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KINESIOLOGY / COACHING

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Factors putting the head at the risk of injury during backwards falls

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Abstract
Background. According to the World Health Organization (WHO), falls are the second most common unintentional cause of death across the world. Physical education classes in Polish schools do not develop safe falling habits in children.

Problem and aim. This study's purpose is to see if students of physical education who play handball professionally exhibit different movement habits during a backward fall than do their counterparts who do not take part in any sports at a sports club. The study also focuses on a biomechanical analysis of the causes of head injury during a backwards fall.

Methods. The study involved 67 first-year physical education students at the University of Zielona Góra, aged 19-24, divided into two study groups. Group B (n=26) was made up of handball players, Group A (n=41) comprised the remaining students. The rotational training simulator RTS was used in the experiment to induce falling backwards.

Results. Group B students made considerably fewer 'head' and 'hips' mistakes when falling backwards, compared with their counterparts in Group A. In both groups the frequency of 'hips' mistake increased with the velocity of falling. Increases in the velocity of falling did not trigger an increase in the percentage of 'head'mistakes in Group B, but only in Group A.

Conclusion. Handball players were found to be at lower risk of head injury in backwards falls. Hitting the ground with the buttocks during a backwards fall may cause the moment of force to act on the head, thus posing the risk of a head injury.

Introduction

According to the World Health Organization (WHO), falls are the second most common unintentional cause of death across the world, after road accidents. 391 thousand people are estimated to have died as a result of falls in 2002. WHO defines 'fall' as an event which results in a person coming to rest unintentionally on the ground, or on the floor, or other lower level [World Health Organization 2019; Yoshida 2007]. A fall can be caused by external factors, e.g. slipping on a slippery floor, or by a force acting directly on a person, e.g. in a bus during emergency hard braking, or by losing consciousness because of a health problem. The latter will not be dealt with in this article, whereas of interest to the author are falls during which a defence reaction can occur on the part of the falling person.

Most research has focused on fall prevention through the elimination of external factors which can lead to a fall at work or through research on ways of improving people's reaction to disturbances of their balance [Simpson 1993; Society *et al. 2001*]. To study the reaction of people to fall-generating forces treadmills are used which can accelerate so as to cause people to lose their balance [Kallin *et al.* 2004]. Also, platforms [Bhatt, Pai 2009] and foot-clamps [Owings *et al.* 2001; Grabiner *et al.* 2008] are used to study backwards falls. In most cases the apparatus used in the experiment measures subjects' reactions to forces generating the loss of balance, but they prevent them from actually hitting the ground, their safety being thus ensured – which is achieved, for instance, by means of special braces which catch subjects mid-air when they lose their balance. There is a dearth of publications on research in which scientific apparatuses are used to cause subjects to fall on a stack of mattresses which reduce the risk of injury [Mroczkowski, Mosler 2018].

Some researchers believe that in certain circumstances a fall is unavoidable, so it is quite reasonable to study people's body movements during falls [Kalina *et al.* 2011; Mroczkowski 2015]. Research methods have been devised which assess the risks of falling backwards by examining body movements on hitting the ground

[Toronjo-Hornillo *et al.* 2018; Kalina *et al.* 2011]. Using fall-inducing forces specific movement habits have been identified in backwards falls [Mroczkowski, Mosler 2018]. It is, however, questionable whether the movements occurring in those methods can be classified as 'falls' along the lines of WHO's definition of 'fall'. The problem here is in creating conditions which are safe for falling people. A fall in real life can pose danger to health. Naturally, for safety reasons research methods have to provide a degree of safety unlike in real-life falls.

Kalina's Susceptibility Test of Body Injuries During a Fall (STBIDF) begins with the command "Lie down safely as fast as you can" [Kalina *et al.* 2011]. The person in the test proceeds from standing position to supine position in an intentional way, i.e. clearly not in accordance with the WHO's definition of 'fall'. An important feature of the test is that the tested person is not familiar with the assessment criteria. Research shows that people who know the criteria get results significantly different statistically from the results of people who do not. However, it has been agreed that STBIDF does find out top some extent about movement habits in fast physical task, because a considerable number of tested people cannot improve their performance even when they have learnt the criteria [Mroczkowski *et al.* 2017]. This is especially the case with head mistakes. Besides, numerous studies have found that much better results are achieved in this test by people who practise sports in which falls are practised [Boguszewski, Kerbaum 2011; Boguszewski *et al.* 2015], such as martial arts in which safe falling has to be mastered before the practitioner can engage in combat. Such studies are evidence that STBIDF can be used to assess people's susceptibility to backwards-fall injury.

In Spain research is under way on assessment of correctness of movements relied on INFOSECA scale for the systematic observation of backwards fall [Toronjo-Hornillo *et al.* 2018; DelCastillo-Andres *et al.* 2018; DelCastillo-Andres *et al.*2019]. The execution of the test task is different than in STBIDF: the tested person, standing with knees bent and eyes closed, is being held by the hands and then let loose to fall on a mattress. An advantage of this method as compared with STBIDF is that the person does not lie down of their own accord and does not know the moment when they are about to fall down. Analysis concerns movements made while falling on the ground. The falling person stands no chances of keeping balance since the initial position makes it impossible. In real-life circumstances the fall, however, begins in a standing position, so there is more time for defensive reaction and the dynamics of the fall are different. The absence of visual information can make defensive movements different from real-life reactions. An advantage of the above-described methods is that they do not require any apparatuses and the tests are easy to carry out. INFOSECA and STBIDF criteria are similar despite the procedural differences between them. INFOSECA assesses a movement as either correct or incorrect, whereas STBIDF awards 1 point for a correct movement and 0 points for an incorrect one. This assessment method is also used for analysis of movement habits in backwards falls resulting from the loss of balance caused by the rotating training simulator (RTS).

The loss of balance is a result of the force of inertia causing the person to fall down, which is a step forward compared with the previously described non-apparatus methods. RTS was used with physical education students to show movement habits exhibited by them in backwards falls [Mroczkowski, Mosler 2018]. The simulator is meant for people whose work or sports discipline involves falling. The creator of RTS thus limits the research to adults characterised by a high degree of physical fitness. It cannot be, however, assumed that RTS induces falls identical with real-life ones. For ethical reasons, as has been observed by other researchers [Feldman, Robinovitch 2007], re-creating such conditions in a laboratory is impossible. For safety reasons, people training with the simulator fall on a mattress. In its current version, RTS emits a sound signalling the occurrence of the fall-inducing force [Mroczkowski, Mosler 2018].

The research carried out so far has shown that playing handball improves movement habits when falling backwards [Mroczkowski 2018]. Such research was done using the STBIDF test. This article describes movement habits checked by means of the RTS.

This article's purpose is:

1) to assess the correctness of movements during a backwards fall in students of physical education,

2) to see if students playing handball have different movement habits compared with non-sportsmen students,

3) carry out a biomechanical analysis of the causes of head injuries sustained in backwards falls,

4) to see how a falling mistake, hitting the ground with the buttocks, can affect head injuries.

Biomechanical analysis of the moment of the force acting on the head during a backwards fall

Figure 1 shows a graphic interpretation of the forces acting on the head as a result of hitting the ground with the buttocks during a fall. This analysis does not take account of the forces originating in the muscles acting on the head and it focuses on a backwards fall executed in a way similar to the gymnastic backwards roll [Mroczkowski, Mosler 2018]. To simplify the analysis, it is assumed that the trunk is straight during the fall – from the point of view of biomechanics it can thus be seen as one segment. The trunk and the head can be seen as two links in the kinematic chain with the connection between them being like a flexible joint. The impact of hitting the ground with the buttocks with force $\boldsymbol{F}$ induces the force of reaction $\boldsymbol{R}$ which causes forces of inertia to act on the head. The force of reaction $\boldsymbol{R}$ can be divided into two component force, $\boldsymbol{X}$

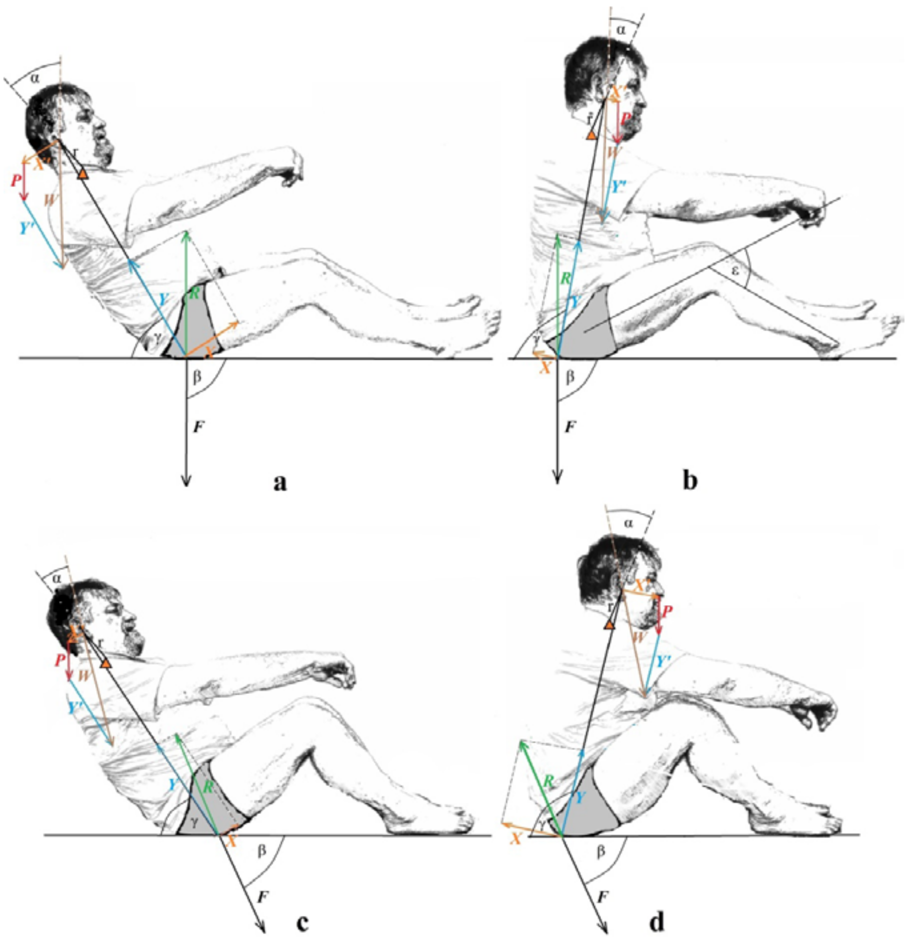

Figure 1. Relationship between the changes in the moment of the force acting on the head and the changes in the value of the angle ß between the force F and the horizontal plane and in the value of the angle between the trunk and the horizontal plane γ. The Figures *a* and *b* show the fall with identical values of the angle ß and varying values of the angle of the plane γ – as do the Figures *c* and *d*.

and ***Y***, which are transmitted onto the head. Their values are subject to change, since not all energy of the impact will be transmitted onto the head. The diminished ***X*** and ***Y*** component forces, ***X'*** and ***Y'***, along with the weight of the head ***P*** bring about the resultant force ***W***, whose vector is anchored in the head's centre of gravity and whose value is the resultant of the polygon of forces. The resultant force through the arm r brings about the moment of the force acting on the head as defined by the formula:

$$M= rW\sin\alpha \qquad (1)$$

The arm r covers the distance from the head's centre of gravity to the point at which the pivotal movement of the neck begins. An approximate graphic description shows the relation of changes of the moment of the force acting on the head and the changes of the angle β between the force ***F*** and the horizontal plane γ and the angle between the trunk and the horizontal plane γ. According to the principles of biomechanics, the fall should be executed in a way similar to the rolling of a car wheel [Mroczkowski 2015]. Body parts should come into contact with the ground through rolling. Hitting the ground with the body should be avoided, especially at the beginning when the buttocks come into contact with the ground. This goal is achieved by decreasing the value of the angle β between the force ***F*** and the horizontal plane. Such a change of the angle is possible if the falling person manages to bend the legs at knees sharply, creating the angle ε.

For the head the most dangerous is the moment of the force ***W*** which makes it tilt backwards during the fall (Fig. 1a, c). The value of this momentum will increase with the decreasing of the angle γ and the increasing of the angle ß (Fig. 1a). At the same time the increasing of the angle ß is caused by the decreasing of the knee-bend angle ε. Such changes of the angles γ, β, and ε bring about the increasing of the angle α and the value of sinα (formula 1).

2. Materials and Methods

Research method

Rotational training simulator RTS was used in the experiment to induce falling backwards. Its validation procedure along with a detailed description of the research method using RTS was described [Mroczkowski, Mosler 2018]. In RTS-induced falls the person holds on to a pole while standing on a board which accelerated to a desired speed. On hearing the sound signal the person lets go of the pole and the board comes to a halt, which causes inertia forces to induce the person's fall. The researcher running the experiment can exclude persons from further participation if the way they fall poses risks to their health.

In the experiment the students took part in two tests. In the first, 'immediate fall test' (IFT), they did not try to prevent themselves in any way from falling when the fall-inducing forces were at work. Such a way of falling is sometimes used by sportsmen in order to reduce the risk of injury or to get a more favourable decision by the referee. The second, 'forced fall test' (FFT) differed from the first in that that the students only fell when the fall-inducing force was strong enough to cause a fall and the students tried to keep their balance, thus delaying the fall. They fell inadvertently, which makes it justified to say that event occurring in FFT is a fall in accordance with the WHO's definition [Mroczkowski, Mosler 2018].

The assessment method used in this author's study is similar to STBIDF assessment criteria: a correct movement earns 1 point, while an incorrect one – 0 points [15]. The study involved students who did not make the 'hands' mistake while falling, which otherwise would have reduced the kinetic energy of the fall during the trunk's first contact with the ground [Feldman, Robinovitch 2007; Mroczkowski 2015]**.** In this way the experiment was only limited to finding a relation between the 'head' mistake with the 'hips' mistake during the fall. The 'head' mistake was understood as the bending of the head backwards when the body position changed from vertical to horizontal, resulting in hitting the ground with the head. In backwards falls, the chin should be pressed against the chest. The 'hips' mistake did not occur if the knees were bent at an angle ε of more than 90°. The knee angle was measured using physiotherapy's standard methods (Fig. 1b) [Clarkson 2000]. The assessment of the mistake was made by looking at consecutive frames of the video material from the tests.

In the tests, the students were accelerated to three velocities: V1 = 1.15 m/s, V2 = 1.3 m/s, V3 = 1.5 m/s. Lower velocities were excluded, because they increased the number of students who did not fall in FFT, which would have made it difficult to collect a desired number of results for statistical analysis. Therefore, only those students who would fall at all three velocities in FFT were selected for the tests. When forced by RTS to fall, all the students fell in a manner similar to performing a gymnastic backwards roll (Fig. 2) [Mroczkowski, Mosler 2018].

Research material

When assembling cohorts assumptions were made similar to the ones in Mroczkowski's research [Mroczkowski 2018]. The study involved 67 first-year students of physical education, three-year programme, at the University of Zielona Góra, aged 19-24, divided into two study groups. Group A was made up of 41 students who said that earlier they had not practised any sport in a sports club. Their physical education consisted solely of PE classes at school. Group B was made up of 26 students who had practised for at least four years handball in a first- or second-division sports club. In group A, the students height was 178 ± 5.2 cm, weight – 82.1 ± 8.1 kg, while in group B their height was 182 ± 6.3 cm and weight – 83.3 ± 9.3 kg.

The research was carried out over the period of 2014-2018. All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Commission for Bioethics at the Regional Doctors' Council in Zielona Góra (4/55/2014).

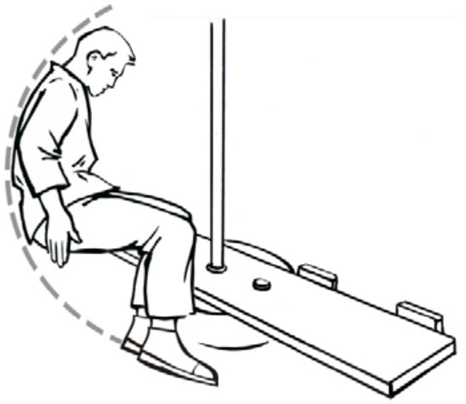

Figure 2. An RTS-induced fall executed in a way similar to a gymnastic roll backwards.

Statistical methods

In order to compare the percentages, or fractions, of mistake occurrence t-test test was used for fractions. The fraction has a binominal distribution with an NP mean and an NPQ variance with a tendency for normal distribution with the same parameters when N increases. Where P is a fraction, i.e. a frequency of occurrence of mistakes, Q=1-P and N is the number of observations. Even for small N binominal distribution can be replaced with normal distribution. The difference between fractions, i.e. percentages of occurrence is significant when the probability p for the test is <0.05.

3. Results

In both groups the percentage of 'hips' mistakes increases with the velocity in the test. Statistically significant changes are found between run 1 and run 3 and between run 2 and run 3 of both IFT and FFT tests. Similarly, the number of 'head' mistakes increases with velocity.

Table 1 T- test comparison of percentages of mistakes between velocities for groups A and B combined (n=67) and for IFT and FFT tests, separately for 'hips' and 'head' mistakes.

	number of mistakes			%			probabilities	
velocities	1	2	3	1	2	3	1 z 2	1 z 3
IFT- hips	35	44	55	52.24	65.67	82.09	0.1164	**0.0003**
IFT- head	16	28	36	23.88	41.79	53.73	**0.0290**	**0.0005**
FFT- hips	45	51	60	67.16	76.12	89.55	0.2522	**0.0020**
FFT- head	14	26	30	20.90	38.81	44.78	**0.0251**	**0.0038**

Table 2 T-test comparison of percentages of mistakes between velocities for group A (n=41) for IFT and FFT tests, separately for 'hips' and 'head' mistakes.

	number of mistakes			%			probabilities	
velocities	1	2	3	1	2	3	1 z 2	1 z 3
IFT- hips	27	32	38	65.85	78.05	92.68	0.2226	**0.0036**
IFT- head	14	25	33	34.15	60.98	80.49	**0.0172**	**0.0001**
FFT- hips	33	36	40	80.49	87.80	97.56	0.3671	**0.0155**
FFT- head	13	23	28	31.71	56.10	68.29	**0.0289**	**0.0014**

Table 3 T-test comparison of percentages of mistakes between velocities for group B (n=26) for IFT and FFT tests, separately for 'hips' and 'head' mistakes.

	number of mistakes			%			probabilities	
velocities	1	2	3	1	2	3	1 z 2	1 z 3
IFT- hips	8	12	17	30,77	46.15	65.38	0.2596	**0.0158**
IFT- head	2	3	3	7.69	11.54	11.54	0.6401	0.6401
FFT- hips	12	15	20	46.15	57.69	76.92	0.4090	**0.0269**
FFT- head	1	3	2	3.85	11.54	7.69	0.3030	0.5547

Table 4 T-test comparison of the percentages of 'head' mistakes in group A between the velocities in case of students who made 'hips' mistakes at the first velocity. The left side of the table refers to IFT test, the right side – to FFT test.

A 1IFT- hips =1 (n=27)			A 1FFT- hips =1 (n=33)	
1IFT- head	2IFT- head	p	1FFT- head	2FFT- head
44.44	77.78	**0.0151**	36.36	66.67
1IFT head	3IFT- head	p	1FFT- head	3FFT- head
44.44	88.89	**0.0011**	36.36	81.82

Table 5 T-test comparison of the percentages of 'head' mistakes in group B between the velocities in case of students who made 'hips' mistakes at the first velocity. The left side of the table refers to IFT test, the right side – to FFT test.

B 1IFT- hips =1 (n=8)			B 1FFT- hips =1 (n=12)	
1IFT- head	2IFT- head	p	1FFT- head	2FFT- head
25.00	25.00	1.0000	8.33	25.00
1IFT head	3IFT- head	p	1FFT- head	3FFT- head
25.00	25.00	1.0000	8.33	16.67

Table 6 T-test comparison of the percentages of mistakes between IFT and FFT tests in groups A and B, separately for each velocity.

A n=41	% mistakes			% mistakes	
velocities	IFT- hips	FFT- hips	p	IFT- head	FFT- head
1	65.85	80.49	0.1387	34.15	31.71
2	78.05	87.80	0.2439	60.98	56.10
3	92.68	97.56	0.3083	80.49	68.29
B n=26	% mistakes			% mistakes	
velocities	IFT- hips	FFT- hips	p	IFT- head	FFT- head
1	30.77	46.15	0.2596	7.69	3.85
2	46.15	57.69	0.4090	11.54	11.54
3	65.38	76.92	0.3629	11.54	7.69

Table 7 Comparison of groups A and B using t-test

	1-A	1-B	p	2-A	2-B	p	3-A	3-B	p
IFT- hips	65.85	30.77	**0.0067**	78.05	46.15	**0.0093**	92.68	65.38	**0.0060**
IFT- head	34.15	7.69	**0.0159**	60.98	11.54	**0.0002**	80.49	11.54	**0.0000**
FFT- hips	80.49	46.15	**0.0049**	87.80	57.69	**0.0064**	97.56	76.92	**0.0090**
FFT- head	31.71	3.85	**0.0081**	56.10	11.54	**0.0005**	68.29	7.69	**0.0000**

Statistically significant changes are found between run 1 and run 2 and between run 1 and run 3 of both IFT and FFT tests (Tab. 1).

An analysis of the percentages of ‘hips’ mistakes in particular groups shows that in group A the percentages increase significantly between runs 1 and 3 of both IFT and FFT tests. A similar analysis of ‘hips’ mistakes shows that the percentages increase significantly between runs 1 and 2 and between runs 1 and 3 of both IFT and FFT tests (Tab. 2)

In group B the percentage of “hips’ mistakes increases significantly between run 1 and run 3 of both IFT and FFT tests (Tab. 3). At the same velocities the percentage of mistakes is lower in group B, compared with group A. The number of ‘head’ mistakes is found only to increase between runs 1 and 2 of both IFT and FFT tests. The changes in the percentages are not, however, statistically significant and the number of mistakes is generally much lower in group B than it is in group A.

It was found that for a significant number of the students, making the ‘hips’ mistake in the first run of IFT (n=27) and FFT (n=33) tests, the number of ‘head’ mistakes grew significantly in the next run at higher velocity (Tab. 4).

In group B, in IFT (n=8) and FFT (n=12), no correlations were found between making ‘hips’ mistakes in the first test run and ‘head’ mistakes in the second run at higher velocity. The differences that occurred were statistically insignificant (Tab. 5).

The percentage of ‘hips’ mistakes was always higher in both groups at the same velocities in FFT test, compared with IFT test. The percentage of ‘head’ mistakes in group A at the same velocities was always lower in FFT test, compared with IFT test – the same results were obtained for group B at velocities 1 and 3, while at velocity 2 the percentages did not differ. Yet no significant statistical differences were found in the percentages of mistakes at the same velocities between IFT and FFT tests (Tab. 6) in groups A and B.

Table 7 contains data indicating that in group B the number of ‘head’ and ‘hips’ mistakes at the same velocities in IFT and FFT tests was lower than it was in group A. The differences in results between the groups were statistically significant.

4. Discussion

Table 7 contains data indicating that group B students make considerably fewer ‘head’ and ‘hips’ mistakes when falling backwards, compared with their counterparts in group A. This finding, thus, shows that playing handball may contribute to developing a movement habit which lessens the risk of injuries sustained as a result of a fall.

Tables 1, 2, and 3 suggest that in both groups the frequency of ‘hips’ mistake increases with velocity. Movement habits in handball players were insufficient to prevent them from making this mistake – it is unclear why this is so. A person about to fall down should increase the knee angle ε – as follows from the biomechanical analysis presented in this article. The time for doing this gets ever shorter with velocity. The results seem to suggest that there may not be enough time to increase the knee angle, especially in FFT test, since the falling person fights to remain in vertical position, which delays and shortens the time for reaction, i.e. changing the knee angle, when the fall actually begins. This is confirmed by the results in Tables 2 and 3, containing data indicating a higher percentage of the ‘hips’ mistake at each velocity in both groups in FFT test, compared with IFT test.

The question arises whether the technique of falling used in the experiment is a proper one when a specific strong horizontal fall-inducing force occurs. Eliminating the ‘hips’ mistake seems crucial, because this mistake brings about the moment of the force acting on the head, which can cause the head to hit the ground. As a result, head and trunk injuries can be sustained. It has to be pointed out that the experimental circumstances differ slightly from real-life ones – the falls are studied using mattresses which absorb the impact of hitting the ground, while the person in the experiment anticipates the occurrence of fall-inducing force. In real-life it cannot be known if movement habits of handball players would be sufficient to prevent them from hitting the ground with their heads when stronger forces of inertia are at work.

It appears justified to carry out research on the risk of body injury which can be sustained as a result of falling in conditions created by RTS using the technique of backward fall with side-alignment of the body – as described by Mroczkowski and Mosler [2018]. This method of falling is often described in martial arts [Momola, Cynarski 2006; Tohei 1978]. Such research, however, would require certain modification of the research method. The initial findings by this author suggest that the results obtained using RTS confirm the desired results obtained when falling using the above-mentioned technique.

Table 3 contains data indicating that an increase in the velocity of falling did not trigger an increase in the percentage of ‘head’ mistakes in group B. At the same time an increase in the velocity of the students who made the 'hips' mistake without making the 'head' mistake at a lower velocity did not cause them to make this mistake (Tab. 5). During the fall, due to movement habits in handball players in group B, the moment of the force generated by muscles responsible for supporting the head counterbalanced the moment of the force acting upon the head resulting from inertia forces. Falling backwards often occurs in the game of handball, so the habit of holding one's head in a safe way when falling might have been acquired by them. This observation concerning this habit in handballers has been confirmed by the earlier research using the non-apparatus test called STBIDF [Mroczkowski 2018].

Using this article's biomechanical analysis of moments of forces acting on the head, the results obtained in group A can be explained. The students in this group lack a proper movement habit, which results in limited action of muscles supporting the head during the fall. Thus, in approximation, the biomechanical model described in this article proves useful to explain the correlation of the 'head' mistake with the 'hips' mistake. The results for group A in Table 2 contain data indicating that due to increasing velocity there is an increase in the number of 'hips' and 'head' mistakes. Table 4 contains data indicating that at the lowest velocity the students, who had made the 'hips' mistake and not the 'head' mistake, made significantly more 'head' mistakes at higher velocities. Such a relationship is not found in group B (Tab. 5). Therefore, making the 'hips' mistake is a factor responsible for the 'head' mistake in group A. This is explained by the increase in the value of the force of inertia which induces the fall and the increase in velocity [Mroczkowski, Mosler 2018].

Table 6 contains data indicating that in group A in FFT test, compared with IFT test, there are fewer 'head' mistakes at particular velocities, whereas there are more 'hips' mistakes. Yet the differences are statistically insignificant. In this author's view, however, those findings definitely deserve more attention and point to the need for further research on this issue.

Here, certain imprecision of the research method shines through – the method should be examined using the biomechanical analysis presented in this article. The video material with RTS-induced falls shows certain differences in the execution of falls between IFT and FFT tests: compared with IFT test, in FFT test the students strived to maintain their balance and – so they inclined their trunks and heads more from the horizontal plane and, as a result, hit the ground at a bigger γ angle between the trunk and the ground (Fig. 1 b,d). The information about those differences in the execution of falls is not fully given, since in the findings there is no information about the trunk-ground angle.

The assessment method adopted in the experiment is similar to that in STBIDF which does not take account of the angle between the trunk and the ground and whose creator recommends the 'cradle' position to be in while falling. It should not, however, be surprising that this aspect is omitted, since an exact measurement of this angle is difficult in the case of all students going through the tests, especially when the trunk is bent. The bending of the trunk and the adoption of the principle of rolling in a circle during a fall is recommended from the point of view of biomechanics [Mroczkowski 2015] INFOSECA scale assesses how well the shape of a sphere is achieved and the bending of the iliac joint is maintained during a fall, which is related to the restriction on the decreasing of the trunk-ground angle. The adoption of INFOSECA assessment criteria in this aspect is, nevertheless, unacceptable, because the initial position for RTS-based tests is standing position.

The biomechanical analysis presented in this article shows that the value of the moment of the force acting on the head during a fall depends on the force of inertia. The direction and magnitude of the force of inertia are of great importance, too. The inertia force is affected by the knee angle and the trunk angle at the time of the contact with the ground. The highest value of the moment of the force acting on the head occurs at a low angle ε of the knee joint and a low inclination of the trunk γ from the horizontal plane (Fig. 1a).

The above justifies the finding that in group A in FFT test, compared with IFT test, the percentage of 'head' mistake is smaller at higher velocities. In this author's view, this could be a result of the bigger angle of the trunk inclination from the ground plane, so the head can be affected by moment of the force inclining the head forwards and not backwards (Fig. 1 b,d). At the same time, in FFT test the velocity of hitting the ground with particular body parts can be lower – and so can the force of inertia acting on the head, as results from the work done by the muscles striving to keep balance [Mroczkowski and Mosler, 2018].

Moon, Sosnoff [2017] and Mroczkowski [2015] conclude that technique of falling have a significant effect on reducing impact load during a fall and might be effective to reduce the impact load of falling. According to Reguli, Senkyr and Vit, [Reguli *et al.* 2015], there is no ideal technique of falling. It should be adjusted to its prospective use – for instance, to a sports discipline to be practised. It does not make sense for footballers, or volleyball players or general public to practice judo falls to avoid injuries. According to Mroczkowski [2015], the technique of falling should respond to the physical circumstances which trigger it – for instance, whether the vertical or horizontal velocity is higher. It is certain that during a fall with strong vertical velocity the falling person stands no chances of moving one leg backwards, so in the test the technique resembling the gymnastic roll backwards was a correct one. An example of this is jumping on a trampoline where accidental landing outside of the it should be symmetrically on both legs immediately followed with a roll backwards [Mroczkowski, Hes 2015].

Although selecting the best fall technique will always be subject to debate, it is unquestionable that falls have to practised to develop a specific movement habit. Holding the head correctly seems especially important, which, as the findings attest, has been achieved by handball players. Such a movement habit may protect the head from injury in case of forces whose strength allows the falling person to react. A proper habit of holding one's head is especially important for the elderly, since in this social stratum the rate of head injury caused by falling increases with age [Hsu *et al.* 2018].

The results obtained by this author using RTS cannot be compared with other authors' findings, since there are no publications on backwards falls inducing apparatuses. Besides, RTS is invention and it is not mass produced so as to be used on a larger scale [Mroczkowski 2014].

The findings of this author's research confirm the observation that injury need not be an unavoidable consequence of a fall [Kalina *et al.* 2011]. Through training, proper movement habits can be developed. The results of group A students confirm the observation that physical education classes at Polish schools do not develop safe falling habits in children [Mroczkowski 2015; Kalina, Barczynski 2010; Mroczkowski, Sikorski 2015], which is likely to be the case in many countries. Certain steps have been taken in Spain, in the form of 'Safe Fall' programme [Toronjo-Hornillo *et al.* 2018; DelCastillo-Andres *et al.* 2018], and in Japan where school PE curricula include judo, sumo, and kendo [Kalina, Barczyński 2010; Bennett 2009] – the first two requiring the ability to fall safely. Such initiatives should be promoted elsewhere in the world – in accordance with the WHO's calling for implementation of educational programmes based on the research on falls.

5. Conclusions

Physical education programmes in Polish schools do not involve the teaching of movement habits which protect the trunk and head against injury during a fall. Hitting the ground with the buttocks or the trunk during a backwards fall causes inertia forces to act on the head, thus posing a risk of head injury. The moment of the force acting on the head increases with the decrease in the angle between the trunk and the ground and with the decrease in the bending of the knees at the time of impact. Techniques of falling should be sought which protect against hitting the ground with buttocks in a backwards fall if the horizontal forces causing the fall are strong. Handball players are found to have developed movement habits which lessen the risk of head injury in backwards falls. Therefore, practising certain sports disciplines may develop movement habits which occur in backwards falls.

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Statement: Neither my manuscript titled "Factors putting the head at the risk of injury during backward fall" nor any part of its content are currently under consideration for publication or already published in any other journal. I recommend my article for publishing in the "Ido Movement for Culture".

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Czynniki wpływające na zagrożenie uszkodzenia głowy podczas upadku do tyłu

Słowa kluczowe: upadki, biomechanika upadku, kinezjologia, sport, sztuki walki, edukacja zdrowotna

Abstrakt

Cel. Według Światowej Organizacji Zdrowia (WHO) upadki są drugą z najczęstszych niezamierzonych przyczyn śmierci na świecie. Zajęcia z wychowania fizycznego w polskich szkołach nie rozwijają u dzieci prawidłowych nawyków ruchowych podczas upadku.

Problem i cel. Celem badań było sprawdzenie, czy studenci wychowania fizycznego ćwiczący profesjonalnie piłkę ręczną posiadają inne nawyki ruchowe podczas upadku do tyłu, niż ich koledzy, którzy nie uprawiali sportu w klubie sportowym. Badania koncentrowały się również na biomechanicznej analizie przyczyn urazów głowy podczas upadku do tyłu.

Metody. W badaniu wzięło udział 67 studentów pierwszego roku wychowania fizycznego na Uniwersytecie Zielonogórskim w wieku 19-24 lata, podzielonych na dwie grupy badawcze. Grupę B (n=26) tworzyli piłkarze ręczni, grupa A (n=41) – pozostali studenci. W eksperymencie wykorzystano trenażer obrotowy RTS służący do wymuszania upadku do tyłu.

Wyniki. Studenci z grupy B popełniają znacznie mniej błędów „głowy" i „bioder" podczas upadku w tył, w porównaniu z ich kolegami w grupie A. W obu grupach częstość błędu „bioder" wzrasta wraz ze wzrostem prędkości upadku. Wzrost prędkości upadku nie powodował wzrostu odsetka błędów „głowy" w grupie B, a tylko w grupie A.

Wnioski. Piłkarze ręczni okazali sie mniej podatni na urazy głowy podczas upadku do tyłu. Uderzenie pośladkami o podłoże podczas tego upadku może wywołać moment siły działający na głowę, stwarzający ryzyko jej urazu.