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A comparison of selected biomechanical parameters in speed-endurance athletes

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Introduction. **Sports can be divided according to different disciplines or types of physical efforts involved. Long-term sport training leads to adaptive changes in the human body, which can result in spinal overload syndrome. The knowledge of the biomechanics of a given sport helps to protect athletes from this spinal disorder.** Aim of Study. **Using data from available literature an attempt was made to compare two different sports: field hockey and fencing in terms of their biomechanical properties.** Results. **The two sports share a number of similarities. Firstly, both may involve significant overloads of the lumbar spine because of the performance of uncoupled movements. Secondly, the knee joints in players of both sports may also be overloaded mainly because of numerous 90° flexions with rotations.** Conclusions. **Fencers and field hockey players are exposed to overloads of the spine and the knees. A special prophylactic and therapeutic program should be developed both for novice and elite athletes of both sports.**

KEYWORDS: field hockey, fencing, overload, muscle balance, coupled movements.

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What is already known on this topic?
Long-term highly specialist sport training leads to overloads of the human body. The knowledge of the biomechanics of a given sport helps to protect athletes from degenerative changes. While the biomechanical properties of some sports have been well described, in other sports this information is still insufficient.

Introduction

The categorization of sports according to the type of physical effort involved is a complicated issue. In athletics, identifying particular disciplines as strength, endurance or speed events is relatively simple. However, the majority of sports are rather described as involving combinations of effort types. Team sports can be defined as either speed-endurance (e.g. football or field hockey) or strength-endurance disciplines (e.g. volleyball). Technical skills are highly important factors affecting the competition outcome. There are sports that can be called resistance-endurance disciplines, such as are rowing and canoeing, where athletes must continuously overcome water resistance during a race.

Martial arts are sports in which strength, speed (response time) and endurance are of fundamental importance. This is the reason why boxing, taekwondo or mixed martial arts training must be versatile and include all these aspects. Fencing, however, is a combat sport in which strength preparation is not that essential. A fencing bout is won by the competitor who manages to hit the opponent first, not by the one who hits the opponent with a greater force.

Long-term and highly-specialized training not only leads to the mastery of a given sport but also to adaptive, and often unfavorable, changes in the musculoskeletal system. It is caused by the overloads of muscles. There are two types of muscles which, depending on their morphology, respond to overloads in a different way.

The first type consists of phasic muscles. They are mainly composed of fast-twitch fibers and perform the dynamic function. They also require large amounts of oxygen and nutrients and a protracted time for regeneration. In response to overloads they become lengthened and weakened. The examples of phasic muscles are the rectus abdominis muscle or the gluteus medius muscle.

The other type includes tonic muscles, which have more slow-twitch fibers and thus perform the static function. They are adapted to long-term activity and require relatively little oxygen and nutrients as well as a short regeneration time. In response to overloads tonic muscles become hypertonic and shortened. The examples of tonic muscles include the iliopsoas muscles and the rectus femoris muscle [1].

The imbalance of tension between both types of muscles can lead to biomechanical disorders in the musculoskeletal system. The most common syndrome in athletes is lumbar hyperlordosis, which occurs when the hip flexors together with the lumbar spine erectors become tight and shortened, while the abdominal muscles and hip joint extensors are lengthened and weakened [1, 2]. On the other hand, overloads of stabilizing muscles can lead to their inefficiency. The forces arising around the spine are then directly transferred onto the passive stabilizing system, i.e. the ligaments, joint capsules and inter-vertebral discs. Degeneration of these structures results in changes of bone structure [3]. All these consequences of long-term training can be observed in all sports, regardless of the effort type involved.

Aim of Study

On the basis of available literature the present study attempted to compare two different speed-endurance sports: field hockey and fencing, in terms of their biomechanical properties.

Biological and biomechanical characteristics of fencing

Fencing is a combat sport, in which male or female competitors fight with one of three types of weapons: the foil, the sabre and the épée. The fencing weapons differ from each other in blade type (shape, length, weight), valid target (torso or all body parts) and hitting techniques (cuts or thrusts). A fencer has to wear protective clothing, a facemask and a vest with electronic sensors that signalize accurate hits.

An international fencing tournament lasts about 9-11 hours, fencing bouts last 47-122 minutes altogether and during this time a fencer covers a distance of 250-1,000 meters. After each completed action a short break occurs to let fencers return to their starting positions. A fencing action can last from 5 to 15 seconds, and the action-to-break ratio is 1:1, 1:3 or 2:1, depending on the weapon. A single action consists of preparatory movements followed by a highly intensive attempt to hit the opponent. Heart rate (HR) measured in a women's épée competition ranged from 167 to 191 bpm (an average 179 bpm). It was observed that fencer with lower HR win the bout [4].

Points in fencing are awarded for hitting the opponent's valid target with the weapon, often by way of lunges (Figure 1). A fencing lunge is a complex and highly coordinated movement. Its precision is improved during years of training. During a bout it is preceded by an on-guard position in which fencers balance the body, with the knees slightly bent, the forearm of the weapon hand parallel to the leading foot in front of the rear foot.

An attack in a fencing bout is commenced by a flexion of the shoulder and extension of the elbow followed by a lunge. The depth of a lunge is controlled by an eccentric action of the front leg muscles: quadriceps and hip extensors. In a full lunge, the rear leg, whose role is to provide the power to perform a fast attack, is positioned in extension, abduction and external rotation

Figure 1. A fencing lunge

in the hip and extension in the knee. It has also been proven that the attack is stronger when the rear foot is perpendicular to the leading foot [5]. Apart from the legs, the spinal column also participates in a lunge. The lumbar spine flexes in the sagittal plane, bends toward the weapon side in the frontal plane and rotates in opposition to the weapon side in the transverse plane.

As in any other sports, multiple repetitions of movements characteristic for a particular discipline can lead to negative changes in the human body. In fencing, the lumbar spine and the knee joints seem to be most threatened by overloads. Flexion of the spine, combined with rotation, strongly affects the intervertebral joints and intervertebral discs. Furthermore, the asymmetric character of fencing makes the dominant side more overloaded, which can result in a limitation of the range of movement in the frontal and transversal planes.

Biological and biomechanical characteristics of field hockey

Field hockey is a team sport in which the aim is to put the ball into the opponent's goal using hockey sticks. A field hockey match consists of two 35-minute halves during which two teams of 11 players (men or women) compete against each other. The team which scores more goals wins. Field hockey games can be played outdoors, on a 91 × 55 m field covered with artificial grass, or indoors following some rule modifications forced by gym sizes. Players in a team are divided into such formations as the goalkeeper, defenders, midfielders and forwards, with each formation attempting to accomplish different tasks. The goalkeeper and defenders protect their own goal; the forwards try to score goals and the midfielders create offensive actions and assist the defenders.

A field player during a field hockey game covers an average distance of 10 km, although there are differences between formations: 9.3 km for defenders, 10.3 km for midfielders, and 10.8 for attackers. The longest distance is covered by walking or jogging (around 9 km altogether), and the shortest distance by sprinting (around 250 m). The forwards are the fastest, and defenders are the slowest players. An average HR for a field hockey player is 135 bpm, and there are no significant differences in HR between the formations [6].

The main technical elements of field hockey are dribbling, passing and shooting. Contrary to ice hockey, where the puck can be touched with both sides of the stick, in field hockey the ball can be only played with the flat side. This rule together with the short length of the stick (95 cm) forces a field hockey player to adapt a special posture. To dribble the ball players must flex their lower limbs slightly in all joints, bend the lumbar spine forward in the sagittal plane and to the right in the frontal plane, and set the right arm in external rotation and the left arm in internal rotation.

Shots and passes in field hockey can be performed in a number of different ways: drives, flicks, scoops, pushes and slap shots. In this study only two of them are analyzed: drives and drag flicks. A drive in field hockey is similar to a golf swing (Figure 2). It demands, however, further flexion of both the lumbar spine and the lower limb joints due to the length of the stick. By rotating the trunk in the transverse plane, the player takes a backswing with the arms and then makes a shot by swinging the arms forward and rotating the trunk to the left.

Performing a drag flick is more demanding for the body. Firstly, the player has to stand wide (this provides a large

Figure 2. A field hockey player performing a drive

support plane), flex the lumbar spine fully in the sagittal plane, side bend to the right in the frontal plane, rotate to the right in the transverse plane and slightly flex both upper limbs in all joints. Secondly, the player puts the stick, which is parallel to the ground, next to the ball. Finally, the player pushes the ball by transferring their weight onto the left foot, rotating the lumbar spine to the left and swinging both arms forward (Figure 3) [7]. It has been proven that a hockey player can perform a stronger and more accurate shot when his/her both feet are placed away from each other and the lumbar spine is flexed as far as possible [8, 9].

It can be noticed that in field hockey players the lumbar spine is strongly affected by chronic overloads. Submaximal or maximal flexion with a rotation of the spine is present in each technical element of field hockey, e.g. in passes, shots, or dribbles. A long-term repetition of these plays highly overloads the body structures around the lumbar spine, the pelvis, and, especially, the intervertebral discs. These movements cause that the shear component of the resultant force in the disc is highly increased, and this is the force in which the nucleus pulposus pushes on the anulus fibrosus. As a consequence, micro ruptures in the posterior part of the anulus fibrosus arise, which is also weakened by increased lordosis [10]. Repeated overloading makes the anulus fibrosus become unable to resist this force; it breaks and the nucleus pulposus penetrates the spinal canal. If the disc is damaged, it loses its shock absorbing properties and, therefore, compression forces are directly transferred onto the vertebral bodies, leading to the changes of the bone structure [3].

Figure 3. A field hockey player performing a drag flick

Several studies were conducted on the topic of overload induced changes in field hockey players [11, 12, 13], and they revealed a high number of functional and structural disorders in the players.

Pathobiomechanical comparison of fencing and field hockey

A biomechanical comparison between fencing and field hockey reveals significant similarities between both sports, e.g. between a fencing lunge and a field hockey drag flick. First of all, both fencers and field hockey players stand in a forward lunge position. The only difference is the side of the front foot: in fencing, the right foot is in front in right-handed fencers, whereas in field hockey the left foot has to be in front. The reason behind this difference was mentioned before. In fencing, the key point is to hit the opponent quickly and accurately rather than with force. Therefore, the necessity to perform a backswing with the weapon is eliminated. Still, there is a need to shorten the distance between the weapon tip and the opponent.

In field hockey, however, the strength with which the player pushes the ball exerts a direct influence on its speed. The higher the speed of the ball is, the less time the defenders and the goalkeeper have to react. Therefore, the left foot has to be in front due to the stretch-shortening cycle (SSC) as it allows a player to perform a better swing in order to hit the ball with force. It also means that the main movement is preceded by the backswing in the opposite direction. Depending on the purpose, the backswing can be wide and slow or short and fast. The SSC is more effective when the time between the backswing and the swing is as short as possible [14]. The SSC is used in all asymmetric sports which demand great strength, e.g. shot put and javelin throw in athletics, spiking in volleyball or throwing a ball in baseball. For the same reason, in martial arts such as boxing, a right-handed boxer places his left foot in front in order to perform a quick left straight or a strong right hook.

Balancing on slightly flexed lower limbs is a common position in many sports. A volleyball player in reception, a basketball player in defense, a field hockey player preparing to receive the ball or to shoot, a fencer during a bout – all of them move on their flexed lower limbs, which allows them to react faster because the time to stretch the hip and knee extensors is eliminated from the stretch-contraction cycle. Nonetheless, maintaining the hip and the knee in flexion has a negative influence on the biomechanics of the spine.

Muscle balance analysis in field hockey players showed [13] that the iliopsoas, rectus femoris and hamstrings are symmetrically hypertonic in a significant number of players (from 60% to 100%). This situation disturbs the functioning of the hip and knee joints. The strong biomechanical connection between the hip and the lumbar spine makes the muscle imbalance in the hip joint transfer onto the lumbar spine, leading – in this case – to hyperlordosis.

Fencers were shown to have significantly higher spine curvatures in the sagittal plane [10]. It can be noted that a fencer, as well as a field hockey player, has increased lumbar lordosis while standing, and during bouts when they frequently perform maximal flexions. Since no research on this issue is available this only allows us to assume that fencers present a similar scheme of muscle tone imbalance and pain symptoms.

In both sports a maximal flexion and rotation is performed in the hip joints and the spine, especially in its lumbar part. Fencers while attacking, rotate the spine in the opposite direction to the armed hand, while field hockey players, when executing a forehand shot, first perform the backswing by rotating to the right and then the swing by rotating to the left. The biomechanics of the spine in both sports is therefore of utmost importance.

Research shows that the spine movements in the frontal plane are always coupled with movements in the transverse plane [15]. The direction of both can be the same or opposite, and it depends on the position of the spine in the sagittal plane. Therefore, for the lumbar spine in flexion, side bending and rotation are coupled to the same side. In extension, side bending and rotation are coupled to the opposite side. It is caused by the plane of the intervertebral facet joints, which in these movements slide against each other. There is a possibility to perform an uncoupled movement, e.g. flexion, bending to the right and rotation to the left, but then both joint facets become compressed, leading to a hard stop. A multiple repetition of uncoupled movements leads to a degeneration in the intervertebral joints visible in X-rays. Both fencing and field hockey involve uncoupled movements of the spine: in fencing, at the end of an attack, and in field hockey, at the end of a swing.

Fencing and field hockey are asymmetric sports. It is particularly visible in field hockey, where the ball can be touched only with the flat side of the stick. A player must assume, as described above, a characteristic posture and – independently of the dominant hand – the right hand must always hold the stick in the middle, while the left hand at the end. This asymmetric character causes overloads of the upper limb muscles and its girdle. Muscle balance asymmetry is also predicted in fencers, because the fencing weapon is always held by the dominant hand.

The equipment used in both sports (a field hockey stick and a fencing weapon) enhances the overloading of the lumbar spine. Flexion of the upper limb increases the momentum of the force of its gravity and it has to be balanced by the tension of the lumbar spine erector muscles. This tension has to be balanced by lumbar spine stabilizers – in this case mainly by the external abdominal oblique muscle. When this stabilizer is inefficient lumbar lordosis increases and the compression forces affect the posterior part of the vertebral body more strongly. In fencing and field hockey the weight of the upper limbs is increased by the weight of equipment (a hockey stick from 340 to 790 g, a fencing weapon from 500 to 750 g). Holding the upper limbs in flexion away from the trunk increases their gravity – the momentum grows significantly and, therefore, the spinal erector muscles as well as stabilizing muscles have to work stronger.

It is worth noticing that in field hockey players the lumbar spine is disordered in the frontal plane as well. The quadratus lumborum muscle, which performs side bending, is significantly hypertonic on the right-hand side among field hockey players [13]. Side bending to the right is a common movement during a fencing bout; therefore, it is highly probable that the frequency of its increased tone is similar in both groups of athletes.

The rectus femoris and the hamstring, despite moving the hip, are the main muscles that move the knee joint. Prolonged imbalance between them limits the mobility of the joint and can lead to structural changes. Moreover, the end phase of an attack and a drag flick forces the knee joints to be positioned in flexion over 90 degrees. In field hockey, moreover, there is a rotation as well. It creates an unfavorable situation for the active and passive joint stabilizers. Muscles have to eccentrically stop the movement, while the ligaments and the menisci have to receive the arising shear forces. Long-term repetitions of this movement can lead to traumas or overload injuries of these structures.

In one research survey [13] players of the Polish Field Hockey National Team admitted experiencing knee pain, which was not caused by trauma, i.e. by twisting the joint or being hit with a stick. This suggests that prolonged functional disorders lead to menisci degeneration noticed in MRI scans [11].

A study of ground reaction forces during a fencing lunge showed large forces affecting all joints of the lower limbs, which causes the possibility of bone and posterior cruciate ligament injuries [16]. There is also a scientific solution to this problem. It is suggested that fencing shoes be redesigned since they could absorb axial shocks similarly to running or squash shoes [17].
The discussed comparison shows several similarities between two sports that seem to be completely different. The main difference between them is the covered distance during a bout or a game. However, the position of a player in action exerts a similar influence on their posture and, therefore, leads to chronic overload induced changes in the lumbar spine.

Conclusions

Numerous studies proved that the lumbar spine, due to its function in biokinematic chains, receives high loads that are close to destructive values [3, 18]. The loads on the moving segment cause a stress which may lead to overload injury. Beside any other pathogenic factors, mechanical forces seem to play a key role in causing lumbar spine disorders, especially in its lower segments. These disorders may be split into two types [1, 19, 20]. The first type is a trauma when a sudden injury affects a previously healthy segment. The second type is a chronic injury, when the final destruction of tissues is preceded by a long-term progressive degeneration. These injuries are highly notable among athletes practicing strength, strength-endurance and speed-endurance sports. In this study a comparison of lumbar spine overloads in fencers and field hockey players was made.
It is supposed that the main cause of lumbar problems in the analyzed athletes is chronic overloading as the fencer's and field hockey player's spine is subject to a high number of temporary loads that often excess mechanical and biological endurance. This process has several stages [1]. First of all, functional disorders appear in muscles and other soft tissues around the spine (Stage I). Subsequently, they affect the intervertebral and pelvic joints (Stage II). At this moment the effects of overloading are reversible (Stage III): they can be reduced by an appropriate therapy or a change in a physical activity. However, when mechanical stress in prolonged, it leads to morphological changes in the intervertebral discs, joints and vertebral bodies. These changes are irreversible (Stage IV) and they can be found in athletes, e.g. rowers.
Long-term repetition of the two characteristic movements in fencing and field hockey, i.e. flexion and extension, heavily loads the lumbar spine [18]. Each flexion increases tension and pressure in the posterior part on the annulus fibrosus. It leads, through years of training, to permanent damages in the disc, which once damaged will never fully heal [19]. A characteristic feature of this disorder is a frequent recurrence of sudden and acute pain. Athletes usually ignore those symptoms and, by further practicing, continuously overload the pathologically changed structures. This, in turn, leads to changes in bone structure and to the rise of bone mineral density. This process does occur in professional fencers and field hockey players.
In consideration of athletes' health, a prophylactic and therapeutic program should be developed for both fencers and field hockey players to minimize the risk of overload disorders in the spine and lower limbs joints.

What this study adds?
This study reveals several biomechanical similarities between two completely different sports. Thus, conclusions from studies about overloads in field hockey can be adapted to fencing in order to reduce the negative influence of sport training on the human body.

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