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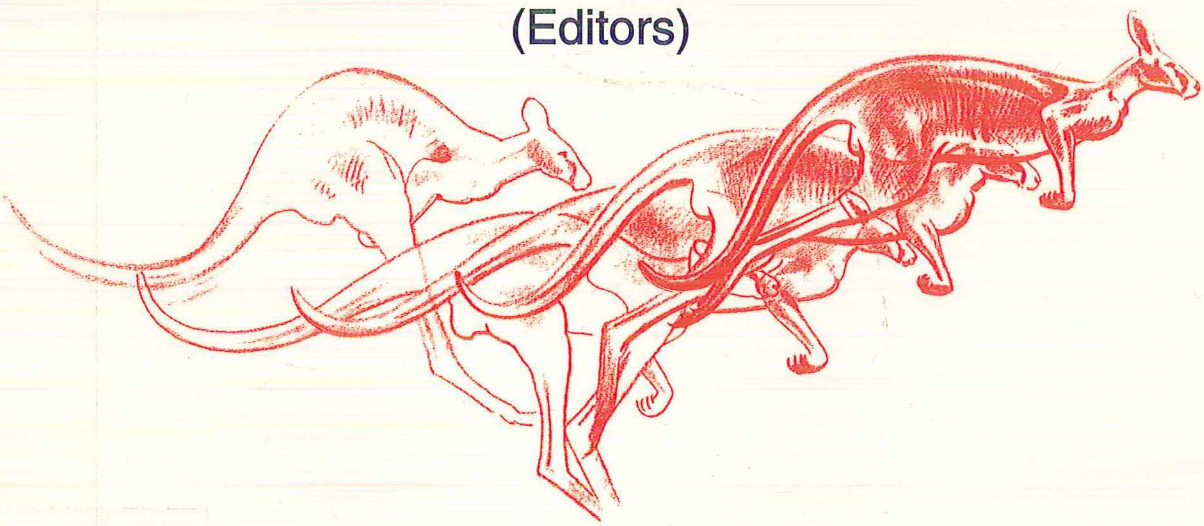
Spiros Prassas (Ed.)

ISBS '99

Applied Proceedings of the XVII International Symposium on Biomechanics in Sports

ACROBATICS

Spiros Prassas
Ross Sanders
(Editors)



School of Biomedical and Sports Science

EDITH COWAN UNIVERSITY

PERTH WESTERN AUSTRALIA

ISBS'99

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APPLIED PROCEEDINGS:

ACROBATICS

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Edith Cowan University
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PREFACE

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

The papers comprising these proceedings were written by international experts in acrobatic and gymnastics activities. 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)

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BIOMECHANICAL RESEARCH IN GYMNASTICS: WHAT IS DONE, WHAT IS NEEDED

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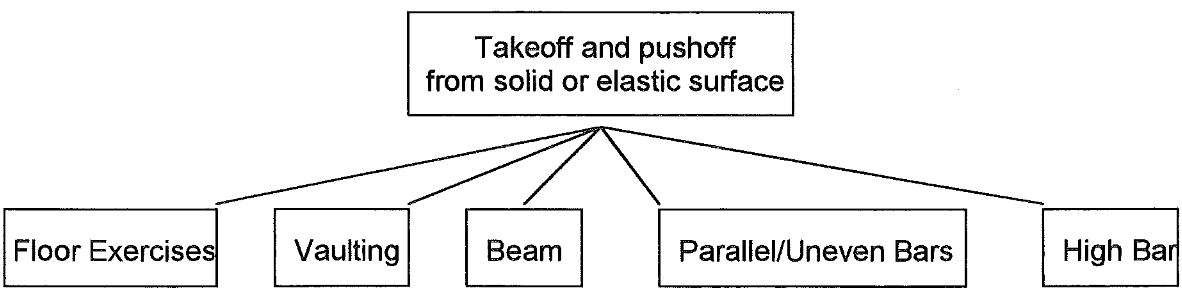
INTRODUCTION:

As you may all know, gymnastics is a unique sport placing high demands on competitors. Male gymnasts are required to compete on six apparatuses, while female gymnasts are competing on four. With the exception of vaulting, which requires the execution of a single skill, competitors on all apparatuses perform routines composed of a series of individual skills. It has been estimated that several hundreds and possibly thousands of skills and skill combinations already exist, and the number is always increasing with the addition of new ones. Although a good number of these skills share common principles and therefore can be grouped together, the number of groups is still quite large making it extremely difficult, if not impossible, for anyone to examine and study all gymnastic skills and identify specific principles applicable to 'the sport of gymnastics'. For comparison purposes, human gait, a single physical activity, has been the subject of over 1000 biomechanical research studies, and, predictably, it will be the subject of many more. How many studies are needed then to be able to "understand" gymnastics? The answer is obvious and intimidating. In light of the numbers' reality, attempts have been made for grouping gymnastics skills into a few categories comprised of 'tricks' that share common elements, making thus the study more manageable. The most recent classification was made by Brüggemann (1994a) who, building upon Hochmuth and Marhold (1987, as reported by Brüggemann, 1994a), grouped gymnastic skills into the following five categories:

1. Takeoff and pushoff from solid or elastic surface;
2. Rotations in vertical plane about a fixed or flexible horizontal axis of rotation;
3. Rotations in a vertical plane about a vertical axis of rotation;
4. Airborne rotations, and;
5. Landings. As the chart below indicates, takeoff and/or pushoff skills are performed on the majority of both men's and women's apparatuses.



A chart similar to the above, would show that rotations in a vertical plane about a fixed or flexible axis of rotation include skills mainly in the high bar, uneven and parallel bars, and rings. Airbome rotations include somersaults and/or twisting rotations in floor exercises, beam, release/regrasp and dismounts from high bar, uneven and parallel bars, and dismounts from rings. Landings are incorporated into dismounts from every apparatus and to various skills performed on the floor and balance beam. Finally, leg circles and scissors are unique skills performed on the pommel horse and less on the floor and the parallel bars. There is a lot to be learned by reviewing previous work. And, I believe that re-inventing the wheel is wasteful. Therefore, in reviewing biomechanical research in gymnastics, I have drawn upon previous work including reports by Brüggemann (1994a) and Prassas (1995a). Space limitations makes it impossible for this review to be exhaustive. For this reason, only a selective number of gymnastics research has been included. The studies mentioned here should not necessarily be viewed as been more significant than work that has been omitted. Availability and language of the published studies (mainly English) were some of the criteria—albeit important ones—for inclusion. Research on some apparatuses such as the pommel horse and most of the women's events is very limited and so is related literature presented here.

CONCEPTS:
Listed below are some commonly found concepts in biomechanical research as applied to gymnastics:

Angular momentum: Describes the quantity of angular motion possessed by the gymnast. It is made up of the sum of the angular momenta of the body's segments. Quantities influencing angular momentum are the rotational speed of the gymnast, the point about which the gymnast is rotating, and the gymnast's body configuration. In airbome activities such as dismounts and somersaults, the angular momentum is constant—'conserved'. As a result, when body configuration changes, the angular speed changes. For example, the gymnast slows down when he/she "opens up" before landing. Or, when a body part slows down, another body part speeds up, or vice versa—the last been refered as transfer of (angular) momentum.

Moment of Inertia: Describes the level of resistance to changes in rotational speed. It depends on the mass of the gymnast and how that mass is configured about the point of rotation (axis). A gymnast's moment of inertia, for example, progressively increases as he/she goes from a tucked to a piked to a layout position during somersaulting.

Torque: Describes the rotational effect of a force. It depends on the (magnitude of) force and its distance from the point of rotation (axis). Whereas, for example, the gravitational force (the weight) of a gymnast doing a giant swing is the same throughout the swing, the corresponding torque increases as the weight moves away from the bar and decreases as it comes closer.

Kinetic energy: Describes the amount of energy a gymnast has because of his/her linear and/or angular motion. The faster he/she moves, the more energy he/she possesses.

Computer simulation: Describes the (re)production of a movement by computers. It offers the advantage of trying a skill repetitively and/or under different conditions. Caution should be exercised to ensure that the 'different' conditions are realistic, i.e. they represent what can be done by real gymnasts.

WHAT IS DONE

FLOOR EXERCISES:
The great majority of floor exercises consist of jumping/rotating elements interconnected by simpler transitional skills. Understandably then, most research in floor exercises examines the takeoff and (on occasion) landing characteristics of various types of *somersaults*, mostly backward. Hwang, Seo and Liu (1990) investigated takeoff mechanics of three different types of *backward somersaults* performed at the 1988 Seoul Olympic games including the contribution of the different body parts to the total angular momentum. , i.e. the required 'spin'. It was found that, in all cases, the legs' contribution to the total angular momentum was dominant. Similar takeoff mechanics were found by Kerwin, Webb & Yeadon (1998) who investigated the production of angular momentum in double *backward somersaults* performed during the 1996 Olympics. Angular momentum and center of mass (CM) kinematics of single and double *backward somersaults* were investigated by Brüggemann

(1983). Knoll (1993) examined the same parameters when studying implications for *round-off* and *flic-flac* techniques concluding that maximum height and takeoff angular momentum must be optimized. Most recently, takeoff and landing characteristics of double back *somersaults* on the floor performed at the 1994 World gymnastics championship were studied by Geiblinger, Morrison and McLaughlin (1995a; 1995b); the (kinematic) results presented are in agreement with previous literature. *Forward somersaults* have received less attention. The Russian one, favoured by the majority of gymnasts, has been studied by Knight, Wilson and Hay (1978) who concentrated mainly on the action of the arms. Ground reaction forces for the *Russian* type of *somersaults* were also examined by Miller and Nissinen (1987) in order to investigate their characteristics in relation to performance. In summary, there is a wealth of information and good understanding of somersaults' takeoff requirements. Landings, however, have not been studied as much and, consequently, they are not as well understood. In addition, there is a lack of information on the extremely high loads placed on the muscle/tendon system during the short contact time in both takeoffs and landings. These loads are augmented when combinations such as backward somersaults immediately followed by forward ones are performed.

VAULTING:

Vaulting is the only apparatus involving a single movement. Partially for this reason, it might be the apparatus most researched (at least in proportion to the number of skills performed on it) and best understood. Studies by Bajin (1979), Dainis (1979), Brüggemann (1984), Takei (1989; 1990; 1991a; 1991b; 1992; 1996; 1998), Takei and Kim (1992), Li (1998), and Krug, Knoll, Koethe, and Zocher (1998) have examined springboard parameters, parameters while in contact with the horse, and/or landing parameters. In addition, the correlation between mechanical variables and the scores given to the vaults has been investigated. As a result, it is generally accepted that, in vaulting, running approach horizontal velocity and takeoff springboard linear and angular parameters are more important than parameters during horse contact—that means that it is very difficult to compensate for errors made during takeoff, while in contact with the horse. It is also generally accepted that the initial (takeoff) angular momentum is invariably reduced during contact with the horse and converted to vertical velocity. A model for gymnastics vaulting developed by Dainis (1981) for the airborne and horse-support phases of vaulting may be one worth the effort for every coach to study it and understand it. The model establishes some of the aforementioned relationships, clearly showing that initial (springboard) 'takeoff velocity and distance from the horse to be the principle variables affecting the outcome of the vault'.

HORIZONTAL BAR:

Research on the horizontal bar has focused mostly on dismount takeoff requirements and the mechanics of associated giant swings. Some transitional techniques and an ever increasing number of release-regrasp skills have also been investigated. George (1968) offered some of the first descriptive data for four different types of *giant swings*. Yeadon (1997), Yeadon, Lee and Kerwin (1990), and Kerwin, Yeadon and Lee (1990) utilised data obtained at the 1988 Seoul Olympic Games to determine the contributions of contact and aerial techniques in twisting techniques used in *high bar dismounts* and to examine the necessary modifications in body configurations and angular momentum needed in multiple *somersault dismounts*. It was found that twisting techniques relate to the timing of the twist within the two somersaults and that the tilt angle relates to the body configuration and number of twists. Takei, Nohara and Kamimura (1992) found significant correlations between vertical release velocity, height above the bar and total time in the air (which are, of course, inter-related) and successfully performed *double somersault dismounts*. Kinematic release data for *double layout* and *triple somersault dismounts* were presented by Park and Prassas (1995). Additional kinematic, kinetic and EMG data for *giant swings* have been reported by a number of investigators (Boone, 1977a; Cheetham, 1984; Prassas and Kelley, 1985; Okamoto, Samurai, Ikegami and Yabe, 1989; Yamashita, Kumamoto and Okamoto, 1979) and the transition to the *inverted giant swing* (the "stoop-in") was studied by Prassas, Terauds and Russel (1988). In order to establish profiles for the different dismounts and release-regrasp skills and to identify differences between the techniques studied, Brüggemann, Cheetham, Alp and Arampatzis (1994b) studied the mechanics of seventy *dismounts* and *release-regrasp* skills performed at the 1992 Barcelona Olympic Games. The seventy movements were divided into 10 groups and, among them, three groups were found to be significantly different in terms of maximum values and timing of a variety of kinematic and kinetic variables. *Release-regrasp* techniques have been studied by Prassas and Terauds (1986), Prassas (1990), Gervais and Talley (1993), Brüggemann et al. (1994b), and Cuk (1995a). The energetics of high bar *giants* have been studied by Okamoto, Sakurai, Ikegami, & Yabe (1989) and most recently by Natta (1988) and Arampatzis and Brüggemann (1998). In summary, there is a good understanding of the mechanics of giant swings and a number of release-regrasp skills and dismounts in the horizontal bar.

RINGS AND PARALLEL BARS:
The skill level and their type in these apparatuses has rapidly changed over the last decade with swinging skills comprising currently a major part of gymnasts' routines. Research, however, has not progressed equally. With regard to the **rings**, Nissinen and Brüggemann (reported by Brüggemann, 1987) presented kinematic and kinetic profiles of straight arms *giant swings* contradicting coaching opinions. Geiblinger, McLaughlin and Morrisson (1995c) reported kinematics of a case study of the 'stretched double feldge backward to forward swing in hang'—the so called *'O' Neil'.* Yeadon (1994) studied twisting techniques used in *dismounts* at the 1992 Olympic games, concluding that the majority of gymnasts use asymetrical use of the arms to initiate twists. Research on the **parallel bars** is also not extensive. The *feldge* (or beach basket) has been studied by Boone (1977b) and Takei, Dunn, Nohara, and Kamimura (1995) who compared the (traditional) *inner* and (newer) *outer grip techniques* in the *feldge to handstand mount.* It was concluded that the outer grip has advantages over the inner by elevating the body's CG more at regrasp. Liu and Liu presented a case study on *swings in the extended hang* (Liu and Liu, reported by Brüggemann, 1994a). A quasi-static movement, the *press handstand*, was studied by Prassas, Kelley and Pike (1986) and Prassas (1988; 1991). Prassas reported also on the techniques of two basic skills, the *back toss* (1994) and the *backward somersault dismount* (1995c). The dynamics of both skills have been investigated by Prassas and Papadopoulos (1998). Differences in vertical and horizontal forces during the upward, pushoff phase were found and these differences were related to the greater height attained in the back toss and the need for different horizontal flight displacements. Lastly, a case study of the double back somersault dismount was presented by Manoni and DeLeva (1993a) who also reported on different types of forward somersaults (1993b).

MISCELLANEOUS RESEARCH:
As it was said previously, women's gymnastics research is limited. Among the few studies conducted, Brown, Witten, Espinoza, & Witten (1996) investigated ground reaction forces in two relatively simple *dismounts* from the **balance beam**, which were found to be over 10 times body weight. In a follow up study, for more difficult (somersault) *dismounts*, the forces were found to up to 13 times body weight (Brown, Witten, Weise, Espinoza, Wisner, Learman, & Wilson, 1996). As a result, they suggested that, at least in practice and possibly in competition, gymnasts should be allowed to roll out of various dismounts—a suggestion highly unlikely to be adapted by gymnastics' governing bodies. Knoll (1996) found that gymnasts employ the same biomechanical mechanisms in the performance of *acrobatic tumbling exercises* on floor and balance beam, i.e. trade-off between take-off angular momentum and take-off linear velocities. Research in the **uneven bars** is limited to studies of the *overgrip giant swing* (Witten, Brown, Witten, & Wells, 1996), *overgrip* and

undergrip dismount giants (Prassas, Papadopoulos, & Krug, 1998), and uneven bar *dismounts* (Prassas, 1996). In general, similarities between the mechanics of uneven bars and high bar dismount giants result in similarities in some of the take-off dismount conditions. However, differences in the beat action through the bottom of the swing, differences in the physical characteristics, design and construction of the apparatuses and anthropometric differences between male and female gymnasts may explain some of the velocity and related parameter differences between the two apparatuses. Whereas the **pommel horse** is considered one of the most difficult apparatuses and relative research could be of extra value to practitioners, research is limited to a case study comparing the *Thomas flaire spindle* and the *Magyar spindle* (Cuk, 1995b). It was concluded that, although the (kinematic) results suggested that the former may be more difficult, the fact that gymnasts perform the Magyar spindle less frequently suggest that it is more difficult—"they (the gymnasts) know best how difficult an element is".

SUMMARY: Table 1 summarises some of the literature by apparatus.

WHAT IS NEEDED

The volume of scientific research in gymnastics is considerable and ever increasing. With few exemptions, related research has attempted to answer questions related to the 1) Jumping, 2) Twisting/somersaulting, and/or 3) Swinging requirements of the sport. Subsequent papers in this volume deal in depth with some of these questions. The majority of the existing research efforts have been descriptive in nature offering limited information to scientists and to practitioners. Within the sport's uniqueness and multifaceted approach, however, biomechanics is uniquely positioned to assist with regard to:

1. understanding of already existing techniques,
2. new skill development,
3. increase in safety, and
4. equipment design and/or modification.

Questions such as: *what it takes to do a quadruple somersault? how many twists are possible? how flexible the bar(s) should be? or how springy a floor, or a spring board should be*?...are legitimate questions and biomechanics may assist in finding proper answers. For that purpose, descriptive studies of specific skills should continuously be undertaken—for description is the first step in understanding, and for providing (realistic) input parameters to simulated skills. Scientific efforts, however, that attempt to develop principles applicable to an ever larger number of gymnastic techniques would be more valuable. The ultimate success would be the development of a set of principles applicable to all new and existing skills that would have the ability to 'explain the sport of gymnastics'. It is very optimistic to predict that such a set of principles would be developed in the near future, but without dreaming, it will never occur. Lastly, in being consistent with ISBS's pledge to "bridge the gap between the researcher and the practitioner", it will be of tremendous value if scientists find a way to trickle a greater portion of the existing and new information down to the practitioners, the coaches and athletes. This information should be presented in a meaningful and understandable—to the practitioners—form.

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Table 1 Summary of Gymnastics Research

Skills	Information on:
Floor Exercises	
Double back somersaults Layout, Tucked, With twist(s) Front somersaults	Takeoff velocity, linear/angular momenta, body position, contributions of body parts to angular momentum Landing body configuration Ground reaction forces, arm motion
High Bar	
Giant swings Overgrip, Undergrip, Inverted, Dismount	Joint angles, angular momentum, kinetic energy, force on the bar, joint torques, EMG activity
Release/regrasp skills Gaylords, Tkatchovs, Gingers, Kovacs, Kolman, Pegan Mariniches	Release requirements: linear velocity, CM position, body configuration, angular momentum Some flight and regrasp properties/requirements Preparatory giant swing requirements: kinetic energy, CM velocity, angular momentum/velocity, body angle
Dismounts multiple somersaults ...with/without twist(s)	Takeoff mechanics: linear velocity, body position, body configuration, angular momentum, kinetic energy Some landing mechanics
Parallel Bars	
Back toss	Takeoff velocity, angular momentum, body position/configuration, upswing dynamics
Feldge mount	Body configuration, body position, linear/angular velocity—inner/outer grip differences
Front/back somersaults	Linear/angular momentum of pushoff swing
Dismount	Takeoff velocity, angular momentum, body position/configuration, upswing dynamics
Rings	
(Giant) swings	Reaction forces, body configuration
Dismounts	Twisting techniques (contac vs. aerial) and segmental contributions
Pommel Horse	
Magyar spindle Thomas flaire spindle	Joint angles, segments' angular velocities
Vaulting	
Handsprings Handsprings with twist Handsprings with somersaults	Running/springboard takeoff mechanics. Preflight characteristics. Horse contact mechanics. After flight and landing characteristics. Vaulting mechanics/judges scores correlation
Uneven Bars	
Giant swings Overgrip/undergrip	Joint angles, angular momentum, force on the bar, joint torques
Dismounts multiple front/back somersaults	Takeoff mechanics: linear velocity, body position, body configuration, angular momentum, kinetic energy Some landing mechanics
Balance Beam	Ground reaction forces

COMMUNICATING WITH COACHES: ENVISIONING DATA

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INTRODUCTION:

Coaches and scientists have developed an uneasy relationship based on coaches' needs for the latest training and performance information and scientists' needs for application of their work. Although coaches believe that sport science is a vital part of training enhancement, safety, and progress (31), a survey of gymnastics coaches in the United States indicated that the most dominant means of gaining information regarding these factors was obtained from other coaches in gymnastics clinics and symposia. The majority of coaches (80%) indicated that they attended gymnastics clinics more than twice per year. Reading journals and magazines was a distant second to symposia as the most important means of gaining coaching information. Coaches are not scientists. The 'training is a laboratory' analogy is often pushed too far. If sport scientists are to serve coaches more efficiently and effectively, it will be important for sport scientists to understand how coaches work and how coaches use scientific information. What aspects of training and performance should receive the highest priority? What facts, principles, and guidelines should be interpreted? Into what 'language' should science be translated? Interpretation and translation without regard to context is usually a sterile and inaccurate exercise. Scientists should carefully consider these issues when interacting with coaches. In order to cover these three ideas I would like to start with the last issue first - context and translation.

KNOW YOUR AUDIENCE:

Little is known about coaches that scientists can use to better understand their intended audience. In 1989 a survey was conducted at the USA Gymnastics Coaches Congress (35). The survey was completed by 95 coaches. Results revealed that the majority of gymnastics coaches were young former gymnasts (26-35 yr), had a bachelors degree, some experience in coaching (11-15 yr), and made a modest amount of money ($15,000-$25,000 USD/yr). The majority of the respondents trained both male and female gymnasts (71.6%). A second survey was conducted to determine the sport science and education background and needs of the gymnastics coach (31). More than 90% of the respondents (N=110) indicated they agreed or strongly agree that sport science publications and seminars could help them improve their coaching. More than 75% of the respondents believed that USA Gymnastics should provide more education programs.

National sport governing bodies are also consumers and gate keepers with regard to the direction and implementation of sport science. A Canadian survey of sport national governing bodies (SNGB) showed that physiology, sport psychology, and biomechanics were the most common *currently used* areas of science involvement with their sport (4). The SNGBs indicated that sports medicine held the highest priority for *future* sport science involvement, followed by sport psychology, biomechanics, and physiology. The ranks of the science areas that were considered *currently* most important to the SNGBs were sport psychology, physiology, biomechanics, and sports medicine. The *future* roles of sport science in SNGB programs was: 1st - education of coaches, 2nd - preparation of athletes, 3rd - interpreting existing research, 4th talent identification, and 5th carry out new research (4). The somewhat inconsistent nature of these responses points to an important lack of consensus regarding the role of sport science as seen by the national governing bodies of sports.

What is a Sport Scientist?:
Coaches are not scientists. Sport scientists work with the 'laws' of nature. These laws are universal and eternal, nonnegotiable, and self-reinforcing. The scientific community is strongly elitist, based on professional competence and seniority. Interpretations of facts are rejected unless they fit nicely with pre-existing knowledge. Sport scientists try to reduce the number of variables influencing an outcome so that causation can be more easily disentangled. Scientists look for answers that are right or wrong, and time is not of the essence (24).

What is a Coach?:
Coaches are a lot like clinical physicians. The coach does not have the luxury of time. The coach deals with individuals, he/she can only rarely conduct a statistically significant study of his/her athletes. Coaches must act before all the facts are in. A coach will probably never achieve the kind of certainty that a scientist seeks. Coaches rely on tradition, consensus of colleagues, advice of mentors, and simple imitation (30, 33). Coaches are more concerned with solving training and performance problems, not determining causation. Coaches must rely to a large extent on the unique and developing performance tendencies presented by the athlete. The coach cannot apply a 'laboratory-level' of control over his/her athletes. Training goals can only be accomplished by negotiation with the athlete (24). When a coach is confronted with new information, he/she must decide if the information applies to a particular athlete, which athletes should use it, which coaches should use it, the importance of growth and development, what alternative explanations are available, and many others. These problems add layers of uncertainty to the implementation of any scientific information. Unfortunately, the coach has to make these decisions with incomplete facts, sometimes large degrees of uncertainty, and varying contexts. Coaches often use many approaches/variables simultaneously in trying to solve a training or performance problem. If several approaches may work, the coach usually does not have the time to test each one separately and relies on a sort of 'shot-gun' approach. Disentangling causation from such an approach is practically impossible (41).

Coaches sometimes feel betrayed by the sport scientist's inability to give the coach a 'straight answer' on what to do with the training or performance problem at hand. Moreover, the inability of sport scientists to accurately predict athlete performance has not gone unnoticed (20, 21, 38-40). The sport scientist's training often results in a serious inability to give the coach a 'best guess' when customary scientific certainty is unavailable or unattainable. Sport scientists tend to see training and performance problems through the lens of their own specialties and often perform studies in areas where coaches don't need the help. The sport psychologist may see a performance problem as a mental error (e.g., fear), the exercise physiologist may see the problem as lack of fitness (e.g., strength), the nutritionist may see the problem as a lack of something in the diet, and the biomechanist may see the problem as an error in technique. Coaches must solve individual athlete's problems, and although there are ways to deal with an individual's performance in a scientifically rigorous way, sport scientists are seldom trained in these methods (3, 12, 15, 25, 27, 28). As scientists consider how to interface with coaches, it is important that they try to think like a sceptical, stubborn, and hassled coach.

INTERPRETING DATA FOR COACHES AND ATHLETES:
Experience has demonstrated that coaches prefer to be shown rather than told. Although coaches are usually college educated, with a few exceptions coaches don't usually have a background in science. Moreover, coaches seldom have the time to study in the academic sense. Given these constraints, it is important that the sport scientist present information in a graphic and vivid manner. Sport scientists are accustomed to the IMRAD approach of publishing scientific work, and efforts have been made to help coaches to understand scientific writing (13, 37). However, scientific publication almost seldom reaches the coach. The U.S. Olympic Committee, Sport Science and Technology Committee, now insists on a

one page 'coach's' report involving only the 'punch line' of the research findings. The National Strength and Conditioning Association also requires an 'Application' portion of scientific publications in its main research journal. These efforts, although laudable, do not address the fact that effective presentation and interpretation of science is a difficult task (2, 43, 44).

Along with scientific publication and information for coaches; scientists should also return individual athlete information that can serve the athlete and coach in directing training. A poor but typical example of providing feedback to United States National Team Gymnasts is shown below. Each athlete received a packet of information on 42 tested variables. The athlete's datum for each variable was listed in a large table covering one page along with the group means and standard deviations. There were no graphic depictions. The variables were covered in a boiler-plate 'Data Explanations' (DA) document covering 3.5 pages. A 'mean' was described as an 'average' in the DA document but remained a 'mean' on the table with the athlete's data. Although the variables were explained to indicate what the tests measured, there was no information regarding what the tests results could mean for training or performance. The report was a disquieting example of presenting what the scientist understood, rather than what the coach *needed* to understand. Below is an example of the text for a variable:

Data...	**Explanation...**
Vertical Plyometric Jump 40	The total number of inches the gymnast jumped using only the lower legs and ankles to elevate.'

Table I presents data from the feedback document in a different format. Table I shows how data might be portrayed so that a 'profile' of the athlete could be generated (1, 9). The nearest percentile rank to the athlete's value is shown in a shaded region. Emphasising the athlete's values in this format results in a 'picture' of the profile of the athlete. If multiple tests are performed and the format of the table is maintained, the coach can easily compare one profile with another. Moreover, the coach can compare several athletes by simply lining up the tables. Normative information is available on gymnasts for some aspects of performance and laboratory testing (17, 18, 26, 32, 36). Even with little knowledge about what a particular variable means, the coach can examine profiles as shown in Table I and determine that the athlete is proficient or deficient in some areas when compared to opponents and team mates. Patterns from such data displays show up quickly, and the coach will pursue more information in those areas where his/her athletes differ from the norm.

Biomechanists are often unusually gifted at using technical equipment, particularly computers, to produce graphic displays of technical information. Of course, Table I could be converted to a graph. Modern computers and software allow data to be graphed vividly with only a few mouse clicks. Experience has shown that coaches are becoming more familiar with computers, but they usually do not keep up with the latest developments.

Biomechanics software provides some astonishingly graphic, interactive, and useful tools for coaches seeking to know more about skills and techniques. Because traditional kinematic analyses has been too expensive and difficult for coaches to undertake, I created 16 programs to display gymnastics skills and quantitative information (i.e., parameter graphs) for coaches. The analyses are only two dimensional, which is of course constraining from a scientific standpoint, but the tradeoff in time and accessibility has compensated. The United States Elite Coaches Association for Women's Gymnastics (USECA) funded a graduate student to digitize the skills. Access to gymnastics competitions for video records has been supported by both USA Gymnastics and the USECA. The data were collected and analyzed via the Peak Performance Technologies, Inc. (Englewood, CO) system using common methods. The data files from the analyses were then archived and provided to coaches of USECA and USA Gymnastics as a function of their membership. Each month three to six skills (i.e., data files) are sent to the membership via a floppy disk enclosed with the monthly newsletter. Membership in the USECA ranges from 400-500 coaches in the U.S. At the current time we have archived over 150 skills.

Table I Example Athlete Profile Percentile Ranks from the Normal Distribution

Labels	Wingate	Wingate	Standing	Height	Weight
	Ave Power	Peak Pwr	Vertical Jump		
	W/kg	W/kg	Inches	cm	kg
Average	7.173	9.083	14.096	151.36	46.85
Std Dev	0.551	0.846	3.799	7.1	8.23
Percentile	Data Values	Data Values	Data Values	Data Values	Data Values
99.9	8.83	11.62	25.5	172.7	71.5
95	8.08	10.47	20.3	163.0	60.3
90	7.93	10.25	19.3	161.2	58.2
85	7.75	9.96	18.0	158.7	55.4
80	7.64	9.79	17.3	157.3	53.8
75	7.54	9.65	16.6	156.1	52.4
70	7.46	9.52	16.1	155.1	51.1
65	7.39	9.41	15.6	154.1	50.1
60	7.31	9.29	15.0	153.1	48.9
55	7.24	9.19	14.6	152.3	47.9
Ave 50	7.17	9.08	14.1	151.4	46.8
45	7.10	8.97	13.6	150.4	45.8
40	7.04	8.87	13.1	149.6	44.8
35	6.96	8.75	12.6	148.6	43.6
30	6.89	8.64	12.1	147.7	42.6
25	6.80	8.52	11.6	146.6	41.3
20	6.71	8.37	10.9	145.4	39.9
15	6.60	8.20	10.1	144.0	38.3
10	6.41	7.92	8.9	141.6	35.5
5	6.27	7.70	7.9	139.7	33.4
0.1	5.52	6.54	2.7	130.1	22.2

This experience has taught us that if coaches are provided with software that is relatively easy to use (although it can be improved), they will use the technology to enhance their understanding of skills. Anecdotal reports about the software have indicated that the stick figure graphics programs are the most commonly used. A program showing animated stick figures with resultant velocity vectors plotted from any chosen joint centre has been mentioned as very useful. Moreover, coaches have reported that seeing the path of the centre of mass during a skill has changed their views of how a skill should be performed, and what to look for in designing drills. The coaches rarely use the programs designed to graph position, displacement, velocity, and acceleration. Gymnasts also use the software in order to more fully understand a skill with which they are having difficulty. Figure 1 shows an example screen display from one of the programs.

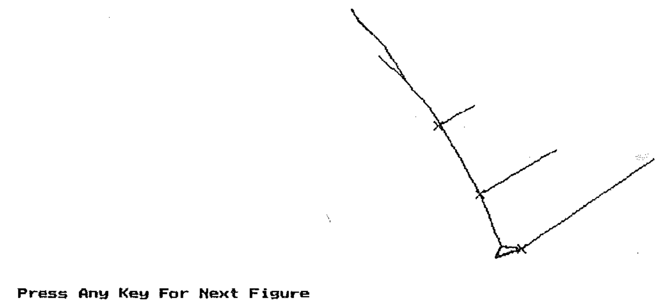

Figure 1 - An example screen display from one of the programs.

My programs are primitive when compared to some new software systems for the analysis of computer captured video (i.e., .AVI files). (14, 42). The reasonable price and versatility of these programs will likely bring coaches' analysis capabilities to unprecedented levels. An example of a NEAT System screen is shown in Figure 2. Currently coaches are pursuing computer based analysis and a gymnastics coach has developed his own commercial software that is used by many coaches to analyse and compare skill performances (8).

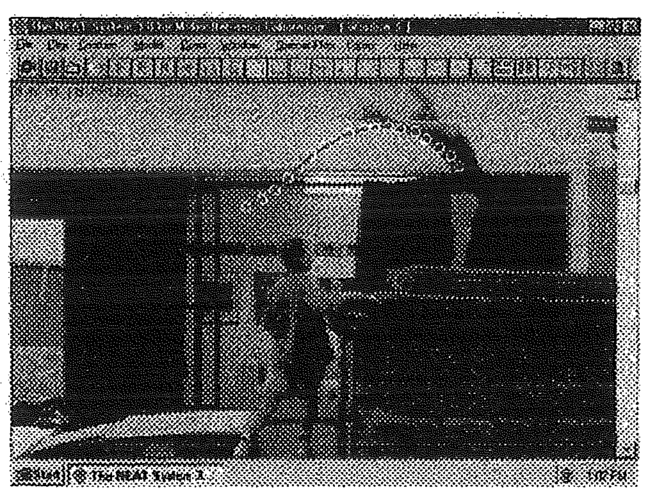

Figure 2 - A NEAT System screen capture showing a the gymnast after completing a Yurchenko vault drill. The program allows the user to digitize one point, providing position, displacement, and velocity information. The program also allows up to 6 files to be displayed simultaneously, angle calculation, and displays of frame sequences.

The combination of computers and video has also been used to combine kinetic and other data with performance video in real time. The systems are expensive, but providing this kind of information for coaches and athletes is perhaps the epitome of vivid display. Electromyography, force platform data, strain, and other variables have been combined with performance video tape to provide an 'overlay' format so that coaches and scientists can easily see the movement and the data. The primary limitation of this format comes is that coaches may not understand what the data are telling them. Experience has shown that when first confronted with this type of analysis, some coaches are not sure what to do with the information. Sport scientists must take considerable care describing and presenting this type of information so that coaches are not overwhelmed with the new insight provided by the technology (Dr. Jill McNitt-Gray, personal communication, Figure 3).

Figure 3 - Screen capture from a system created by Dr. Jill McNitt-Gray and colleagues at the University of Southern California. Note that the horizontal component force is shown on the upper screen, and the vertical component force is shown on the lower screen. The skill is a tumbling take off, and the data are obtained from a force platform directly below the tumbling surface.

Finally, simple video can be augmented by several methods. For example, combining two camera views in a 'split screen' or 'picture in a picture' format can give the coach simultaneous front and side views of the performance. A video editor with A and B roll capabilities, two cameras, and a separate VCR can provide simultaneous views for modest cost. The video capture computer systems described above can also provide split screen type views, but the video images cannot be displayed precisely simultaneously. A 'frame counter' device (not the same as the typical numbers one sees in the view finder) can also be combined with a video image so that time can be determined quickly by simply counting the frames. Frame counters are placed in line with the camera so that a small number image is placed on the video screen and recorded on tape. Some video cameras also provide this function. Tiny video cameras no larger than a floppy disk, transmitters the size of a thick postage stamp, and video receivers allow coaches and scientists to put cameras in unprecedented places providing views of performance never before seen. We have placed a tiny camera on head gear for both gymnasts and divers while transmitting the image to a receiver. We've also recorded the image on a tiny on-board VCR. In this way we can 'see' what the gymnast or diver can 'see.' Subtle aspects of performance can also be recorded by placing tiny cameras close to the apparatus for views of grip, foot contact, and so forth.

What are the Research Priorities?

As outlined above, coaches and scientists do not see the performance world the same way. Helping coaches can be very challenging because coaches often want to solve a hundred problems at once and often cannot clearly define the problem in scientific terms. Because scientists want to keep variables to a minimum, they will need to take a divide and conquer approach when helping coaches and athletes.

Athlete preparation can be divided into the following five categories of training and performance:

1. physical,
2. technical,

3. tactical,
4. psychological, and
5. theoretical or philosophical

Athlete preparation must proceed roughly in this order to be maximally effective. First, the athlete must be fit, healthy, and mature enough to perform all aspects of the sport. Second, the athlete must be able to perform well the age and development appropriate skills of the sport. Third, the athlete must be able to optimally combine the skills and strategies of the sport. Fourth, the athlete must be able to deliver his/her fitness, skills, and tactics in the decisive moments of the contest. And fifth, the athlete must be able to reconcile the demands of sport and performance with those ethical and moral issues that provide meaning to the athlete's life. Within these categories lies a great deal of room for education and investigation.

Physical: Prevention of injury and enhancement of safety are probably the most crucial contributions that biomechanists can make for coaches and athletes. Injury in gymnastics continues to be the most serious problem faced by coaches and athletes at all competitive levels (10, 45). Because gymnasts collide with apparatus as part of their performance, the apparatuses need assessments that reflect the 'tuning' of the equipment for long term use of gymnasts with varying sizes and masses (16, 22, 23, 47, Paine and Sands unpublished data).

Biomechanists can assist coaches by developing and validating training equipment that enhances fitness. It has been shown that power should be trained with ongoing power measurement during the exercise (6, 7). Measuring power in practical and accurate ways requires instrumentation that is scarce or nonexistent in gymnastics training gyms. The traditional approach of determining one repetition-maximums and sets and repetitions is no longer considered optimal.

Coaches and scientists must prepare athletes physically *before* they prepare them technically. Biomechanists can provide extensive and decisive information regarding the forces and torques that will be encountered during the performance of particular skills. Unfortunately, biomechanists have trouble keeping up with the dizzying progress of skills in gymnastics. However, most skills usually have a 'root' technique that leads to the more demanding performance (e.g., a back somersault leads to a double back somersault). Analysis of these skills both kinematically and kinetically will go a long way to assisting gymnastics coaches' training decisions.

Technical: Gymnastics coaches often ask for the 'biomechanically perfect' technique for a given skill. Coaches would like an idea of whether their idiosyncratic view of performance technique is optimal. Biomechanists can often identify crucial aspects of performance. The subtleties of technique combined with individual anthropometric and fitness differences makes a single and perfect technique for all athletes a near impossibility. The sheer number of skills also becomes daunting. However, biomechanists can contribute enormously to the coach's understanding of how skills are actually performed. Modeling gymnastics skills has been undertaken, but the models are usually and necessarily simplified and seldom presented in a way that coaches can understand (11, 46, 48). These mathematical models do not fulfill the desire of the coach to have a 'gold standard' of technique that will work for all athletes in all settings. Some efforts have been made in providing 3D animations using multimedia software. However, these efforts are not based on data (19).

Our latest efforts in this area are building on the 2D kinematic archive of skills by selecting 'root' skills and combining kinematics with electromyographic information from selected muscles. This type of work could be augmented by adding kinetic information from force platforms, accelerometers, strain gauges, and so forth. Moreover, if biomechanics laboratories could collaborate to divide up the skills of gymnastics into specific areas, each contributing to the total archive, the progress of gymnastics skill analysis and presentation would be vastly increased. Of course, placing these skills on the internet would further facilitate access and delivery.

Tactical: Tactical information refers to the strategy of performance. For example, the selection and sequence of skills is a tactical problem for the coach and gymnast. Dr. Jill McNitt-Gray has shown that 'sticking' forward somersaulting/landing skills is much more difficult than 'sticking' backward somersaulting/landing skills (personal communication). Error distributions of gymnastics routines have also been studied to show that performance errors can reflect tactical routine composition and appropriateness of difficulty selection (34). Although this type of information is not traditionally thought of as 'biomechanical,' computer processing of errors and performance via systematic observation may be a way for computer technology to further serve coaches and athletes.

Psychological: Psychological preparation is beyond the emphasis of this particular document, but biomechanics can have an influence on the athlete's psychology. Perhaps the most important contribution is demonstrating to the athlete and coach that technical problems can dominate over psychological issues such as dedication and motivation. Often when athletes cannot perform to expectations, the coach reverts to psychological explanations that may be inappropriate (29).

Theoretical: Theoretical issues involve ethics, aesthetics, and other aspects of philosophy. Sometimes the theoretical category of preparation involves the athlete's relationship to his/her artistic expression or his/her relationship to competition. Biomechanics can assist the athlete as one of the foundational and fairly objective aspects of preparation and performance.

CONCLUSION:

Gymnastics and biomechanics is a natural partnership. If sport scientists can begin to deliver their information to coaches via symposia that coaches attend, publications that are both vivid and easy to understand, and information that serves to solve current coaching problems, I believe that sport science can contribute much more to gymnastics than it currently does. Biomechanists have prided themselves on 'bridging the gap' between science and sport, but few have studied the influence of such efforts. It will behove all sport scientists to become more intimately familiar with coaches and their needs if the scientist is to have an impact beyond scholarly publications. Biomechanists are among the most crucial specialists that can enhance gymnastics performance.

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INTERNATIONAL SOCIETY OF BIOMECHANICS IN SPORTS

MINIMISING INJURIES IN GYMNASTICS ACTIVITIES

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Injury is currently a cause of impaired performance for elite New Zealand gymnasts. Maintenance and improvement in gymnastics performance by reducing the risk of injury is desirable. This paper aims to a) outline the incidence and nature of gymnastics injury and the evidence in the literature for risk factors associated with gymnastics injury, and b) to outline a prospective study currently being conducted with elite New Zealand gymnasts to assess the relationship between injury risk during gymnastic competition and training, and physical and medical factors. Detailed gymnastics training and competing information, and injury report forms are collected. Musculoskeletal, psychological, medical and anthropometric screenings are conducted every three months. Preliminary results indicate that training and musculoskeletal variables are possible risk factors for gymnastics injury.

KEYWORDS: Gymnastics, injury, risk factors.

INTRODUCTION:

Injury is currently a cause of impaired performance for elite New Zealand gymnasts. This paper aims to outline the incidence and nature of gymnastics injury and evidence in the literature for risk factors associated with gymnastics injury, and to outline a prospective study conducted with elite New Zealand gymnasts to assess the relationship between training, physical and medical factors and injury risk during gymnastic competition and training.

Injury Rate in Gymnastics:

Table 1 compares injury rate data from studies that have included training/competition exposure time as the denominator. Differences in injury rates between the studies are most likely indicative of how an injury was defined within each study. If an injury is broadly defined as "any gymnastics-related incident that resulted in a gymnast missing any portion of a workout or competitive event" (Cain, Cochrane, Caine and Zemper, 1989, p.813) then the reported injury rate will tend to be higher than a study that narrowly defines an injury as a problem that was attended to by a physician (Snook, 1979).

Table 1 Injury Rates Obtained from Prospective Competitive Gymnastics Studies

Study	Country	Gender	Study length	Subject #	Injury rate*
Lindner & Caine (1990)	Canada	Women	3 years	178	0.5
Bak et. al. (1994)	Denmark	Women	1 year	46	1.4
Bak et. al. (1994)	Denmark	Men	1 year	37	1.0
Kolt & Kirkby (1995)	Australia	Women	1.5 years	64	3.4
Caine et. al. (1989)	USA	Women	1 year	50	3.7
Weiker (1985)	USA	Women	9 months	766	4.3
Weiker (1985)	USA	Men	9 months	107	1.3
Sands et. al. (1993)	USA	Women	5 years	37	22.7

* Injury rates expressed as number of injuries per 1000 hours of exposure

For example, the study by Sands et. al. (1993) included very minor injuries, whilst Lindner and Caine (1990) carefully excluded injuries that gymnasts were able to 'work through' in training or competition. The problem with excluding less severe injuries is that many of the common gradual onset/overuse type injuries will not be reported. In order to reliably compare studies (both within and across sports), injury definitions must be standardised, and they must be sensitive enough to register the very common 'non-specific' overuse type injuries that gymnasts suffer regularly (McAuley, Hudash and Shields, 1987).

Reinjury: There is only one gymnastics epidemiological study describing the incidence *rate* of reinjury. The NCAA (1994) reported 2.2 reinjuries per 1000 athletic exposures[1] for women, and 0.5 reinjuries for men. Caine et. al. (1989) expressed reinjury as a percentage of total injuries and found that 33% of all injuries were attributable to earlier occurrences of the same injury. The authors suggested that this figure indicates that gymnasts often return to training and competition before they are fully rehabilitated.

Practice vs. competition: Data from studies investigating the proportion of injuries occurring in practice compared with competition have found that between 79% and 97% of injuries occur during practice (Pettrone and Ricciardelli, 1987; Kerr and Minden, 1988; Garrick and Requa, 1980; Lindner and Caine, 1990; Wadley and Albright, 1993; NCAA, 1994). However, when time spent competing compared with practising was accounted for, (i.e. exposure denominator data were included) it was found that the injury rate was three times greater in competition than in practice (NCAA, 1994). These data indicate that although most injuries occur during practice (due to spending more time practising than competing), the injury rate is greater in competition.

Injury Onset:
The onset of sports injuries is typically categorised as being either gradual (overuse) or sudden (acute). Injury onset data from epidemiology studies, presented in Table 2, indicate that, with the exception of one study by Caine et. al. (1989), between 57% and 82% of injuries recorded in gymnastics were of a sudden nature. No explanation for this anomaly was cited by Caine et. al., however, the authors were uniquely thorough in ensuring all injuries were recorded. That is, injury data were gleaned from several sources including training diaries, coaches reports, onsite inspection by the primary investigator, and interviews with the athletes. This is in direct contrast with Sands et. al. (1993) who left the reporting of injuries completely to the athletes. Consequently, it is likely that the percentage of gradual onset injuries is reduced by negligent recording of 'non-specific' overuse injuries (McAuley et. al., 1987). In some cases, gymnasts perceive their overuse type injuries as being so common that they do not report them as injuries (Meeusen and Borms, 1992). The reporting of injuries is also influenced by how an injury is defined, and because, generally, no distinction is made for an acute injury that is superimposed on a chronic injury mechanism (Caine et. al., 1996).

Table 2 Comparison of Injury Onset from Prospective Studies of Women's Competitive Gymnastics

Study	Country	Study length	# of Subjects	# of Injuries	Injury onset (%)	
					Gradual	Sudden
Caine et. al. (1989)	USA	1 year	50	147	56	44
Weiker (1985)	USA	9 months	766	95	43	57
Wadley & Albright (1993)	USA	4 years	26	106	43	57
Bak et. al. (1994)	Denmark	1 year	46	41	39	61
Snook (1979)	USA	5 years	70	66	33	67
Sands et. al. (1993)	USA	5 years	37	509	31	69
Lindner & Caine (1990)	Canada	3 years	178	90	22	78
Pettrone & Ricciardelli (1987)	USA	7 months	2558	62	18	82

[1] One athletic exposure was defined as one athlete participating in one practice or event that exposed him or her to the risk of injury. Therefore, this statistic only normalises the data for the *number* of training or competition sessions, and does not allow for differences between athletes in terms of *hours* spent training.

Type of Injury:

A comparison of injury type from prospective studies of women's competitive gymnastics (see Table 3) indicates that sprains (19% - 47%) and strains (6.4% - 35%) are consistently the most common type of injury to female gymnasts. A study of male gymnasts has also reported that sprains and strains are most common (NCAA, 1994). The high proportion of these injuries is not surprising given the highly repetitive nature of impacts associated with landings from dismounts, and during floor routines (Caine, Lindner, Mandelbaum, and Sands, 1996). The data in Table 3 are also influenced by injury definition and data collection methods. The high proportion of non-specific overuse type injuries in the study by Caine et. al. (1989) is indicative of their thorough injury recording methods, whilst the lower percentage of mild injuries reported by Wadley and Albright (1993) and Snook (1979) reflects that injuries for these studies were defined as problems presented to medical staff.

Table 3 Comparison of Injury Type from Prospective Studies of Women's Competitive Gymnastics

Study	Abrasion	Concussion	Contusion	Dislocation	Fracture	Sprain
Caine et. al. (1989)	0	0.7	4.1	0.7	3.4	19.0
Lindner et. al.(1990)	2.2	0	6.5	4.3	24.8	19.4
Garrick et. al. (1980)	—	—	5.0	—	10.0	38.0
Kolt and Kirkby (1995)	—	—	—	—	12.3[1]	29.7
Bak et. al. (1994)	—	—	8.2	—	4.1	47.0
Pettrone et. al. (1987)	0	0	9.7	6.4	27.4	41.9
Snook (1979)	0	0	4.5	6.1	16.7	30.3
Wadley et. al. (1993)	0	0	3.8	0	5.7	33.0

Study	Inflammation	Laceration	Non-specific[2]	Strain	Other
Caine et. al. (1989)	10.2	0	40.1	17.7	4.1
Lindner et. al.(1990)	6.5	1.1	11.8	11.8	9.7
Garrick et. al. (1980)	—	—	—	30.0	17.0
Kolt and Kirkby (1995)	—	—	—	23.2	—
Bak et. al. (1994)	24.5[3]	—	—	12.2	4.1
Pettrone et. al. (1987)	8.1	0	0	6.4	0
Snook (1979)	25.8	7.6	0	9.1	0
Wadley et. al. (1993)	14.1	0	8.5	35.0	0

1. represents reported proportion of growth plate injuries only
2. includes cases diagnosed as stress reaction or overuse type injuries
3. represents reported proportion of tendonitis or inflammatory injuries

Location of Injury:

A comparison of injury location data from prospective studies of female competitive gymnasts (see Table 4) indicates that the lower extremity was injured most often (54.1% - 70.1%), followed by the upper extremity (15.1% - 25%), and the spine/trunk region (7.5% - 16.7%). Of the lower extremity injuries, ankle injuries were most common, followed by the knee and then foot/toes. In the upper extremity, the wrist, elbow and hand/fingers were most often injured as a percentage of total injuries, and for the spine/trunk region, injuries to the lower back were most frequent.

Table 4 Comparison of Injury Location (%) from Prospective Studies of Women's Gymnastics.

Body location	Caine (1989)	Lindner (1990)	Garrick (1980)	Weiker (1985)	Bak (1994)	Wadley (1993)
Head	4.1	4.1	4.0	3.2	2.4	1.9
Spine/Trunk	15.0	16.7	13.0	7.5	9.8	16.0
Upper extremity	20.5	22.9	31.0	18.1	17.1	15.1
Lower extremity	63.7	54.1	52.0	70.1	68.3	66.9

For male gymnasts, there is evidence to indicate that along with a higher proportion of lower extremity injuries (36.4% - 43.1%), there is a higher proportion of upper extremity injuries (36.4% - 53.8%) when compared with women (Bak et. al., 1994; Weiker, 1995; Lueken, Stone and Wallach, 1993). In terms of specific body parts for the men, there were a large proportion of lower back, ankle, knee, wrist and, in particular, shoulder injuries. The high frequency of shoulder injuries in male gymnasts is most likely the result of extra physical demands placed on the shoulder area in events such as rings, pommel horse, and horizontal bar.

Head/Spine/Trunk: There is little doubt that, although not as common as lower extremity injuries, the severity of lower back problems in gymnastics is of considerable concern. Case-studies indicate that gymnastics lower back injuries tend to have a gradual onset (which may reduce the reported incidence of back problems), involving primarily advanced level gymnasts (Caine et. al., 1996). This implicates experience and competitive level as risk factors for injury. Common sites of lower back injury include vertebral bodies and intervertebral discs. Severe injuries include vertebral endplate abnormalities, and pars interarticularis damage with resultant spondylolysis (stress fracture) and spondylolisthesis (slipping of one vertebra onto another) (Caine et. al., 1996). The movements most likely to result in lower back injury are chronic repetitive flexion, extension and rotation demanded of the spine and its associated structures during gymnastics (Hall, 1986). In addition, the extreme loading forces resulting from dismount and tumbling landings place the spine and lower extremities under enormous stress (Caine et. al., 1996). This stress has been implicated in pars interarticularis spondylolysis and spondylolisthesis, and in the genesis of vertebral growth plate disorders which may disrupt growth and/or lead to chronic degenerative changes in the spine (Brukner and Khan, 1993).

Lower extremity: In gymnastics, the lower extremity, like the spine, is involved in absorbing large repetitive forces over a long period of time. The magnitude of these forces is approximately four times body weight (BW) for takeoffs (Takei, 1991), and 12 times BW for landings (Panzer, Wood, Bates and Mason, 1988). Data gleaned from prospective studies indicates that lower extremity injuries typically occur suddenly from a 'missed move' (Linder and Caine, 1990), and are most often ankle sprains, lower leg strains (Caine et. al., 1989) and knee dislocations (Linder and Caine, 1990). Lower extremity injuries with a gradual onset typically include ankle impingements (from chronic pointing of the foot), lower leg stress fractures and compartment syndromes (from the repetitive stress associated with landing), and patellofemoral knee problems (from biomechanically dysfunctional tracking of the patella) (Meeusen and Borms, 1992).

Upper extremity: Upper extremity forces have magnitudes of 1.5 times BW for vault, 3.9 times BW for horizontal bar, 9.2 times BW for rings, 2.0 times BW for pommel horse and 3.1 times BW for uneven bars (Caine et. al., 1996). Case and cross-sectional studies indicate a large number of gradual onset injuries involving the distal radius, and distal humerus, and include distal radial growth plate disorders, and, primarily in females, osteochondritis dissecans of the humeral capitellum (loose bodies in the elbow) (Caine et. al., 1996). Both of these problems are severe, and are the result of shear and compressive forces to stressed and immature joints (Singer and Roy, 1984). Shoulder injuries are especially common amongst male gymnasts and are most frequently muscle strains (acute), or shoulder joint impingements (chronic) (Meeusen and Borms, 1992).

Injury Severity/Time Loss:
The quantity of time lost in training or competition as a result of injury is influenced by many factors including injury definition, personal motivation, peer pressure, coaching ethos, and the fact that for most injuries, gymnasts are able to keep training on a different apparatus. In research where *injury* and *recovery time* are clearly defined and recorded, some useful data are obtained. Caine et. al. (1989), reported that 41% of injuries required less than 8 days of recovery (defined as returning to previous training level), 33% required between 8 and 21 days, and 26% required more than 21 days recovery. In contrast, Lindner and Caine (1990) reported that only 3% of injuries required less than 8 days recovery, 34% between 8 and 21 days, and 67% more than 21 days. This large difference is due to the fact that Caine et. al. were careful to register all injuries including minor strains, whilst the injury definition used by Lindner and Caine was designed to exclude minor injuries. This highlights the need to standardise injury definitions in order to compare different studies within and between sports.

Injury Severity/Catastrophic Injuries:
Catastrophic injuries include fatalities and serious injuries such as quadriplegia. In gymnastics, the very few reported case-studies of catastrophic injuries occurred on the trampoline, mini-tramp, and to a lesser extent, the springboard. Most of these injuries occurred whilst performing back or forward somersaults on the trampoline. The case-studies also reported that catastrophic injuries were most often sustained by highly experienced gymnasts (and/or trampolinists), which may indicate these gymnasts are more at risk of catastrophic injuries due to the complexity of the manoeuvres they are performing (Caine et. al., 1996).

Drop-Out and Long-Term Impact of Injuries:
It has been reported that injury acts as a potential source of motivation for drop-out in gymnastics (Caine et. al., 1996). Dixon and Fricker (1993) retrospectively examined injuries to 42 male and 74 female elite artistic gymnasts at the Australian Institute of Sport between 1982 and 1991. They reported that 7% of the gymnasts retired from gymnastics due to injuries requiring surgical intervention, including meniscus lesions, a cruciate ligament rupture, and a stress fracture of the foot. In Caine et al's study (1989), 42% of the elite club gymnasts dropped out of gymnastics during the year long study. This difference reflects the fact that retrospective examinations of medical reports (as in the study by Dixon and Fricker) preclude the possibility that a gymnast leaves as a result of numerous chronic injuries.
An investigation into the long term effects of injury by Wadley and Albright (1993) reported that 45% of previously injured gymnasts still were bothered by the injury approximately three years later. Furthermore, 46% of the gymnasts reported that their injury was not fully recovered after three years, but that they were still "capable of strenuous physical activity" (Wadley and Albright, 1993 p.314). These studies tend to suggest that, although injuries to gymnasts may be chronically long term, they are not catastrophic in nature, and nor do they prevent retired gymnasts from leading a physically active existence.

Injury Risk Factors for Gymnastics:
Epidemiological risk factors are categorised as being either extrinsic or intrinsic. There are no studies that indicate with any degree of certainty that a particular risk factor *causes* an injury. This is mostly because injuries very rarely occur as a result of one single risk factor (Caine et. al., 1996). The results of studies attempting to investigate analytical epidemiology should be viewed with caution given the design limitations present in nearly all such studies. In most cases, these studies are able to *link* a risk factor with injury – but this in no way suggests that the risk factor *causes* the injury. For example, Steele and White (1986)

reported that taller gymnasts are more at risk of injury. This does not suggest that a particular gymnast's height caused an injury, but rather that height may be one of several contributing factors in the occurrence of an injury.

Intrinsic risk factors: Intrinsic risk factors are athlete based characteristics that predispose an individual to injury. These include physical characteristics, motor/functional characteristics, and psychological influences.

Physical characteristics: Biomechanical efficiencies may be gained with particular physiques: decreased height and weight elicit a greater ratio of strength to weight, greater stability and a decreased moment of inertia. Body fat adds to mass without adding to power producing capability therefore fat mass is detrimental to the gymnast. In addition there is an emphasis on leanness for aesthetics by coaches and judges. There may be an increased risk of injury during periods of rapid body growth (Caine, Cochrane, Caine, and Zemper, 1989) due to "increased moments of inertia, increased muscle-tendon tightness, and decreased epiphyseal strength" (Caine et. al., 1996, p.233).
Lindner and Caine (1990) reported that 'injury prone' gymnasts were characterised by rapid growth, with greater body size, age and body fat. However, it was suggested by Caine et. al. (1996) that greater body size and body fat tend to characterise older gymnasts who have also had more years of training and compete at higher levels. In other words, the risk factors of age, body size, and body fat percentage confound with the competition level. Steele and White (1986) reported that weight, mesomorphy, standing lumbar curvature, age and height accounted for 70% of the observed variance in injury-proneness as evidenced by previous history of injury for elite British female gymnasts.
Claessens et. al. (1996) investigated physique as a risk factor for ulnar variance in 156 skeletally immature elite female gymnasts. It was concluded that female gymnasts who were more mature and had a physique characterised as relatively tall with high lean body mass were at a greater risk for developing positive ulnar variance. There was no relationship between ulnar variance and training characteristics. Further research is required to ascertain the relationship between gymnastics injury and height, body weight, body fat, and musculoskeletal biomechanical characteristics.

Motor characteristics: Many physiological or motor characteristics, including flexibility, muscle weakness, balance, and endurance, have been indicated as potential risk factors in gymnastics and other sports. However, for the most part their relationship to injury risk is unclear. Studies often gather data using retrospective or cross-sectional designs, but this leaves the relationship between injury and potential risk factors uncertain (e.g. Steele and White, 1986). In such studies, the 'chicken or egg' type question of whether the injury causes the risk factor, or the risk factor causes the injury, remains unanswered.
Perhaps the most publicly bandied about risk factor in modern sport is flexibility (either too much or too little!). In gymnastics a large degree of flexibility is demanded of the gymnasts (for aesthetic and skill reasons), and yet it is unclear whether or not a high amount of flexibility (and associated destabilisation of the joint structures) does increase the risk of injury (Caine et. al., 1996). The British "Training of young athletes" study indicated that strength and flexibility did not exert a significant role in determining injuries for elite gymnasts aged between 9 and 18 years (Maffullini et. al., 1994), however, the incidence of injuries was not high. The number of push-ups performed in two minutes may be predictive of musculoskeletal injuries in army trainees (Jones et. al., 1993) but it is not known whether this type of relationship is valid for gymnastics injury. Further studies on functional skills and the risk of injury are required in gymnastics.

Psychological characteristics: Researchers have recently begun to investigate the influence of psychological factors, including life stress, anxiety, and self-esteem, on the risk of injury to gymnasts (Kerr and Minden, 1988; Kolt and Kirkby, 1995). There appears to be some evidence that anxiety is related to the occurrence of injury (Kolt and Kirkby, 1994).

However, studies published to this date have used retrospective designs which makes it impossible to determine whether or not the gymnasts were anxious because they were injured, or because the injury led to increased anxiety.

Extrinsic risk factors: Extrinsic risk factors are those that impact on an athlete externally, including exposure (time and event), training methods, environmental conditions (e.g. time of season), and equipment.

Exposure to activity: As gymnasts become more skilled, the amount of time spent training increases (exposure time), and consequently the *number* of injuries increases. Also, research generally supports an increase in injury *rate* as competition level increases (Caine, 1989; NCAA, 1994; Mackie and Taunton, 1994; Weiker, 1995). This is possibly because, as gymnasts reach a higher level of competition, they perform more complex (and risky) manoeuvres. Caine et. al. (1989) reported that the most injury prone gymnasts (based on time loss due to injury) were elite level competitors.
Research on the men's and women's gymnastics event most associated with injury indicates that the largest percentage of injuries occur on the floor (Garrick and Requa, 1980; Caine et. al., 1989; Lindner K.J., Caine, 1990; Wadley and Albright, 1993; Sands et. al., 1993; NCAA, 1994; Bak et. al., 1994). However, studies are required that include *event specific* exposure time as the injury rate denominator. Therefore, it is uncertain as to whether the number of injuries on the floor is due to the nature of floor exercises themselves (e.g. repetitive trauma from tumbling) or because more time is spent on the floor, or a combination of the two.

Training conditions: Epidemiological research has indicated that a higher proportion (Linder and Caine, 1990; Weiker, 1985; Pettrone and Ricciardelli, 1987) and rate (NCAA, 1994) of injuries occur when gymnasts are not assisted by spotters. There is no doubting the importance of spotters in reducing the likelihood of injury, yet it is the nature of gymnastics that eventually a gymnast must perform a complex routine unassisted.
When investigating injury patterns during gymnastics training sessions, Lindner and Caine (1990) reported an increased risk of injury with length of time on a particular apparatus. This was attributed to poor concentration, and the authors recommended that training sessions should involve more rotations to decrease the likelihood of a gymnast becoming inattentive. Furthermore, their data indicated that more injuries occurred when gymnasts were performing well learned, basic or moderately difficult manoeuvres. This indicates that, although there is evidence of an increased risk of injury with increased movement complexity (as reported by Caine et. al., 1989), many injuries occur performing less complex movements simply as a consequence of inattention on the part of the gymnasts.
There is epidemiological evidence that sudden onset injuries occur more frequently relatively early in training sessions (Caine et. al., 1989, Lidner and Caine, 1990). This is possibly because of one or more of several reasons: a) insufficient warm-up; b) poor progressions into training routines; and c) more complex skills are practised early in a training session when gymnasts are most fresh. Seasonal variations (based on altered training regimes at specific times of the year) in the incidence of injury have also been investigated (Dixon and Fricker, 1993). These studies have reported increased injury rates: a) following periods of reduced training or immediately after a holiday (Caine et. al., 1989, Sands et. al., 1993) possibly due to the sudden increase in training intensity; b) immediately prior to competition (Sands et. al., 1993; Kerr and Minden, 1988) perhaps as a consequence of increased anxiety, and/or performing under-prepared routines; c) during competitive routine preparation (Caine et. al., 1989, Sands et. al., 1993), again, because routines are hurriedly prepared, or because of increased levels of fatigue; d) during competition (Caine et. al., 1989, Sands et. al., 1993) where anxiety is at its highest and there is less protection (spotting and landing pads).

Equipment: Improved gymnastics safety equipment, in the form of sprung floors, sprung beams, thicker landing mats and fibre glass rails has offset the expected decrease in injury

incidence by enabling the performance of increasingly complicated and risky performance routines (Caine et. al., 1996). The high rate of injury during competition has led to some suggestions of increasing the thickness of landing mats used in competitions. Poorly attended safety equipment is implicated in the occurrence of some injuries such as the numerous reported cases of gymnasts spraining an ankle by landing between badly aligned mats.
Further research is required on the effect of the intensity of activity, the types of equipment and the types of activity (e.g. warm-up and stretching) on injury risk.

THE NEW ZEALAND ELITE GYMNASTICS INJURY STUDY

The New Zealand Gymnastics Science and Medicine Advisory Committee considered options for the reduction and prevention of gymnastics injury including improved design of training sessions, increased monitoring of gymnastics safety equipment, and comprehensive monitoring of gymnasts by medical professionals. The "New Zealand Elite Gymnastics Injury Study" was developed and aimed to develop a computerised data base of gymnastic injuries and their possible risk factors (training, musculoskeletal, anthropometric, medical and psychological variables); to provide timely and appropriate medical and scientific advice upon identification of injury risk factors or injuries; and to provide educational material on risk factors for gymnastics.

METHODS:

The aim of the screening and prospective study was to investigate the ease of collecting injury, training, and musculoskeletal data with the aim of identifying risk factors for gymnastics injury in a selected cohort of 19 elite gymnasts. Ethics was gained from the University of Auckland ethics committee, and funding was obtained from Sports Science New Zealand. An introductory seminar was run for the gymnasts, their coaches and parents to explain the aims of the study and the possible benefits to the gymnasts. Gymnasts were asked to fill in a sample training and injury form to ensure understanding of what was required for the data collection period. Gymnast demographics, detailed training and competing information, and injury report forms have been collected prospectively for six months. Musculoskeletal, psychological, medical and anthropometric screenings have been conducted every three months. Weekly feedback on training and injury information was given to gymnasts. This paper outlines the preliminary results from the initial screening session, and two months of training & injury data collection.

Gymnastics Population Studied:

For practical reasons the number of gymnasts in the study was limited to the 19 New Zealand elite/developmental squad gymnasts (6 male artistic 18.4±3.6 years old; 9 female artistic 14.6±1.2 years old, and 4 rhythmic 17.6±2.1 years old) based in Auckland. The average gymnastics experience at the start of the study for the women artistic gymnasts was 7.7 +/- 1.7 years, for the men was 9.1 +/- 4.3 years and for the rhythmic women was 7.8 +/- 1.0 years.

Training and Competition Information:

Training information was collected in an attempt to correlate injury to training factors such as time spent on individual apparatus, or total amount or intensity of training. Competition information was collected to allow a comparison between injury rates in competition and training and the factors associated with gymnastic performance under competition. Gymnastics activity forms were filled in by the gymnasts at the end of each session and were collected weekly.

Injury Data Collection/Injury Definition:

The definition of injury was agreed upon by the coaches, gymnasts and researchers at the information seminar and was a compromise between vigorous research definitions and a definition that was practical for data collection in the gymnasium: An injury occurring in gymnastics that requires medical attention OR a gymnastics injury that is an ankle sprain, a knee sprain, a shoulder sprain, or a back sprain/strain that prevents or restricts the gymnast from training or competing in any activity/apparatus in any way and/or for any length of time.

Musculoskeletal Screening:
Musculoskeletal screening was conducted by two sports physiotherapists using standard clinical tests (see Table 5). The tests chosen from a bank of possible procedures were those considered to target the anatomical regions that appear to be most clinically affected. Some tests were directed to reveal muscle weakness in core trunk stabilisers and the associated hypermobility of compensating structures, especially the thoraco-lumbar spine and hip joints, i.e. detecting overuse injuries to the lower limb and lower back. Proprioceptive (balance) skills critical to stability, but often impaired post-injury without the athletes/coaches knowledge, were also examined. Muscle balance details were then summarised along with low to high risk areas, to enable medical and coaching management to focus on key issues for each gymnast.

Medical Screening:
The objective of the medical screening was to identify any problem areas that would need attention such as low blood iron levels or asthma. Standard medical procedures and tests were conducted by two sports medicine doctors. Blood and urine samples were taken by a clinical laboratory.

Anthropometric Screening:
The objective of the anthropometry screening was to provide gymnasts with information on their levels of body fat and muscularity. Bone lengths and widths were also measured so that follow-up sessions could identify whether growth was occurring. Full anthropometry profiles were developed using ISAK criteria (Norton and Olds, 1997) and were conducted by two certified anthropometrists.

RESULTS AND DISCUSSION:
All of the gymnasts reported that the activity and injury forms were easy to complete, and only required approximately 2-5 minutes to complete (unless an injury occurred). It is noted that when feedback is provided to the coaches and athletes it usually results in a change in training, nutrition, psychological support etc. in an attempt to improve performance. Given the ethical considerations involved in *not* giving medical and scientific feedback to the gymnasts when required, the study was designed to be descriptive, i.e. to document the changes in training with the incidence of injury. The study is on-going, hence a summary of the first two months of data is presented.

Screening:
Gymnasts had somatotypes consistent with international gymnasts, although three gymnasts were referred to the nutritionist given low sums of skinfolds and one gymnast was also referred given large sums of skinfolds. Medical screening indicated that 32% of the (6/19) gymnasts had asthma but this was under medical control. A variety of medical conditions were present in the gymnasts including low back pain, Servers disease, patellofemoral pain, Osgood-Schlatters disease, elbow dislocation, shoulder subluxation/tendonitis, anterior ankle impingement, and L5/S1 spondylolisthesis.
Musculoskeletal screening (see Table 5) indicated that all gymnasts exhibited lower abdominal strength below the physiotherapists stated required levels for core stability; All gymnasts exhibited patterns of lumbar dysfunction due to muscle imbalance factors; Both artistic groups were tight in their iliotibial band and rectus femoris thigh muscles; The rhythmic gymnasts exhibited hypermobility in both their thoracolumbar spines and hip joints. The range of motion tests showed similar results on both left and right sides. The hip quadrant test also produced some problems in all three groups. The balance test results

were poor, which was suprising given that gymnastics requires a high level of balancing ability.

Gymnastics Activity:
Time spent on activities within a gymnastics training session was fairly evenly distributed (see Figure 1 for the artistic women's results) except for men's vault which received less time than the other events. Time was fairly evenly distributed for competition activities (see Figure 2 for the artistic women's results) except for rhythmic gymnasts who spent a large proportion of the time (44%) in warm-up.

Table 5 Musculoskeletal Screening Test Results for the Gymnasts, Mean ± Standard Deviation (minimum-maximum)

Screening test	Women's artistic (n= 9)		Men's artistic (n= 6)		Rhythmic (n= 4)	
	right	left	right	left	right	left
Ankle dorsiflexion in standing (∫)	30.6±4.6 (20-35)	30.6±8.5 (10-40)	31.2±8.5 (20-42)	34.2±7.4 (25-45)	27.5±9.6 (15-35)	26.3±10.3 (15-35)
Hip internal rotation in 90∫ flexion in sitting (∫)	37.8±5.7 (30-50)	37.2±6.2 (30-50)	37.5±9.4 (25-50)	36.7±12.1 (20-55)	31.3±2.5 (30-35)	31.3±2.5 (30-35)
Hip external rotation in 90∫ flexion in sitting (∫)	32.2±7.1 (20-45)	31.7±5.6 (25-45)	35.8±8.6 (25-50)	35.8±7.4 (25-45)	32.5±2.9 (30-35)	33.8±4.8 (30-40)
Modified Thomas illiopsoas (∫)	9.1±8.3 (-10-15)	11.7±10.3 (-15-20)	4.2±19.3 (-25-20)	8.3±13.7 (-15-20)	18.8±7.5 (15-30)	16.8±9.1 (10-30)
Modified Thomas rectus femorus (∫)	55.6±8.5 (40-70)	53.3±7.1 (40-65)	45.8±15.6 (30-75)	45.8±12.8 (35-70)	47.5±6.5 (40-55)	48.8±9.5 (35-55)
Iliotibial band (∫)	10.6±4.6 (0-15)	9.4±4.6 (0-15)	7.5±6.1 (0-15)	9.2±4.9 (0-15)	3.8±4.8 (0-10)	3.8±4.8 (0-10)
Latissimus dorsi wall test (∫)	24.8±4.4 (18-33)	26.5±1.9 (24-28)	27.7±3.3 (25-34)	27±1.8 (25-29)	31.7±5.8 (25-35)	35±0.0 (35-35)
Balance test closed, eyes closed (s)	14±8.0 (3-20)	12.2±6.3 (6-20)	10.8±8.4 (4-20)	11.3±9.2 (2-20)	4±0.0 (4-4)	13±0.0 (13-13)
Balance test eyes closed, head tilt (s)	7.6±4.2 (1-14)	8.3±5.7 (2-19)	6±4.1 (2-13)	4.7±3.6 (1-10)	4.8±2.8 (2-8)	6.5±5.9 (1-13)
Abdominal stability	4.3±0.7 (3-5)	—	4.7±0.8 (3-5)	—	4.4±0.9 (3-5)	—

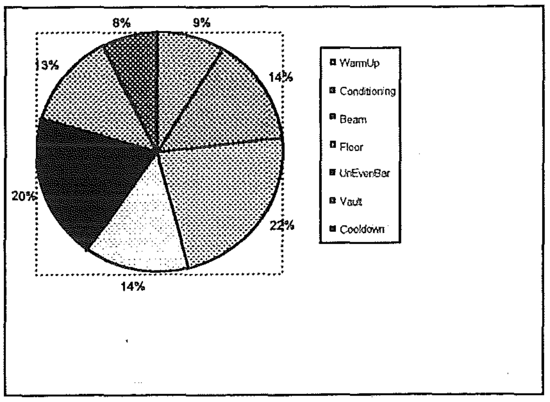

Figure 1 - Percentage of time spent in training activities for artistic women. women.

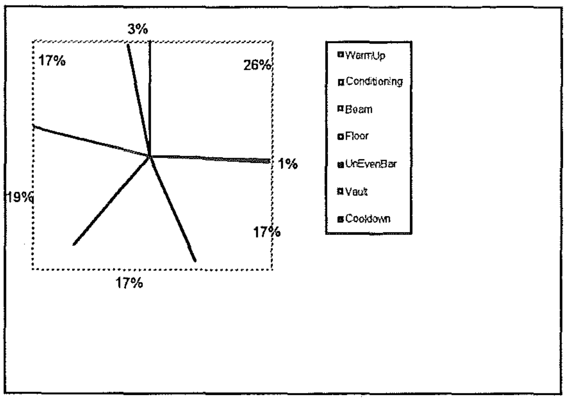

Figure 2 - Percentage of time spent in competition activities for artistic

There is limited gymnastics injury information that includes *event specific* exposure time as the injury rate denominator. Therefore, it is uncertain as to whether the number of injuries on the floor is due to the nature of floor exercises themselves or simply because more time is spent on the floor, or a combination of the two. The current study collects event specific training times and records what apparatus was being used at the time of injury, therefore should lead to a clearer picture regarding any relationship between injury and apparatus.

Perceived intensity of activities was higher in competition than in training for all events except for conditioning. This supports a relationship between intensity and injury risk as the injury rate was generally higher in competition than in training (see Table 6). Overall levels of perceived intensity were moderate. The differences in intensity between competition and training indicate that intensity levels during training should be higher to replicate the competition environment.

Perceived concentration levels were higher in competition than in training, and perceived fatigue was lower in competition than in training, yet the injury rate was higher in competition. Overall levels of concentration were subjectively rated lower than expected by the researchers. This highlights the need for concentration to be improved. The relationship between injury and levels of concentration and fatigue need to be further examined.

Table 6 Injury Rates for New Zealand Male, Female and Rhythmic Gymnasts

Study	# of injuries in training	# of hours training	Training injury rate*	# of injuries in competition	# of hours in competition	Competition injury rate*
Males (n=6)	4	19920	0.20	2	2595	0.77
Females (n=9)	5	31245	0.16	4	2595	1.54
Rhythmic (n=4)	2	16785	0.12	0	4245	0.00

*number of injuries per 1000 hours training or competition

Table 7 Injury Characteristics for New Zealand Male, Female and Rhythmic Gymnasts

Onset	Localisation of Injury	Perceived Injury	Session	Apparatus	Minutes into session
Artistic men					
Gradually	Wrist	Ligament sprain	Competing	Pommel	40
Gradually	Achilles tendon	Overuse	Training	Conditioning	80
Suddenly	Head	Concussion	Competing	Pommel	40
Suddenly	Elbow	Inflammation	Training	Floor	80
Suddenly	Not specified	Bruise, graze	Training	Parallel bars	180
Suddenly	Chest	Ligament sprain	Training	Rings	180
Artistic women					
Gradually	Other	Bruise	Competing	Beam	40
Gradually	Lower back	Muscle tendon strain	Competing	Vault	40
Gradually	Hamstring	Muscle tendon strain	Training	Floor	100
Suddenly	Ankle	Uncertain	Competing	Beam	80
Suddenly	Knee	Ligament sprain	Competing	Uneven bars	80
Suddenly	Ankle	Ligament sprain	Training	Floor	120
Suddenly	Knee	Uncertain	Training	Floor	180
Suddenly	Wrist	Muscle tendon strain	Training	Floor	120
Suddenly	Ankle	Ligament sprain	Training	Warm up	20
Rhythmic women					
Gradually	Hip, Lower back	Overuse, inflammation	Training	Ribbon/Rope	100
Suddenly	Hip, Gluteals	Muscle tendon strain	Training	Warm-up ballet	40

Injury Characteristics:
Table 6 gives the injury rates for males, females and rhythmic gymnasts in the New Zealand study. The injury competition rates were higher than injury training rates for men's artistic and women's artistic. The injury rates for the New Zealand study are consistent with international injury data for gymnastics. Table 7 shows the injury characteristics for the 19 gymnasts in the two month period. The onset of sudden injuries was 67% for the male artistic gymnasts, 67% for the women artistic gymnasts, and 50% for the rhythmic gymnasts. The percentages of injuries in training were 67% for male artistic gymnasts, 56% for women artistic gymnasts and 100% for the rhythmic gymnasts. Injury localisation was noticeably different for all three groups (see Table 7). Rhythmic gymnasts suffered most injuries to the hip region of the body. Artistic women suffered most of their injuries to the lower extremities (ankle and knee) while artistic men suffered the majority of their injuries to the upper extremity (elbow and wrist).
The estimated time missed due to a physical gymnastics problem was 240 minutes of competition for one artistic female gymnast, 3945 minutes of training for eight artistic female gymnasts, 450 minutes of training for two rhythmic gymnasts, and 570 minutes of training for two artistic male gymnasts.

PRACTICAL SUGGESTIONS FOR COACHES AND ATHLETES:
The following recommendations were based upon the evaluation of the initial two months results by medical, scientific and gymnastics personnel.

- Appoint a physiotherapist to attend the gymnasium weekly to check for injuries and provide advise where needed.
- Appoint a strength conditioner to train gymnasts once a week in core stability.
- Provide gymnasts with information on what types of injuries may occur and what actions should take place if injury does occur.
- Continue to record training and injury data.
- Train coaches in sports first aid and ensure a well maintained first aid kit is available.
- Audit the safety of gymnastics equipment and ensure maintenance is scheduled.
- Encourage gymnasts to voice concerns to their coaches.
- Encourage coaches to individualise training programmes.
- Encourage gymnasts to seek help from the Sports Psychologist.

CONCLUSION:
The initial aims of the study have been met in that a computerised data base of gymnastic injuries and their possible risk factors has been developed (and continues to be added to), and timely and appropriate medical and scientific advice upon identification of injury risk factors or injuries has been provided. Preliminary results indicate that training and musculoskeletal variables are possible risk factors for gymnastics injury. Statistical regression procedures will be used after 1 year of the study to assess any relationships between the proposed risk factors and injury occurrence and severity.
It is suggested that injury data and training data continue to be collected, that risk factors be assessed and interventions developed to reduce the impact of the risk factors, that the effectiveness of the interventions be evaluated, and that clear and frequent communication with all parties is essential. Although data collection can be somewhat laborious and time consuming, the results do provide coaches and athletes with subjective data to assess the training program and the impact on the gymnasts' musculoskeletal growth and general health.

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LEARNING HOW TO TWIST FAST

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Progressions are presented for learning aerial twisting forward single and double somersaults with 1½ twists and backward single and double somersaults with one twist. These progressions are based on the results of computer simulations and make a single change in technique from one stage to the next. They are best introduced on trampoline and then transferred to the gymnastics apparatus. It is possible to make rapid progress in learning complex skills in relative safety provided that consistency is achieved at each stage before progressing to the next. The advantage of using aerial twist is that it makes takeoff and landing much easier and safer.

KEYWORDS: twist, somersault, simulation, model, coaching, progressions

INTRODUCTION:

The orientation of a gymnast during a twisting somersault may be described by the angles of somersault, tilt and twist (Figure 1). Somersault rotation takes place around a horizontal axis through the mass centre while twist rotation is around an axis fixed in the body. The direction of somersault relative to the fixed axis does not change during a twisting somersault and neither does the direction of twist (left or right) relative to the longitudinal body axis. Tilt is the angle between the twist axis of the body and the vertical somersault plane.

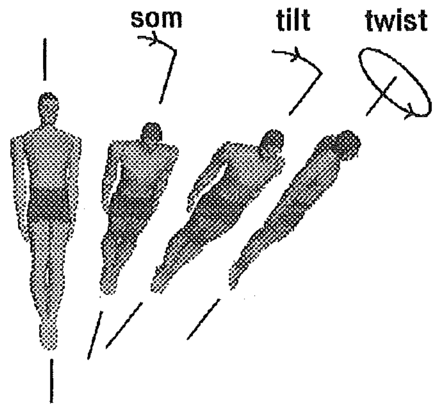

Figure 1 - Angles of somersault, tilt and twist

ANGULAR MOMENTUM:

During the flight phase the total angular momentum about the mass centre will remain constant. Suppose for simplicity that no twist is taken from the gymnastics apparatus so that at takeoff the only rotation is the somersault about a horizontal axis through the mass centre. The angular momentum may be represented by the horizontal vector **h** in Figure 2. At takeoff the twist axis is perpendicular to **h** and there is no twist. If the twist axis becomes tilted out of the vertical somersault plane later in the somersault there will be a component of angular momentum in the direction of the twist axis and the gymnast will twist. If the tilt angle is greater, the twist component of angular momentum will be greater and the twist will be faster.

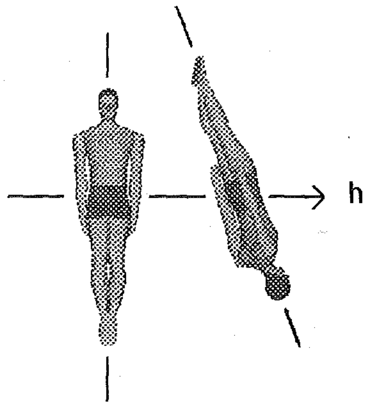

Figure 2 - There is a component of the angular momentum h along the twist axis when the body is tilted out of the vertical somersault plane.

RIGID BODY MOTIONS:

To understand the mechanics of a multi-link system performing somersaults with twist, it is helpful to look at the rotational motion of a rigid body. There are only two general types of motion that a rigid body can exhibit (Yeadon, 1993a). The first of these is the ***wobbling somersault*** in which the body somersaults about a horizontal axis but also has an oscillating motion in which it twists one way and then the other (Figure 3). During this motion the body also tilts first one way and then the other so that the head is to one side of the feet and then later to the other (see the first and last images in Figure 3). Thus adopting a piked position may not only slow the twist in a movement, it may also effectively stop the twist.

Figure 3 - During a wobbling somersault the twist oscillates left then right.

The second type of motion is the ***twisting somersault*** in which the twist is always in the same direction (Figure 4). During this motion the body is always tilted in the same direction away from the somersault plane. This tilt varies with the twist and is smallest for an even number of quarter twists (images 1, 6, 11 of Figure 4) and greatest for an odd number of quarter twists (images 3 and 9 of Figure 4). This variation in the tilt angle is known as *nutation* from the theory of spinning tops (Synge and Griffith, 1959) and is important for the understanding of how aerial twist is produced (Yeadon, 1993c). In the twisting somersault shown in Figure 4 the variation in the tilt angle is quite large since the arms held wide.

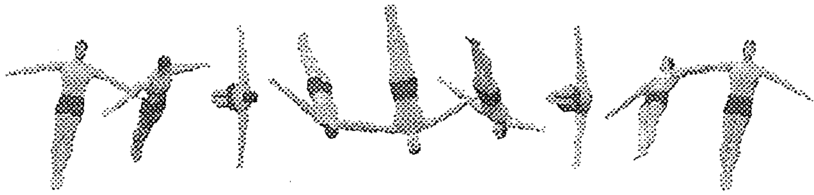

Figure 4 - During a twisting somersault the twist continues in one direction.

CONTACT TWIST:
Angular momentum is built up while the body is in contact with the gymnastics apparatus so that it is somersaulting at takeoff. Twist may be initiated in a similar way by turning the arms and trunk in the direction of the twist while the feet are in contact with the takeoff surface. During the aerial phase of a contact twist the body becomes tilted away from the vertical after half a somersault and then automatically becomes untilted as the somersault is completed (Yeadon, 1993b). The disadvantage of contact twist is that the gymnast will be twisting when landing and this could lead to a greater risk of ankle injuries. In high bar dismounts there is even more of a potential problem since only ¾ or 1¾ somersaults are completed and the body is likely to still be tilted on landing.

AERIAL TWIST:
The way in which a cat rights itself by producing a half twist in mid-air after being dropped in an inverted position has been studied for more than a century (Marey, 1894; McDonald, 1960). Some coaches have thought that this is a major mechanism that gymnasts use to produce twist (Biesterfeldt, 1974). The twist is produced by using a hula-hoop circling movement of the hips during the aerial phase. If the initial angular momentum is zero it must remain so during flight and so the angular momentum associated with the hip circling produces a twisting of the whole body in the opposite direction (Kane and Scher, 1969). A simulation of this movement is shown in Figure 5 in which the hips circle to the right producing a twist to the left. The body moves from a forward flexed position through a side arch over the right hip, into a back arch, through a side arch over the left hip and ends in a forward flexed position again, having completed a half twist. A skilled trampolinist can produce a full twist using two cycles of such a movement while airborne.

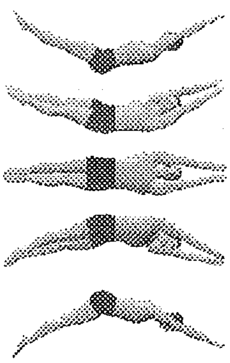

Figure 5 - Computer simulation of an aerial half twist using the "hula" or "cat" technique.

It is evident that gymnasts do not use this hula technique to produce multiple twists during the aerial phase of a somersault since the body typically remains straight during the twist. If somersault is present then any technique that tilts the body away from the somersault plane will result in twist in order to maintain constant angular momentum (Frolich, 1980). If one arm is raised laterally in a plain jump while lowering the other, the whole body will tilt in order to maintain zero angular momentum (upper sequence of Figure 6). If the same arm movements are made during a somersault, a similar amount of tilt results and the body automatically twists in order to maintain constant angular momentum (Yeadon, 1993a).

CREATING TILT:

Tilt can be produced after takeoff using asymmetrical movements of the arms. The upper sequence of Figure 6 shows that when these lateral arm movements are made during a jump the body tilts in the opposite direction to maintain zero angular momentum. That is, the rotation of the arms in the anti-clockwise direction must be counteracted by an equivalent rotation of the rest of the body in the clockwise direction. When the same arm movements are made during a somersault this tilt results in twist as shown in the lower sequence.

Lowering the right arm and raising the left arm will cause the body to tilt to the left. This tilt will cause the body to twist to the left during a forward somersault. Similarly lowering the left arm will cause the gymnast to twist to the right during a forward somersault.

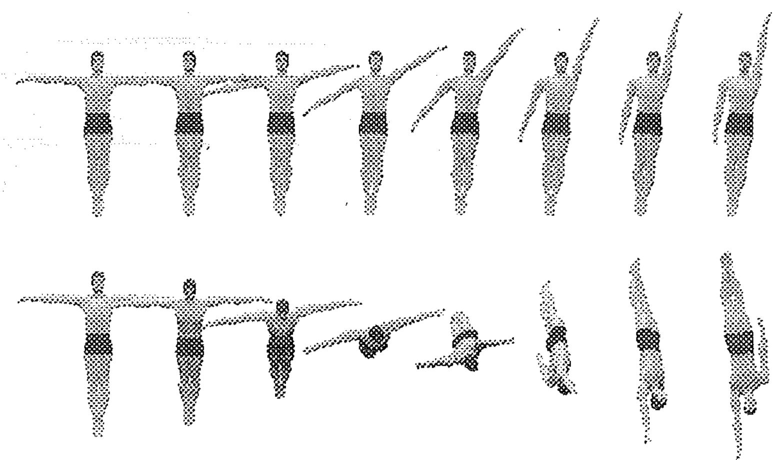

Figure 6 - Asymmetrical arm movement produces tilt (a) when there is no somersault and (b) when the body is somersaulting forwards.

Any movement in which left-right symmetry is not maintained is likely to produce some twist. In the simulation shown in Figure 7 the body makes a partial hula movement while extending from a piked to a straight position. In a plain jump this hula movement with wide arms produces tilt while the body is in a side arch configuration (Yeadon and Atha, 1985). The upper sequence shows that such movements also produce a small amount of twist when there is no somersault. When somersault is present the hip movement produces tilt which results in a rapid twist as shown in the lower sequence (Figure 7). The advantage of this technique is that the arms may be held symmetrically and this gives a cleaner look to the movement. For a twist to the left the body flexes over the right hip as the gymnast extends from the piked position. The hip action is very similar to performing a quarter of a hula-hoop movement while extending the body. This action may be rehearsed with the gymnast standing on the floor before it is attempted during a forward somersault.

It is fortuitous that the hula movement that produces a twist to the left in a jump also produces tilt which will result in a twist to the left in a forward somersault. During the takeoff for a forward somersault from the floor, the body flexes forwards at the hips so that initially it is piked which is an appropriate starting position for this twisting technique.

Figure 7 - Production of tilt using asymmetrical hip movement (a) when there is no somersault and (b) when the body is somersaulting forwards.

Aerial twist is a result of producing tilt after takeoff. The advantage of using aerial twist is that the twist stops when the tilt is removed. Therefore, unlike landing from contact twist, the gymnast is more likely to have stopped twisting and to land squarely.

LEARNING FORWARD SOMERSAULTS WITH 1½ TWISTS:

The following progression may be used to learn a forward somersault with 1½ twists and a double forward somersault with 1½ twists in the second somersault. The progression is based on using asymmetrical hip movement to produce the tilt. This technique is most appropriate for the twisting double somersault since the twist has to be initiated in the airborne phase of the skill. The progression starts with the gymnast performing a non-twisting somersault with the body initially slightly flexed at the hips (Figure 8). During the forward somersault the gymnast should concentrate on keeping the arms spread wide. The upper sequence shows the body configurations without the somersault. All sequences shown in this progression are based on computer simulations produced using the model of Yeadon, Atha and Hales (1990).

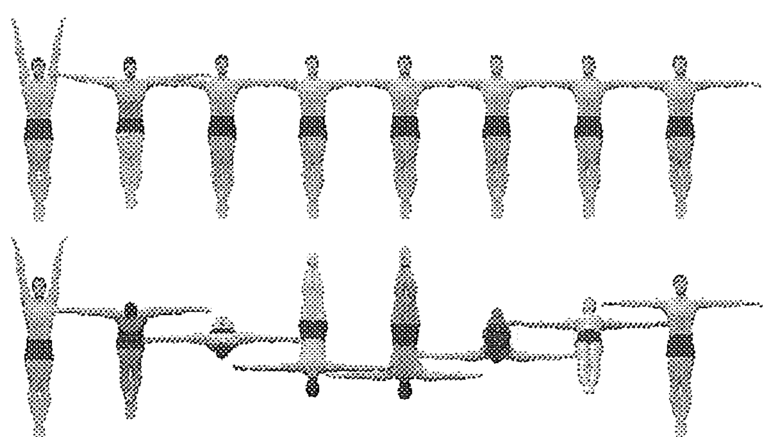

Figure 8 - A forward somersault from a shallow piked position with wide arms.

The next step is for the gymnast to perform the forward somersault with a half twist (Figure 9). The body flexes over the right hip soon after takeoff. Again the gymnast should concentrate on maintaining the arms in a wide spread position. In order for the gymnast to stop the twist the tilt created by the asymmetrical hip movement must be removed. This may be achieved by again using asymmetrical hip movement (Figure 9). This skill should be practised until a half twist can be done with arms held wide.

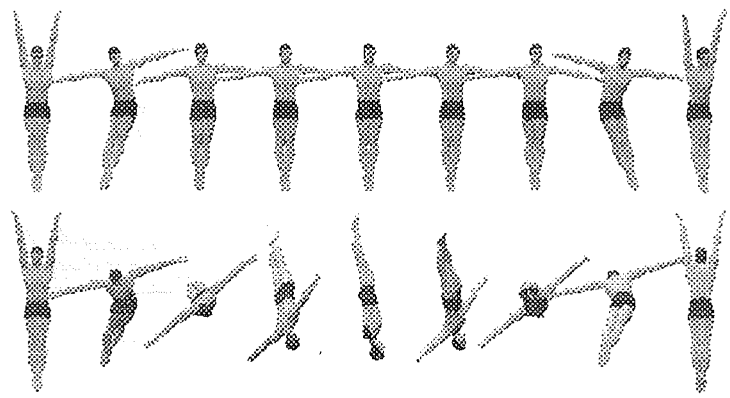

Figure 9 - Using asymmetrical hip movement to produce a wide arm half twist in a forward somersault.

Next the gymnast should progress to a forward somersault with 1½ twists. The twist should be started in exactly the same way as the half twist and then the arms should be moved to the sides so that 1½ twists are produced (Figure 10). The arms should be held wide during the hip movement in order to produce sufficient tilt. Once the twist has started, lowering the arms to the sides will reduce the moment of inertia about the twist axis. To maintain constant angular momentum there must be a corresponding increase in the gymnast's twist rate. It is therefore beneficial to return to the half twist skill to and ensure that it is performed with arms held wide. The twist is again stopped by removing the tilt using asymmetrical hip movement (Figure 10).

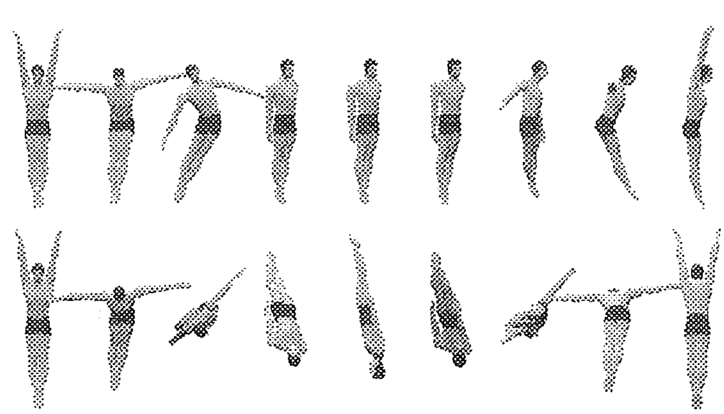

Figure 10 - Using asymmetrical hip movement to produce 1½ twists in a somersault.

The next step for producing 1½ twists in a double somersault is to perform a half twist in a double somersault. The same technique used in the half twisting single somersault may be used to produce a wide arm twist in a double somersault (Figure 11). The body is flexed over the right hip as extension is made from the piked position. With more hip flexion the tilt is greater and the arms can be held wider. The half twist in the second somersault should be performed with wide arms and a straight body (Figure 11).

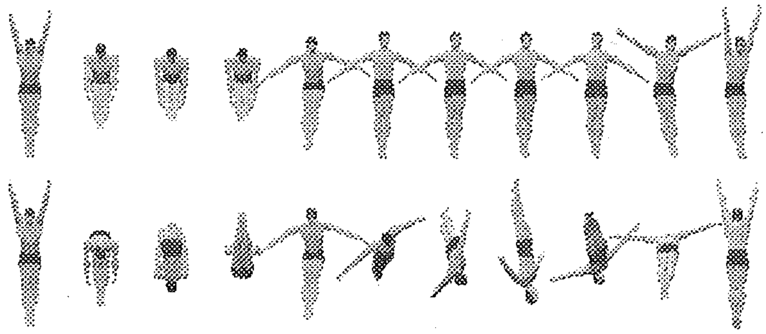

Figure 11 - A double somersault with a wide arm half twist in the second somersault.

The final stage is to perform the double somersault with 1½ twists. To do this the arms must be brought close to the body once the twist has been initiated. The arms should be wide when the twist is initiated and then brought close to the body after the twist has started (Figure 12). It is important to remember that sufficient somersault is needed at takeoff to allow the body to be fully extended during the twist. In order to remove the tilt both asymmetrical hip and arm movements are used (Figure 12). Typically the right arm is abducted away from the body after 1¼ twists and subsequently the left arm is also abducted. Common errors when first attempting this skill are to under-rotate the somersault, to start the twist too early, and to fail to use a wide arm position during the asymmetrical hip movement. In order to avoid such tendencies the wide arm double somersault with a half twist should be learned correctly and practised sufficiently before attempting the 1½ twists. Once the gymnast becomes familiar with the movement, the arms will not need to be spread so wide for the initiation of the twist.

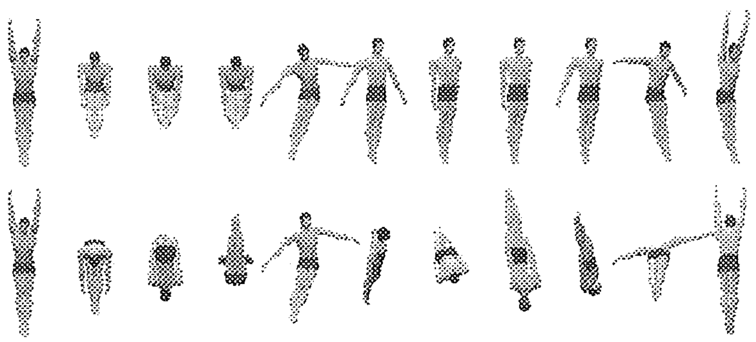

Figure 12 - A double somersault with 1½ twists in the second somersault.

LEARNING BACKWARD SOMERSAULTS WITH ONE TWIST:

This progression is based on using asymmetrical arm movements to produce the tilt which leads to aerial twist. The initial movement comprises a straight backward somersault in which the arms are lowered from an overhead position and then held wide (Figure 13). It is important that the arms move from an overhead position to the sides. Any tendency to lower the arms down the front of the body parallel to the sagittal plane should be corrected. The upper sequence of Figure 13 shows the arm movement without the somersault.

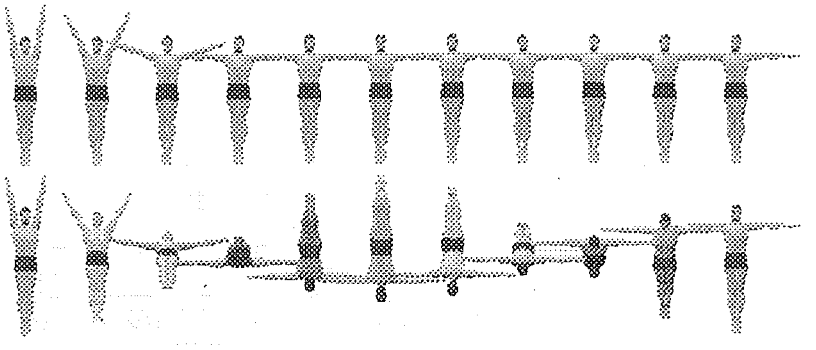

Figure 13 - A backward layout somersault with wide arms.

The next movement starts in exactly the same way but the left arm is lowered further than the right arm so as to produce the tilt required for a twist to the left. This results in a wide arm backward somersault with an aerial half twist to the left in the second half of the somersault. It is important that the wide arm position is maintained throughout the movement. This ensures that the gymnast must produce sufficient tilt in order to achieve a half twist with wide arms. Failure to maintain a wide arm configuration may lead to difficulties in producing sufficient twist in the next stage. The amount of somersault rotation completed will be similar to that of the non-twisting somersault.

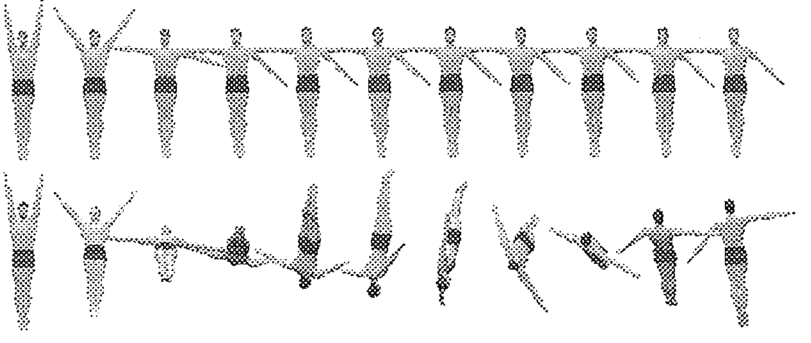

Figure 14 - A backward somersault with half twist using wide asymmetrical arms.

Once a half twist with wide arms can be performed consistently it is a relatively simple matter to produce a full twist by bringing the arms close to the body once the twist has started. There will be a tendency to over-somersault this skill since the arms are lower than in the previous two movements. This reduces the moment of inertia about a transverse axis and leads to a faster somersault. The effect of this over-rotation can be counteracted to some extent by raising the arms in front of the body on landing. Although this method does produce a backward somersault with one twist, most of the twist occurs late in the movement and the gymnast cannot see the landing area throughout the skill.

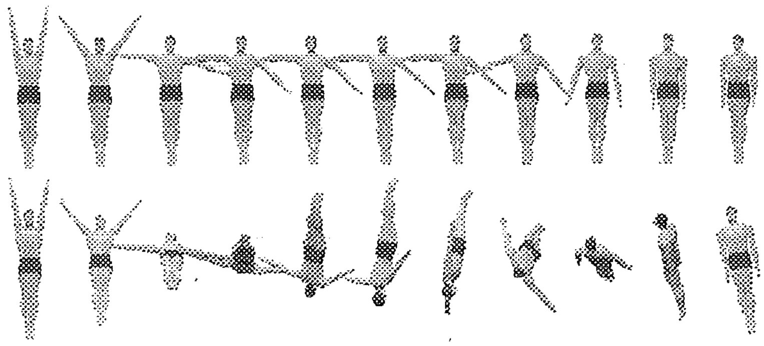

Figure 15 - A backward somersault with one twist with a wide asymmetrical arm start.

A more traditional looking full twist may be produced by first lowering the left arm and then the right (Figure 16). The tilt is removed by first raising the right arm and then the left near the end of the movement. In the upper sequence of Figure 16 it can be seen that in a plain jump the tilt disappears as soon as the arms reach a symmetrical position. In the twisting somersault shown in the lower sequence the situation is different since the right arm is lowered at around the quarter twist position and this changes the somersault angle slightly rather than the tilt angle. The phasing of the twist in this movement allows the gymnast to view the landing area throughout the somersault. Since the twist stops once the tilt has been removed, a safe and stable landing is possible. This technique is useful for learning somersault dismounts with one twist from the high bar.

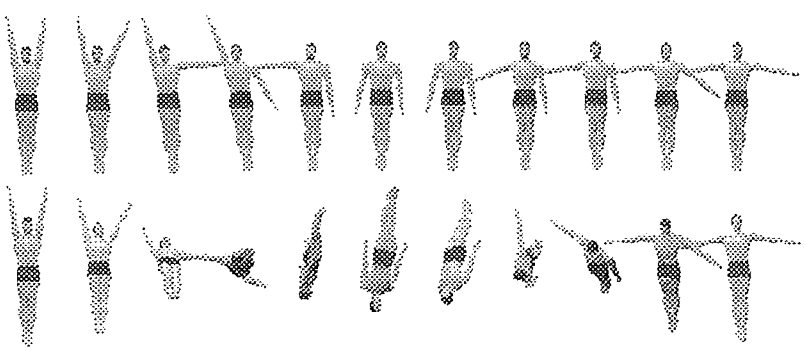

Figure 16 - A backward somersault with one twist using asymmetrical arms.

Introducing twist into a double backward somersault may be done in much the same way. Note that a straight double somersault is not as simple as it may look (Figure 17). If a rigid body is somersaulting about its intermediate principal moment of inertia the motion is unstable in the sense that twist will build up exponentially until the body completes a half twist (Hinrichs, 1978; Marion, 1965). In practice this will pose a potential problem for somersaults about a lateral axis when the body is held straight. Yeadon and Mikulcik (1996) showed that the build-up of twist may be prevented by the gymnast making in-flight corrections using small asymmetrical arm movements.

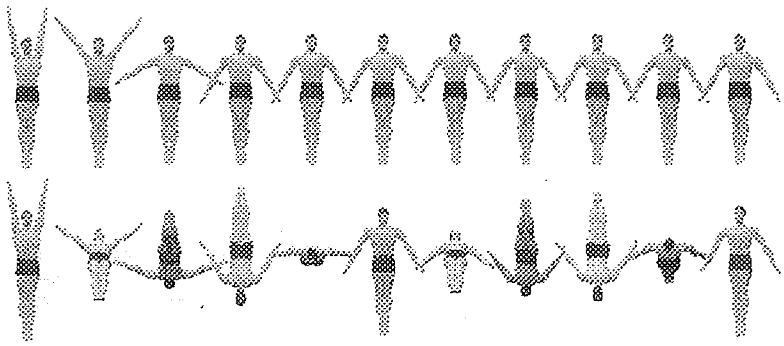

Figure 17 - A straight double backward somersault.

The build-up of twist can be used to good effect to produce an aerial twist using only a small asymmetry in the arm positions. Figure 18 depicts a theoretical simulation of a double somersault with one twist in the last 1¼ somersaults. During the first three quarters of a somersault the arms are spread wide but with a small asymmetry. This leads to a slow build-up of tilt and twist during the first somersault. The twist is accelerated by adducting both arms towards the end of the first somersault. As one revolution of twist nears completion, first the right arm is abducted and then the left arm in order to remove the tilt and stop the twist. Since this asymmetrical arm movement for stopping the twist comprises exactly the same technique as for preventing the build-up of twist in a straight somersault it is likely that learning this type of control in a twisting somersault is carried over into the control of non-twisting somersaults and vice versa.

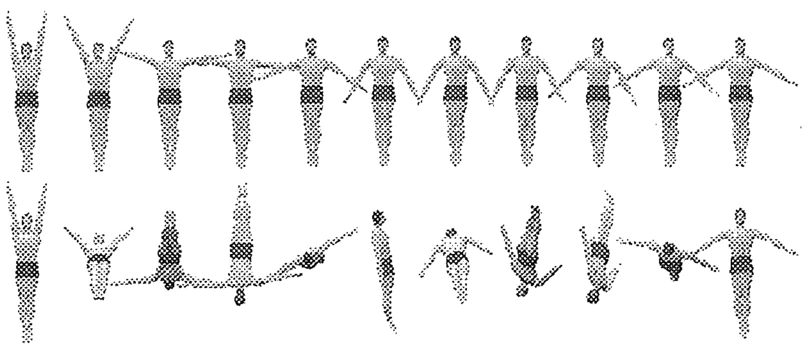

Figure 18 - A straight double backward somersault with one twist in the second somersault.

A straight double somersault with two twists may be produced in the same way by using slight more arm asymmetry in the first somersault and adducting the arms close to the body (Figure 19).

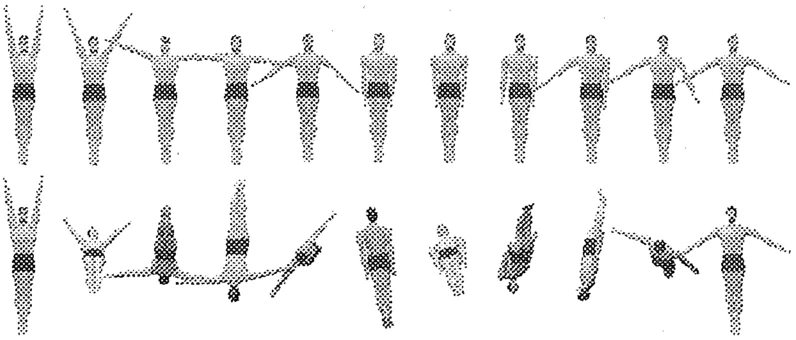

Figure 19 - A straight double backward somersault with two twists in the second somersault.

CONCLUSION:

Methods for producing aerial twist in somersaults using asymmetrical movements of the arms and hips have been described. These techniques are most easily introduced on the trampoline and should then be transferred to the floor or apparatus dismounts. The advantages of the progressions are that they allow rapid progress to be made with safety since each step in a sequence changes just one element at a time.

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SWINGING IN GYMNASTICS

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INTRODUCTION:

Swinging is a key component of all supporting and hanging gymnastics exercises. The focus of this presentation will be on vertical circling. Four exercises in competitive artistic gymnastics fall into this category; rings, parallel bars, asymmetric bars and high bar. Swinging in the vertical plane is used for example to link strength and balance positions with smooth circling movements as seen in rings and parallel bars routines. Swinging is also used by gymnasts to increase angular momentum often in preparation for release and regrasp movements or dismounts as seen in asymmetric bars and high bar routines. The first of these will be referred to as a **linking swing** and the second as an **accelerating swing**. In this presentation, a gymnast swinging on a single bar (Figure 1) will be used to outline the mechanics of swinging and then two examples of skills will be featured to highlight 'linking' and 'accelerating' swings.

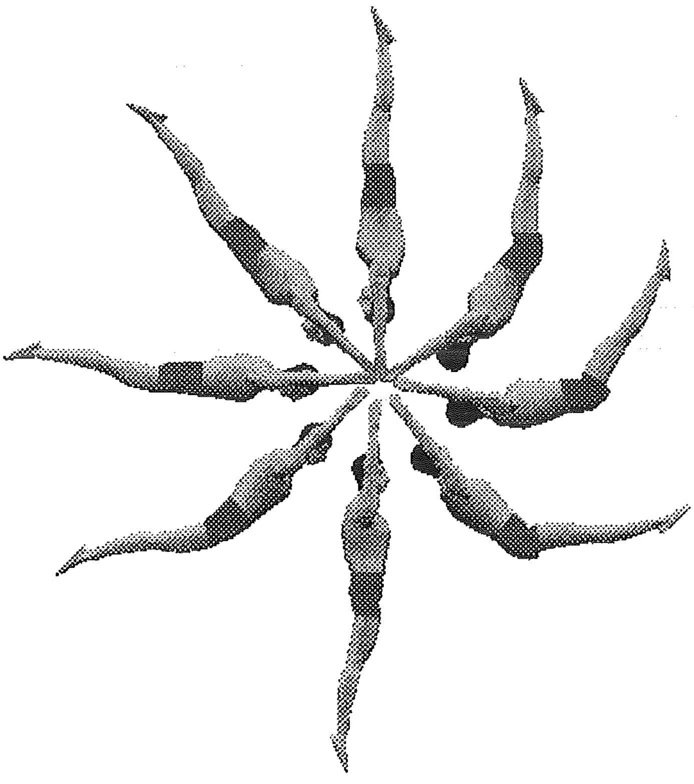
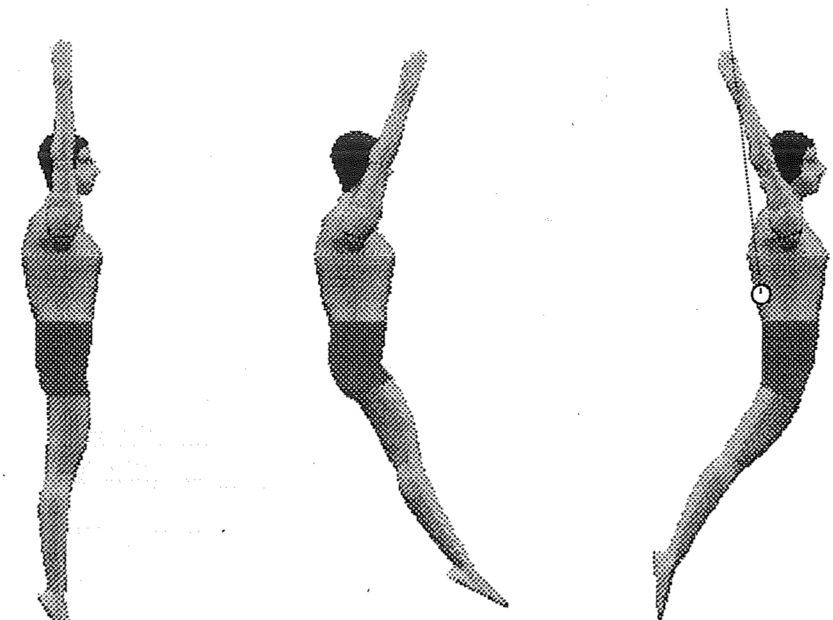


Figure 1 - Highbar long-swing.

MECHANICS OF SWINGING:

The mechanics of all swinging in gymnastics can be summarised simply - to increase rotation a turning force is needed. The larger the turning force and the longer that the turning force acts the greater the increase in the gymnast's capacity to rotate. The special term in mechanics which is used to describe this capacity to rotate is **angular momentum** and the special term for turning force is **torque** or **turning moment of force**.



(a) (b) (c)

Figure 2. Gymnast in (a) straight extended, (b) piked and (c) arched body shapes showing the location of the mass centre (CM) in relation to the gymnast's body.

To aid in explaining the mechanics of swinging three basic terms from mechanics need to be established:

1. The **mass centre** (CM) is an imaginary point at which the weight of the gymnast can be considered to act. In a stretched body configuration the CM is the maximum distance from the hands (Figure 2a). If the gymnast adopts a piked body shape the CM moves beyond the body into the space between the thighs and the trunk, and closer to the hands (Figure 2b). Similarly if the gymnast arches, his CM moves behind the body and closer to the hands (Figure 2c). The CM is a particularly useful concept in gymnastics because it enables the whole body of the gymnast, irrespective of the body configuration, to be represented by a single point and in so doing simplifies the mechanics.

2. The **weight** of the gymnast is a force acting downwards which is equal to the mass (m) of the gymnast multiplied by gravitational acceleration (g). Gravity always acts downwards. The weight (mg) of the gymnast is shown as a downward force at the CM, (Figure 3).

3. The **moment arm** is the perpendicular distance between the axis at the bar and the weight force. The moment arm for the weight force will always be horizontal since the weight always acts vertically downwards. In Figure 3 the moment arm is shown as a dashed horizontal line.

THE BACKWARD GIANT CIRCLE: The torque acting on a gymnast is shown at a single instant during the downswing in a backward giant circle (Figure 3). Strictly speaking there are other forces acting, including the frictional forces at the hands and air resistance, both of which are opposing the motion of the gymnast. However, in relation to the weight force, these forces are small and can be regarded as negligible at present. The bar also bends and applies forces which will be considered in more detail later.

The torque or turning moment of force in Figure 3 is equal to the weight force (mg) multiplied by the moment arm length (d). This torque is acting to turn the gymnast in an anti-clockwise direction and so is tending to increase the backward rotation of the gymnast.

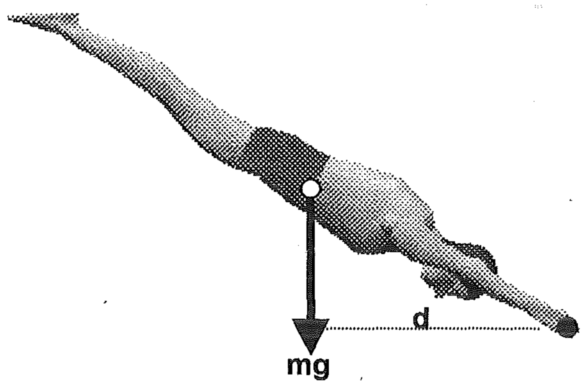


Figure 3 - A gymnast in a straight body position on the downswing. The small white circle is located at the gymnast's mass centre (CM), the weight (mg) of the gymnast is the only force acting downwards at a distance (d) from the axis at the bar.

If the gymnast's body position in the giant circle is considered to be viewed on a clockface, at 12 o'clock he would be in a handstand position (Figure 4a) with a moment arm length of zero. There would therefore be no torque acting on the gymnast. At 9 o'clock (Figure 4b) the moment arm would be at its maximum length and hence the torque acting on the gymnast would also be at a maximum. By 6 o'clock (Figure 4c) the torque would again have returned to zero.

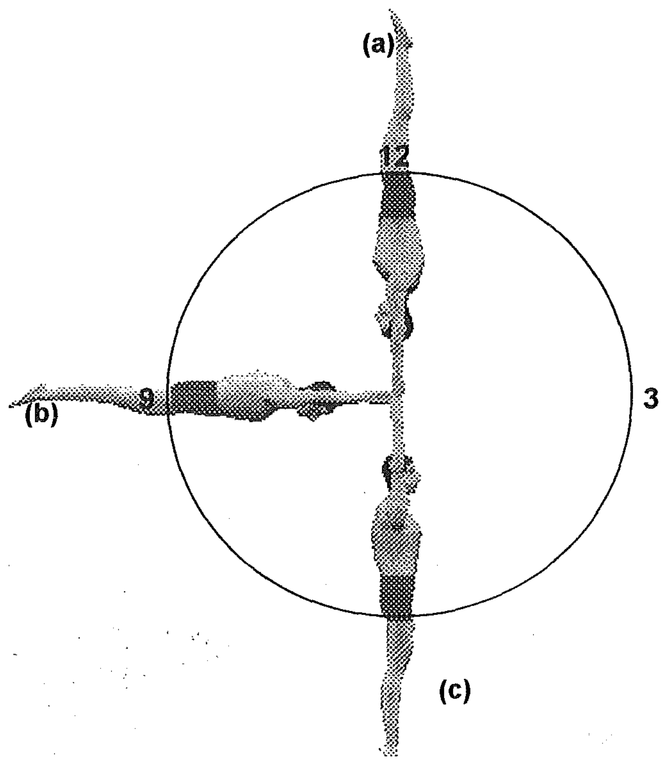


Figure 4 - Gymnast in a straight body position at three locations during the downswing around the high bar. (a) at 12 o'clock with zero torque, (b) at 9 o'clock with maximum torque and (c) at 6 o'clock with zero torque.

Between positions a and b in Figure 4 the gymnast's torque would increase and then between b and c it would decrease. The gymnast's weight is a fixed value since his mass and gravitational acceleration ($g = 9.81\ m.s^{-2}$) are both constant. Therefore the only factor influencing torque is the length of the moment arm. By remaining straight throughout the downswing, the moment arm length is controlled by the angle that the gymnast's CM makes as it circles around the bar. Similarly, once the gymnast passes under the bar, if he remained straight, the moment arm would again be controlled only by the angle that the gymnast's CM made with respect to the bar. If the gymnast did nothing else he would circle back to the handstand position on top of the bar. However, this would only be true whilst there were no frictional forces at the hands or air resistance opposing the motion. In the gymnasium both these resistances are present and so the gymnast would not complete the circle but would 'stall' somewhere around 2 o'clock in Figure 4. In the overgrasp grip as shown in Figure 5, the gymnast is performing the backward giant circle and the frictional forces between his hands and the bar act at a tangent to the bar in the opposite direction to his motion. The frictional forces are therefore producing a torque throughout the giant circle which is slowing him down. Air resistance against his body will also be slowing him down throughout the movement.

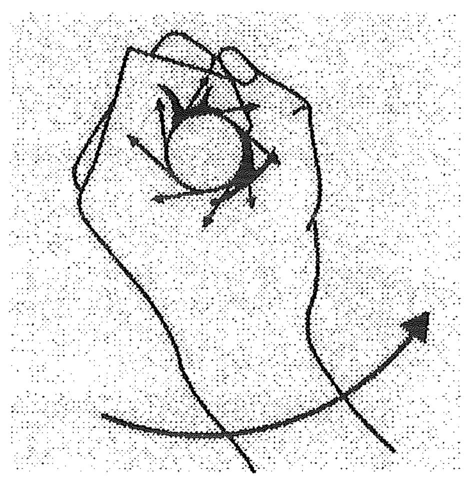


Figure 5 - Frictional forces opposing the direction of motion in the giant circle. Ref: Hiley (1998a) adapted from Hay (1994).

Fortunately for the sport, gymnasts are not inanimate and can vary the configuration of body segments to alter motion. As shown in Figure 2b, when the gymnast altered his body configuration from extended to piked, the CM moved slightly closer to his hands. That is the radial distance between the CM and the bar decreased slightly and hence with it the moment arm was also reduced. It is the latter distance that determines the torque and so piking would reduce torque. If a gymnast wishes to maximise the torque, he needs to maximise the moment arm length. This means keeping the mass centre as far away from the bar as possible. The straight body shape is the best configuration to achieve this objective.

In summary, on the downswing, keeping the body straight increases the moment arm length and therefore increases the torque.

Once the gymnast passes under the bar, the body weight force will act to oppose the gymnast's motion. In other words, the weight force, which always acts downwards, is now producing a torque in a clockwise direction whilst the gymnast wishes to continue circling in the anti-clockwise direction. If the gymnast were to remain perfectly straight the circle could not be completed. All that is needed is for the gymnast to reduce the torque slightly by shortening the moment arm between the weight force and the bar to achieve the desired effect.

Keeping the body straight also increases a gymnast's resistance to rotate. **Moment of inertia** is the special term in mechanics used to describe a body's resistance to change its angular motion. The higher the moment of inertia the greater the resistance and so the longer it would take for a gymnast to fall from a handstand position above the bar to a hanging position below the bar. By remaining extended on the downswing a gymnast therefore takes advantage of two factors: the moment arm and the swing-down time are maximised.

To maximise his rotation a gymnast should stay 'as long for as long as possible'.

When a torque acts over a time period, **angular impulse** is created. Angular impulse quantifies the gymnast's change in **angular momentum**, or his capacity to rotate. The greater the angular impulse the greater the change in angular momentum. To gain the greatest increase in angular momentum a gymnast should aim to keep both the torque and the swing-time high. Conversely when the gymnast passes under the bar, he now needs to reduce both the torque and the swing-time. By shortening his body he can achieve both since his CM moves closer to the bar reducing his moment arm and his moment of inertia. To achieve a reduction in the moment arm and the moment of inertia, the gymnast can adopt a shallow 'dished' body position by slightly altering the angles at the hips and shoulders (Figure 1). To achieve this slight change in the body's configuration the gymnast uses muscular contractions to 'close' the hip and shoulder angles. In so doing the gymnast is taking some of the energy stored in a chemical form in his muscles and converting it into mechanical energy of movement. If the amount of energy transferred from his muscles exactly balances the energy lost due to friction at the bar and from the air, the gymnast would return to a stationary handstand position above the bar. If the energy transferred from the gymnast's muscles is greater than that lost due to friction, the excess energy would be seen as extra rotational energy. In other words the gymnast would have increased his speed of rotation through the handstand position above with the bar.

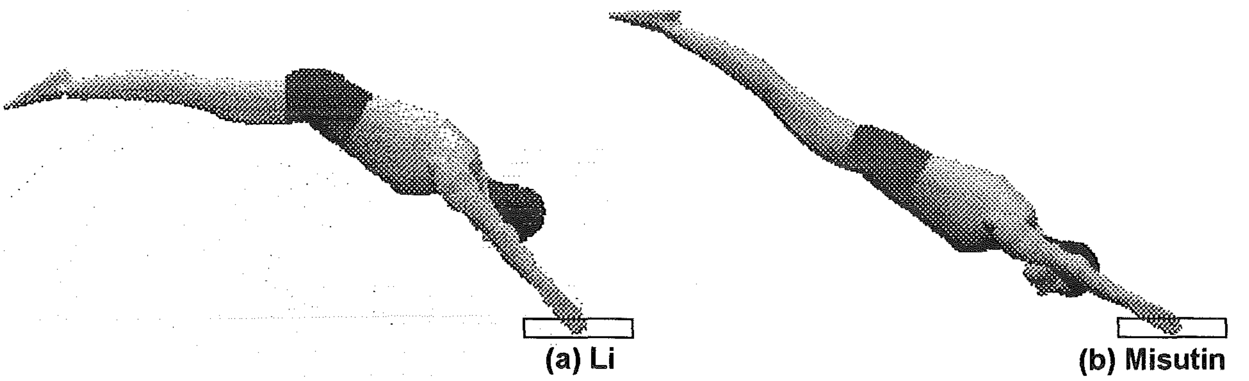
A gymnast's circling motion around a bar is controlled by the timing of small changes in the joint angles at the hips and shoulders.

ELASTIC ENERGY: There is another form of energy in bar circling and that is **elastic energy** stored in the bar. FIG 'Code of Points' states that a high bar should deflect 100 mm when loaded with a force of 2200 N (approximately equivalent to the weight of 3½ male gymnasts) and return to its original horizontal position when the load is removed. The bar is therefore a **spring**. As the gymnast swings the bar will deflect from its resting neutral position. (Look at Figure 1 to see that a gymnast's hands move around the central neutral bar position throughout the circle). The greatest force occurs when the gymnast is travelling fastest at the bottom of the circle and so the bar will be bent most at this point. The force at this time will exceed the weight of 4 gymnasts in a standard giant circle and be as much as the weight of 6 gymnasts in an accelerated giant circle. As the gymnast rises on the upswing the bar will begin to return to its original position and in so doing return some energy to the gymnast. The amount of energy stored in the bar is proportional to the deflection of the bar. Not all the energy stored in the bar will be returned and so the gymnast needs to input some extra energy from his muscles to compensate for this loss. A 'springy' bar is beneficial in a number if ways and later in the section on the accelerated giant circle the motion of the bar will be considered in more detail.

Two examples of circling in gymnastics will be used to illustrate these mechanical relationships in action. First a long-swing with full pirouette on parallel bars or **Long-swing Diamidov** will be used to examine a linking swing and secondly an **accelerated giant circle** will be used to examine ways of increasing angular momentum in preparation for a dismount.

Long-swing Diamidov:

The longswing Diamidov was first seen in competition during the Friendship Games in 1984. Two techniques have been regularly used to execute this skill on parallel bars. One method demonstrated by Li Jing of China, and the second, based on the technique introduced by Yuri Balabanov (formerly of the USSR), and more recently developed by Misutin of the Ukraine. Both gymnasts have enjoyed World and Olympic success using different techniques, but which is the preferred method and why? There are two parts to the action of interest, the swing and the pirouette. The pirouette is partially determined by the angular momentum developed during the swing. Observation of the two performers shows Misutin raising his free arm to the side of his body during the pirouette. Li adopts a very narrow body shape during the pirouette. Earlier information on moment of inertia clearly showed that reducing moment of inertia reduces a body's resistance to rotate and so in the pirouette a narrow shape should enable the twist to be performed more readily. An earlier study of Li's technique (Liu and Liu, 1989) reported that Li experienced some difficulty in regrasping the second bar as he ended his pirouette and that his CM was slightly off centre. Conversely, observation of Misutin in action suggests that he has ample time to pirouette and regrasp the bar. However, Misutin appears to contravene the idea that a narrow shape is preferable when twisting. It is well documented that tilting the body during a somersault produces twist (Yeadon et al., 1990) and so perhaps the arm raising action by Misutin towards the end of the 'somersault' rotation aided the twist as a result of tilting the body. Video analysis (Kerwin et al., 1993) however, showed that the somersault angular momentum was insufficient to generate enough twist to be of any value. The answer lies in the alternative explanation that the arm raising tilted the body and shifted the CM towards the supporting bar and aided the balance of the gymnast giving him time to spot and place the second hand on the bar at his 'leisure'. Both techniques require sufficient angular momentum about the somersault axis to complete the rotation and since the gymnast begins in a stationary handstand position, this angular momentum can only be created during the downswing phase of the skill. By placing digitised images of the two gymnasts body configurations next to each other it is possible to highlight small but important differences between the two techniques.

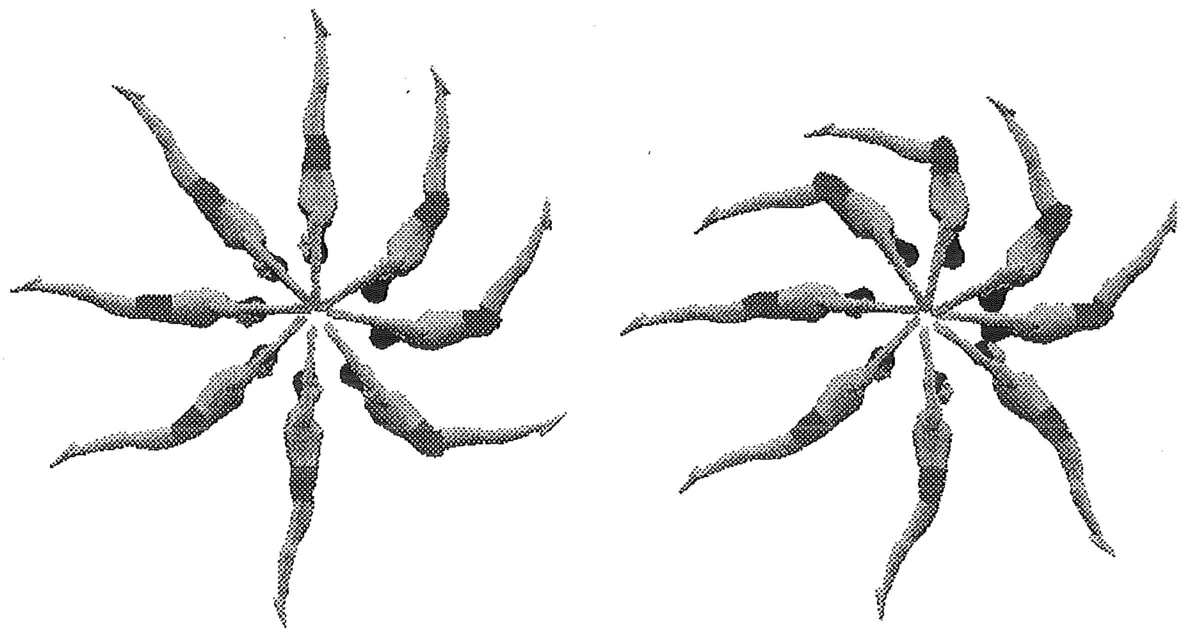


(a) Li **(b) Misutin**

Figure 6 - Li and Misutin during the downswing phase of the Diamidov on parallel bars.

Li is slightly dished on the downswing whilst Misutin is completely extended. Misutin's technique is therefore more effective in producing angular momentum since his moment arm is greater and his total downswing time is slightly longer. Under the bar, both gymnasts adopt a slightly hocked shape to clear the floor before extending on the upswing into the pirouette position. Misutin however, has more angular momentum to 'play with' and so can afford to be more leisurely in his execution. He can remain fully extended and although his arm is raised sideways and his actions appear slower, he has more time and hence more control of the fine adjustments in the pirouette. Li on the other hand is slightly short of angular momentum and has to adopt a more flexed body shape to complete the somersault rotation and at the same time fit in the pirouette. Thus although the side arm action is clearly beneficial for control it is only possible as a result of the very effective downswing technique creating the required angular momentum.

THE GIANT CIRCLE: The giant circle on high bar and asymmetric bars is the most important element in swinging gymnastics routines. This skill forms the basis of the whole exercise and with slight variations becomes a range of skills. The **accelerated giant circle** will be used to illustrate the accelerating swing and will highlight the subtlety of timing in the angle changes at the hips and shoulders which elite gymnasts have mastered. The aim of accelerating a giant circle is to increase angular momentum in preparation for either a release and regrasp movement or for a dismount. To perform a double straight backward somersault dismount for example, the angular momentum needed is substantial (Kerwin et al., 1990).



(a) Traditional **(b) Scooped**

Figure 7 - Two types of accelerated giant circle (a) traditional, and (b) scooped.

Two distinct techniques have evolved in gymnastics to accelerate the giant circle. A **'traditional'** technique (Figure 7a) in which the giant circle is performed in a manner similar to the basic swing described earlier, but with the emphasis being placed on increasing the gymnast's rotation on every circle. In addition a second **'scooped'** technique has been developed in which a gymnast remains piked whilst passing over the bar (Figure 7b). In the traditional technique the gymnast maintains an extended body configuration from the handstand position. There is then a slight 'arching' of the body prior to the bottom of the circle followed by a 'dishing' as the gymnast passes under the bar. This hip hyper-extension and flexion adds energy into the system and increases the rotation. On the upswing phase the characteristic shallow pike is seen with the gymnast extending into the handstand configuration close to the top of the circle. In contrast the scooped technique is characterised by an extended body position as the gymnast passes through the horizontal on the downswing followed by hyper-extension. The kick through to the dished shape is delayed and appears as a more distinctive piking action late in the upswing which continues over the top of the bar. The gymnast does not extend completely until he is at about 9 o'clock on the downswing. In both these versions of the skill the aim is to increase angular momentum in preparation for bar release. Three questions come to mind:

1. Why have two techniques developed ?
2. Which is the better technique?
3. Is there another technique that would be better than either of these?

Answering these questions is not straightforward. The simple mechanical analysis of the swing described earlier, although acknowledging the importance of the subtle timing of hip and shoulder angle changes, does not enable an ideal sequence and timing of changes to be determined. Also the fact that the bar bends horizontally as well as vertically means that the length from the gymnast's CM to the bar is not defined as simply as appeared earlier. What would be needed to answer these questions experimentally is a gymnast who could perform all the possible variations in hip and shoulder angle changes, at precise times and at prescribed speeds. The gymnast could then be set the task of performing the many thousands of possible combinations of movements whilst being recorded on video tape so that his angular momentum could be calculated. No gymnast could achieve this. A 'model gymnast' who would never get tired, who could do exactly what has been prescribed and who would not introduce any personal variations into the skill would be ideal. What is being described is a 'robot gymnast'. A robot is a physical model but a computer simulation model could be produced to carry out all of these tasks and answer these questions providing that one could be designed and programmed to behave like a real gymnast swinging on a real highbar. This task has been completed by Dr Michael Hiley as part of his PhD research studies (Hiley, 1998a) at Loughborough University. The human body is an extremely complex biomechanical system and to replicate all its features in a computer model is currently impossible. However, a simplified version of the biological and mechanical features of the gymnast and bar which represent the behaviour of a real performance can be produced. The computer model comprises a gymnast and bar, both of which are governed by the laws of mechanics. To construct the model, a gymnast's physical size and strength had to be measured. A member of the Great Britain senior men's national squad acted as the subject. Video recordings of him performing a series of long-swings on an instrumented highbar were recorded so that any predictions from the model gymnast could be compared with reality to ensure that the model was accurate. The physical size of the gymnast was determined using an inertia model (Yeadon, 1990). The output was mass, CM and moment of inertia data for the individual gymnast. The strengths of the muscles around the hips and shoulders were determined using a dynamometer and the deflection of the high bar under a range of loads was determined to establish the 'spring' like characteristics of the apparatus. The computer model produced is represented in Figure 8.

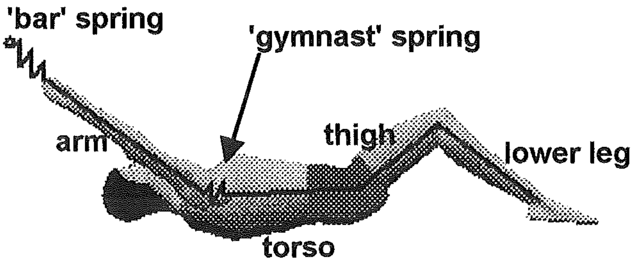


Figure 8 - The computer simulation model, (Hiley, 1998a).

The model comprises four body segments; arm, torso, thigh and lower leg and has springs at the end of the arm to represent the bar and at the shoulders to represent the 'stretching' characteristics of the gymnast. The 'gymnast' spring located at the shoulder in the model represents the elastic stretching and recovery of the gymnast and includes shoulder, spine and wrist extensions, which occur under the large loads experienced during the giant circle.
To address the three questions a series of 'experiments' were conducted. The model gymnast was instructed to make selected movements by specifying the exact times and

speeds at which hip and shoulder angle changes should be made. Checks were made to ensure that the muscle strength required to complete the movements was within the previously determined limits. All the movements were therefore biologically possible and in many ways similar to the sorts of instructions that a coach would give to a gymnast, albeit in a more precise manner than is typical in the gymnasium. To address the three questions raised earlier, a scoring system was needed so that each performance could be rated and a particular trial identified as being better or worse than previous attempts. The objective in the accelerated giant circle is to increase rotation and so the amount of angular momentum generated would be an ideal score to use. The last 1¾ rotations of the bar prior to release were studied. The model gymnast was given a speed of rotation over the bar at the start of the accelerated giant circle, based on previous video analyses, of just under 130°/second (~1/3 rev/sec). The point of 'release' was set for a theoretical double layout somersault dismount at 8° below the horizontal as reported previously (Brüggemann et al., 1994). It takes thousands of trials to investigate all possible combinations of joint angle changes within a giant circle. After many days of computing a solution was reached which maximised the model gymnast's angular momentum without exceeding his strength limits. Two solutions were arrived at, one with marginally more angular momentum than the other. The graphics sequences representing these solutions are shown in Figures 9 and 10.

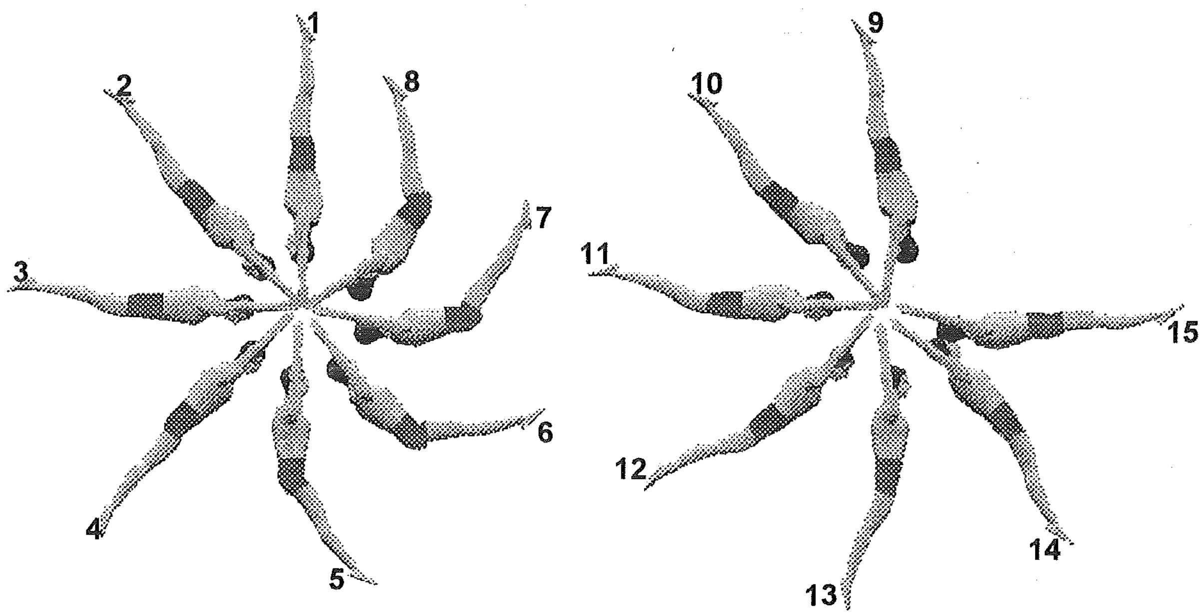


Figure 9 - The 'Global' optimum giant circle technique.

The global optimum technique is the result of the best of all possible permutations of joint angle changes and depicts a sequence very similar to the 'traditional' circling technique shown in Figure 7a. The graphics sequence begins at position 1 in the left hand figures and shows the first complete circle. The right hand figures show the final ¾ of the circle leading up to release. Notice the gymnast 'dishing' through the bottom of the circle (4 - 6) and extending through the handstand over the top of the bar (8 - 9). The amount of angular momentum generated for this modelled gymnast was 125 units and represents enough to complete 2½ layout backward somersaults in the dismount. This optimum technique therefore produced more angular momentum than would be required for a standard double layout backward somersault dismount. During the computing process, a second optimum solution was found which produced 3% less angular momentum than the technique shown in Figure 9. The graphics sequence for this second technique is shown in Figure 10. The starting position and speed of rotation over the bar are the same as for Figure 9 and the first part of the downswing looks very similar to the global optimum. The dishing under the bar at point 5 is less pronounced although by position 6 the body configurations are very similar in the two techniques. From points 7 to 11 however this second 'local' optimum technique is quite different to the former 'global' optimum technique. The gymnast maintains a piked shape through the top of the circle and does not completely extend until he is approaching the horizontal on the final downswing. This local optimum solution is much closer in appearance to the 'scooped' technique shown in Figure 7b.

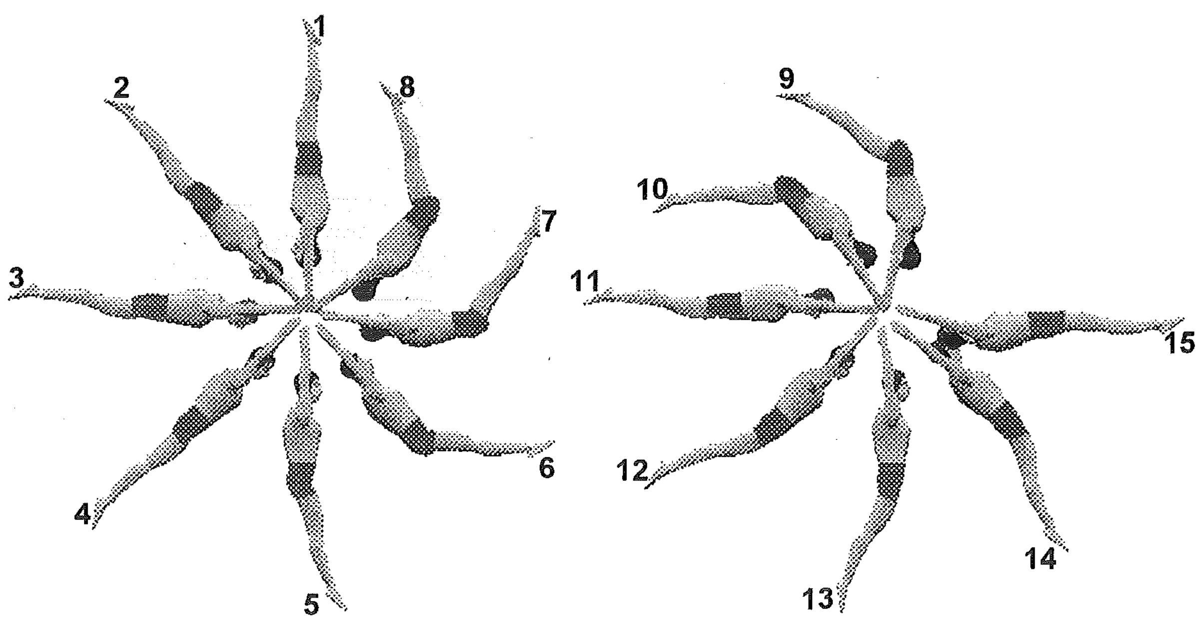


Figure 10 - The 'local'optimum giant circle technique.

Returning to the three questions presented earlier:

1. Why have two techniques developed ?
2. Which is the better technique?
3. Is there another technique that would be better than either of these?

Question 1. It would appear that two techniques have developed since both are good techniques for producing large amounts of angular momentum and so both serve the desired purpose of accelerating the giant circle. The two techniques arrived at by gymnasts and coaches are remarkably similar to the theoretical optimum solutions arrived at by the modelling process.

Question 2. If only the maximum amount of angular momentum is the criterion, then the global optimum solution is better than the local optimum solution. The global solution is closest to the traditional circling technique. Why then might gymnasts favour the 'scooped' technique? Perhaps more strength was needed, or perhaps the total energy cost for the gymnast was higher for the global technique. Interestingly the gymnast was found always to be working well within his strength limits in the previous calculations and only on the final action leading up to release did the joint torques approach values close to the gymnast's maxima. The simulations were run again with the gymnast's strength reduced by 25%. This time the global optimum solution was found to be the scooped technique rather than the traditional technique. It would therefore appear that both techniques are good and perhaps when a gymnast is tired towards the end of the routine there is a case for using the scooped rather than the traditional technique. It is not obvious from the images why the scooped technique should be as effective at generating angular momentum. For example, the principle of 'staying as long for as long as possible' on the downswing does not appear to have been adhered to. Closer examination of the scooped technique however shows that extra horizontal acceleration by the gymnast as he passes over the bar, bends the bar more in the backwards direction and moves his mass centre further from the neutral bar position than the body shape alone would indicate. Simple mechanics can therefore sometimes be deceptive and highlights the need for more powerful simulation modelling techniques.

Question 3. Is there another technique which is better than either of the two presently in use? The optimum solution for the gymnast in this study was shown in Figure 9. If the real gymnast could mimic these joint angle changes exactly as prescribed by the model this would be the best of all possible techniques for him. However, as shown, changing the gymnast's strength changed the optimum solution. Similarly a precise optimum for any gymnast would depend on his physical size and condition at the time. So whilst it would be possible to determine the best possible technique for an individual gymnast, it is likely that the two techniques already in use are individual interpretations of optimum solutions and the absolute best solution is probably going to remain a theoretical one.

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TALENT IDENTIFICATION IN ELITE GYMNASTS: WHY BODY SIZE IS SO IMPORTANT.

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INTRODUCTION:

Gymnastics has moved over the last 25 years into an era characterised by ahtleticism, agility and small body size. Through the 1970's with Olga Korbet and Nadia Comanichi and into the 80's with Oksana Omilianchik and Mary-Lou Retton, contemporary gymnastics certainly witnessed the 'child champion'. Small and strong; the body shape these athletes had led them to bring the complexity of women's gymnastics to a level never witnessed before.

Recently, for application in the current Olympic Cycle, the Federation of International Gymnastics raised the minimum age of senior women gymnasts from 15 to 16 years. This change acknowledged that young girls with small bodies often achieved higher levels of performance early in their careers and was an attempt to reward girls who stay in the sport to physical maturity.

Contrary to this, during the last decade we have witnessed some taller, more linear, gymnasts such as Svetlana Boginskia and current World Champion Svetlana Chorkina; both substantially taller women have been able to work the Code of Points to their advantage. But now moving into the new millennium, all available information indicates that the next 'Code of Points' will possess an *acrobatic* bias. This bias will encourage those athletes with the acrobatic athletic structure currently being characterised by American - Vanessa Atler; an athlete who is compact in body size, explosive and dynamic in performance and displays complex acrobatics. A new open ended judging criteria, similar to that used in diving, will be implemented and more difficult and complex routines will be rewarded with higher scores.

Taking this into consideration, smaller gymnasts with a high strength to weight ratio are better able to handle their own weight during complex skills, particularly those involving rotation around one or more axis of the body. Biomechanical principles underlie this trend in both physique and style. Selection of the appropriate body type prior to training is critical to be successful in elite gymnastics in this day and age.

SELECTION OF ATHLETES:

Of all female sports, gymnastics has one of the most obvious trade-mark body images. Research suggests that female gymnastics is more dependent on genotype, with participants already possessing the basic physique of small stature, short limbs, broad shoulders, and narrow hips. If body type is so critical to successful performance in gymnastics, it seems logical to encourage girls with inappropriate morphology into alternative sports in which they can have success. Lack of success and lack of skill improvement can be factors leading to attrition of children from sport. This will limit attrition by female participants from sport as they experience enjoyment from and commitment to a suitable activity.

Successful performance depends upon the delicate interplay between the inertial properties of the body segments and the external and internal forces which act on those body segments (Jensen, 1978). Segmental inertias represent direct constraints on the efforts of the sportsperson to develop linear and angular momentum. Consequently, those with large segmental inertias require large forces in order to maintain movement patterns similar to a sportsperson with smaller segmental inertias. Hence the tendency is for people with low segmental inertias to be successful in sports requiring rapid rotational sequences, such as gymnastics.

BODY GROWTH:
When the overall body size of an individual changes due to growth, it is the interplay between the changes in each individual body segment which affects the ability of the athlete to perform. Jensen (1981) reported that as the moments of inertia of the individual segments of the human body increased due to growth, there was an increased compensation in the force patterns in order to maintain or improve the performance of rotational movements. There is also evidence to suggest that, as a girl passes through puberty, there is a substantial decrease in performance of rotational movements due to large increases in the body segment moments of inertia (Jensen, 1981). These changes in inertia represent constraints to which the body must adapt if the level of motor performance is to be maintained or improved.

TRAINING:
In order to achieve an internationally competitive level of gymnastics performance an extraordinary amount of training is required. The effect that this training has on the delicate balance of the developing body is difficult to measure. Girls who are initially identified as having the necessary potential to be included in a intensive gymnastic training centre often already possess a smaller, stronger and leaner morphology than the average. It appears that body lengths are strongly influenced by heredity, while body widths and girths can be more influenced by training (Malina, 1978; Salmela, 1979).

Self selection for gymnastics and training may result in a decreased intensity of growth, delayed onset of the symptoms of sexual maturation and altered rhythm of the consecutive stages of development (Ziemilska, 1985). The often found delay in menarche has been attributed to: net caloric deficit with exercise over time, low weight to height ratio, critical body weight, and the composition and altered hormonal levels.

The inverse relationships between skill level and physical characteristics such as adipose tissue, weight and body size, along with the direct relationship between high power to weight ratios and extremely high skill levels, indicate the need for regular intensive training. In general, the body responds in a normal manner when the level of training is reduced. Hence it appears important that girls need to possess the small body prior to beginning training and grow slowly.

An (unpublished) study recently completed by Richards, Elliott, and Ackland, assists in the understanding of the relationship between morphology and intensity of growth experienced by subjects who participated in training for gymnastics. Thirty seven females, aged initially between 10 and 12 years of age, completed a mixed longitudinal study conducted over 3.3 years. Testing sessions at four-monthly intervals comprised measures of structural growth including height, mass, skinfolds and segment lengths and determination of the inertial parameters of the leg, thigh and trunk segments using the elliptical zone modelling technique. Tests of functional development comprised the assessment of gymnastics performance (front and back saltos, a twisting vertical jump and a v-sit action), a vertical jump, as well as lower limb, upper limb and trunk strength assessments. The sample was divided into two training groups to distinguish between elite and moderately trained gymnasts.

The results indicated that the sample was smaller in body size than the general population. Furthermore, the elite gymnasts were smaller than the moderately trained gymnasts and other results were similarly consistent across the gymnastics performance tests. High levels of angular momentum did not enhance the resultant performance. Performance of the back salto was not so dependent upon leg strength as were the front salto and the twisting jump; the former relying more on technique than strength for a good performance. The power to mass ratio was a very strong predictor of jump height on the vertical jump test, though this test related little to gymnastics performance. Vertical jump height was shown to be a poor predictor for successful gymnastics performance.

Subjects of smaller height and slimmer build performed better on the gymnastics activities. Those girls who grew substantially during the course of the study were less likely to perform well on the gymnastics activities. The subjects who grew a lot during the study and had an absolute larger body size were also those who displayed high levels of leg power and strength, though this did not enhance their performance. Those athletes who had a high strength to mass ratio were better able to take-off in a closer to vertical position to perform the saltos more successfully, particularly the back salto. The trunk strength for mass ratio appeared to be the strength measure that was most affected, in a negative direction, by large changes in body size.

The level of training undertaken by the subjects during the course of the study significantly affected their ability to perform the gymnastics activities successfully. The highly trained gymnasts were able to produce higher levels of trunk velocity on both the front and back saltos, higher amounts of longitudinal rotation on the twisting jump and produce a faster v-sit action.

The performance of both training groups improved with increasing age and this improvement affected the highly trained and moderately trained gymnasts in a similar pattern. The amount of angular momentum able to be produced on take-off significantly increased with the age of the gymnast. This was caused by a parallel increase in whole body moment of inertia. High levels of angular momentum had a detrimental effect on the success of the front salto. Higher levels of leg power were produced by the moderately trained gymnasts and this variable also increased with age. This finding was contrary to the results for the trunk and upper limb strength measures as well as strength to mass ratios, which displayed increases for both training intensity and with age. The only exception was leg strength, which was found to be similar between the moderate and elite trained gymnasts.

In order to facilitate greater understanding of the relationships between structural growth and functional development, actual growth and performance histories were examined for four case histories. Case one, an elite gymnast, experienced a low level of growth thus maintaining a small body size, which, combined with her level of training, improved gymnastic performance. Although case two was particularly strong, her high level of growth, particularly in body mass and moment of inertia, did not enable her to maintain her performance. This, coupled with reducing her training during the course of the study resulted in a deterioration in performance. A low growth rate and small actual body size enabled case three to achieve a high level of skill although she only performed a moderate amount of gymnastics training. Case four had a large actual body size and grew quickly, which combined with a moderate level of training, resulted in a reduced level of gymnastics performance, although she maximised her technique and performed at a level above what would have been predicted for her morphology.

A number of conclusions and recommendations regarding talent selection and subsequent training in elite gymnastics can be drawn from this study.

- At 12.5 years of age, smaller, slimmer gymnasts performed better on the gymnastics skills. This must have ramifications to talent identification programs and selection of athletes specifically for gymnastics. Girls who are naturally small in structure and slim have a greater chance of being a good performer.

- Although bigger gymnasts also had stronger legs, this did not help them to outperform the smaller more agile gymnasts. Hence it may be that a small structure is a better predictor to good performance than being strong.

- Gymnasts who had a high strength to weight ratio also produced high levels of performance. Therefore, strength is only a relevant predictor of good performance if it is considered closely with body mass. This was particularly obvious in skills where there was less technique involved. The results indicate that as the skill became more technical (ie the back saulto) girls with good technique could outperform those with a high strength : weight ratio.

- Girls who grew significantly in height over the three years of the study had poorer performances. Hence it could be assumed if growth can be slow and steady without large accelerations, which are normal with adolescence, a young gymnast has a better chance of maintaining improvements in performance.

- Great increases in mass over the period of the study were particularly detrimental to performances involving the twisting action. When a gymnast twists she needs her body to be as narrow as possible to permit speedy rotation. Large gains in body mass hinder this action.

- Development of leg power seem to be unaffected by growth of these subjects over the course of this study. So, it may be that adolescent growth in girls may not hinder progression in other sports such as athletics, but in technical sports where rotation of the body is concerned any increase in body size may effect performance.

- Athletes who trained at a high volume (ie., over 20 hours per week) performed better in the gymnastics tests. Hence, for improvements in gymnastics, many hours of training are required.

In summary, from these results, for optimal performance in gymnastics the following factors are important:

- a small body
- small steady increases in growth
- high strength : weight ratio
- training greater than 20 hours per week.

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THE BUNGY 'MECHANIC' AS AN AID TO TRAMPOLINE COACHING

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This study describes the characteristics of an aerial 'mechanic' developed to utilise the rebound characteristics of bungy cord and used in the teaching of intermediate and advanced trampoline skills. An elite trampolinist was filmed while in the harness and take-off and landing velocities were derived at maximum tension and in free bouncing. Time in the air, and support during flight, were identified by the coach as positive characteristics of the system. Five athletes exposed to nine coaching sessions using the system commented positively.

KEYWORDS: trampoline, coaching, harness, bungy.

INTRODUCTION:

The basic requirements of a competent trampoline performance are determined by the characteristics of all projectile motion as applied to humans in flight. (Brancazio 1984, Hay 1993, Yeadon 1997)The trampolinist is required to perform a number of somersaulting and twisting movements while in the air, and as the routine is comprised of ten consecutive bounces it is imperative that at each take-off there is a minimum horizontal component of the take-off velocity. The basic mechanical requirements then are to gain maximum time in the air, and to confine the take-off and landings to a relatively small area of the trampoline bed.

The trampoline itself is a nylon weave mat attached to a rigid steel frame standing 1.2m above the floor. With rules of competition providing for a minimum ceiling height of 8m it can be seen that a competitor 1.8m[1] in height who will perform at least the preliminary bounces in an upright stance may have available a displacement maximum of 5m. A competitor will rarely bounce too close to the ceiling, but then too will rarely be in an upright position at peak flight. The parameters of this study are based on a maximum displacement of the athlete of 5m, providing a maximum time in the air of approx 2secs and a take-off velocity in the region of 9.9m/s.

The trampolinist in performing a routine is obviously restricted to the area of the bed from which to bounce but prefers to stay within a more limited area of approximately 1 x 2m in the centre of the bed. Therefore while the performer must adopt a stance while in contact with the mat to initiate rotation at take-off - in order to complete the required rotations - there must also be minimal horizontal component of take-off velocity to keep the performer within the confines of the trampoline. This requires considerable control and the techniques employed in maintaining that control form a large portion of practice and learning time. Time in the air is also essential, to complete complex moves, hence the trampoline coach places considerable emphasis on extending that time in the air in the first learning phase.

The adjustable bungy guidance system described in this paper provides the required increased time in the air for the completion of more advanced skills, but also removes the need of the learner to attend completely to the directional control of take-off. The system provides a safe learning environment by slowing the athlete during descent, and maintains the specificity of trampoline activity by always initiating another take-off after each landing. The major benefit perceived by the authors however is the ability to adjust the tension within the system, providing a graduated guidance not available with traditional harness systems.

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[1] cog 55% of standing ht.

There is a considerable difference of opinion on the usefulness of harnesses in the coaching of trampoline, and while there is considerable literature on the detail of twisting/somersaulting movement (Yeadon 1993, Sanders 1995) there is certainly a paucity of information (Hans[2] 1999) on the subject of harness use. For the purposes of this study four NZ coaches were asked for an opinion on the use of harnesses.

TRAMPOLINE COMPETITION:
International trampoline competition until 1999 was conducted and controlled by the International Trampoline Federation, but is now the responsibility of the International Gymnastics Federation. While the grade system begins at level 7 and moves through to 'elite' level, competition in New Zealand begins at level 3. A competition performance is comprised of a compulsory routine performed by all competitors in the grade, and either one or two (elite only) optional routines developed from the 'moves[3]' available for that grade. A routine is comprised of ten 'moves' performed in sequence. Normally there would be no 'straight' (non-rotating or twisting) bounces between moves although there is no regulation that forbids the use of a single 'straight' bounce within a routine[4]. All routines are graded for difficulty using the accepted FIT rating scale and there are ceiling limits on difficulty at each grade. A competitor competing in grade 3 for instance may perform no more than two of three specific moves that signal a competitor's ability to compete in grade two. At grade one there are five moves which if used, take that routine into the elite grade. All open international competition is competed for amongst elite grade performers.

All routines are judged for form, with the difficulty component included in the final score. As in similar activities such as diving and gymnastics a performer may select a performance of lesser difficulty that may enhance the ability to control form, or increase the difficulty rating that may compromise form. Form is judged on a 10-point scale with five judges scoring the routine. Scores at both ends of the range are omitted, the remaining three totalled to find a final score for form, to which the difficulty component is added[5].

Difficulty is calculated from the written description of the routine delivered to the judging panel prior to competition. During the performance a 'difficulty' judge checks that the routine is delivered as described, and makes adjustments as required. The final score is derived from both scores by adding the total (3 judges) form mark to the difficulty mark. At the very elite end of competition difficulty may exceed 14, while at level three difficulty ratings may begin as low as 3.

THE BUNGY GUIDANCE SYSTEM:
Bungy cord is constructed from round section, extruded latex rubber thread, bound into an elastic rope. At commercial bungy jumping facilities there will usually be two ropes, one for those weighing less than 75kg, and another for those over 75kg. The rope is constructed to allow for the height of the jump and the required closeness to the ground or water at full stretch. The important factor in each case is the fully extended length of the rope with a given load, as is the case in this system.

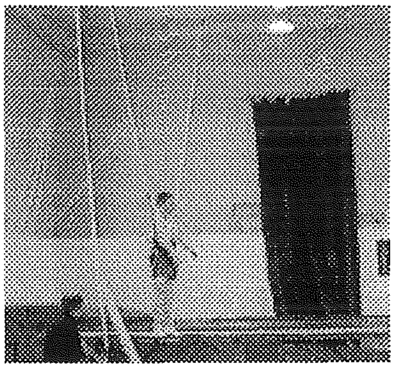
An aerial 'mechanic' was constructed of a pair of 9mm non-elastic nylon ropes passing through two pulleys suspended from the roof approximately 6m from the surface of the trampoline. When used as a normal mechanic these ropes are attached to a rotating harness by two 'D' shackles. When used in the bungy system the bungy cord is attached directly to the harness (Figure 1) providing the required stretch characteristic at the performer end of the system. The pulleys in the roof are

[2] Personal communication.
[3] What happens in the air between take-off and landing
[4] A straight bounce must not be used to begin or end a routine
[5] In diving the form score is multiplied by the degree of difficulty (DD)

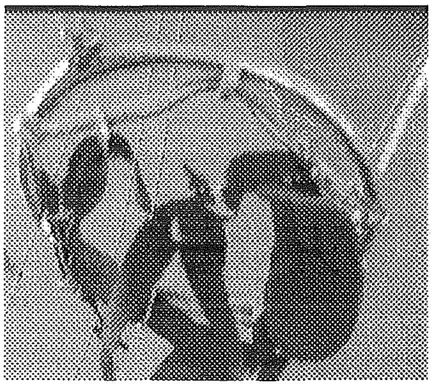
5m apart providing a wide angle at attachment to the harness and minimal interference with the arms of the performer during bouncing. At the coach end of the system the ropes pass through a locking device attached to a stanchion at trampoline level. The locking device provides the means of adjusting tension in the bungy and is an essential element in the guidance system.

For the purposes of this system three pairs of bungy cord were prepared. Each cord is 1.2m in length and constructed of standard 1.2mm, 10 thread tape. The 'stiffest' of the three is made up of 210 threads, the medium cord of 170, and the 'lightest' of the three contains 130 threads. Breaking strain of the cord is 3000kg/mm2 and the elongation of the cord at break is 700%. It can be seen from the description of the facility above that it is not possible in this system for the bungy cord to be stretched more than 400% while in use, and the three cords (Figure 2) easily accommodate a range of masses from 30kg to 70kg.

The locking device in this system provides an ability to adjust tension, or stretch, in the bungy cords. Adjustment of the tension provides a graduated level of support during the learning process. In the first stages the cord may be tensioned to such an extent that when at rest the athlete is only just touching the trampoline bed (Figure 1). This 'maximum' situation provides the athlete with stability and control at take-off, further acceleration after take-off, more time in the air to learn the move, and a slowing descent that brings the learner to a halt just as he/she meets the trampoline bed. Reduction in tension to an 'intermediate stretch reduces the assistance at take-off, continues to provide stability and control at take-off, adjusts time-in-the-air to a more realistic value, and reduces the assistance upon landing. A 'minimal' stretch simulates reality, all vertical assistance is gone, the guidance providing control and stability of the twisting harness.



The Bungy Harness 'loaded'



The twisting harness rotates within the outer rim

Figure 1 - Harness used in the Bungy Guidance System

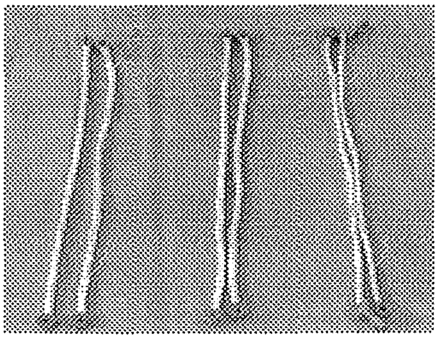


Figure 2 - Three Bungy Cords of Differing Diameters

METHOD:

For the purposes of the development of the bungy system, take-off velocities and time in the air of an elite performer were derived from video record during 'straight' bouncing, both within the bungy harness and without any physical assistance. The video record was gathered using a Panasonic MS4 SVHS movie camera on VHS mode at 25fps and a shutter speed of 1/500th. The video record was captured on Asymetrix 4 video data capture software, take-off velocities and time in the air derived using the 'measurement' mode of Video Expert II.

RESULTS:

During unassisted bouncing the performer registered a take-off velocity of 8.2m/s and as would be expected a similar velocity was registered at landing. The accelerations registered during bouncing at various tensions of the bungy harness indicate that when the tension was high the athlete after take-off did not slow as quickly as when bouncing without assistance or restraint. In addition the rate of descent was slowed quite markedly during the latter stages. The following tables demonstrate these characteristics.

A questionnaire was administered to five athletes involved in a skill learning project using the bungy harness. The questions asked were designed specifically for that research project but included an opportunity for the athlete to comment generally on the bungy harness system. All five commented positively on the system, the detail influenced by age and experience.

Table 1 Corrected Take-off Velocity Data

Bungy		Unassisted (corrected)
2.710		4.172
5.629		5.937
7.208	Take-off	7.208
7.569		7.578
7.565		7.538
7.539		6.923
7.328		6.362
6.925		5.789
6.274		5.867
5.967		5.455
5.461		5.070
5.310		4.422
5.014		4.078

The data in Table 1 are velocity data derived from video recorded at 25 fps (each increment 0.04 sec). The data has been smoothed using a moving three point average and the Unassisted' column has been corrected to provide identical take-off velocities in both cases. The time represents 0.08 sec prior to take-off from the bed, and the following 0.4 sec as the athlete is propelled into the air, and begins to slow under the influence of gravity.

With the bungy harness at maximum tension (Column 1) it can be seen that the velocity change takes place more slowly than when no harness is used. The bungy influenced pattern of acceleration will provide a greater height, and thus more time in the air, with less effort from the athlete.

Table 2 Corrected Landing Velocity Data

Bungy		Unassisted (corrected)
-4.889		-2.946
-5.139		-3.453
-5.331		-3.825
-5.622		-4.334
-5.769		-4.786
-5.921		-5.183
-6.237		-5.386
-6.709		-5.958
-7.447		-6.668
-8.205		-7.240
-7.650	Landing	-7.441
-6.441		-7.137
-4.783		-6.168
-3.233		-4.437
-0.789		-3.559
2.710		4.172
5.629		5.937
7.208	Take-off	7.208

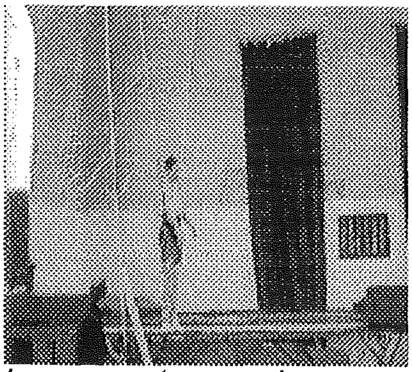
The data in Table 2 has been treated as in Table 1. (moving three point average, and corrected to bring the two take-off velocities into line) It represents the velocities during the 0.4sec prior to landing, and during the rebound phase of the trampoline and bungy cord up to take-off. The data in both tables is taken from the same two bounce sequences.

It can readily be seen from the data that the athlete in the bungy harness (Column 1) has fallen from a greater height – the velocity in the first row considerably greater than in column 2 - yet lands at almost the same velocity as the athlete in free fall. This demonstrates the rapid slowing during the latter stages of descent.

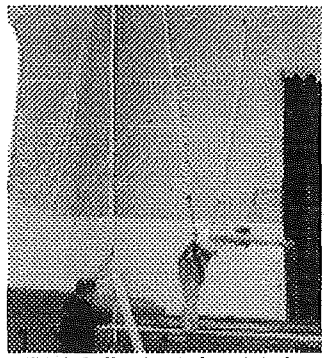
DISCUSSION:

When the athlete is strapped into a harness supported by bungy cord on either side, any force in the vertical plane will initiate a bouncing movement, similar to that experienced on a trampoline. With the bungy supported harness, plus the trampoline, the athlete experiences the up and down movement, but with the stretch characteristics of the bungy cord providing a portion of the take-off velocity from the bed. This removes another of the attention requirements of the athlete, 'working' the trampoline bed, and allows the athlete to attend almost completely to the movement in the air. As the athlete rises from the trampoline bed the bungy cord contracts but within a very short distance (Figure 3) the athlete is free in the air as in a trampoline performance and the bungy does not come into effect again until the athlete is approaching landing.

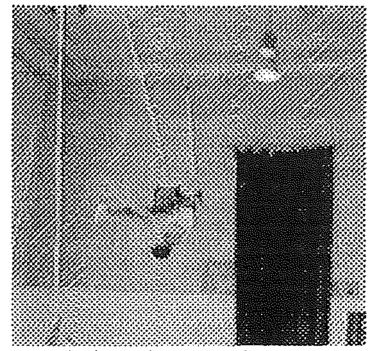
Close examination of the position of the harness on the athlete's body when at maximum tension shows that the harness is in fact slightly higher on the body than the centre of mass of the athlete. This can provide an eccentric force counter to the direction of rotation about the transverse axis and in fact in testing lead to a number of interesting 'non-rotating' somersaults by the principal author. For the competent trampolinists however this slight resistance to forward and backward rotation accentuated the need to develop strong rotational forces at take-off, and is though to be beneficial.



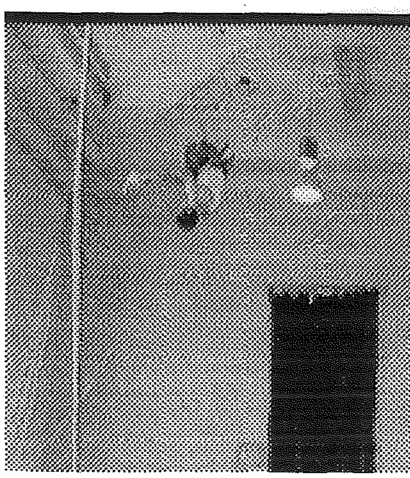
bungy at maximum stretch (note position of harness relative to cog.)



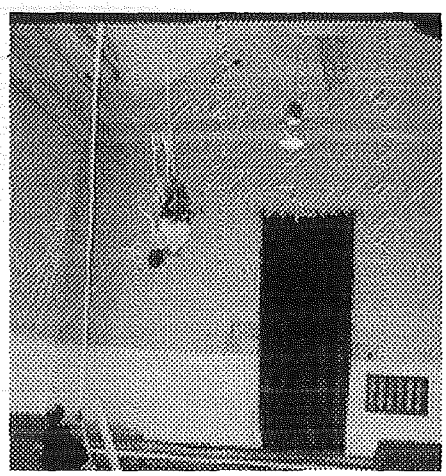
cord at full stretch at take-off



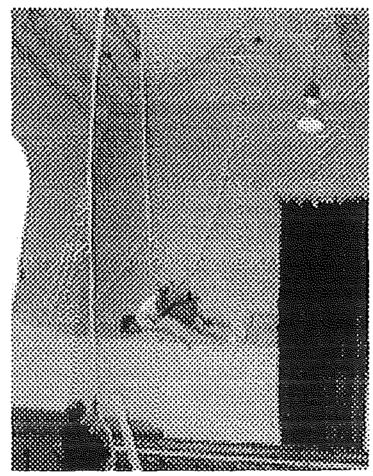
cord tension reduces as he rises through the first somersault



second somersault at peak with no support



coming into the half-out with bungy still loose



completing the landing with support from the bungy

Figure 3 - Matthew learning the Triffus (piked forward triple somersault with half twist) in the bungy harness.

The picture sequence above demonstrates almost all of the perceived advantages of the bungy harness system. As the athlete takes-off the bungy cord provides vertical velocity as in a good trampoline take-off. During ascent, assistance from the bungy is minimal and in effect the flight of the athlete is determined by gravity. As the performer begins to fall there is a normal acceleration due to gravity until the final stages during which the bungy cord slows the rate of descent providing extra time for the athlete to control the landing and prepare for the next bounce.

CONCLUSION:

Coaches and experienced trampolinists involved in the development of the system identified the following as positive aspects that may facilitate the learning of new skills.

- Safety – when the correct weight of bungy is at maximum tension it is not possible for the athlete to land on the trampoline bed on anything other than the feet.

- Bungy tension can be adjusted to provide take-off velocities required for the skill level of the performer, and time in the air required for the completion of a new skill.

- Assistance at take-off provided by the bungy allows athlete to attend completely to initiation of move, especially 'chest up'.

- At peak of trajectory athlete is on own, no support, as in free flight.

- Time in the air can be adjusted to simulate desired performance.

- Bungy slows descent providing time for the learner to complete move with some control

- Landing is followed immediately by take-off as in routine, without attention but as in whole routine.

- Allows combinations up to and including performance of complete routine

- Performer may practice in bungy without coach being involved in support, coach attention totally on analysis of skill

- Performer may practice new skills on their own with minimal coach involvement. This enhances coach time in the practice environment.

- Training in advanced skills can be initiated at an earlier age and stage of the performer's skill development. Complicated skill patterns may be introduced to younger performers, and the system provides for experimentation without serious safety considerations.

- Adjustable tension provides for reducing support as subject becomes more confident/experienced. Level of support may range from almost complete to neglible. The authors refer to this as graduated guidance.

The authors are convinced of the benefits of the bungy harness guidance system and while there are obvious applications in the teaching of diving and acrobatics, there are many other possible uses of the specific characteristics of bungy in a number of other partially airborne activities.

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MOTOR SKILL ACQUISITION ON TRAMPOLINE USING A BUNGY GUIDANCE SYSTEM

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The purpose of this study was to investigate the bungy harness system and its effect on motor skill learning on the trampoline. Eleven trampolinist's of varying ability, from elite performer to beginner, were separated into a control (n=5) and a test (n=6) group and were trained over a four day period using a variety of guidance techniques including the bungy 'mechanic'. Both groups attempted to integrate two new moves into their trampoline routines. Pre and post trial judging of routines were completed. Results showed a small increase in skill learning for both groups. However, no noticeable improvement in post-test results for the test group occurred. There were some encouraging implications in the use of a bungy mechanic which support further research in its application as a device for physical guidance.

KEY WORDS: bungy, motor skill acquisition, physical guidance, trampoline.

INTRODUCTION:

In the teaching of trampoline skills coaches commonly use a process called 'active' or 'physical' guidance (Macrae and Holding, 1965). This type of learning had been called error-free learning (Singer and Pease, 1976) where the participant is restricted to the appropriate movement pattern through the use of a physical barrier or hands-on manipulation by the teacher or coach. In trampoline the coach may stand alongside the performer and provide physical support while the athlete is doing somersaulting motions, or initiate twisting motions by applying a force to the trunk or legs at the correct time (Figure 1).

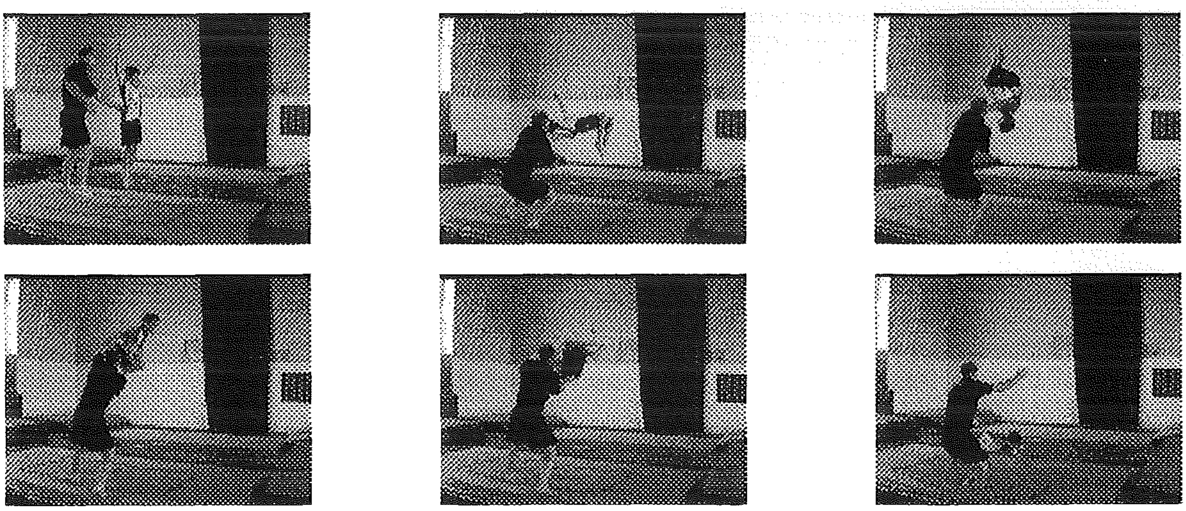

Figure 1 - Catching tuck doublesomersault

The coach may also use a catching harness commonly known as a 'mechanic' in the teaching of moves. The mechanic is a harness supported by ropes (Figures 2a-b) and the system constrains the performer and removes the threat of significant errors, for example: premature travel from the trampoline. The coach is also able to control the rate of fall of a subject should they loose control in the take-off or flight phase of the move.

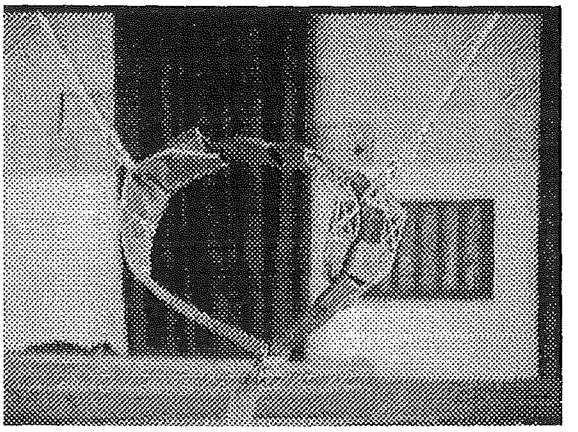

Figure 2a - A simple non-twisting harness

This study considers a more advanced form of physical guidance using bungy cord[1] within the catching mechanic. This cord is attached at one end directly to the twisting belt and at the other end to the ropes leading to roof pulleys and back down to a floor anchor as shown in Figures 3a and 3b below. In the case of the bungy mechanic (bungy guidance system) this anchor is a locking device which allows for variation in tension on the bungy cord.

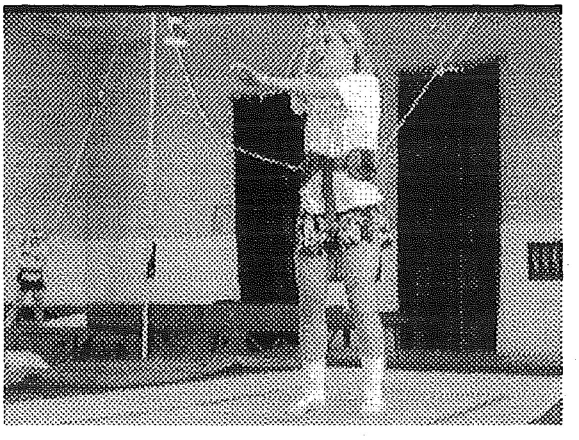

Figure 2b - Athlete prepares for a pike double back somersault in the rotating harness

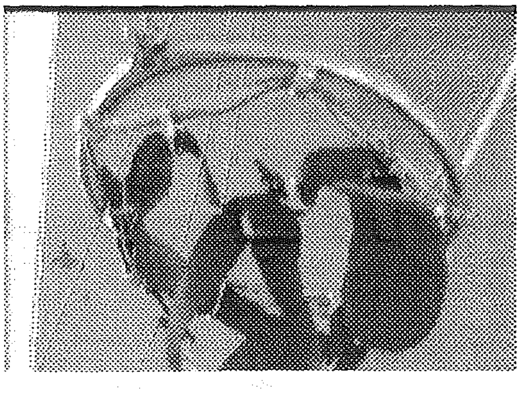

Figure 3a- (The twisting harness rotates within the outer ring)

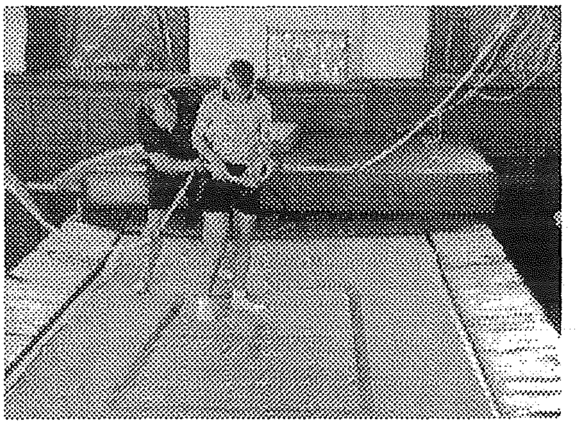

Figure 3b - Athlete ready to use the Bungy Mechanic

[1] Details in 'A Bungy Guidance System...' D.McClymont. (previous paper in these proceedings).

Such a device allows for some control of skill initiation by the athlete while the bungy cord constrains inappropriate actions leading to travel and reduces the consequences of errors. It also has additional guidance properties as it reduces the effect of gravity in the ascent and descent phases of the move and assists with correct body position in the take-off phase. The use of this type of harness also assists greatly in developing confidence and removing psychological barriers. These may well make a major contribution to our findings but are not covered in this investigation.

Lippman and Rees (1997) found that error correction was an important ingredient in skill learning. This aspect of the bungy mechanic will be reviewed along with its ability to allow athletes to connect a number of skills to form a routine, essential for progression in the sport. The purpose of this study was to identify the benefits to be derived by using a bungy harness system and to consider its potential use as an advanced form of guidance mechanism for trampoline training. The research would also consider the contribution such a device could make to error correction in acquisition of trampoline moves and in aiding trampolinists in the difficult task of combining a range of moves into a competitive trampoline routine.

METHOD:

Eleven subjects (8 female, 3 male) currently competing at levels 3 to Elite and in an age range of 7-20 years, were judged according to International Trampoline Federation (F.I.T.) criteria both before and after a series of coaching sessions using either traditional[2] or bungy guidance systems. Each athlete prepared a competition routine plus two moves that they would wish to learn and include in future routines.

A test and control group were drawn by lot, and each performer was exposed to the same coach for nine six minute coaching sessions over a period of four consecutive days. The control group learned the two new[3] skills using traditional coaching techniques of manual and rope harness guidance, while the test group learned their moves with the bungy guidance system.

Prior to instruction each athlete was informed that they would be expected to use self-reflection techniques (mental practice) during and between sessions and that the coach would, during instruction, ask the athlete for an opinion on progress. Feedback from the coach to the athletes in both groups during instruction was a mixture of error-correction, reinforcement, and motivational feedback as delivered in his usual style.

On day one each athlete warmed-up as for competition then performed the pre-selected routine. The routine was judged using F.I.T. criteria[4] and for the purposes of the research the athlete was offered the opportunity to perform the routine up to a total of three times until satisfied with the performance. Only scores from the last routine completed by each athlete were used. The judged performance was followed on day one by two six minute training sessions, with five minute break, in which the coach instructed the learner on the new skill. On days two and three the learner received three six minute periods of instruction with five minute break between each. The emphasis in these sessions was on including the new moves into the previous routine.

On the final day there was one six minute session in which the learner 'fine tuned' the new routine, a five minute break, then judging as on day one of the new routine.
In each case the new moves learned were of greater difficulty than those replaced,

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[2] the combination determined by the coach's traditional methods

[3] these moves to be "new" in that prior to this study the athlete was unable to perform the move as part of a routine.

[4] five "form" judges, upper and lower scores rejected, plus "difficulty" judge score added.

increasing the difficulty rating of the routine. Difficulty calculations for trampoline moves is an important factor contributing to the overall result in this study and will be considered within the discussion section.

RESULTS:

Table 1 records the difficulty, form, and total scores for the pre-test routine. Final scores for ME7^ were not derived due to technical problems.

TABLE 1.

Pre-Test Scores. (Dec 18th) 10 bounce trampoline routine.

Comp No.	Dif Score	Form 1	Form 2	Form3	Form 4	Form 5	Final Score
M31*	2.9	6.6	7	6.8	6.7	6.4	23
F32*	1.7	7.9	7.9	8	7.8	8.4	25.5
F29*	4.6	7.5	7.6	7.4	7.3	7	26.8
F211*	5	7.9	7.8	8.2	8.1	8.3	29.2
F112*	5.9	8	8.1	8.2	7.8	8.1	30.1
F33^	2.7	7	7.2	7.3	7.5	6.8	24.2
F26^	4.2	7.8	7.8	7.8	7.9	8.4	27.7
ME7^	9.2	7.8	7.6				N/C
F28^	3.7	7	7	7	6.3	6	24
M210^	5.9	7.4	7	7.3	6.9	7.2	27.4
F113^	5.5	7.8	7.4	7.6	7.6	7.4	28.1

*Control Group
^ Test Group

Table 2 records the difficulty, form, number of new moves included and total scores for the post-test routine. Note that two of the eleven participants were unable to demonstrate a full trampoline routine and were therefore excluded from the study results. A number of the participants were unable to include new moves in a routine after the nine sessions.

Table 3 records a comparison of the scores from the pre-test and post-test results. Results proved to be inconclusive with the test group showing a similar level of improvement to that indicated for the control group. Two athletes from the control group were able to demonstrate minor improvements in score (M31*, F112* n= +0.4) but neither could include the new moves into their routines. Their results indicate an improved performance by them in the post-test either as a result of the four days training, or through normal variations in judging accuracy. One person within the control group did include the two new moves and showed a similar final score for the post-test (F29* n = -0.1). It must be remembered that the post-test score also includes the addition of the extra difficulty attributed to the new moves.

TABLE 2.

Post-Test Scores. (Dec 21st) 10 bounce trampoline routine.

Comp No.	Dif	New Moves	Form 1	Form 2	Form3	Form 4	Form 5	Final Score
M31*	3	0	6.7	6.8	6.1	7.2	6.9	23.4
F32*	1.8	1	7.6	8	7.5	7.9	7.6	24.9
F29*	4.9	2	7.4	7.4	7.2	7.2	6.8	26.7
F211*	5	0	7.9	8	7.4	7.5	8	28.9
F112*	5.9	0	8.1	8.3	8.2	8.3	7.9	30.5
F33^	3.5	2	6.8	6.9	6.7	6.5	6.2	23.5
F26^	4.6	1	7.8	7.5	7.7	7.7	7.7	27.7
ME7^	9.3	0	7.5	7.8	7.9	7.9		N/C
F28^								N/C
M210^	6.1	1	7.1	7.2	7.1	7	7	27.3
F113^	5.5	0	7.6	7.5	7.6	7.5	7.6	28.2

*Control Group
^Test Group

TABLE 3.

Pre and post test comparisons of 10 bounce trampoline routine scores for control and test groups.

Name.	Comp No.	Pre- test Difficulty	Form Score	Total Score	Post -test Difficulty	New Moves	Form Score	Total Score	Change
Mark	M31*	2.9	20.1	23	3	0	20.4	23.4	0.4
Joanna	F32*	1.7	23.8	25.5	1.8	1	23.1	24.9	-0.6
Nicole	F29*	4.6	22.2	26.8	4.9	2	21.8	26.7	-0.1
Koren	F211*	5	24.2	29.2	5	0	23.9	28.9	-0.3
Kelly	F112*	5.9	24.2	30.1	5.9	0	24.6	30.5	0.4
Ruth	F33^	2.7	21.5	24.2	3.5	2	20	23.5	-0.7
Emily	F26^	4.2	23.5	27.7	4.6	1	23.1	27.7	0
Mathew	ME7^	9.2	N/C	N/C	9.3	0	0	N/C	N/C
Belinda	F28^	3.7	20.3	24	N/C	0	0	N/C	N/C
John	M210^	5.9	21.5	27.4	6.1	1	21.2	27.3	-0.1
Alice	F113^	5.5	22.6	28.1	5.5	0	22.7	28.2	0.1

*Control Group
^Test Group

Results within the test group were also inconclusive. Two athletes (M210^ n= -0.1) and (F26^ n = 0.0) did manage to include one new move into their post-test routine while maintaining a reasonable post-test score. Another (F33^ n = -0.7) managed to include both new skills but as a consequence received a lower overall score in the post-test.

Three members of the control group and four members of the test group who were unable to include the new moves in their post-test routine, as identified in table 3. However, each of these athletes had success in that they were able to complete one or more of the new moves without the assistance of a mechanic or of any guidance, but within the time constraints of the study were unable to include the new moves in a routine.

A seven question survey was administered to athletes as a further measure of perceived success. Results from this survey were also inconclusive. Both groups found the training enjoyable indicating they received useful feedback. Their general comments also support this. One interesting result was the self-reported improvement in understanding of the new trampoline skills with (n=4) respondents within the test group rating their understanding at 5 (1= not very much, 5 = very much). Fewer within the control group indicated this level of improved understanding.

DISCUSSION:

A number of key benefits did come from the use of the bungy guidance system. The inconclusive result in this study may be due to specific difficulties inherent in studying subjects in 'real life' contexts. Kernodle and Turner (1998) suggest there should be more research of actual sports training while acknowledging the difficulty of controlling for extraneous variables. One major limitation in the use of 'real life' subjects is controlling for prior learning. A study by Sanders (1995) while investigating the effect of ability on technique highlights the problem. His study investigated eleven New Zealand trampolinists ability to do twisting forward somersaults. Sanders was able to show that although trampolinists could complete these moves there was substantial variability in the quality of their technique, as determined by body position at take off. This proved to be an important consideration in the present study as some athletes were obviously ready to progress whilst others were far from being technically competent to proceed with the integration of new skills. This variable could not be factored into the results where a demonstration of a skill and its integration into a routine was the only empirical measurement device. It would be useful in a future study to be able to control for ability according to the two variables hip lateral flexion and hip angle cited by Sanders. It would then be possible to compare the results of a test group using a bungy guidance system against a control group using standard guidance techniques.

There is little research in guidance related to skill learning in gymnastics and trampoline. James (1971) completed a brief study investigating the use of video feedback on trampoline performance. A study by Baria and Salmela (1988), investigated feedback guidance techniques in gymnastics. This study focussed on behavioural factors and the effect of reinforcement on performance. A study by Williams (1989) on video modelling hoped to show that this approach would improve understanding and form in learning a vault in gymnastics. Although subjects were given a clear visual picture of what the move should look like this was of no value for them in translating perception into action. An earlier study by Graydon and Townsend (1984) used a harness on trampoline to investigate proprioceptive and visual feedback for learning a front somersault. This study found that the blindfolded subjects showed a higher level of learning on the forward somersault than those learning a badminton task under similar conditions. For the present study the factors identified by Graydon and Townsend highlight the usefulness of a guidance mechanism in connection with an internal process of reflection by the subject.

We know from literature on guidance that there is benefit to be gained from using some form of guidance early on in the learning process Schmidt (1988). In the present study we saw that athletes reported an ability to both understand moves learnt and an ability to translate this into skill learning outside of the guidance mechanism. Many of these skills were quite complex. Some of this understanding although unproven may be attributed to an ability to commit errors without substantial consequences and it is this benefit which needs to be further investigated.

Figures 4a-e show an athlete attempting a double twisting double backward somersault (fullfull). Figures 4a-d show under-rotation of this move in the flight phase caused by a lack of hip flexion at take-off.

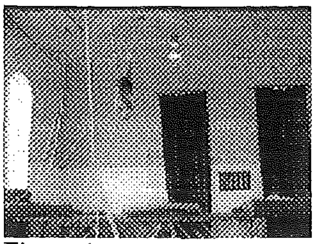
Figure 4a

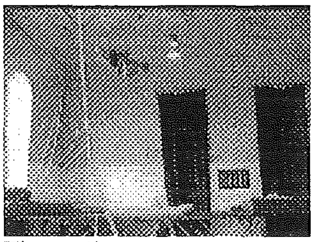
Figure 4b

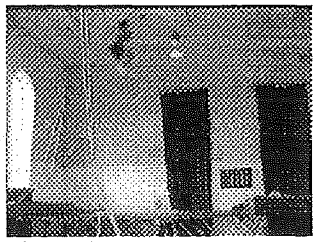
Figure 4c

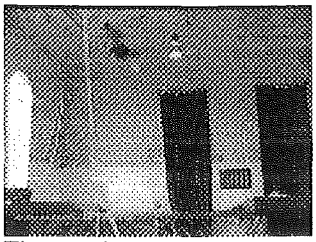
Figure 4d

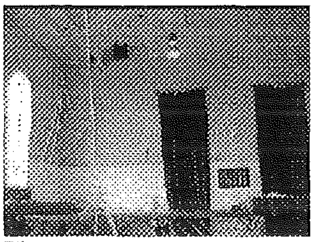
Figure 4e

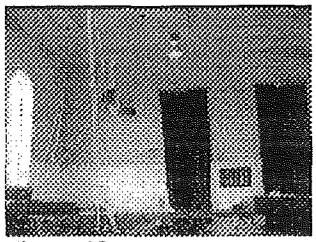
Figure 4f

Figures 4a-f - Athlete doing fullfull/ with error

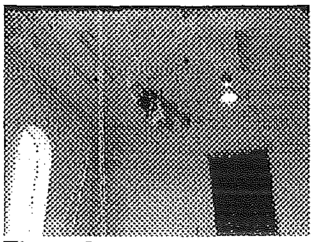
Figure 5a

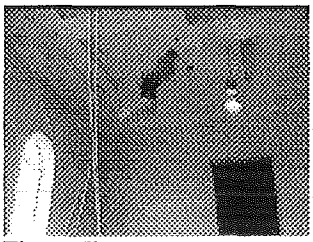
Figure 5b

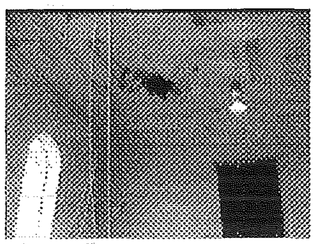
Figure 5c

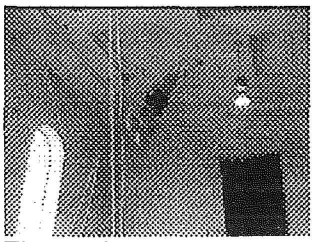
Figure 5d

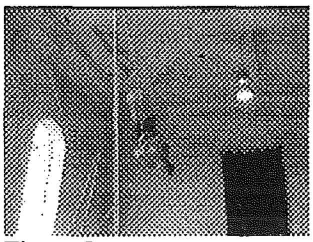
Figure 5e

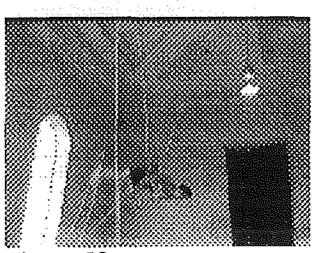
Figure 5f

Figures 5a-f. - Athlete doing fullfull without error

Figures 5a-f show the same move four attempts latter with a general resolution of the error and successful completion of the skill. Because of the lessened effect of gravity in the descent phase the athlete has more time to understand the motor pattern and can learn the skill through trial and error learning.

It was noticed throughout the trial that those athletes using the bungy mechanic were willing to experiment more freely with movement patterns as has been the case in this example of this athlete learning the fullfull.

Lippman & Rees (1997) showed the value of mistakes in practice in their study of the sensory perceptions of college students. They indicated: 'If an incorrect response is prevented, then no stimulus consequence is possible'

They point out that this approach is not normally associated with guidance in gymnastics where a 'faded' or reduced guidance technique is commonly used thereby reducing the likelihood of errors. Sherwood (1996) also reported the benefits of random practice in developing a spacial error detection capacity in a study within a controlled environment. Milman (1994) a past world trampoline champion indicates a principle of 'overcompensation' which essentially means to work both sides of the movement (make mistakes in over and under rotation of moves). Over-compensation is a form of trial and error learning and it applies to all aspects of the movement including balance, accuracy, timing and force This principle is clearly illustrated with the example of an athlete learning the fullfull (Figure 6a-f). He is able to try out different hip flexion for initial rotation of the move and aerial twist initiation techniques while accepting and utilising the consequent movement outcome (often error) to learn the most appropriate technique. He finds out which method works best by trial and error and then practices and refines the correct action. The feedback is immediate and is therefore more powerful as shown in early research by Ammons (1956) and Macpherson et al (1949). The feedback is also augmented with verbal feedback from the coach. This combination of physical guidance and verbal feedback is reported in a study by Winstein; Pohl and Lewthwaite (1994) to have a positive effect on learning provided the verbal feedback does not interfere with the learning received through the immediate feedback received by the athlete.

Another key element in the development of a trampoline routine is the ability to combine moves. While practicing to successfully achieve this goal, the trampolinist requires error control. Coaches have the responsibility of reducing the possibility of major errors and traditional guidance techniques focus on error control as the primary goal. Error learning can still result although major errors are no longer possible because of the constraining effect of the bungy cord.. This effect is even more dramatic for combinations of moves. There is a divergent view among coaches about the detrimental effect of relying on guidance and general safety devices such as harnesses to overcome this problem. Some coaches report difficulty in removing such devices for the psychological crutch they provide for users.

In trampoline maintaining an error free approach to training usually means substantial time is spent thoroughly learning a new move prior to its inclusion in a routine. Unfortunately, substantial work is then needed in learning how to combine this move with those around it and this work must occur as a separate process from the initial skill learning process. It would therefore be expected that a guidance system that allowed for genuine integration of skills sequentially while maintaining error reduction would facilitate faster learning. One specific benefit of a bungy mechanic is this ability to allow for multiple skill combinations in both twisting and somersaulting phases. It may be that in the present study not enough time was given to allow for the benefit to become apparent. Combining is made physically easier for athletes through the extra air-time afforded by the bungy in the descent phase of each skill. This allows the athlete to 'set' for the next move and pay attention to the requirements for completing this skill. This concept is similar to that identified by Milman (p129) as slow motion practice where he comments: "in gymnastics I often carry athletes slowly through a somersaulting movement so they can become aware of every part of turning over".

Figure 6a shows the athlete toward completion of a double back somersault a new move she was learning as part of this trial. Figure 6b shows the opening of the skill and the beginning of the 'set' for the next move to follow. Because she is in the descent phase of the move the bungy harness is about to begin to slow her. Without the bungy system she would not be able to complete the skill and set up the barani shown here in Figures 6d-f as is evidenced by her inability to include this move in her post-test routine.

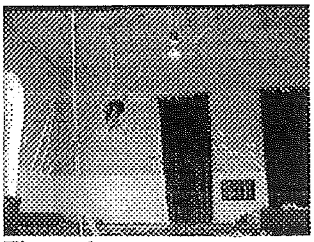

Figure 6a.

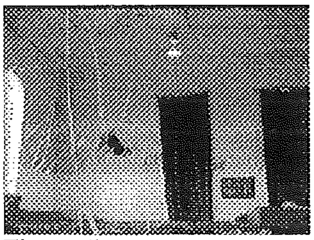

Figure 6b.

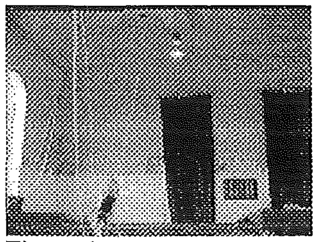

Figure 6c

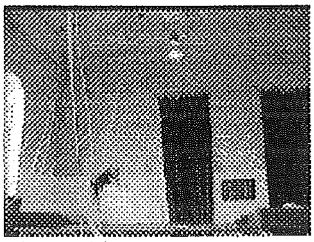

Figure 6d

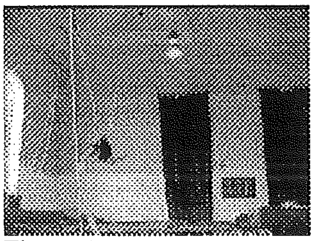

Figure 6e

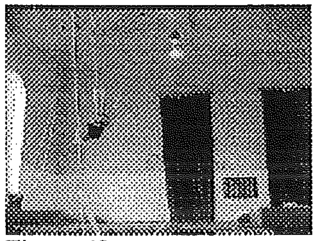

Figure 6f

Figure 6a-e - Athlete doing double back, barani

SUMMARY AND CONCLUSION:

In this study the effect of training using a form of physical guidance called a bungy mechanic was investigated. Inferences of benefit from bungy use were not proven as results were inconclusive. A main reason for this was difficulty in determining prior learning in athletes chosen for the study. A number of unique features of the bungy cord were found to be particularly useful in this learning environment. Athletes were encouraged by the nature of the bungy guidance system to experiment and learn through trial and error. This was evidenced by increased understanding of the moves being learnt by the athletes and increased ability to complete moves outside of the guidance device. This study did not however determine any measurable benefit for athletes in its use. The bungy mechanic has several advantages over more traditional guidance methods, the most important being its contribution to multiple skill learning. It would be of value to repeat this study over a longer period of time controlling for prior learning through the use of an appropriate measurement tool. It may also be that the characteristics of bungy cord may mean it has value as a guidance mechanism in other sporting applications.

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