

Article

Susceptibility to Head Injury during Backward Fall with Side Aligning of the Body

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Abstract: (1) Background: The aim of this article is to investigate the susceptibility to head injuries in physical education students who do not train a specific sports discipline and those who use the fall performed backward with side aligning of the body technique. The other goal is the biomechanical analysis of the impact of the fall technique on the likelihood of head injury. (2) Methods: the study included 57 students, divided into two research groups. Group A consisted of 32 students who had not practiced any sport in a sports club before. Group B consisted of 25 students who, by practicing martial arts, had acquired the skill of the fall performed backward with side aligning of the body. A rotating training simulator (RTS) was used to force the fall backwards. (3) Results: students from group B made significantly fewer “head” errors when falling backwards than in group A. Increasing the speed of falling did not increase the number of “head” errors in group B, but only in group A. The type of the fall test performed affected the increase in the number of “head” errors only in group A. (4) Conclusions: practicing selected sports disciplines in which the fall backwards occurs can protect one against head injuries by acquiring appropriate motor habits. The use of the fall performed backward with side aligning of the body technique with the occurrence of horizontal inertia forces causing a fall reduces the risk of head injuries.

Keywords: falls; injury prevention; biomechanics of a fall; public health; martial arts; kinesiology

1. Introduction

“Fall” is defined by World Health Organization (WHO) as an event which results in a person coming to rest inadvertently on the ground or floor, or other lower level [1,2]. A backward fall can lead to serious bodily injury. The consequence of the fall may be contusions of the body as well as bone fractures, which are especially dangerous for the elderly due to possible problems with bone fusion. However, it is the head hitting against the ground [3] that is particularly dangerous, as this can result in fatalities. Falls are also the cause of dangerous injuries of the cervical spine [4,5].

Some scientists have found that proper movement habits in a fall can protect against certain bodily injuries to some extent. The scientific literature reports that most countries do not teach in their schools appropriate movement habits during falls [6,7]. This work analyses backward falls of which a person is aware and can respond with specific motor reactions during the fall. Such movement reactions are possible if the values of the forces causing the fall do not exceed certain values [8].

Most research has been concerned with fall prevention by means of the elimination of external factors leading to a fall at work or through research on ways of improving people’s reaction to their balance disturbances [9,10]. Accelerating treadmills are traditionally used to analyze people’s reactions to fall-generating forces causing them to lose their balance [11]. Platforms [12] and foot-clamps [13,14] can also be used to study backward falls.

Some researchers claim that, under certain conditions, falls are unavoidable, so it is quite reasonable to study what happens to a human body in a fall [6,15]. To assess the risks of falling backwards

research methods have been devised which examine body movements on hitting the ground [15–18]. These nonapparatus methods describe fall movement patterns similar to those performed during a gymnastic backward roll. One can also come across falls performed backward with side aligning of the body. This kind of fall is taught in some martial arts [6,19,20].

The aim of this article is to investigate the susceptibility to head injuries in physical education students who do not train a specific sports discipline and those who use the fall performed backward with side aligning of the body technique. The second goal is the biomechanical analysis of the impact of the fall technique on the likelihood of head injury. The rotating training simulator (RTS) was used in the course of the research as it forces a backward fall utilizing inertia forces [6,21]. The loss of balance is induced by the inertia force leading to the person's falling down, which is a step forward compared to the previously described nonapparatus methods [22]. During the validation of this method, it was found that physical education students reveal certain motor habits when falling backwards [6]. The simulator itself is devised for people whose work or sports discipline involves falling. Its creator thus limits the research to adults with a high degree of physical fitness.

2. Biomechanical Analysis of Backward Fall Techniques

The fall techniques can be divided into those performed in a way similar to a gymnastic backward roll and falls performed backward with side aligning of the body [6]. They are presented in Figure 1. Figure 2a,b show the measurement of the path length while rolling on the ground during a fall, for the same person. This person assumed the body postures found in the particular fall technique. In Figure 2a, the length of the path was measured from the end of the coccyx to the C7 cervical vertebra for the fall performed in a way similar to a gymnastic backward roll which was 89 cm. Rolling over the head in this form of a fall is prevented by the appropriate ejection of the body through the movement of the upper limbs [23]. If during a fall performed as shown in Figures 1a and 2a rolling over the head would have taken place, this could have posed a risk of dangerous changes in stresses in the cervical spine.

Figure 2b shows the distance measurement for the fall performed backward with side aligning of the body, which was 175 cm. In this case, the measurement starts with the left foot and ends with the right hand. The measurements show that the rolling path is significantly longer. From Figure 2a,b it can be seen that the contact begins with, e.g., left leg, then goes the buttocks and the trunk, and ends up on right upper limb [5]. An example of using a fall performed backward with side aligning of the body can be found in the film [24].

During the technique performed in a way similar to the gymnastic backward roll the first contact of the body with the ground at a certain speed begins with the buttocks. The right direction of velocity in which the buttocks contact the ground is important so that, in accordance with Newton's third law of dynamics, at this moment, a large reaction force from the ground is avoided. Such a reaction of the ground may cause inertia forces acting on the head as a result of it's hitting the ground [22]. Especially when the head is in the way of the body rolling. The acting forces can cause injuries to the head as well as to the cervical spine. Most injuries to the cervical spine occur during a sharp flexion or extension of the neck, often accompanied by axial compression or distraction [25]. Protection against this force can be achieved by adopting an appropriate bending angle in the knee joint as well as the proper positioning of the torso [22].

In the technique of the fall performed backward with side aligning involves rolling on the ground from the very beginning of the fall. A longer total rolling distance in this case may result in lower stresses on the parts of the body in successive contact with the ground during rolling. As Mroczkowski reports, such stresses are smaller if the radius of the rotational movement performed by the body is large, even at higher rolling speeds [8]. Head hits are less likely with this fall technique. This is because the head is not on the rolling line of the body. At the same time, the position of the frontal plane of the body is not parallel to the ground, so the head is further away from the ground than in the previous

method. In order for this to be possible, the torso must be twisted appropriately when performing this fall technique, facilitating the contact with the ground with the lateral position of the lower limb.

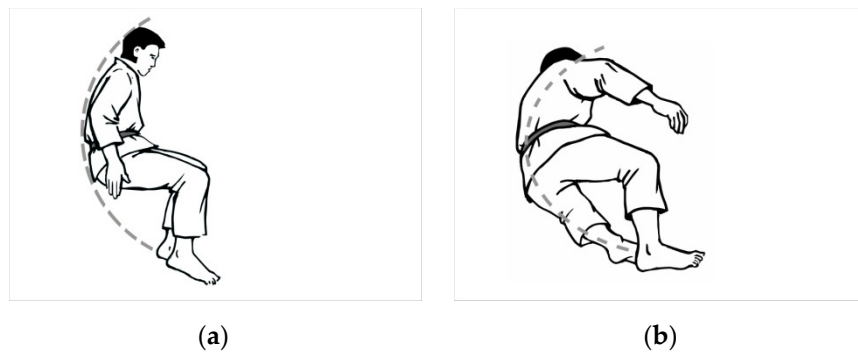


Figure 1. The back fall techniques (a) performing similar to a gymnastic backward roll (b) with side alignment of the body.

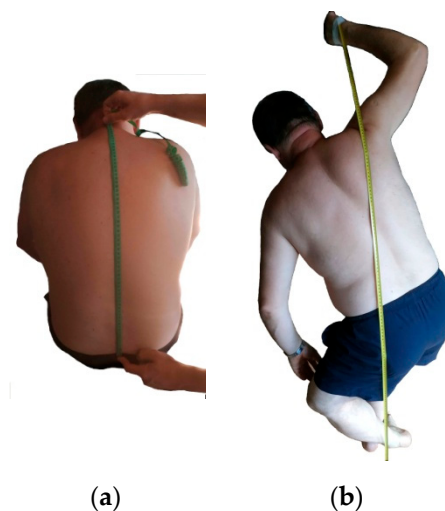


Figure 2. The measurement of the path length while rolling on the ground during a fall, for the same person (a) performed in a way similar to gymnastic backward roll (b) with side alignment of the body.

3. Materials and Methods

3.1. Research Method

The experiment used a rotational training simulator (RTS) to induce backward falls. Its validation procedure along with a detailed description of the research method with RTS has been described by [6]. In RTS-induced falls the person holds onto a pole while standing on a board which is then 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 results in inertia forces leading to the person's fall. The researcher in charge of the experiment may decide to exclude persons from further participation if the way they fall may threaten their health condition. In the experiment the students participated in two tests. In the first one, the 'immediate fall test' (IFT), they did not attempt to prevent themselves in any way from falling when the fall-inducing forces began to work. Such a way of falling is sometimes used by sportsmen in order to reduce the risk of injury or trick a referee to get a more favorable decision. The second, 'forced fall test' (FFT) differed from the first one in that the students only fell when the fall-inducing force was strong enough to cause a fall and they tried to keep their balance, thus delaying the fall. They fell inadvertently and thus it can be said that the event occurring in FFT is a fall according to the WHO's definition [4]. In the tests, the students were accelerated to the following velocities: $V1 = 1.15 \text{ m/s}$,

$V_2 = 1.3$ m/s, $V_3 = 1.5$ m/s. Only students who fell at all the three speeds in the FFT were selected for the tests.

The assessment method adopted in this author's study resembles the susceptibility test of the body injuries during the fall (STBIDF) assessment criteria: a correct movement earns 1 point, while an incorrect one scores 0 points [6,15]. Only the occurrence of the 'head' error during the fall was taken into account in the assessment. The 'head' error was defined as bending of the head backwards when the body position changed from vertical to horizontal, resulting in hitting the ground with the head. In the opinion of the author, this interpretation of the "head" error is appropriate for any fall technique. The "hip" error was not assessed as in the fall performed backward with side aligning of the body, the lower limb positioning did not meet the assessment criteria developed for the fall technique performed in a way similar to the gymnastic backward roll. The study included the students who did not make the 'hands' mistake when they were falling. The "hands" error poses a risk of injury to the upper limbs, while reducing the kinetic energy of the fall during the first contact of the torso with the ground [8,22,26]. In this way, the research was able to accurately assess the impact of the fall technique on the risk of head injury.

3.2. Research Material

When selecting groups, assumptions were made similar to the ones in Mroczkowski's research [6]. The study involved 57 physical education students at the University of Zielona Góra, aged 19–26 and divided into two study groups. Group A consisted of 32 students who claimed that they had not practiced any sport in a sports club. Group B consisted of 25 students who, by practicing martial arts, mainly aikido during extracurricular activities, had acquired the skill of a fall performed backward with side aligning of the body. In group A, the students were 175 ± 4.9 cm tall, their weight was 80.3 ± 7.1 kg; in group B they were 173 ± 5.3 cm tall and their weight was 81.7 ± 8.1 kg. There were no selection criteria for the research groups in terms of students' weight and height—the selection was random. The only selection among students was made in terms of the already-acquired method of falling as well as the exclusion from the research in cases of making the "hands" error [22]. The research was carried out from 2015 to 2019. It was conducted in accordance with the Declaration of Helsinki, and its protocol had been approved by the Commission for Bioethics at the Regional Doctors' Council in Zielona Góra (4/55/2014). All respondents gave their written consent to participate in the research. The group A students fell down through the RTS using the technique similar to the gymnastic backward roll. (Figure 1a). Students from group B adopted the fall performed backward with side aligning of the body technique (Figure 1b).

3.3. Statistical Methods

In order to compare the percentages or fractions of mistake occurrence, a t-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 a small N binominal distribution can be replaced with normal distribution. The difference between fractions, i.e., the occurrence percentages, is significant when the p probability for the test is <0.05 .

4. Results

Analyzing the results for individual groups, it was revealed that in group A the percentage of head errors increased with the increase in speed, being statistically significant between tests 1 and 3 for the IFT test and for FFT between tests 1 and 3, and 2 and 3 (Table 1).

Table 1. Comparison with t-Student's test of error percentages between speeds for group A ($n = 32$) and for each immediate fall test (IFT) and forced fall test (FFT), separately for 'head' mistake.

Velocities	Number of Mistakes			%			Probabilities		
	1	2	3	1	2	3	1 z 2	1 z 3	2 z 3
IFT	12	19	25	37.5	59.4	78.1	0.1	0.0010	0.1056
FFT	6	13	21	18.8	40.6	65.6	0.1	0.0001	0.0451

In group B for head error, an increase in error percentage only between test 1 and 2 for the FFT test is demonstrated. However, these changes are not statistically significant. The percentage of errors committed is definitely lower than in group A (Table 2). For the IFT, there are no head errors at all, as well as in tests 1 and 3 in the FFT.

Table 2. Comparison with t-Student's test of error percentages between speeds for group B ($n = 25$) and for each IFT and FFT, separately for 'head' mistake.

Velocities	Number of Mistakes			%			Probabilities		
	1	2	3	1	2	3	1 z 2	1 z 3	2 z 3
IFT	0	0	0	0.0	0.0	0.0	1	1	1
FFT	0	1	0	0.0	4.0	0.0	0.3124	1	0.3124

In Table 3, the one-tailed test was used because the null hypothesis of equality of the IFT and FFT in favor of the alternative hypothesis that the FFT leads to a lower error rate than the IFT method was to be refuted. It was found that in group A for the same speeds the percentage of errors made was always lower in the FFT test compared to the IFT. Significant differences occurred for speed 1. In group B, in study 1 and 3, there were no errors, while for the speed of 2, the percentage was higher in study F compared to I. There were no significant statistical differences between the IFT and FFT (Table 3) in group B. Based on Table 4, it can be concluded that in group B there was a lower percentage of head errors for the same speed in the same type of IFT and FFT test compared to group A. The differences between the results obtained in the groups were statistically significant.

Table 3. Comparison of Student's t-test of error percentages between IFT and FFT tests for groups A and B and for each velocity separately.

A $n = 32$		% Mistakes		Probabilities
Velocities		IFT	FFT	p
1		37.5	18.8	0.0476
2		59.4	40.6	0.0668
3		78.1	65.6	0.1331
B $n = 25$		% Mistakes		
Velocities		IFT	FFT	p
1		0	0	1
2		0	4.0	0.1562
3		0	0	1

Table 4. Comparison of groups A with B using Student's t-test (1-A, 2-A, 3-A—error percentages for group A for the respective velocities V1, V2, V3. The same designation was adopted for group B).

	1-A	1-B	p	2-A	2-B	p	3-A	3-B	p
IFT	37.5	0	0.0006	59.4	0	0.0000	78.1	0	0.0000
FFT	18.8	0	0.0221	40.6	4	0.0014	65.6	0	0.0000

5. Discussion

The results obtained in the article show that people who had acquired the habit of the fall performed backward with side aligning of the body by practicing martial arts turned out to be significantly less likely to injure the head during a fall (Table 4). During all the tests performed, only one person during one attempt in the FFT had the “head” mistake of defending themselves too long before falling (Table 2). A survey among students revealed that students in group A had not received training in safe falls. In group B, however, students had undergone such training. Teaching falls is essential before practicing self-defense techniques in aikido, for example [19,20,27]. The results obtained therefore suggest that through practicing falls, one can get into the habit of protecting the head from hitting the ground.

Some scientists show that there is significantly less susceptibility to injury to the body during a STBIDF fall test achieved by people who practice martial arts and sports [28,29]. Other reports show that handball players who acted in a way similar to the gymnastic backward roll had a much lower risk of injuring the head during a fall compared to physical education students who had not trained a specific sport [22,30]. According to a survey carried out among coaches, these skills did not result from additional training, but rather from the experience gained by players falling backwards during the game. Summarizing the current scientific reports suggests that the risk of head injury during a backwards fall is less significant for those who practice sports requiring backward falls during competition.

According to Reguli, Senkyr and Vit, [31], there is no ideal falling technique. It should always be adjusted to its prospective use—for instance, to a sports discipline to be practiced. It does not make sense for footballers, or volleyball players, or the general public to practice judo falls to avoid injuries. Based on biomechanical analysis, Mroczkowski states that it is important to take into account the direction of the velocity with which a person hits the ground and the type of correct fall technique depends on it [8]. If the vertical component of velocity is large compared to the horizontal component, it is important to move to the roll as quickly as possible. In this case, the fall technique performed in a way similar to the gymnastic backward roll makes sense. It is especially important in jumping on a trampoline [32] where the vertical component of velocity is very large. In general, for various types of gymnastic jumps, symmetrical movements are necessary in order to result in a symmetrical load in the hip joints during landing after the jump.

However, the question arises as to what technique of falling back should be of the most use in everyday life. A common cause of falls is a slip, which is dominated by the horizontal component of speed. Performing jumps in the vertical direction during daily physical activity is rare—it concerns only sports to a larger extent. If the fall causes acceleration in the horizontal direction, the fall performed backward with side aligning of the body appears to be a suitable fall technique. However, considerations on adjusting the appropriate fall technique to the specific physical conditions causing it should be supplemented with measurements of acceleration obtained by individual body segments during impacts against the ground [22].

In the opinion of the author of the article, research should be undertaken in order to answer the question which movement habits acquired through school gymnastics during the roll-back exercises may be useful during a backwards fall in terms of head protection. Certainly, doing the so-called cradle is beneficial [15]. However, the head-rolling aspect in the final stage is debatable. The head can be protected by the proper ejection of the body by the movement of the upper limbs against the action of rolling over the head [6,23]. This is to prevent the head from contacting the ground. The research conducted by the author of this article with the use of the RTS on about 700 physical education students in the field of falling back did not show the students to use such ejection. The time for making such a move is too short, especially in FFT [22]. As a result of the high acceleration (at higher speeds produced by the RTS) and causing the fall, it often resulted in rolling over the head in group A. Therefore, it is justified that some athletes should often use it, for example, handball players and volleyball players to roll along the shoulder line at the end of this type of a fall [6]. The nonapparatus tests developed so

far, examining the susceptibility to injuries during a backwards fall, have not adequately analyzed the movement of the body under the influence of forces that could cause a roll over the head. This is because the fall was not induced by an external force [15,16].

The results obtained in group A confirm bad motor habits during the fall. The increase in the fall speed resulted in a significant increase in the number of head errors in both tests (Table 1). It was found that the number of head errors was smaller for the FFT test than for the IFT, and the difference was significant for the first speed (Table 3). The claim may thus be made that “if you do not have the appropriate movement habits, then do not fall for the fall.” In group B, the results did not differ, i.e., the type of test did not affect the risk of head injury. The reduction in the number of head errors in group A (Table 3) may be influenced by the forward tilt of the torso to prevent falls. Such positioning of the torso reduces the value of the moment of force acting on the head while hitting the buttocks on the ground during a fall, which causes the “head” error [22]. As the fall speed increased, the number of head errors between tests did not differ significantly in terms of statistics. This may be due to the inertia force with increasing speed on the RTS increases [6]. As a result, the performance of tilting the torso forward is more difficult. However, as shown by other studies in the FFT test, with a decreasing number of head errors in people who do not practice a specific sport, the number of “hip” errors that can cause pelvic damage is significantly increased [22].

The results obtained in this article suggest that the fall performed backward with side aligning of the body technique with the horizontal direction of the force inducing the fall produces good results. Such conclusions are justified by the results obtained and the biomechanical analysis. This analysis suggests that a longer total rolling path can better distribute the stresses on individual parts in contact with the ground than in a way similar to the gymnastic backward roll. The analysis of the film frames showing the fall reveals that the decisive moment when the inertia force is applied to the head occurs in group A when the buttocks contact the ground. This is not observed in group B. These observations are consistent with other reports in which the occurrence of the “head” error with the “hip” error was found in people not exercising a specific sports discipline [22]. At the same time, it should be noted that the analysis of the backward fall techniques considers the fall caused by the RTS through a short-term application of the inertia force. In this case, by using a fall performed backward with side aligning of the body, as presented by Mroczkowski in the film [21,24], it is possible to return to the standing position after falling. It is possible both when performing a fall backwards, forwards, or sideways using the principle of rolling in a circle. It would be difficult to do something like this if the force causing the rearward fall was long-lasting. Such cases occur, for example, in judo fighting. The competitors then additionally hit the ground with their hands in order to absorb the impact of the body on the ground [8,20].

The obtained results show that, in people with a high level of physical fitness due to their field of study of physical education, the correct technique of falling is of great importance in order to avoid head injuries. However, such skills were not acquired during school education, but in nonschool forms of physical activity. This points to the lack of adequate education in this area for all students in Poland. According to scientific reports, such phenomena also occur in other countries.

The results of the article concern the falls of the group of athletic young people. Failure to acquire proper motor habits when falling backwards in school age significantly increases the risk of injury in old age. The elderly have an increased tendency to falls [33].

6. Conclusions

Practicing selected sports disciplines in which the backwards fall occurs can protect one against head injuries by acquiring appropriate motor habits. The use of the fall performed backward with side aligning of the body technique with the occurrence of horizontal inertia forces causing a fall reduces the risk of head injuries.

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