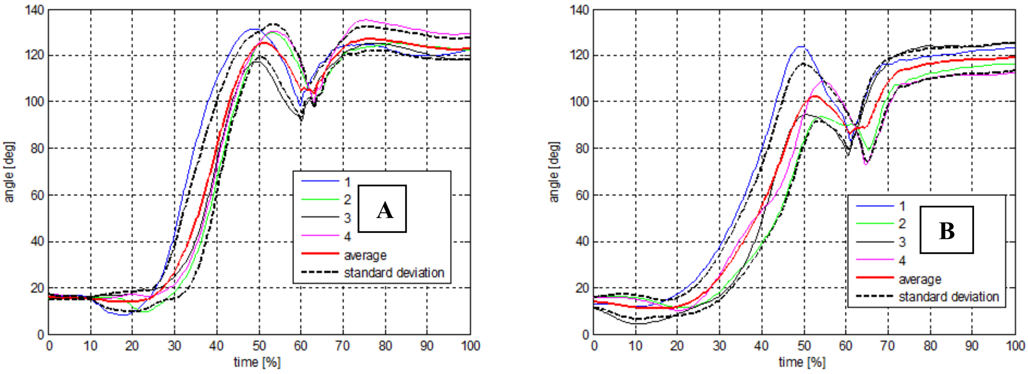

Figure 7. Flexion angle in the elbow

obstacle during the significant moments during both movement phases. Only during the second and third throwing off balance, his torso is relaxed in the initial phase. During the collision with the wall, the torso is located in the angle of 33° to 37° in relation to the wall. After approx. 15% of the lapse of time to stopping, the body centre mass stabilises itself in the angle of 15° to 19°. This prolonged time of stiffening the muscles allows for picturing the unfavourable conditions for the body which involve absorbing the energy from colliding with the hard vertical obstacle.

Similarities and evaluation of effectiveness of amortisation after collision of a body with a vertical obstacle based on the *safe falls theory (SFT)*

Both men during the collision with the wall shield and protect the head by raising arms up in the entire phase two (palms at the height of the face) and at the same time flex in the elbow joint (elbows are moved to the side) and colliding with the obstacle with the elbows not the head (Figure 7). Almost identical course of this manoeuvre (after lapse of approx. 12% of time) in man A could indicate a very high experience in such motor activities. It can be also proven by the greater similarity of both characteristics. Among all biomechanical characteristics of the collision performed by both men with vertical obstacle in laboratory conditions, the flexion angle in the elbow joint is the most similar. This is the most important element of head protection but also of knee and chest protection against the effects of uncontrolled collision, in particular with vertical obstacles. Sudden change of flexion angles in the elbow joint in the moment of contact of the upper limbs with the wall (in the case of man A within the range from approx. 118° to approx. 135° and in the case of man B within the range from approx. 95° to approx. 125°) to reach the lowest values: 95° to 110° and 75° to 90°respectively (i.e. after the lapse of approx. 15% of the time of the second phase of the collision) is an empirical description of the amortising function of the upper limbs during the collision with the obstacle. Another phase of this manoeuvre is constituted by the increase in the flexion angle in the elbow joint to the values registered during the contact of the upper limbs with the wall. Relative stabilisation of the angle to stopping the movement of the body centre mass favours the performance of the amortising actions by the remaining body parts (head, knees, hips, torso).

In accordance with the *safe falls theory*, one of the elements allowing for reducing the negative effects of the collision and ensuring the correct amortisation of the collision includes increasing the body surface in contact with the obstacle. The analysis of both man postures showing the beginning and the end of phase two (Figure 8), i.e. the collision with the obstacle, provides the evidence of high similarity solely in respect of the body surface in contact with the obstacle. Both men in the moment of the contact with the obstacle have their arms in the horizontal position with simultaneous flexion in the elbow joint amounting to approx. 90 degrees (Figure 7). Such position of the upper limbs ensured the head protection against the collision with the obstacle and at the same time the optimal contact surface with the obstacle (it is constituted by palms and forearms). Thus, body surface in contact with the obstacle of both men is almost identical due to their somatic resemblance (even greater similarity results from the body proportions used to amortise the collisions).

In accordance with the *safe falls theory*, the equally important element favouring the effective amortisation of the collision force is prolonging the duration of the collision (i.e. phase two). This time in both men is similar (Table 1 and 2) and is prolonged by correct amortising strikes with the arms.

Tested men differ in the third rule of the safe falls theory - during a fall the muscles tend to play the amortising role best, if the joint system, which they run, is set at the most convenient angle. The basic difference in the movement of men after the collision with the obstacle lied in the optimal relaxation of the lower limbs muscles by man A, allowing for reduction of collision energy. Preliminary preparation for the effective collision was allowed by a slight jump combined with leg wide apart. Furthermore, the average results of feet position by man A at the beginning and end of phase two (Figure 8) reveals their slight withdrawal after landing, which may be interpreted as the habit which additionally supports the effects of collision developed during the repeated exercises.

Apart from greater muscles relaxation of man A and performed jump, a synthetic evaluation of body control during collision with vertical obstacle forced by an external force (including also watching the videos) inclined to refer to all those defensive actions as the active model. While approaching the wall, man A attacks it in some sense by vigorous pulling the arms to the torso and equally dynamic strike just before the collision preceding the movement of the remaining body parts. Man B approaches the wall in a not active way (almost straight blue line on Figure 8 which illustrates the way of body centre mass) and stiffens unnecessarily various groups of muscles, whereas the only clear defensive actions are arms exposed in accordance with the methodology adopted and turn of the head to the side during the contact of hands with the obstacle. The manoeuvre of the head is very necessary in conditions of more significant accelerations (when the amortisation with hand would turn to be insufficient, a person turns the head to the side to avoid frontal collision of the face with the wall). Nevertheless, due to the entire empirical argumentation, this model is conventionally referred to as the "passive" one.

The figures of both men on Figure 8 are the examples of both models. Man A finishes the collision with almost parallel position of the body in relation to the wall (bending angle of the torso is close to 0).

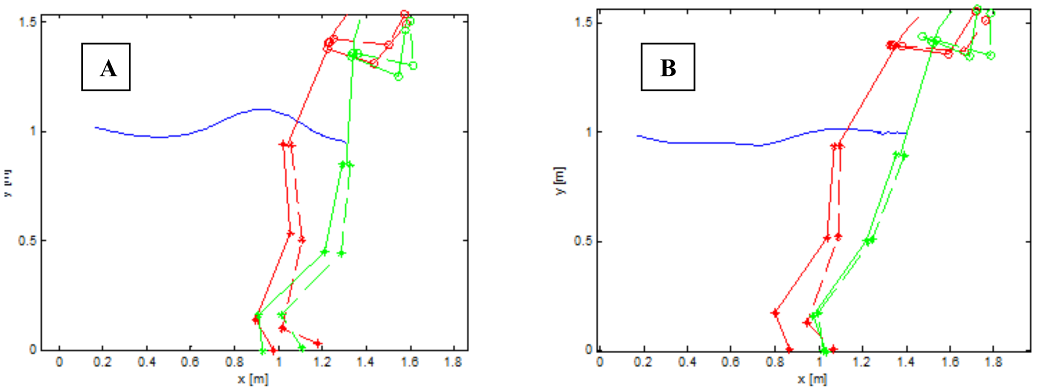

Figure 8. The arrangement of both men's bodies during the contact with the obstacle (the beginning of phase two is marked with red, whereas stopping the movement of the body centre mass is green)

There are differentiated movements of various body parts, which finally give effect of the optimal dispersion of the collision energy. After the collision, man B maintains stiff knees, which at the degree of the torso of 20° in relation to the wall enhances the negative feelings during the collision of the hands with the wall, because the energy is cumulated mainly on those body parts.

DISCUSSION

In the scientific literature, there are a few studies on biomechanical analysis of the professional collisions of a person with vertical obstacles (when a person is in motion and the obstacle is stationary). The issue of the collisions is however seen in different contexts: sport [6-8], accidents in road traffic and during daily physical activity [16-18].

The results presented by Fant et al., [20] who summarizes the issues of injuries among cyclists and their specifics in collision with cars, are interesting. The authors used the MADYMO (TASS International, The Netherlands) simulation program to perform a sensitivity analysis and establish essential parameters affecting bicycle-related head injury in a side collision with a car (during the simulations they calculated the exact data for the particular situations). The authors demonstrated that the severity of head injury increases with the speed of the car at the moment of the impact. The results show that the friendliest type of the car is SEDAN with low impact edge and wedge-shaped front hood, whereas the least friendly vehicle type is the SUV with a high-placed impact edge and a high nose. The worst values of HIC_{36} (Head Injury Criterion; 36 represents the time interval, in milliseconds, between the initial and final time intervals during HIC which reaches its maximum value) were determined for trekking bikes, which means an upright position because the head in upright position has the highest impact velocity.

Simulation studies on head injuries during collisions [21, 22] not only supplement this knowledge but also provide important information to improve methodology of safe falling and amortising collisions of the body with vertical obstacles, which is not included in the systems of combat sports and martial arts. The above-mentioned examples of circumstances in which such events occur, reveal the scale and seriousness of the problem. The video *Rotational collision of body with a wall* included in the ArchBudo Academy demonstrates the way of a collision with a wide vertical obstacle of a man, who is running fast. Rolling of the body caused after collision with such obstacle (with simultaneous increasing time of braking or braking distance during collision itself) constitutes the example of respecting all principles of the *safe falls theory* [19]. This method of protecting own body during the collisions with vertical obstacles and the methodology of teaching are not common in the methodological textbooks. The only exception is constituted by *Combat sports propedeutics – basics of judo* [4]. This method may be applicable in activities of especially rescue services and intervention of police officers, soldiers, etc. In front of the running person in conditions of limited visibility, a vertical obstacle may emerge suddenly and there will be no more than one second for reaction (which corresponds to two metres of distance between noticing the obstacle and inevitable collision). Those two metres correspond to the conditions of the experiment described in this paper. However, the larger the acceleration of the body mass, which only option is to effectively amortise the collision with vertical obstacle, the greater the probability of reducing the negative effects of collision, which depends on the fact whether a person is able to perform a rotational collision of a body with a wall.

The studies published so far emphasise the significance of the factors deciding about maintaining balance of people above 60 years old and the risk of falling [23-26], the necessity to maintain optimal speed of the walk of the elderly [27] and to regain this ability after injuries of the musculoskeletal system [28] but they also draw the attention to the high probability of falling of young people and people in so-called working age during intervention actions and rescue actions [29]. The aspect of collision with vertical obstacles of this groups of people during their daily or professional physical activity is omitted. Moreover, many scientific publications expose the issue of fall prevention (on the other hand, the aspect of avoiding the collisions is omitted with the exception of cited methodological publications [3-5]). Only a few authors point out that a fall is an inevitable event which affects every person and at the same time provide empirical argumentation that the optimal prevention of body injuries requires actions which eliminate (reduce) the fall risk factors with simultaneous teaching of safe falling [30-31]. Avoiding of the collisions and safe collision with vertical obstacles should be added here.

Among the empirical evidence, the profs that educational effects are not limited by gender, age and type of body build, are the most compelling [30]. Empirical data of this paper and the results previously published on body control during professional, externally forced fall to the side performed by the same men [13] reveal that a 65-year old man who is appropriately trained can more effectively disperse and partially absorb the energy from the collision with hard ground or vertical obstacle than a 40-year old younger man who is also trained.

In 2003, prof. Roman M. Kalina (who demonstrated fall to the side and collisions with the wall in these papers) conducted two familiarisation courses of safe falling for physiotherapy students in UNIPAC University (Brazil). Since 2009, two Polish universities educate students of physiotherapy in the following unique specialities: safe fall of patients after amputation; safe fall of blind and of patients with eye diseases; safe fall of elderly people; safe fall of obesity people; safe fall of patients with mental disorders. The results of the specific tests confirm the high effectiveness of those methods [31, 32]. The education of the students requires the use of various simulations (covered eyes, upper limbs tied with an orthopaedic belt, etc.). At first, students experience the discomfort of the motor functioning of their future patients. Secondly, the basic task of the physiotherapist in the clinical practice is demonstrating the exercises to the patients. We have concluded that e.g. after making sure that a physiotherapist has covered eyes and when the visually impaired is allowed to throw him off balance on the soft ground (e.g. on the judo mat) with a certain force and when he hears the effect of the collision with the ground and soon finds (by touch) that the physiotherapist immediate raised after the fall, a visually-impaired patient gains confidence and motivation for exercises. The preliminary reports from clinical trials confirm the high effectiveness of those methods in a motoric and mental sense [33, 34].

Developed non-apparatus tests [32, 35, 36] and quasi-apparatus test [37] are the significant support for those programmes as the majority of them can be used by visually-impaired patients alone. The rotating training simulator patented by Andrzej Mroczkowski opens the interesting research perspective [38]. This simulator has the following functions: mode for determining the moment of inertia; improving motor habits (the so called training mode); simulating the effect of an external force causing balance lost and a fall. It may have a wide application not only in research process but also in prevention of body injuries due to a fall of sportsmen and numerous professional groups acting in the extreme conditions (as a tool supporting their education and training).

The effects of the implementation in Japanese system of physical education of the *budo* model deserve separate article not only in the aspect of the injury prevention due to a fall and collisions. "The physical education subject «*kakugi*» was modified to «*budō*» for the first time in the postwar. The tree *budō* arts of *sumō*, *kendō and jūdō* were taught thereafter in junior high schools, and *jūdō* and *kendō* at high schools." [39, p. 64]. The basic element of judo training exercises are those involving safe falling (*ukemi waza*). Kendo exercises (Japanese fencing) teach in a natural way how to avoid collisions and to shape a stable body posture. Numerous formal exercises, and *inter alia* judo and sumo fights, strengthen the stable posture of the body and after throwing off balance (which during a fight is almost always a surprise for one of the competitors) force the necessity of controlling the body so that it will safely collide with the ground. The existence of numerous *departments of judo therapy* at Japanese universities and wide application of *budo* in health promotion of elderly people [40, 41], body injuries prevention [42-47] and rehabilitation [48] show how important for health those martial arts are.

CONCLUSIONS

Suitable training causes the person in retirement age to more effectively amortise the collision with own body with hard vertical obstacle than a young adult man with significantly shorter training experience. Completion of the specialist course on safe falling and several years of judo practice significantly increase the abilities of protecting the body of a person in the conditions, when an external force results in the collision with the hard vertical obstacle. Increased probability of the more effective prevention of body injuries or even death in such circumstances requires the inclusion of such simulations to the permanent health-related training.

ACKNOWLEDGEMENTS

The study was conducted within the research project Academy of Physical Education in Katowice: "Reducing vulnerability to body injuries during the fall of people categorized as group being at high risk of losing balance and falling" (Resolution No. 04/2013 Bioethics Committee at the Jerzy Kukuczka Academy of Physical Education, Katowice, Poland).

COMPETING INTERESTS

The authors declare that they have no competing interests.

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Cite this article as: Michnik R, Jurkojć J, Wodarski P et al. Similarities and differences of the body control during professional collision with a vertical obstacle of men aged 24 and 65. Arch Budo 2015; 11: 27-39