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Motor safety during trampolining

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Abstract

Background & Study Aim: Trampolining is qualified as a form of extreme physical activity (extreme sport), however its extreme nature is mainly determined by the coordination difficulty, whereas threat to health or life is above average. This paper has two primary objectives: 1) to provide reasoning based on biomechanics related to the risk of injuries during falls on the trampoline compared to falls of a person during everyday movement (e.g. walking or running on the regular ground); 2) opinions of persons with long-term experience in trampolining regarding safety of beginners during exercises on the trampoline.

Material & Methods: The study involved 25 persons (16 males and 9 females), including 4 coaches (former competitors); 21 of them are currently practicing this sport. The average age of the persons studied is 28 years and the average training experience amounts to 13.5 years. An anonymous questionnaire developed by the authors has been used in the study.

Results: As much as 84% of athletes sustained a serious injury which excluded them from training for a longer time. These injuries most frequently involved injuries to lower extremities (76%), 52% of which were ankle sprains and 29% of them constituted knee sprains. Injuries most often resulted from improper landing on the trampoline's fabric (53%), e.g. to the cervical spine caused by unfinished somersault or twist. Falls to the edges and frames of the trampoline occurred frequently (31%), whereas falls outside the trampoline constituted 16%. Such falls occur often during trainings (74%). As far as recommendations related to prevention of motor safety given to beginners in this discipline are concerned, respondents most frequently pointed to the correct positioning of the head (68%) and the use of a sponge pressed to the torso with the chin during exercises (68%) in order to form this habit.

Conclusions: The result of "the susceptibility test of the body injuries during the fall" (STBIDF) should become one of the criteria used to qualify a candidate to trampolining. Regardless of the STBIDF result, preliminary training should involve the course about safe falling. Biomechanical knowledge of human motor safety during a fall on the regular ground and during jumps on the trampoline may be spread as the element of intellectualization of training.

Key words: biomechanics of a fall, body injuries, extreme sport, rotational movements, safe fall

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Motor safety – is consciousness of the person undertaking to solve a motor task or consciousness the subject who has the right to encourage and even enforce from this person that would perform the motor activity, who is able to do it without the risk of the loss of life, injuries or other adverse health effects [4]

Extreme sport – "extreme form of physical activity are extreme sports, often classified according to the environment in which they are performed (water, land, air), extreme form of physical recreation as well as gainful activity or voluntary service, and all varieties of physical activity that meet at least one classification criterion of the feature associated either with extreme risk of injury or death, or extreme body burden with high level of effort, or extreme coordination difficulty" [11, p. 19]

INTRODUCTION

Jumping on the trampoline consists in making complex movements and somersaults after bouncing from the flexible surface of a trampoline. Jumps were for the first time included in the programme of the Olympic Games in 2000, however their history is far longer. The origin of trampolining should be searched in human desire to seek for various types of fun and entertainment [1, 2]. Currently, greater number of trampolines may be observed in gardens and at playgrounds. Trampoline parks and fitness on trampoline became popular.

However, the history of jumping on the trampoline does not only involve its use for play or sport. They are used during competitions which require specific skills. During the Second World War, the US army used this device to train pilots and navigators and shape their spatial orientation. After the war, trampoline was also used for other purposes. For example, it was used to train both American and Russian astronauts to adapt them to changes in body position in the air [3]. It resulted from large and varied accelerations acting on an exercising person. It was assumed that these exercises will prepare the body of pilots and astronauts to rapid changes of accelerations which will affect them during flights.

Large accelerations generated during exercises may be significant during a fall (on or outside the trampoline) and cause injuries resulting from inertial forces acting on a human body in such case F = –ma. Therefore, improper use of trampoline may be dangerous and lead to many injuries. Motor safety [4] of persons exercising on the trampoline depends primarily on them but also on the coach who asks them to perform certain exercises. Scientific reports provide many information about accidents on trampoline involving children [5-10]. Therefore, trampolining is qualified as a form of extreme physical activity (extreme sport), however its extreme nature is mainly determined by the coordination difficulty, whereas threat to health or life is above average [11].

This paper has two primary objectives: 1) to provide reasoning based on biomechanics related to the risk of injuries during falls on the trampoline compared to falls of a person during everyday movement (e.g. walking or running on the regular ground); 2) opinions of persons with long-term experience in trampolining regarding safety of beginners during exercises on the trampoline.

Biomechanical determinants of human motor safety during a fall on the trampoline

Biomechanical theory developed by Jaskólski and Nowacki may be applied to biomechanical interpretation of falls on the trampoline [12]. They have analysed strain energy of human body during a fall and considered human body surface as homogenous and elastic. They assumed that the entire kinetic entry of a person falling down transforms into a strain energy. Strain was a sum of dilatational and non-dilatational strain energy. They created formula to calculate strain energy per unit volume:

$$e = \frac{k}{t^2 S^2} \qquad (1)$$

where:
S – surface on which the force acts
t – deceleration time during a collision
k – constant in the formula

The formula (1) justifies that strain energy per unit volume of human body may be decreased during a fall by increasing the surface in contact with the ground and extending the duration of this contact. It is obvious that when fall of a person from the same height to the trampoline fabric is compared with a fall to the regular ground (floor), the strain energy per unit will be lower in the first case. This results from extended time "t" of the body strain, because trampoline fabric flexes during the collision with a body of given person. Body strain energy may be decreased by larger contact area with a surface "S" and this will be justified both during fall to the trampoline's fabric (Figure 1) and to the floor.

The main difference in biomechanical considerations on the likelihood of injuries sustained during a fall on the trampoline results from a possibility of bouncing from the ground. At the same time, kinetic energy with which the competitors hit the trampolines is large as it is caused by great height obtained while bouncing from the trampoline.

Biomechanical analysis of motor safety during a fall conducted by Mroczkowski [13] revealed that a method consisting in rotational movement similar to the way in which a car wheel is rolling may decrease body injuries during a fall. Change of energy during a fall can be described by the following formula:

Figure 1. Proper body posture while falling backwards onto the trampoline.

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

where:
f_t – coefficient of rolling friction
N – pressure force
R –radius on the circle along which the falling person moves
T_t – rolling friction
I – inertia moment
w – angular velocity
s – body's path

The author [13] divides falls with given velocity depending on the value of their horizontal and vertical component. If vertical velocity component is substantially larger than vertical one, e.g. during a fall from a great height, it is very important to land at both feet at the same time. Only after meeting this requirement, a person may start to roll along the circle. This case occurs in the majority of falls on trampoline, because vertical component is definitely larger than horizontal one. Landing simultaneously on both feet is important, so that forces acting on the hip joints are comparable. If large forces are generated during landing, some of them are amortised by lower extremities and pelvic girdle. More importantly, they should not cause large inelastic strain in the same time. Muscles may absorb such energy but its excessive amount may result in body injuries. During a fall e.g. outside the trampoline from a great height, some energy may be transformed during landing into inelastic strain energy: E_n, due to the large value of vertical velocity component in relation to the horizontal one. Even if a person starts to roll its body during such fall, some kinetic energy generated during a fall may transform into inelastic energy. In this case, the formula to may look as follows:

$$mg(h_2 - h_1) = E_n + mV^2/2 + Iw^2/2 + s\, f_t N/R \quad (3)$$

(E_n – inelastic strain energy of a landing body).

MATERIAL AND METHODS

The study involved an anonymous questionnaire which was filled by randomly selected coaches and current competitors with a long-year experience in trampolining. The group consisted of 16 males and 9 females. There were four coaches (former players) and 21 athletes. The average age amounted to 28 years and average training experience was 13.5 years. Local bioethics committee has given consent to the study.

In accordance with the aim of the study, the questionnaire constituted a tool to obtain opinions of persons with experience in trampolining about safety of beginners exercising on the trampoline. They key question of the questionnaire pertains to motor safety of persons exercising on the trampoline and is worded as follows: "which of the following recommendations are in your opinion the most important, while beginners exercise on the trampoline, to increase their safety during landing when they get in contact with

the trampoline (please mark recommendations with numbers from 1 to 6 indicating their importance, from the most important one to less significant ones):

- landing on the trampoline, while the first contact of feet starts from toes and ends with heels,
- equal load on both feet during landing in the direction close to vertical,
- keeping legs slightly bent in the knees and stiffening them during contact with the trampoline in landing phase,
- symmetric work of arms while bouncing from the trampoline,
- maintaining proper position of the head while jumping,
- keeping body unrelaxed while getting into contact with the trampoline".

The results have been presented as the sum of assigned significance to the recommendations. The most important recommendation is the one with the lowest amount of points. The more points recommendation gathers, the less significant it becomes. The average result of summed points is a simple indicator in continuum from 1 to 6 significance of given recommendation.

RESULTS

The questionnaire revealed that as much as 84% (n = 21) of examined persons sustained a serious injury which excluded them from training for a longer time (however, all experienced injury). Among persons who suffered from serious injury, 76% of them sustained injury to lower extremities, 52% of which were ankle sprains and 29% of them constituted knee sprains. The smallest number of injuries (19% each) involved upper extremities and spine (Table 1).

The most common cause of injuries was falls on thee trampoline's fabric (Table 2). It primarily and most often resulted from improper landing (which follows from descriptions of the cause related to technical performance of the jumps). More serious injuries, i.e. falls to cervical spine (cervical spine injuries) occurred, because a person did not finish a somersault or rotation. The respondents indicated "loss of spatial orientation during exercises".

The majority of respondents 19 (76%) fell outside the trampoline while jumping. Most of them believed that it resulted from poor control of feet (asymmetric position of feet while bouncing and thus uneven bouncing or bouncing with the use of one leg).

The most similar answers were provided to the question" "how should a person behave during a fall outside the trampoline from a great height while falling and during contact with the ground (please take into account the position of lower and upper extremities, torso and head)". Surveyed persons agreed that in such situation a person should finish the element (should not stop making a somersault) and try to rotate the body during a fall to land with legs down. They pointed out to the following important factors: proper tilt of the head away from the chest; keeping tight legs; legs slightly bent in knee joints; amortise

Table 1. Responses to the question: "what type of most serious injuries have you sustained during trampolining which excluded you from training for a long period of time" (the result does not add up to 100% because some people suffered injury several parts of the body)

Type of injuries	Number/proportion (n = 21)	
	n	%
Lower extremities:	16	76
ankle sprains	11	52
knee sprains	6	29
other lower limb	6	29
Upper extremities	4	19
Spine	4	19

Table 2. Responses to the question: "what was the cause of most serious injuries which occurred during trampolining which excluded you from training for a long period of time".

Cause of injuries	Number/proportion (n = 25)	
	n	%
The falls on thee trampoline's fabric	13	52
The fall on the edges and the frame trampolines	8	32
The fall off the trampoline	4	16

a fall with legs during the contact with the ground (by bending the knee joints more) and quick rotation to the back and performance of a back flip during back somersault and a forward roll during a forward somersault. They referred to "slightly hooking the feet on the ground".

On the other hand, while falling to the upper extremities they recommended to keep them flexed in front of the torso. The respondents clearly emphasised two issues. First of all, they stated that the most serious error is excessive tilt of the head away from the chest which in their opinion may result in loss of spatial orientation. Secondly, keeping the arms straightened in elbows during a fall which may break them.

While asked about behaviour during a fall to the edges and frames of the trampoline, the respondents answered in a similar way as to the question about falls outside the trampoline. They however believed that this situation is more dangerous for them due to possible landing on different ground, e.g. one leg on the mattress and second one on the trampoline.

Sixty eight percent of respondents indicated two ways of shaping the habit for proper position of the head during exercises and jumps: placing a sponge under the chin; self-control and reminding about such position of the head (Table 3).

The respondents believed that the following factors increase the safety during exercises on trampoline: equal load on the feet while landing in direction close to vertical one (56 points, 11 persons, i.e. 44% indicated this recommendation as the most important one); keeping body unrelaxed while getting into contact with the trampoline (60 points, 10 persons, i.e. 40% indicated this recommendation as the most important one). Landing on the trampoline, while the first contact of feet starts from toes and ends with heels was

Table 3. The results of answers to the question: "how in our opinion can the habit of proper position of the head kept during exercises on the trampoline be shaped?" (the result does not add up to 100% since some people indicated more than one recommendation)

Cause of injuries	Number/proportion (n = 25)	
	n	%
Placing a sponge under the chin	17	68
Self-control and reminding about such position of the head	17	68
Looking down on a trampoline when jumping up	7	28

Table 4. The hierarchy of six recommendations which are most important during jumps made by a beginner and declared by persons who practice trampolining (n = 25) in order to increase safety during landing and contact with a trampoline (1 – the most significant recommendation, 6 – the least important one).

The hierarchy of recommendations		Sum of points	Mean [points]	The proportion of declared ranking items					
				1	2	3	4	5	6
1	Equal load on both feet during landing in the direction close to vertical	56	2.24	0.44	0.24	0.08	0.04	0.12	0.08
2	Keeping body unrelaxed while getting into contact with the trampoline	60	2.40	0.40	0.13	0.29	0.05	0.13	-
3	Symmetric work of arms while bouncing from the trampoline	88	3.52	0.12	0.12	0.32	0.12	0.20	0.12
4	Maintaining proper position of the head while jumping	96	3.84	-	0.29	0.04	0.33	0.17	0.17
5	Keeping legs slightly bent in the knees and stiffening them during contact with the trampoline in landing phase	103	4.12	0.04	0.16	0.12	0.20	0.28	0.20
6	Landing on the trampoline, while the first contact of feet starts from toes and ends with heels	115	4.6	-	0.05	0.13	0.25	0.13	0.44

considered as the least important (115 points, 11 persons, i.e. 44% indicated this recommendation as the least important one). However, the average result of declared significance of a recommendation ranges from 2.4 to 4.6 on the ranking scale from 1 to 6 related to importance of given recommendation. All recommendations are grouped in the range of 2.4 (Table 4).

The reason for the uneven load on both feet while landing on the trampoline which could result in fall or injury unrelated to fall is believed to be inappropriate work of arms and unfinished rotational elements while jumping on the trampoline.

All respondents agree that children should be trained in terms of safety of the trampoline (in each case, if it is installed for recreational purposes – e.g. in the garden).

DISCUSSION

Persons with long-term experience in jumping on the trampoline clearly stated that the most serious error is excessive tilt of the head away from the chest which in their opinion may result in loss of spatial orientation. Keeping the arms straightened in elbows during a fall which may break them was considered as also as equal. They are aware of the need for proper control of the leg while making rotational movements and disperse energy from collision to the entire body and not only to lower extremities. Furthermore, while falling to the upper extremities they recommended to keep them flexed in front of the torso.

Theoretical considerations of the authors about biomechanics of fall and collision with the ground are consistent with opinions of persons surveyed. They clearly emphasised that during a fall outside the trampoline from great height it is necessary to land on both feet at the same time and rotate backwards or forwards (in accordance with the direction of rotational movement). Leaving aside the precise language of biomechanics, experienced players intuitively pointed out the need to perform certain rotational element instead of keeping the entire energy of a fall in lower extremities. Therefore, the fastest rotational movement of a body possible was connected by them with rolling in the direction of body rotation (e.g. during back somersault to back flip). Thus, they recommended to avoid large inelastic strain energy of a landing body, although they did not use the precise language of science.

The vast majority also drew attention to proper tilt of a head away from the chest and bringing upper extremities closer to the chest. Nearly all of them pointed out to usefulness of pressing a sponge with the chin during exercises on the trampoline as the important part shaping the habit to maintain the proper position of the head.

This manoeuvre is an elementary criterion during the second and third task of "the susceptibility test of the body injuries during the fall" – STBIDF [14, 15]. Exercising persons are also obliged to clap their hands until they finish their motor task (to lie down from vertical posture on the soft ground as fast as possible, whereas the third task involved jumping from the platform with a height of 16-20. Thus, STBIDF may be used as preliminary criterion to qualify people (children in particular) to exercises on the trampoline.

The third task of STBIDF has also additional diagnostic value. So far, the use of STBIDF [15] provides empirical proof that some persons jump from the platform on one leg instead of both ones. The respondents emphasised on the need to land on both feet at the same time during a fall outside the trampoline and recommend to perform rolling. Persons who on their own make a cradle during STBIDF's each task seem to have predispositions to naturally amortise a collision with the ground after the fall. If during second or third STBIDF task a person studied does not stop clapping, there is high probability that he or she will not underlie hands on the trampoline during a fall.

STBIDF may be particularly useful for preliminary assessment of body injuries risk while exercising on the trampoline. Regardless of the test results, it seems reasonable to recommend that exercises on the trampoline are preceded by safe falling course [16]. Athletes examined by us emphasised the need to train children in terms of safety on the trampoline. This is not about the procedures applicable at sports sections but about purchase of trampoline to be used by children during recreational activity (usually in the garden). At the same time, results indicate that although 76% of respondents fell outside the trampoline, only 16% of injuries were serious. In our opinion, long-term training shapes situational skill to safety collide with the ground. Falls outside the trampoline are on the other hand a frequent cause of injuries sustained by beginners. According to the respondents, more important cause of body injuries is connected by falls to the trampoline which could result from unfinished elements of rotational exercises.

Recommendation of the safe falling course preceding the exercises on trampoline is as important as the results of our questionnaire clearly show that the most serious falls, i.e. to the cervical spine (which may cause cervical spine injuries) are due to unfinished somersault or rotations accompanied by "loss of spatial orientation during exercises". Scientific literature confirms that these errors are the reason of the most serious injuries sustained by exercising persons [10]. At the same time, coach should help during most difficult exercises and use special straps and ropes.

The reason for the uneven load on both feet while landing is believed to be inappropriate work of arms and unfinished rotational elements while jumping on the trampoline. Such event occurred in the career of the second author of this publication, who several times won the championship of Poland in trampolining. While learning a double somersault in the straight position with three rotations in a front position with rotation of a body around its axis, he tried to perform this set of exercises on his own (without direct protection of a coach and additional safety straps). He added additional rotation (around body axis) to the element which he was already capable of doing (i.e. a double back somersault in straight position with two rotations around body axis). He was only secured by a mattress and coach standing nearby. The athlete was able to perform this element twice with too much rotation. During the third attempt, he rotated not quickly enough; he performed somersault and rotations too slow in the frontal plane. Afterwards, he landed on both legs with more load on the left leg. While landing, the attempted to finish the rotational manoeuvre and due to large force and rotation he broke the femoral epicondyle with a large displacement.

After returning to full fitness, the athlete started to learn this set of exercises with the use of rubber straps (a type of bungee) but in squatting position instead of a straight one. When he learned the correct motor habit, he started to repeat the exercises in conditions corresponding to sports competition.

Rotary training device may be used to support exercises on the trampoline performed by beginners [17, 18]. Exercises of rotational movements on this device (the results of unpublished observations) may have positive impact on the feeling of changes in angular velocity typical for changes in inertia moment while performing rotational elements during jumps on the trampoline. Preliminary observations reveal that this may increase motor safety of beginners by teaching them proper landing on both feet faster. It is important, because respondents' declarations show that lower extremities were most frequently injured (76%). However, there are scientific publications which state that beginners often suffer from injuries to upper extremities [9]. According to the authors, injuries of upper extremities may result from their improper control during the fall. The video available at the website (see SMAES Academy at http://smaes.archbudo.com) shows correct and incorrect behaviour during jumps on the trampoline.

The standards of physical education in Polish schools which have been recently introduced [13, 19] emphasise the notion of safe physical activity of students (student's knowledge about accidents and injuries during physical education class). There are no recommendations regarding learning of safe falling techniques. In our opinion, in the case of trampolining it is not sufficient to verbally provide recommendations regarding safety while performing such exercises.

CONCLUSIONS

The result of "the susceptibility test of the body injuries during the fall" (STBIDF) should become one of the criteria used to qualify a candidate to trampolining. Regardless of the STBIDF result, preliminary training should involve the course about safe falling. Biomechanical knowledge of human motor safety during a fall on the regular ground and during jumps on the trampoline may be spread as the element of intellectualization of training.

COMPETING INTERESTS

Authors declare no conflicts of interest.

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