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**XVII International Symposium on Biomechanics in Sports, June 30-July 6, 1999, Edith Cowan University, Perth, Western Australia: Fundamental skills**

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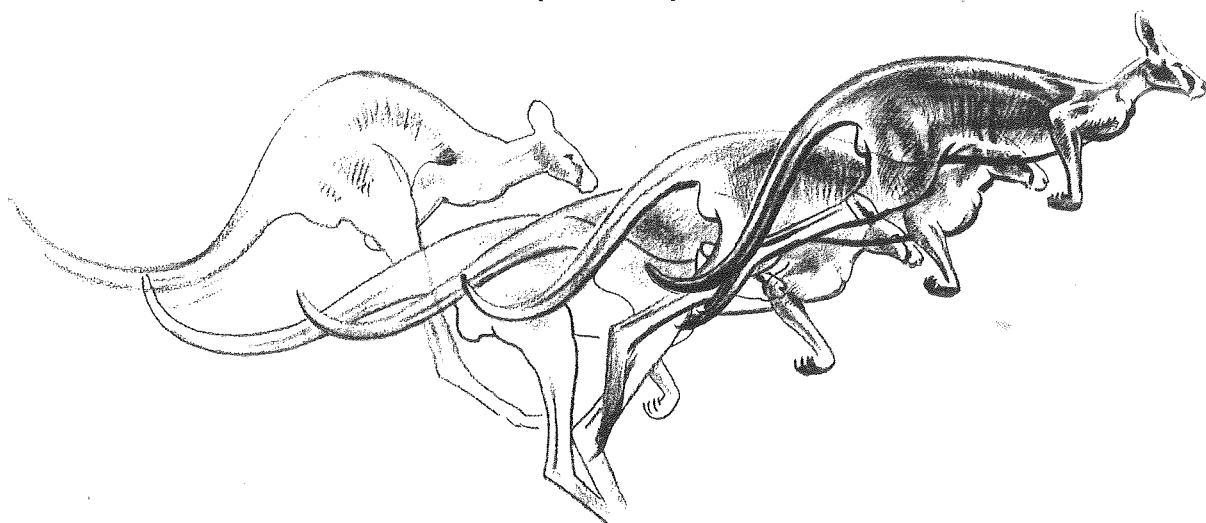
# ISBS '99



Applied Proceedings of the XVII International  
Symposium on Biomechanics in Sports

## FUNDAMENTAL SKILLS

Ross Sanders  
(Editor)



School of Biomedical and Sports Science



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PERTH WESTERN AUSTRALIA



# ISBS '99

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on  
Biomechanics in Sports  
June 30 - July 6, 1999  
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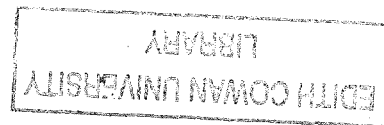


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# APPLIED PROCEEDINGS: FUNDAMENTAL SKILLS

Ross Sanders  
Edith Cowan University  
(Editor)



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Edith Cowan University,  
Perth, Western Australia

## **Applied Proceedings of the XVII ISBS Symposium, 1999: Fundamental Skills**

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# PREFACE

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The International Society of Biomechanics in Sports (ISBS) and the School of Biomedical and Sports Science, Edith Cowan University, are pleased to present the proceedings on fundamental skills from the applied program of the XVII International Symposium on Biomechanics in Sports.

The papers comprising these proceedings were written by international experts in fundamental skills. The International Society of Biomechanics in Sports is confident that this and future publications will contribute to the major goal of the Society, that is, to 'bridge the gap between sports biomechanics researchers and practitioners in teaching, coaching, training and rehabilitation'.

Perth, June 1999

Ross H. Sanders (ISBS'99 Symposium Convenor)

Barry J. Gibson (Head of the School of Biomedical and Sports Science, Edith Cowan University)

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# Table of Contents

## THE DEVELOPMENT OF SPEED AND AGILITY

Glenn Stewart

West Coast Eagles

Perth, Western Australia.....1

## RUNNING WITHOUT INJURIES

Peter B. O'Sullivan

School of Physiotherapy, Curtin University of Technology,

Perth, Western Australia.....7

## JUMPING HIGH

Pekka Luhtanen

Research Institute for Olympic Sports

Jyvaskyla, Finland.....11

## LANDING WITHOUT INJURY: FACT OR FICTION?

Julie R. Steele

University of Wollongong,

Wollongong, NSW, Australia.....17

## THROWING WITHOUT INJURY

Garry T. Allison

The School of Physiotherapy, Curtin University,

Shenton Park, Western Australia.....29





# RUNNING WITHOUT INJURIES

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There is a high incidence of low back pain and hamstring strains in runners. The lumbo-pelvic region is exposed to significant forces during running. The neuromuscular system utilises complex patterns of trunk muscle co-contraction to provide lumbo-pelvic stability to prevent injury and also provide a stable base on which the lower limbs can generate force. These patterns of co-contraction are known to become dysfunctional in subjects with chronic and recurrent low back pain. This presentation highlights the key muscles involved in providing lumbo-pelvic stability and outlines how they can be specifically trained to prevent and manage injury and optimise performance in runners.

**KEY WORDS:** low back pain, lumbar spine, muscle, runners, stability

There is a high incidence of low back pain and hamstring strains in runners (Stinson, 1993). Because the pelvis and lumbar spine is the transitional zone between the lower limbs and the trunk, it is exposed to considerable extension, side bending and rotational forces during running. Forces generated from the lower limbs require a stable base (the pelvis and trunk) from which to generate its power. Floor trunk and pelvic stability or control results in excessive rotational, side bending and extension forces within the spine leading to tissue overstrain and injury (Richardson and Jull, 1995).

The spine without the influence of muscles is an unstable structure. Because of this the neuro-muscular system provides dynamic stability and controls movement, ensuring the stability demands of the lumbo-pelvic region are met during functional loading tasks (Panjabi, 1992). The neuro-muscular system employs varying and complex strategies of co-contraction (opposing muscles working together to stiffen and stabilise a joint or joint system) of the trunk muscles to provide stiffness and stability to the lumbar spine and pelvis, and to provide a stable base on which other joints can act

The concept that different trunk muscles play differing roles in the provision of dynamic stability to the spine was proposed by Bergmark (1989). He hypothesised the presence of two muscle systems in the maintenance of spinal stability.

## 1. The 'Global Muscle System':

The 'global muscle system' consists of large torque producing muscles that act on the trunk and spine without directly attaching to it. These muscles include rectus abdominus, external oblique and the thoracic part of lumbar iliocostalis. The action of these muscles is largely direction specific and although they provide general trunk stabilisation they are not capable of having a direct segmental influence on the spine. Rectus abdominus and external oblique are commonly trained by athletes during trunk curls and oblique trunk curl exercises and the erector spinae during back arch exercises. There is growing evidence that dominant concentric activation of these muscles may be detrimental to the stability of the lumbar spine and may indeed cause inhibition of muscles that have more of a stabilising influence on the lumbar spine and pelvis (O'Sullivan et al., 1997; Wohlfahrt, Jull, & Richardson, 1993). Furthermore it is likely that the unidirectional training of these muscles may compromise the neuromuscular systems ability to stabilise the lumbo-pelvic region with appropriate patterns of co-contraction.

## 2. The 'local Muscle System':

The 'local muscle system' consists of muscles that directly attach to the lumbar vertebrae, and are responsible for providing segmental stability and directly controlling the lumbar segments and pelvis. Lumbar multifidus, psoas major, transversus abdominis, the diaphragm and internal oblique all form part of this local muscle system. The function of muscles such as transversus abdominis, internal oblique, the Diaphragm and lumbar multifidus is more multi-directional and therefore their role is more related to providing joint stability rather than high levels of torque and movement initiation. These muscles act together in patterns of co-contraction and in conjunction with an increase in intra-abdominal pressure to corset and stiffen the lumbo-pelvic region providing a stable base on which large torque producing muscles (global system muscles) and lower limbs can safely and efficiently act (O'Sullivan, Twomey, & Allison, 1997a).

Dysfunction of the local muscle system (particularly within muscles such as transversus abdominis, internal oblique, the diaphragm and lumbar multifidus) and the dominant activity or substitution of the global muscle system (rectus abdominis, external oblique and lumbar erector-spinae) is well documented in subjects with chronic and recurrent low back pain (Hides, Richardson, & Jull, 1996; Hodges & Richardson, 1996; O'Sullivan, Twomey, & Allison, 1997b; O'Sullivan et al., 1997; Roy, Deluca, and Casavant, 1989; Roy et al., 1990). These findings represent a deficit in the appropriate patterns of co-contraction of the muscles around the trunk to stabilise the lumbo-pelvic region during functional loading conditions. Athletes with recurrent and chronic low back pain commonly present with these muscle control faults (O'Sullivan et al., 1997; Roy et al., 1989; Roy et al., 1990). It appears that these faults in some situations arise from a focus on unidirectional training methods and an over emphasis on training the global muscle system. There is growing evidence that athletes, with recurrent or chronic low back pain, are capable of possessing high levels of strength in the global muscle system in the presence of significant dysfunction in the local muscle system with resultant poor lumbo-pelvic stability (Roy et al., 1989; Roy et al., 1990).

Training appropriate patterns of trunk muscle co-contraction to enhance the stability and control of the lumbo-pelvic region has been shown to be effective in managing specific chronic and recurrent low back pain conditions in athletic and non-athletic populations (O'Sullivan, 1997; O'Sullivan, Twomey, & Allison, 1997c; O'Sullivan, Twomey, & Allison, 1998). This training approach also appears to be effective in preventing injury to the lumbo-pelvic region and also preventing recurrent muscle strains in lower limb muscles such as the hamstrings. Anecdotal evidence indicates that improved lumbo-pelvic stability may also result in enhanced athletic performance.

There is growing recognition of the importance of optimal lumbo-pelvic control and stability in runners to prevent injury and optimise performance. Attention needs to be given to the local muscle system and its potential role in providing lumbo-pelvic stability. A re-focus is needed from isolated unidirectional strength training, towards training programs that incorporate appropriate patterns of lumbo-pelvic muscle co-contraction in a sports specific manner. Incorporating lumbo-pelvic control and stability into skill and resistance training is a logical component of training the athlete in the prevention of injury and optimising performance.

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# JUMPING HIGH

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## INTRODUCTION:

Jumping ability is important for athletes in individual and team sports. A jump can be executed with or without a run-up with one leg or two legs and may or not may be accompanied by assisting arm movements. In gymnastics, the jumps with a run up can be performed with mainly two arms. In selected jumps, the takeoff can be taken utilising an elastic surface or board to gain the force impulse and release velocity.

## A MODEL TO EVALUATE JUMPING PERFORMANCE:

A model to evaluate vertical jumping performance can be constructed in different ways. From a purely biomechanical standpoint the total height reached for a header in soccer after take-off; is due to body height, take-off force and duration of the applied force, vertical release velocity produced according the principle of force impulse, body position and movements for the heading action performed in the air (Figure 1).

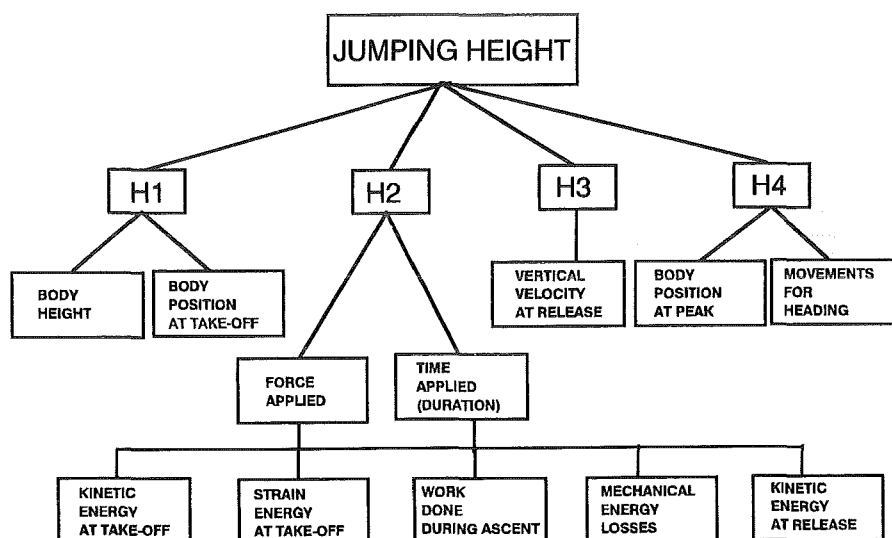


Figure 1 - A model to evaluate jumping performance for heading in soccer.

In general, main attention should focus on the mechanics of takeoff performance.

## FORCE IMPULSE PRODUCTION:

The force impulse production for the vertical release velocity can be evaluated directly as the vertical net impulse of the applied force or indirectly by evaluating the amount of total energy observed in different phases; stored elastic energy during impact or eccentric phase, work done during the ascent or utilisation of the elastic energy and mechanical energy losses due to the inhibitory factors.

Several factors in different body segments, joints, muscles and tendons can be identified which influence the force production during take-off movements:

- muscle strength
- muscle length

- speed of muscle lengthening
- muscle tension
- joint angle
- angular velocities of joints
- order of the angular velocities of the joints
- order of the movements in body segments
- timing and summation of the forces in body segments
- duration of the segmental movements
- exhibitory and inhibitory reflexes

From a neuromuscular point of view the stretch-shortening cycle can explain the positive and negative factors for the muscular force production. A part of the imposed energy during stretching may be stored as potential energy and can reappear during the subsequent shortening of the muscle (e.g. Cavagna 1977). Thus, the concentric work done by the muscle would not be derived entirely from the transformation of chemical energy, but also from stored mechanical energy. The ability to use stored elastic energy is affected three variables:

- 1) time delay between stretching and shortening of the muscle,
- 2) magnitude of stretch and
- 3) velocity of stretch.

Cavagna (1977) has demonstrated that there should not be time delay between eccentric and concentric contraction; otherwise, some of the stored elastic energy would be lost. The greater is the velocity of stretch, the more elastic energy is stored in the elastic components of the muscle (e.g. Rack & Westbury 1974). If the magnitude of the lengthening is too great, a lesser number of cross bridges will remain attached following the stretch, and hence less elastic energy will be stored (Edman et. al. 1978). It has been speculated that inhibitory influences surpass the facilitatory potentiating effects when the stretch load increases above the optimum (Komi 1984). It has been shown that during muscular fatigue the transfer of mechanical energy between the eccentric and concentric phases is drastically reduced and muscle stiffness regulation is altered (Gollhofer et al. 1987).

From a mechanical point of view, the principle of energy conservation, energy production from external and internal forces and energy transfer from energy state to energy state can be applied to take-off performance. Basically, this means the ability of the athlete to utilise energy of run-up (due to the velocity), elastic energy (stored in different tissues, shoe and surface), transfer of the kinetic and elastic energy into the potential energy (rise of C.G.) and transfer of the energy between body segments, in an optimal way.

#### **DEVELOPMENT OF JUMPING TRAINING:**

The influencing factors in reaching maximal rise of C.G. i.e., jumping performance, have been explained in the text. In developing training programs to improve jumping ability, it is important to identify the strengths and weaknesses of the athletes within of the influencing factors, in a priority order. The process includes:

- pre-testing of the athlete
- pre analysis of jumping performance
- planning of individual training program
- training under the proper guidance of an experienced coach
- follow-up to evaluate the effects of the training
- analysis how the special training is to be performed throughout new the season

- feedback for special training in the new season.

When analysing athletes, it is essential to individually evaluate:

- strengths in jumping
- technical faults
- deficits
- possibly limiting factors
- trainable factors

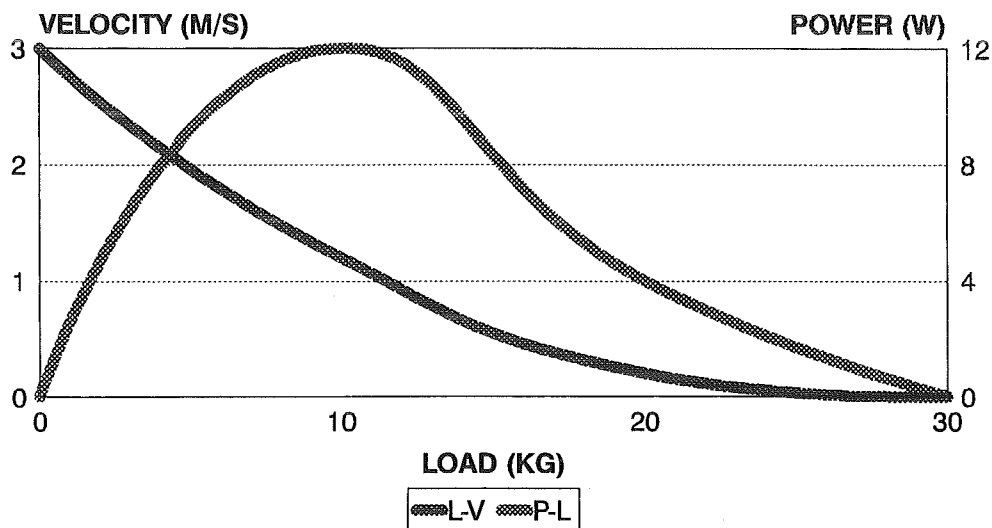
The planned individual training programs have to be individualised with respect to:

- volume
- intensity
- quality.

When individualising training programs, selected scientific principles of the progressive training can be applied combining strength and speed training:

- force-velocity curve
- power-velocity curve
- power-load curve
- jumping height-load curve

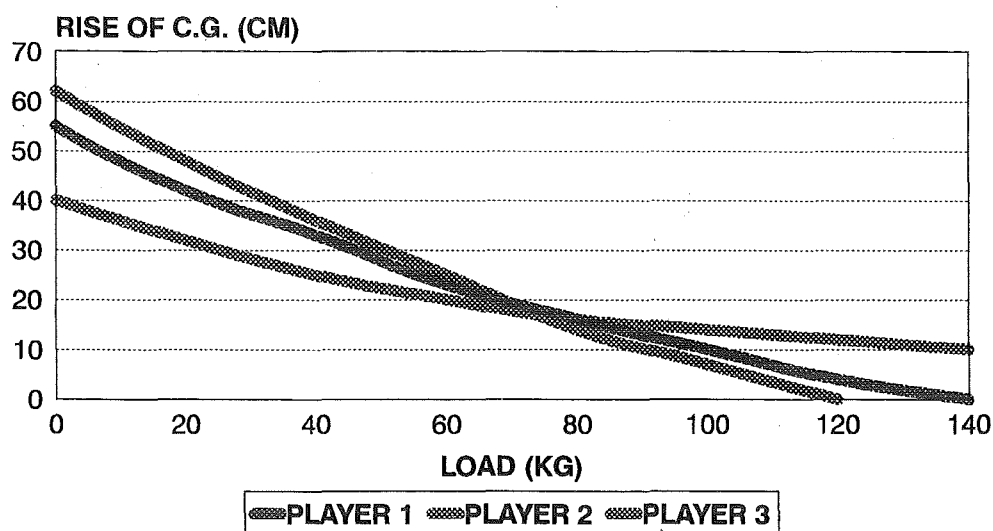
Figure 2 shows an example from a load (external) - velocity curve and load - power curve. The maximal power was achieved with a load corresponding to 1/3 of the maximal load.



**Figure 2 - A load - velocity curve (L-V) and load - power curve (L-P)**

Figure 3 explains an example of three tested athletes (PLAYER 1, 2 and 3).





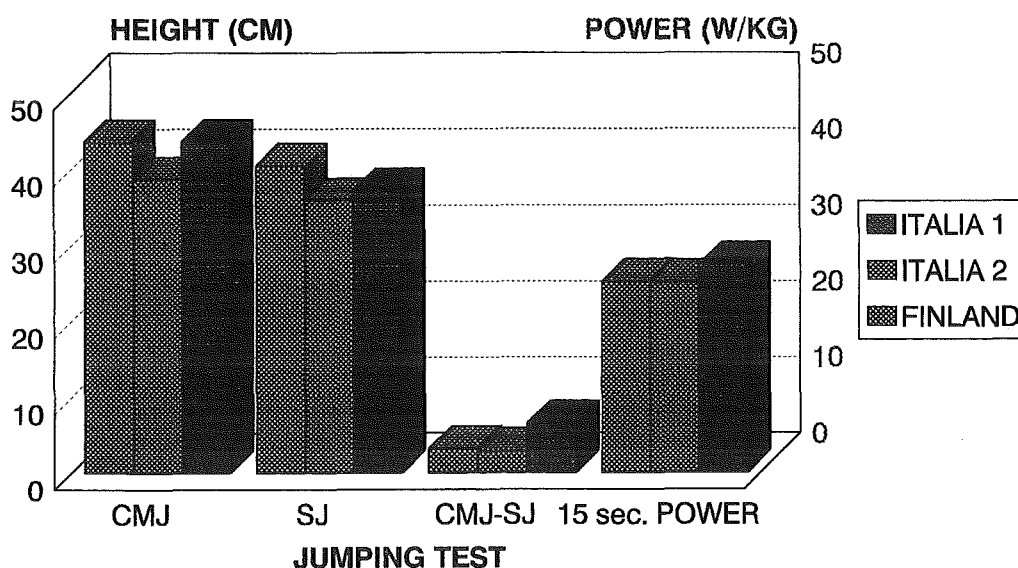
**Figure 3 - Jumping height - load curves of three athletes.**

When studying individual force-velocity curves in order to improve athlete's jumping height, it is important to analyse:

- strength level
- speed level
- muscle elasticity level.

In Figure 3 Athlete 1 had a low rise of C.G. in a jumping test and high isometric leg strength level. Athlete 3 had a high rise of C.G. in a jumping test and low isometric leg strength level. Practically these results mean different training programs for the two athletes.

Figure 4 explains examples on the indirect evaluation of the basic force level in squatting jump in relation to the muscular elasticity utilised in the ballistic counter movement jump.



**Figure 4 - Average height in counter movement jump (CMJ) and squatting jump (SJ) of three different teams, difference of these heights (CMJ-SJ) and jumping power in a series of 15 s.**

## CONCLUSION:

It can be concluded that the athletes can maximise their jumping abilities through basic strength, explosive leg strength and event specific training. Different multi-step jumping exercises with various stepping models and plyometrics training should be included in the program. For jumping strength training should be applied progressive principles as follows:

- individual
- versatile
- differentiation
- loading
- repetitions / sets
- duration
- recovery
- optimisation

A commonly asked question by athletes and coaches is that how much time should be spent only for jumping training. Jumping training should be integrated with other forms of training, at least with speed training. The value of combined speed, jumping, agility, co-ordination and skill training is the highest for the total development of top athletes in ball games.

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## LANDING WITHOUT INJURY: FACT OR FICTION?

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Despite being the compulsory terminal phase of many sports activities, consideration of how athletes should land to reduce potential for lower limb injury is often neglected. Although numerous factors can alter stress placed on the musculoskeletal system during landing, the main factor is an athlete's landing technique. To reduce high impact forces generated when landing, athletes should land with the trunk upright and the foot neutrally aligned, ensure adequate hip and knee flexion, and eliminate any exaggerated 'striding out' action. Two-footed or run-on landings are preferred to single-limb landings where possible. Other factors to be considered when attempting to reduce landing related injuries include selecting appropriate footwear and playing surfaces, and adequate physical preparation in readiness for the demands imposed on the body by landings.

**KEY WORDS:** Landing, lower limb, knee, injury.

### LANDING: WHAT'S ALL THE FUSS?

Landing is the compulsory terminal phase of many sports activities, particularly those that involve running, leaping or jumping (McNitt-Gray, 1993; Steele and Milburn, 1987a). Despite the importance of the skill, there has been, until recently, little precise instructional information in coaching manuals on the biomechanics of how to land safely. Although other skills such as throwing, catching and shooting have been described in detail, there are few statements, even of a descriptive nature, on how to land correctly. This is despite the fact that landings are more likely to result in both acute and chronic injury due to large impact forces or inappropriate impact absorption (Lees, 1981; McNitt-Gray, 1991). To be able to instruct athletes on how to reduce the impact forces generated at landing and to reduce injury potential, coaches must be aware of mechanical principles involved in landings and their influence on the anatomical structures of the lower limb. Therefore, the purpose of this paper is to review the nature of injuries arising from incorrect landings, the biomechanics of landings, and strategies that can be adopted in an attempt to reduce the potential for injury during landing. Of particular interest in the present paper was single-limb landings which involve abrupt deceleration (for example, a one-step stop) to receive a pass as these landings have been identified as a major mechanism of anterior cruciate ligament (ACL; a major ligament within the knee which prevents the shank sliding forward relative to the thigh) ruptures (Steele, 1986).

### KNEES - THE VICTIMS OF POOR LANDINGS:

The human knee is the largest and one of the most biomechanically complex joints in the body. Its components must function together harmoniously to ensure a wide range of mobility while maintaining stability, transmitting large muscular forces, regulating motion against internal and external disturbances, and protecting against deterioration. No engineering bearing resembles this remarkable joint either in construction or in geometric complexity (Seedom et al., 1974). As a consequence of its remarkable complexity, the knee is probably the most vulnerable joint in the human body (Distefano, 1978). This vulnerability has been attributed to the knee's unique architecture, its location, its biomechanics, and the functional demands placed upon it, particularly during high velocity activity (Collins, 1985). Due to its structural and functional vulnerability, the knee is particularly susceptible to ligamentous injury during sports that involve abrupt landings.

Of all the knee ligaments, the ACL is the most frequently injured (Johnson, 1983), presenting with an injury frequency nine times greater than that of the posterior cruciate ligament (Tibone et al., 1986). The incidence of acute ACL rupture in the general population of the United States has been estimated at 1 in 3000 (Miyasaka et al., 1991). However, in high performance

athletes the ACL rupture rate is much higher, especially in sports characterised by abrupt deceleration, landing, twisting, and pivoting (Maguire, 1979; Malone et al., 1993).

Knee injuries are economically costly to the community, via direct medical costs and indirect costs amassed through absenteeism and subsequent productivity losses. Although knee injuries account for only 12% of total sports injuries in Australia, they represent 25% of total injury costs. Egger (1990) estimated that the direct cost of knee injuries in sport per year was as high as \$11.9 million for Rugby League/Union, \$8.9 million for Australian Rules Football and \$5.3 million each for non-contact sports such as netball and soccer. For these reasons, strategies to prevent knee injuries are urgently warranted.

### **WHO SUFFERS KNEE INJURIES DURING LANDINGS?**

Studies have shown that many lower limb injuries, particularly the more severe knee and landing related injuries, occur more frequently to athletes participating in the higher grades of their sport (Hopper, 1986). It has been hypothesised that higher grade athletes are generally more determined and focused upon winning, taking greater risks during play, and thereby were more vulnerable to injury (Hopper, 1986). The greater momentum of more skilled athletes, due to their ability to create higher velocities, combined with increased hours participating in training and competitive environments, will also contribute to an increased knee injury risk for these athletes.

#### **Remember:**

- Landings have been associated with both acute and chronic injury due to large impact forces or inappropriate impact absorption.
- To be able to instruct athletes on how to reduce the impact forces generated at landing and to reduce injury potential, coaches must be aware of mechanical principles involved in landings and their influence on the anatomical structures of the lower limb.
- Due to its structural and functional vulnerability, the knee, particularly the ACL, is susceptible to ligamentous injury during sports that involve abrupt landings.
- Most of the landing related injuries occur to the more skilled athletes.

### **LANDINGS: ENEMY OF THE LOWER LIMB:**

Each time an athlete's foot contacts the ground at landing, the athlete experiences a ground reaction force which has two major components: (i) a vertical component known as the 'vertical ground reaction force' and (ii) a horizontal component known as the 'frictional' or 'braking force'.

**Vertical Ground Reaction Force (VGRF):** Steele and Milburn (1987b) quantified the ground reaction forces generated by 15 centre-court skilled netball players under four different footwear conditions during single-limb abrupt landings. The average peak VGRF recorded for the four conditions ranged from 3.9 to 4.3 times each player's body weight (BW). The average time from when the players contacted the ground until they experienced the peak VGRF ranged from 18 ms (barefoot) to 32 ms (wearing netball shoes). These results were similar to the 20 to 30 ms time to peak VGRF reported for running (Cavanagh et al., 1984; Frederick et al., 1984). Further studies (Table 1) have confirmed the findings of Steele and Milburn (1987b), demonstrating that the VGRF generated during single-limb landings after receiving a pass were greater than the 2 to 3 BW recorded during the less abrupt foot-ground contact in running (Cavanagh and LaFortune, 1980; Clarke et al., 1983; Frederick et al., 1981). Although an athlete may be able to withstand these high stresses if their musculoskeletal system is properly aligned any individual with a skeletal malalignment or unusual footfall pattern at landing may risk injury.

**Braking Forces:** To stop rapidly after landing, an appropriate opposing horizontal friction force must be applied; the faster the athlete wants to stop, the larger must be the frictional force

(Lees, 1984). Steele and Milburn (1987b) reported that the average peak braking force recorded for 15 skilled netball players to stop after receiving a pass was high, ranging from 4.2 to 4.6 BW (Table 1). Individual values as high as 6.5 BW were recorded. The players generated significantly higher braking forces when landing abruptly on the non-dominant extremity compared to the dominant extremity (Steele and Milburn, 1987b). McClay et al. (1994b) noted that of the 11 basketball skills they analysed, the movement that involved abrupt stopping had the highest braking forces. The braking component of the ground reaction force at foot-ground contact during the less abrupt action of running ranges between 0.4 BW to 0.8 BW (Cavanagh and LaFortune, 1980). Steele and Milburn (1987b) hypothesised that the high braking generated in netball when players executed abrupt landings subjected ligaments of the knee to undue stress and acted as a major contributing factor to the high incidence of ACL injuries associated with the game.

**Table 1 Typical Vertical Ground Reaction Forces (VGRF) and Braking Forces (BrF) Generated during Single-Limb Landings**

Reference	Condition	VGRF (BW)	Time to Peak (ms)	BrF (BW)	Time to Peak (ms)
Gauffin and Tropp (1992) <sup>1</sup>	Hop for distance (I)*	2.46	----	----	----
	Hop for distance (U)	2.56	----	----	----
McClay et al. (1994b) <sup>2</sup>	Stopping-basketball	2.70	----	1.30	----
McNair and Marshall (1994) <sup>3</sup>	ACL deficient	4.00	----	----	----
	Controls	4.60	----	----	----
Neal and Sydney-Smith (1992) <sup>4</sup>	Heel landing	5.42	32.0	2.83	26.0
	Forefoot landing	3.96	32.0	2.11	28.0
Steele and LaFortune (1989) <sup>4</sup>	Forefoot landing	5.70	30.6	2.00	23.9
	Heel landing	5.25	31.2	3.30	30.5
Steele and Milburn (1987b) <sup>4</sup>	Barefoot	4.26	18.0	4.23	----
	Netball Shoe	4.02	32.3	4.56	----
	Jogging Shoe	3.92	28.3	4.50	----
	Netball shoe + brace	3.99	31.7	4.61	----
Steele and Milburn (1988b) <sup>4</sup>	Standard pass/rules	3.83	23.8	4.02	29.0
	Rule change (extra step)	3.51	21.0	2.98	23.3
Steele and Milburn (1988c) <sup>4</sup>	Concrete Surface	3.77	24.2	3.80	30.4
	Bitumen Surface	3.90	20.8	3.51	30.0
	Grass Surface	3.90	26.5	3.81	26.4
	Rubber Surface	3.83	27.0	3.54	30.1
Steele and Milburn (1989) <sup>4</sup>	Forefoot Landing	3.30	47.4	2.60	22.3
	Heel Landing	4.50	21.0	4.10	26.0
Steele (1997) <sup>5</sup>	Controls (Limb A)	3.04	39.8	1.66	37.6
	Controls (Limb B)	3.22	42.0	1.88	39.3
	ACL deficient (I limb)	2.96	40.8	1.57	44.2
	ACL deficient (U limb)	3.57	37.3	1.90	37.4

<sup>1</sup> Subjects were 9 ACL deficient patients performing hops for maximum distance. Excessive and repeated ground reaction forces, either in the vertical or horizontal direction, can place the lower limb at risk for ligament damage, articular cartilage degeneration, osteoarthritis, or chronic musculoskeletal disorders (Radin et al., 1982). These same

problems can be exacerbated if the rate at which the ground reaction forces are applied to the lower limb is not reduced (that is, a lack of “cushioning” of the forces). Therefore, not only do the size of the force and the frequency of force application affect the body but the rate at which the loads are applied is also critical (Steele, 1993). As excessive impact forces can have a negative influence on the lower limb, they must be reduced if the potential for injuries associated with landing is to be minimised. At the same time, a delay in the peak of these forces should be achieved to reduce the rate at which these forces are applied to the musculoskeletal system (Clarke et al., 1983).

**Knee Joint Forces During Single-Limb Landings:** Although ground reaction force data provide insight into the loads generated at the foot-surface interface at landing, they do not directly represent the forces experienced at the knee joint. Physiological loading imposed on the knee during normal activity has two major components: (a) joint reaction forces that the knee must transmit to support, accelerate, or decelerate body mass; and (b) muscle forces acting across the knee to control knee motion and provide stability (Shaw and Murray, 1973). The vector sum arising from the joint and muscle forces provides the total load experienced by the knee at any instant in time (Shaw and Murray, 1973).

The joint reaction force that is generated between the tibia and femur (tibiofemoral joint) can be resolved into two main components: (a) a component acting perpendicular to the contacting surfaces of the tibia (*tibiofemoral compression force*); and (b) the component acting in an anterior-posterior direction parallel to the joint surface (*tibiofemoral shear force*) (Nisell, 1985; Shaw and Murray, 1973; White, 1975). The tibiofemoral shear force is the force component which tends to displace the tibia relative to the femur with the ACL restraining approximately 86% of the anteriorly (forward) directed shear force (Butler et al., 1980). Therefore, the size of the tibiofemoral shear force during motion is an important measure of the exposure of the knee to potential ACL injury (Andrews et al., 1983). Typical tibiofemoral forces presented in the literature for activities somewhat similar to the landings discussed in this paper are presented in Table 2. From data presented in Table 2 it is evident that both the compressive and shear forces acting on the knee during landing and decelerative tasks far exceed the peak forces encountered during daily living activities such as level walking, walking up and down a ramp, or climbing and descending stairs (Morrison, 1969, 1970a,b).

Panzer et al. (1988) noted that the peak joint reaction force at the knee during landings following completion of double back somersaults occurred 30 to 50 ms after initial foot-ground contact. The gymnasts were therefore subjected to maximum loads before peripheral feedback could be used to modify their landing strategies according to the imposed loads. The authors claimed this finding implied the gymnasts must therefore select a landing strategy based on previous performances. Furthermore, the anteriorly directed shear force evident during many of the landing tasks would tend to slide the tibia forward relative to the femur at a time when the knee was flexed, in turn, loading the ACL when the knee was in an unstable position (Panzer et al., 1988).

**Remember:**

- As excessive impact forces can be damaging to the musculoskeletal system, they must be reduced to lessen the potential for injury.
- The size of both the vertical and horizontal ground reaction forces generated at landing, and the tibiofemoral forces, must be minimised and the rate at which they are applied to the body must be reduced.
- Although athletes can probably withstand these high stresses if their musculoskeletal system is properly aligned, any individual with a postural malalignment or unusual foot placement at landing may risk injury (Steele and Milburn, 1987b).

**Table 2      Typical Knee Joint Forces Recorded during Abrupt Landing Tasks**

Reference	Task Analysed	Tibiofemoral Compression Force	Tibiofemoral Shear Force
Andrews and Dowling (1993)	Landing from 5-10 cm heights with a stiff knee	2.66-3.53 BW	----
Gauffin and Tropp (1992)	Single-limb jumps for maximum distance (ACL deficient subjects)	----	I: 657 ± 165 N N: 817 ± 159 N
Nisell and Mizrahi (1988)	14 different steps and jumps from 0.20 m and 0.43 m heights	1.49-8.41 BW*	0.01-1.18 BW*
Panzer et al. (1988)	Highly skilled gymnasts performing double back somersault landings	2160 N**	2875 N (anterior direction)
Smith (1975)	Drop-landings (dual-limb) from a 1 m drop height	17-24 BW*	2.9 BW (2000 N)
Steele (1997)	Single-limb landings after receiving a chest pass (ACL deficient and control subjects)	8.3-11.99 BW***	3.40-4.41 BW

\* represents the range of maximum values reported.

\*\* represents the average value reported.

\*\*\* represents the average peak values reported.

#### LANDING TECHNIQUE:

The technique an athlete uses to land is influenced by several factors. The factors include whether there is a need to catch a ball on landing and the type of pass, the speed and style of approach to the landing, movements required or governed by game rules following the landing action, the type of surface on which to land, and the footwear worn by the athlete (Steele, 1993). A change to any of these variables may result in a change in the landing technique used by an athlete. Although dual-limb landings have been investigated extensively, few studies have reported kinematic characteristics of lower extremity motion during single-limb landings associated with abrupt deceleration, particularly landings after receiving a pass. A summary of sagittal plane kinematic parameters characterising knee motion, selected from studies that have investigated single-limb landings is presented in Table 3.

Common characteristics apparent in single-limb landings include initial foot-ground contact with only slight knee flexion and high angular velocity at the knee. Knee flexion during landing has been advocated as beneficial to enhance the body's stability by lowering the total body centre of gravity (Steele and Milburn, 1987a) and to reduce impact loads by absorbing the landing impulse (McNitt-Gray et al., 1993; Naoe and Yamamoto, 1989; Stacoff et al., 1988; Tant et al., 1989). Mizrahi and Susak (1982a) claimed that a relatively high knee flexion angle during landing would decrease stiffness of the leg and, in turn, reduce the impact forces. A relatively high knee flexion angle should also be combined with a large range or amplitude of joint motion over which to dissipate the energy in the muscles (Mizrahi and Susak, 1982a).



**Table 3 Kinematic Characteristics of the Lower Extremity during Abrupt Single-Limb Landings**

Reference	Subjects	Task	Knee Flexion (°)	Knee Displacement (°)	Knee Flexion Velocity (°·s <sup>-1</sup> )
Gauffin and Tropp (1992) <sup>1</sup>	9 ACL deficient	single-limb hops for distance	IC*: 16±10(I) 11±8 (U) PF <sub>y</sub> : 30±12(I) 27±7 (U)	----	431± 50 (I) 530±123 (U)
McClay et al. (1994a) <sup>1</sup>	24 male basketball players	single-limb stop after a 4-step approach	IC: 18.6±11.1	----	Maximum: 500.9
McNair and Marshall (1994) <sup>2</sup>	16 ACL deficient 16 controls	single-limb land from a box	IC: 13.3±1.2(I) 12.4±1.6(C)	12.9±1.2(I)*** 12.8±1.6(C)	----
Steele (1988) <sup>1</sup>	10 female netball players	single-limb stop after accelerating to catch a ball	IC: 17.1 ±4.6 PF <sub>R</sub> : 39.9 ±7.6	----	IC: 163.1±124.1 PF <sub>R</sub> : 928.0±223.2
Steele and Milburn (1987a) <sup>1</sup>	21 female netball players	single-limb stop after accelerating to catch a ball	IC**: 14.3 ± 3.0	----	IC: 207.1±43.9

<sup>1</sup> Results are presented as mean ± standard deviation.

<sup>2</sup> Results are presented as mean ± standard error.

\* IC = Initial foot-ground contact, PF<sub>y</sub> = peak VGRF; PF<sub>R</sub> = peak resultant ground reaction force; I = injured limb; U = uninjured limb.

\*\* Only data collected during landings involving chest level passes when athletes were wearing standard footwear are reported here.

\*\*\* Joint displacement was calculated from IC to peak F<sub>y</sub>.

In analysing kinematic characteristics of 24 professional basketball players performing movement patterns typical of a game, McClay et al. (1994a) noted that there was considerable variability in the data recorded within and between the players. This variability was also evident in the studies reported in Table 3. It would appear that both highly skilled uninjured athletes and ACL deficient patients display a wide variety of strategies to absorb the impact loads generated during abrupt deceleration associated with single-limb landings.

#### Remember:

- Numerous factors will influence the technique an athlete uses on landing. Any change to these factors may also change the landing mechanics.
- Athletes should land with a relatively high knee flexion angle, combined with a large range or amplitude of joint motion over which to dissipate the energy in the muscles, to absorb the impact forces and to provide stability at landing.
- Both highly skilled uninjured athletes and ACL deficient patients display a wide variety of strategies to absorb the impact loads generated at landing.

#### SO WHAT CAN BE DONE TO PREVENT INJURY WHEN LANDING?

It has been strongly advocated that stringent footwork rules in sports such as netball should be changed as they contribute to the incidence of lower limb injuries by placing ligaments of the lower limb, particularly the knee, to undue stress via the high braking forces required to be generated to stop so abruptly. It has been suggested that players should be allowed to

take an additional step(s) on landing to allow them more time over which to decelerate, thereby reducing the size of the braking forces required at landing. But will an extra step help? It has also been hypothesised that the braking forces in landing could be reduced by throwing higher passes, requiring the receiver to jump upwards to catch the ball (Steele, 1986). Jumping upwards on the move would enable some of the player's horizontal momentum to be converted to vertical momentum, thereby decreasing the braking forces generated at landing (Lees, 1984).

Steele and Milburn (1988b) examined the influence of changing both the current footwork rules and passing technique on the forces experienced by netball players at landing after performing a typical attacking netball movement pattern. Results of the study partially supported both proposals in that players generated significantly lower braking forces when they took an extra step on landing *and* after catching a high pass compared to catching a standard chest level pass following the normal footwork rules. Although changing the footwork rules and passing technique influenced the size of the braking forces, they did not significantly influence the rate of loading (cushioning) of the braking forces or the size of the vertical forces experienced at landing (Steele and Milburn, 1988b). However, the vertical forces were cushioned more when players landed after catching a high pass compared to when players landed after either the standard pass or taking an extra step. Furthermore, there was a significantly lower initial maximum vertical force at landing after catching a high pass compared to either catching a standard pass or taking an extra step. This smaller initial maximum vertical force could reduce stress placed on the musculoskeletal system during the movement and therefore lessen the potential for injury (Steele and Milburn, 1988b). These benefits noted for the high pass landing condition were not evident when taking an extra step on landing. For these reasons Steele and Milburn (1988b) recommended that more benefit could be gained by changing passing technique and teaching athletes how to land correctly within the current rules rather than merely changing the rules. More recent work by Otago and Neal (1997) has confirmed the notion that taking an additional step may not be beneficial in reducing injuries in netball. The authors concluded that taking one extra step on landing did not reduce either the forces or torques at the knee joint. However, it was found that a run on landing technique produced significantly lower forces and torques at the knee compared to a landing involving a more rapid stop to pivot.

**Remember:**

- Changing current passing techniques and teaching athletes to land correctly will better minimise potential for lower limb injury compared to changing the rules. That is, players should be coached to throw higher passes (although not lobs) to team members rather than hard, fast low passes (Steele and Milburn, 1988b).

**SO HOW DO WE LAND SAFELY?**

Although research has shown that improvements in surface and shoe design may decrease injury potential, the main factor influencing the safety of a landing is the mechanics of an athlete's landing technique. An athlete who wears appropriate footwear and competes on a suitable surface but lands with the lower limb rigid is more likely to impart jarring shock waves to their body than an athlete who lands wearing poorly designed shoes but who flexes at the knee throughout the landing. Therefore, the first concern for all coaches must be to teach athletes how to land correctly (Steele and Milburn, 1987a).

To minimise the potential for lower limb injury during landings it is recommended that coaches encourage their athletes to:

- use two-foot landings wherever possible to enable the loads to be distributed over two limbs rather than one limb. A two-foot landing also provides a larger base of support and therefore more stability when landing.

- land with the trunk upright. This enhances stability at landing by ensuring the body's line of gravity remains well within the limits of the athlete's base of support (the feet).
- land with the foot neutrally aligned. That is, eliminate excessive rolling in or over on the ankle, avoid excessive inward rotation of the foot, and eliminate pronounced dorsiflexion of the foot (characteristic of an exaggerated heel-strike footfall pattern; Steele, 1993).
- bend the knees and hips throughout the landing action to cushion the forces over a longer time and thereby reduce the jarring effects of landing. Increased flexion also lowers an athlete's centre of gravity which, in turn, enhances their stability (Steele and Milburn, 1987a). A relatively high flexion angle should be combined with a large range or amplitude of joint motion over which to dissipate the energy in the muscles (Mizrahi and Susak, 1982a,b).
- reduce the distance between the leading foot and the hip when leaping to land (usually when catching a ball) by eliminating the exaggerated "striding out" position often adopted at landing. Apart from decreased shock absorption, overstriding can lead to hamstring muscle strains (Davies et al., 1980)
- use a run on step, rather than an abrupt stop, where skill permits a controlled landing to reduce the need for high braking forces at landing, (Netball Australia, personal communications, 1998).

**Remember:**

- The first concern for all coaches must be to teach athletes how to land safely.

**OTHER FACTORS TO CONSIDER:**

Apart from technique, other factors that should be considered when attempting to reduce the potential for landing related injuries include:

- Ensuring that the shoes worn by athletes are suitable to the demands of the activities to be performed, the playing surface and the stresses to be imposed on the body. Shoes can act as a damping element to cushion the landing forces and to minimise jarring on impact (Lees and McCullagh, 1984).
- Ensuring that the surface to be played on provides cushioning of the forces while lowering the size of any excessive vertical and braking forces. However, the surface must still provide sufficient friction to enable the athlete to decelerate upon landing without slipping or sliding (Steele and Milburn, 1988c). Other factors that should be considered when selecting a suitable court surface to ensure athlete safety and comfort are discussed in Steele (1990, 1991).
- Ensuring the athletes prepare their bodies to better withstand the loads to be experienced during landing activities by ensuring adequate physical preparation (strength, power and flexibility) before undertaking landing activities. However, increasing muscular strength and power in isolation is not sufficient. Athletes must be taught how to use their muscles at landing to protect their knees. Muscle activity about the knee during anticipated abrupt deceleration tasks influences knee joint forces during landing via preprogrammed neural messages (Mizrahi and Susak, 1982a). Furthermore, active musculature appears to play a greater role in controlling motion of the lower extremities during landing as the velocity at impact increases. Relatively greater demands are placed on the knee extensor muscles to generate large peak moments at higher landing velocities than on the ankle and hip extensor muscles (McNitt-Gray, 1993). Lees (1981) claimed that alterations to the structure of the motor program, such as would be required in an attempt to reduce force levels during the impact absorption phase of a landing, can only be produced as a result of an appropriate training program.
- Adhering to a suitable warm up and cool down routine before and after participating in landing activities. Warming up is required to ready the musculoskeletal and cardiorespiratory systems for the demands to be placed upon them during landing tasks whereas cooling down prevents pooling of blood in the lower limbs, assists in the

dispersal and metabolism of lactic acid concentrations and replenishes energy stores (Wilson and Hume, 1993).

**CONCLUSION:** If the potential for injury during landing tasks is to be minimised, coaches must develop the necessary theoretical basis upon which to teach the fundamentals of safe landings to junior athletes as well as to refine the existing techniques of experienced athletes. This will enable athletes of all skill levels to achieve optimal technical performance during sports skills while minimising the potential for lower limb injury.

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## THROWING WITHOUT INJURY

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This presentation will address the biomechanical principles of a throw and demonstrate how the task of transferring energy to a projectile incorporates a high level of co-ordination between joints. The active and passive elements that influence the functional stability of joints are also considered. Practical strategies to reduce throwing injuries are provided within the context of motor control adaptive responses with examples specific to women's water polo. Throwing without injury is of great concern to the coach and athlete. This presentation endeavours to provide coaching strategies to minimise injuries in the throwing by athletes.

**KEY WORDS:** Throwing, biomechanics, motor control.

### INTRODUCTION:

The term 'throw' can be used in different context and therefore the term has innumerable definitions. The concept of a throw for the athlete or coach can include both common (i.e. baseball pitch) and not so common throws (i.e. 'takishita' - a manoeuvre in Sumo wrestling).

Many joints and muscles are involved in the overall performance of any type of throw. This presentation will consider some of the possible mechanisms associated with throwing injuries, the biomechanical issues associated with injuries and then reflect on the influence of motor control adaptations. Finally, I will provide some examples of coaching strategies to optimise the training practices with the view to reduce throwing injuries.

### THE PUSH - THROW CONTINUUM:

Common to all types of throwing is the transfer of energy from the athlete to the intended object or projectile. The throw incorporates a transfer of momentum from one proximal body segment to another distal segment. The co-ordination of the transfer of energy from one segment to another changes between different sports. In biomechanical terms there are distinct difference between a throw and a push. For example the push is associated with a synchronised rotations of all segments and a rectilinear pre-release path of projectile. In comparison the throw has sequential rotations of proximal large mass body segments transferring angular momentum to distal segments. A pure throw results in a curvilinear pre-release path of projectile. However, in throws which incorporate a need for accuracy there is often a synchronised component of rotation to work towards a rectilinear pathway. In reality, many sports incorporate different aspects of both of these actions. Rather than a discrete dichotomy one should consider the classification as a continuum and a specific type of throw lies somewhere on this continuum. The exact location on this continuum is influenced by various factors and indeed there may be individual difference between athletes in the same sport.

Some of the most obvious factors which influence the characteristics of the throw (change the position of the movement on the continuum) are shown in Table 1. Each of these may impact on the rate of injuries in different individuals.



**Table 1      Examples of Factors Influencing the Push-Throw Continuum.**

Factor	Comments
Skill	Highly skilled athletes can generate a co-ordinated sequence of peak torques of body segments during the throw. They have more stable patterns of throwing and are more likely to generate appropriate motor control strategies under more stressful conditions.
Size of the ball	The ball size can alter the throwing sequence. For example women's and junior water polo players use smaller diameter balls than do men. Within limits the ball size depends upon anthropometric characteristics (hand size) of the individual.
Mass of the ball	Ball mass influences the sequencing of joint rotations. In a stable motor control pattern minor changes in mass e.g. when the ball gets dirty or wet, should not necessarily alter the pattern. However, individuals may adopt dramatic changes in patterns when the mass reaches the boundary condition of their capacity to adapt to the additional load.
Strength	Individuals without adequate strength will tend to move their performance toward the push (synchronised continuum). Strength could also be range dependent, therefore weak individuals will not move joints to the full range of motion or conversely they may adopt strategies which utilise the passive structures of the joint.

There are, however, other factors that can influence the likelihood of injury when throwing. These involve aspects of functional joint stability and modification of practices by the rehabilitation specialist or coach. These will be the focus of the presentation using specific sports examples associated with water polo throwing.

**Transfer of momentum from the base of support to the projectile:** In the example of a pure throw - a sequentially initiated transfer of momentum from the base of support to the projectile, the kinetic chain is built from the ground up. A strong base of support allows the transfer of energy to each of the body segments in the sequence of the throw. It is clear that the function of each joint can impact on the performance of the subsequent joint in the series. One way of avoiding injury is to maintain functional stability of every joint involved in the sequence of the throw.

#### **FUNCTIONAL JOINT STABILITY:**

One model of functional joint stability involves the interaction of three elements, namely, the passive elements - ligaments etc., the active elements - muscles and the motor control system - the nerves and cortical control systems.

**Passive elements and the range of motion (ROM):** Using a simple model, the joint has a limit of ROM which is governed by passive elements. These could be the bony articulations, ligaments and other connective tissue.

The range of motion should suit the type of throw. A large range of motion in the gleno-humeral joint, for example, can be seen as advantageous since a large degree of external rotation allows a greater range and hence time for the momentum to be transferred to the

projectile. Therefore the passive elements are under extreme stresses during this end of range positioning. This end of range stretch is not independent of the active elements and activation of the muscles eccentrically enhance the subsequent concentric contraction during the acceleration phase of the baseball pitch.

Coaches however should not necessarily focus solely on the mobility of the shoulder complex. The mobility of the spine, specifically rotation in the thoracic spine and lateral flexion in the lumbar spine all provide important contributions to the velocity and overall outcome of the throw. As an example, if a baseball pitcher has reduced lateral flexion in the lumbar spine, say due to pain, then he/she may adopt a motor pattern to compensate. These compensatory mechanisms may be manifest as increased shoulder abduction. This may aggravate an impingement disorder that until then may have been sub-clinical. In a biomechanical sense restricted or impaired movement of the trunk and pelvis may impact on the throw velocity since these segments are responsible for upto half of the throwing velocity. Similarly, the respective internal and external rotation of the stance and lead legs during the 'stride' in baseball are critical in the overall performance of the pitch.

Conversely, increased range of motion of the passive elements are not always an advantage. Throwing actions which utilise specific contact with the ground need to be able to transfer energy quickly and effectively from the ground to the pelvis. The stability of the major lower limb weight bearing joints (lumbar spine, sacro-iliac joint, hip, knee and ankle joints) in the final foot plant of the javelin throw are also critical in the maintenance of a good throwing style. Ligament instability and poor bony joint congruency resulting in functional instability of either the ankle or knee will impede throwing performance and may lead to adaptive techniques which result in secondary injuries. It has been demonstrated that increased knee flexion on release of the javelin correlates with poorer performance. The passive elements can be damaged via repetitive actions (overuse) or one massive loading. These injuries in turn may result in either an increased range of motion or possibly a decreased available range if there is scar tissue or bony/condral surface damage.

**Active elements - through range control:** Although joint surface congruency is important throughout the range, the passive elements make most of their contribution towards the end of range of motion. Therefore the active elements (muscles crossing the joint) have a predominant role of functional joint stability through the range of motion.

In terms of injury, however, the muscles and fascia play a significant role in providing limitations to end of range mobility. Whether this represents a dysfunctional contribution to the end range stability varies between individuals. In most circumstances where the active elements are providing a additional compensatory support at the end of range there may be a propensity of overuse injuries within the active elements (i.e. tendonitis / tenosynovitis). When the active elements are unable to compensate adequately an increased loading may be placed on the passive elements. For example, as the pronator muscle fatigues there is an increased stress placed upon the ulna collateral ligament of the elbow during the pitch, a common site of injury. If the passive elements continue to be stretched and suffer repeated micro tears a functional instability may ensue. The only solutions in such circumstances are to super adapt the active elements, adapt the motor pattern or consider surgical intervention.

Much of the research associated with injury of the throwing shoulder has considered the relationships between the peak torque capacity of internal and external rotators and the range

of movement at the humerus. The concept of stability through range is highly related to the control of the muscles acting in synergy. Finely co-ordinated patterns are required to maintain the optimal joint surface congruency as well as allowing a well controlled locus of rotation during the throw.

**Motor control in throwing:** A different focus of shoulder injury research is the timing of muscle onsets. Altered muscle onsets of synergists across a single joint and the timing of peak amplitudes of muscles acting across joints transferring energy, seems to be related to throwing injuries.

Athletes present with throwing injuries even when dysfunction of the active and passive elements are not present prior to the injury. This can be partly explained by poor motor control. Motor control emerges from the interaction of the throwing task, the individual and the environment.

To throw without injury the individual needs to stay within the limits of the capacity of both the active and passive elements. Athletes under fatigue conditions, under minor injury clouds or other physiological and psychological stressors will compensate to achieve their desired goal. The fastest adaptive element is the motor control system which can vary almost immediately. The coach needs to observe the alterations in the quality of the performance as the athlete attempts to adjust, the appropriateness of the new compensatory pattern needs to be assessed. Short term success may be at the expense of subsequent performances and be associated, in the long-term, with injury to either or both the active and passive elements. Certain sports accept this compromise as part of the sport.

**The interaction of the subsystems:** The overall capacity of the athlete to sustain optimal control of each joint in the sequence of the throw is dependent upon the interaction of the passive elements, the capacity of the active elements and the specific control of the muscles. Most importantly each sub-system interacts and therefore each system can compensate for dysfunction in the other. Although the ability to compensate varies between athletes the amount of compensatory mechanisms is finite for every athlete and therefore when pushed to its limits the body will fail to adapt and injuries will result. Adaptation of each of the sub-systems has a different timeframe. Training and rehabilitation demands on the throwing athlete should reflect these different timeframes. Understanding this difference in time frames should reduce injuries overall.

#### **THROWING WITHOUT INJURY - A DAUNTING TASK:**

The throwing technique may be influenced by internal capacities and the external environment. Therefore it is clearly a daunting task to analyse all the different performance criteria of the throw. A major component of achieving reduced number of throwing injuries is to investigate the mechanism of injury when they do occur. An analysis of the possible mechanisms of injury may include any change in motor control strategy due to circumstances such as the altered task, the external environment, a deficit in the active or passive elements, poor decision by the athlete or some complex combination of all elements. Examples of each are shown in Table 2.

**Table 2 Examples of Factors Contributing to Primary and Secondary Throwing Injuries.**

Adaptive Factor	Example
Change of task	The throwing style/ technique is changed. There is a need for increase in speed, distance, accuracy. The athlete mimics another's style. The projectile changes in size, mass, shape. Change in tactics or instruction by coach.
Change in environment	The support surface interface changes. There is a change in the pacing of the task - internally or externally. Opposition team tactics. The environmental demands change - i.e. heat, cold, humidity.
Active elements	Fatigue, weakness, muscle imbalance. Strains, Delayed onset muscle soreness. Painful muscle inhibition.
Passive elements	Joint surface incongruencies / damage, ligament sprains, capsular damage and scarring, joint swelling and floating bodies. Impingements.
Decision making	The athlete makes a poor decision which causes an increased injury risk. Possibly secondary to poor interpretation of external cues, poor kinaesthesia or poor planning.
Motor control	Sequencing of joint timing, change of plan during throw due to pain or external inputs (opposition players and tactics).

#### **THROWING WITHOUT INJURY - PRACTICAL EXAMPLES:**

Below is outlined the strategy devised and adopted during the two years of training with the Western Australian Women's Water Polo Team. Culminating in 1995 in the National Championships with seven members selected in the Australian team that won the World Championships in the same year. It resulted from the integration of my perspectives as a coach, a physiotherapist and a biomechanist.

**Good role models:** Provide role models for athletes developing the skill, utilise feedback video in slow motion and at speed so the athlete can develop a visual and temporal scheme of the task. Utilise basic principles of simple motor learning during coaching drills. Utilise visual and verbal cues 'Hip - Shoulder - Arm'. Utilise mental rehearsal plans for specific tasks.

**Warm-ups and training:** A throw (shot at goal) is **not** the same as a pass. One does not warm-up the other. Move from general to specific. Have warm-ups planned and timed. Practice game warm-ups at training. The quality of a warm-up program should be judged at training not at a game.

**Performance criteria:** When modifying behaviours redefine your criteria for an appropriate performance. Throwing a goal is not a consistent feedback model for maximising throwing velocity. Teach the coaches to provide appropriate feedback.

**Understand the biomechanics of the elite:** More elite players (men and women) lie more horizontal position in the water for shot preparation. Strength and lean body mass correlate with throwing velocity, the size of the ball can vary performance in terms of accuracy and velocity.

**Concomitant adaptation:** In team sports the activity may make physiological adaptations which increase the risk of throwing injuries. For example, water polo players do many hours of swimming, holding and wrestling. These can lead to impingement problems of the shoulders and tightness of the latissimus dorsi and pectorals. Swimming also increases the range of motion at the shoulder joint. We have found that elite water polo players have a negative correlation of shoulder total flexibility and throwing velocity - probably the opposite of what one would expect however this was a population with hypermobility to start with.

**Is the task internally paced or externally paced?** This may generate different patterns of throwing sequences. Practice 'hold' strategies and externally paced drills. Also develop decision making drills which stress the individual with similar aerobic demands which occur in the game. For externally paced tasks develop a sequence of check measures which focus the individual to perform with little distraction from external sources.

**Game specific situations - faking/baulking:** The athlete tries to make the goalie jump in anticipation of throwing. If successful the goalkeeper will be out of position when the ball is actually thrown. In practice some athletes perform a sequential rotation fake of the shoulder. This is so realistic that the goalie will react, however, the fake was realistic and the athlete with less skill is then unable to actually throw the ball with any accuracy or speed within the timeframe that it requires the goalie to recover. In terms of injury, some athletes were able to throw the ball with an altered fake sequence but for various reasons this tended to place additional stressors on their shoulder. Utilising a head fake or some other cue such as holding the breath became options for some athletes.

#### **CONCLUSION:**

The throw is characteristically associated with a sequence of proximal to distal transfer of angular momentum and peak angular velocities. Therefore the interaction of all the joints can impact on the subsequent joint loading. Shoulder and elbow throwing injuries may reflect dysfunction in other joints in the sequence. In throwing without injury the stability and mobility of all the joints in the throwing sequence should be considered. The careful observations of the coach/biomechanist play an important role in the understanding of strategies that develop as compensatory mechanisms to internal and external factors. Manipulating these in the training, warm-up and rehabilitation protocols will enhance the possibilities of throwing without injury.

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