BIOMECHANICS OF THE FOOT AND ANKLE AND INJURY RATE IN WOMEN'S AEROBIC DANCE

by

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ABSTRACT

Abnormal biomechanics of the ankle joint, rearfoot and forefoot, that can lead to overpronation, are frequently cited as the cause of injuries to the lower limb in the running population. These findings are extrapolated to other types of aerobic activity without the benefit of a separate analysis. The primary purpose of this study was to examine a group of healthy female subjects (N = 195) for ankle, rearfoot and forefoot abnormalities and follow them through a 12 week period of aerobic dance classes to determine if the abnormalities found, had a relationship to the injury rate of the group. A secondary purpose was to examine general lower limb flexibility as measured, by a sit and reach test, to see if a relationship existed between lower limb flexibility and subsequent injury rate. Injury rates were graded on a four level scale ranging from soreness that did not require alteration of the subject's activity level (Grade I) to an injury that required medical intervention (Grade IV). Grade I injuries were regarded as complaints only. Fifty-six

Grade I injuries and 25 Grade II to Grade IV injuries were recorded. Subjects were contacted bi-weekly. There was not a significant relationship between; (1) dorsiflexion and subsequent injury rate X^2 $(1, \underline{N} = 382) = 0.949$ $(p > 0.05)$; (2) rearfoot varus or valgus and subsequent injury rate X^2 $(1, \underline{N} = 382) = 0.136$, $(p > 0.05)$; (3) forefoot varus and subsequent injury rate X^2 $(1, \underline{N} = 382) = 2.163$, $p > .05$. Similarily, there was not a significant relationship between lower limb flexibility and subsequent injury rate, X^2 $(1, \underline{n} = 193) = 2.213$, $p > .05$. This study did not find a relationship between foot and ankle biomechanical abnormalities, or general lower limb flexibility, and subsequent injury rate in women's aerobic dance.

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Dedication

To Sue, and she knows why.

Introduction

The last twenty-five years has seen an increase in the awareness of the public regarding the beneficial effects of exercise. The increased awareness has resulted in a variety of types of regular exercise which place an emphasis on cardiovascular fitness. The most common of these are running or jogging and aerobic dance. The increase in participation by the public has resulted in an awareness of the overuse type of injuries suffered by the participants (Renstrom & Johnson 1986). This interest in overuse injuries has been chiefly fueled by runners' injuries and a great deal of research has examined the problems of the running population. However, aerobic dance has become the largest organized fitness program for women, with over 90% of the YM/WCAs in the United States offering an aerobic dance program (Legwold 1982), and yet little research on the safety of an aerobic dance type of program has been done. Siscovick (1988) stated that more research was needed on the incidence of musculoskeletal injuries and the role of risk factors, such as host characteristics, in popular forms of exercise such as aerobic dance.

Abnormal biomechanics of the foot have been implicated in the overuse type of injury to the lower extremity in athletes (Renstrom & Johnson 1985) . Taunton, Clement, & McNicol (1982); and Viitasalo & Kvist (1983) cited excessive pronation as the most frequently observed abnormality. Excessive pronation placed an increased stress on the muscles and ligaments affecting the foot, due to the excessive motion allowed at heel-strike, mid-stance, or toe-off. The increased stress predisposed the athlete to over-use injuries and a decline in performance. The major biomechanical factors that contributed to excessive pronation were abnormal rearfoot motion (varus or valgus), forefoot varus and limited dorsiflexion of the ankle joint (Donatelli, 1987; Katoh, Chao, Laughman, Schneider & Morrey, 1983; Root, Orien, & Weed, 1977).

Overpronation was aggravated by variables collectively referred to as training errors. These other variables included distance run per week (James, Bates & Osternig, 1978; Powell, Kohl, Casperson & Blair, 1986), amount of participation in an activity (Richie, Kelso & Bellucci, 1985), lack of flexibility (Blair, Kohl & Goodyear, 1987; Francis, Francis & Welshons-Smith, 1985), excessive participation in one activity only (Garrick, Gillen & Whiteside, 1986) and previous injury (McQuade, 1986).

Aerobic dance classes have become the largest systematic fitness activity for women (Garrick et al. 1986). These classes involve a series of exercises for strength, flexibility and cardio-vascular fitness performed to music. Although little research had been done on the type and cause of injury rates in this population, virtually all authors cited biomechanical causes, or training errors that led to an overuse syndrome (Garrick et al., 1986; Ritchie et al., 1985; Vetter, Helfet, Spear & Matthews, 1985). The type of injuries suffered were similar to those found in runners and chiefly involved the lower extremities. Vetter et al. (1985) found plantar fasciitis, shin splints and patello-femoral syndromes were the most commonly suffered injuries. Ritchie et al. (1985) also found foot and ankle injuries to be the most frequent.

Analysis of the current literature of aerobic type of activities (chiefly running) revealed varied scientific and clinical opinions regarding the principle cause of these types of injuries. Much of the literature was antecdotal (Kerr, 1984; Legwold, 1982; McKenzie, Taunton & Clement, 1986; Subotnick, 1975; Taunton, 1979) or failed to find statistically significant results regarding the various factors.

McQuade (1987) was unable to find a significant difference between activity level, gender, or shoe type in a retrospective study of running injuries. Warren and Jones (1987) examined biomechanical variables in athletes in a study to predict plantar fasciitis. They were unable to identify biomechanical variables which were causal factors precipitating plantar fasciitis and concluded that the onset of plantar fasciitis may not be the result of a biomechanical problem.

Powell et al. (1986) in an epidemiological review of running injuries that did not examine biomechanical factors, concluded that miles run per week is the only well-established cause of injury. They felt that age and gender did not play an important role in risk of injury to runners. Previous injury may have been a factor in subsequent injury but they concluded that there were not enough data to confirm this. The principal problem with the data they reviewed was that they did not provide enough information to establish risk factors.

Garrick et al. (1986) in a study of 411 aerobic dancers found a very low injury rate and felt that a history of previous injury and lack of involvement in other fitness activities were the only important causal factors. They felt that aerobic dance offers minimal risk of injury.

In contrast, Ritchie et al. (1985) in a study of aerobic dance found injury rates of 43% for students and 76% for instructors. They attributed the injury rate to the amount of time danced, dancing barefoot and to the type of floor surface.

The traditional method of examining risk factors was through retrospective studies of injured athletes (Garrick et al, 1986; Kannus, Niittymaki & Jarvinen, 1987; McQuade, 1986; Powell et al., 1986; Ritchie et al., 1985; Sperryn & Restan, 1983; Taunton et al., 1982). Most retrospective studies of athletic injury concentrated on either biomechanical risk factors or non-biomechanical (training error) risk factors.

Only one study was found that examined the injury rate in athletes that was prospective in examining the biomechanics of overpronation. In a pilot study, Iles & Collis (1987) examined biomechanical factors in 20 healthy subjects in a 12 week fitness program. All subjects were measured for dorsiflexion, rearfoot and forefoot abnormalities prior to commencement of a running and exercise course. They were able to demonstrate a significant relationship between forefoot varus and subsequent injury rate but not between rearfoot abnormalities or limited dorsiflexion and subsequent injury rate.

A search of the literature failed to reveal either a prospective study on injury rates in aerobic dance or a study dealing with biomechanics of overpronation and injury rate in aerobic dance.

In order to examine the risk factors associated with injury rates in aerobic dance, measurements of three biomechanical variables, rearfoot motion, forefoot motion, and passive ankle dorsiflexion, were studied in 212 participants in a 12 week prospective study. In addition, lower limb flexibility as measured by a sit and reach test, was also examined to see if a relationship existed between lower limb flexibility and subsequent injury rate.

Hypotheses:

1. A significant relationship will exist between the degree of limited dorsiflexion and subsequent injury rate in aerobic dance.
2. A significant relationship will exist between the degree of rearfoot varus/valgus and subsequent injury rate in aerobic dance.
3. A significant relationship will exist between the degree of forefoot varus and subsequent injury rate in aerobic dance.
4. A significant relationship will exist between lower limb flexibility as measured by a sit and reach test and subsequent injury rate in aerobic dance.

Definition of Terms:

Pronation: A triplane motion consisting of simultaneous movement of the foot or part of the foot in the direction of abduction, eversion and dorsiflexion.

Supination: A triplane motion consisting of simultaneous movement of the foot or part of the foot in the direction of adduction, inversion and plantarflexion.

Subtalar neutral: "the neutral position of the subtalar joint is that position of the joint in which the foot is neither pronated nor supinated. From this position, full supination of the normal subtalar joint inverts the calcaneus twice as many degrees as full pronation everts it." (Root, Orien, Weed,& Hughes, 1971, p 26)

First ray: The first ray consists of the first cuneiform and the first metatarsal.

Positions of the foot:

Inversion: Motion occurring when the foot or any part is tilted on the frontal plane so that the plantar surface of the foot or part faces toward the midline of the body.

Eversion: Motion ocurring when the foot or any part is tilted on the frontal plane so that the plantar surface or part faces away from the midline of the body.

Varus: A fixed structural position of the foot or a part of the foot which it would assume if it were inverted.

Valgus: A fixed structural position of the foot or part of the foot that it would assume if it were everted.

Plantarflexion: Motion occurring in a sagittal plane in which the foot or the distal part of the foot moves further away from the tibia.

Dorsiflexion: Motion occurring in a sagittal plane in which the foot or distal part of the foot moves toward the tibia.

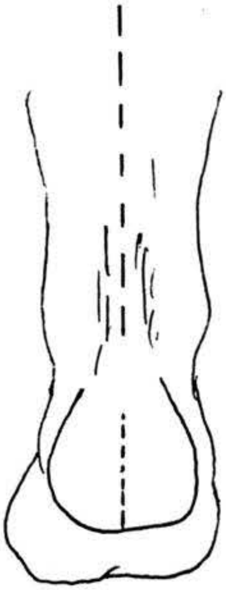

Figure 1: Subtalar Neutral

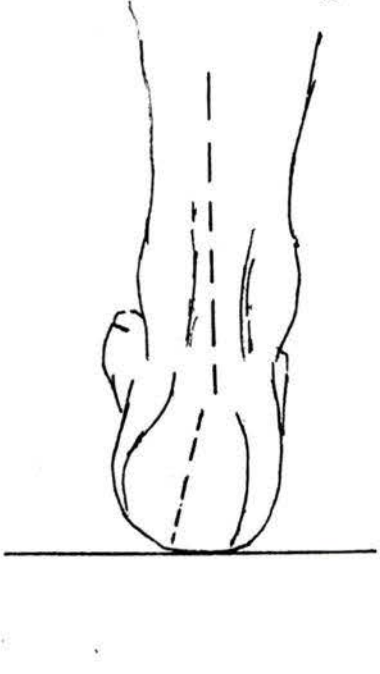

Figure 2: Subtalar Varus

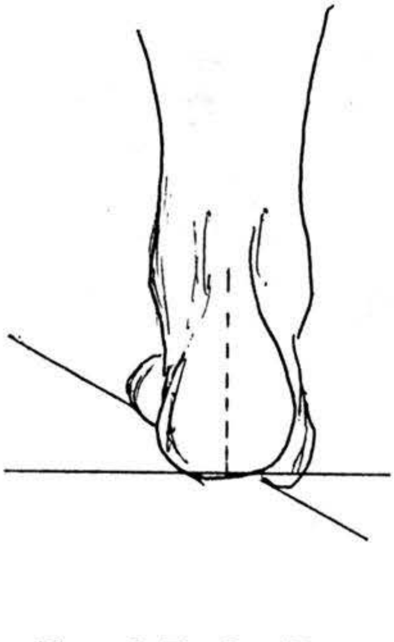

Figure 3: Forefoot Varus

Review of Literature

History

The interest in aerobic type of activities has generally been credited to Dr. Kenneth Cooper. He coined the term "aerobics" for any program of exercise that provided continuous stress on the cardiovascular system in a training mode for at least twenty minutes, three times a week. The program could take many different forms of exercise such as running, swimming or biking. The goal was to improve the efficiency of the cardiovascular system and thereby improve general health and reduce the risk of cardiovascular disease. The development of exercise classes to music in the early 1970's, colloquially known as aerobic dance, has been generally credited to Ms. Jackie Sorenson (Chiles & Moore, 1981; Eichoff, Thorland & Ansorge, 1983; Garrick et al., 1986). The success of this form of exercise was evidenced by the fact that estimates of its popularity ran to almost 10 % of the population in the United States (Koszuta, 1986).

Definition of Aerobic Dance

A typical aerobic dance class consists of three parts (Chiles & Moore, 1981) encompassing not only cardiovascular fitness but also strength and flexibility.

Classes usually begin with a warm-up period lasting up to ten minutes and consisting of gentle stretching and mild exercise. This is followed by the "aerobic " section that consists of heavy continuous running, jumping, bouncing or dance steps for at least 15 minutes and up to a period of thirty minutes. The intent of this section is to get the participant's heart rate up to a range in which cardiovascular training will occur. The third section is the cool-down period which may also encompass moderate floor exercises, such as situps,leading to a period of stretching and relaxation. Variations on this basic program are many and may include for example, the use of hand weights, increasing the amount of dance steps to increase coordination, and maintaining one foot on the floor at all times to eliminate the "bouncing'.

Cohen (1984) felt that aerobic exercise must use large muscle groups that could be worked continuously through rhythmical and repetitive motion. The exercise component required three variables; intensity, frequency, and duration. Heart rate must be elevated to at least 60% and preferably to 70 - 85%. of the age related maximum. The individual should train at 60% of the VO_2 max .(the maximum amount of O_2 that can be transported to the lungs and working tissues during peak exercise, p.51). He recommended a duration of at least 15 minutes, with a frequency of three days a week.

In this study, aerobic dance was defined as dance programs encompassing at least 20 minutes of continuous aerobic type of activity done to music, offered at the five facilities; the Nautilus Club, Fit Commitment, the Fitness Place, the University of Victoria, and the YM/WCA.

Physiological Effects

The prime aim of aerobic dance is to increase the cardiovascular fitness of the participant (Chiles & Moore, 1981). Most research into aerobic dance has examined the physiological effects of this form of exercise by using an improved VO_2 max. as their determining factor.

Cearly, Moffat & Knutzen (1984) examined maximal oxygen uptake in college women in two-day-per-week (AD2) and three-day-per-week (AD3) aerobic dance classes. Their participants followed a program that consisted of an initial fifteen minutes of continuous dance at 75% estimated maximal heart rate and progressed to thirty minutes by the end of a ten week study. They found a significant increase in VO_2 max. for the AD3 group when compared with a control and the AD2 groups. Pre-post testings found no significant differences either for maximal heart rate or body weight. They concluded that aerobic dance does improve cardiovascular fitness but that three days per week was the minimum requirement to achieve a benefit.

Foster (1975) used four subjects that had their expired respiratory gases collected while performing an aerobic dance routine. The group mean load value was 33.6 ml/kg/min which was felt to be sufficient to elicit a training response. Foster recommended three, 30 minute classes per week to meet accepted minimum of duration and intensity for cardiovascular training.

Igbanugo & Gutin (1978) monitored four subjects for expired air and heart rate in low, medium and high intensity aerobic dance classes. They concluded that the results of mean energy expenditure and heart rates justified aerboic dance as a modality for cardiorespiratory training and rehabilitation as well as for weight reduction. It should be noted that the study used only four subjects (two men and two women) in three different levels of classes.

Rockerfeller and Burke (1979) examined six young women in a three day per week, 30 minute aerobic class for a 10 week training period. Significant pre-post test differences were found for VO_2 max., maximal pulmonary ventilation, maximal working capacity on a bicycle ergometer, submaximal heart rate, and submaximal perceived exertion. They concluded that aerobic dance of this intensity was able to elicit significant physiological and psycho-physiological (perceived exertion) changes.

The training responses of college women to aerobic dance and jogging were compared by Milburn & Butts (1983). Fifteen dancers and 19 joggers were compared with a 12 subject control group for VO_2 max., maximal treadmill running times and maximal heart rates over a seven week period. The experimental subjects trained four days a week, for 30 minutes a day, at an intensity of 83 - 84% of their initial maximum heart rates. Significant differences were found in the experimental group for all variables examined. The researchers concluded that aerobic dance and jogging were equally effective for improving cardiovascular endurance.

Physical work capacity, cardiovascular function and body composition in aerobic dancers were examined by Dowdy, Cureton, DuVal & Ouzts (1985). They followed 28 women (18 in an experimental group) for 10 weeks in a 45 minute, three day a week aerobic class. Heart rate during submaximal treadmill walking, VO_2 max., resting heart rate and blood pressure, and body composition were measured before and after and compared with a control group. The experimental group had significant improvement in VO_2 max., resting heart rate, time on the treadmill and heart rate during submaximal stages of the treadmill test. They did not find a significant difference in blood pressure, body weight, percent fat, fat weight, fat-free weight, sum of skinfolds and sum of girth measurements. They concluded that aerobic dance does offer cardiovascular benefits but dietary manipulation is needed to alter body composition.

Lowdon & Ross (1985) in a seven week study of 27 females, new to aerobics, had a dropout rate of 41%. Only one of the subjects quit due to an injury. Although they were able to demonstrate improvement in mobility, timed sit-ups, VO_2 max. and treadmill test sub max scores, they could not demonstrate any changes in pre-post test weight or percent body fat. They felt that beginners may be overstressed and recommended emphasizing long term gains and special group classes for the very unfit, overweight and sedentary.

Blessing, Wilson, Puckett & Ford (1987) examined the effect of hand-held weights on physiological changes in aerobic dance. Twenty-eight college women were measured for body composition and VO_2 max. prior to random assignment into a hand-held weight group and a non hand- held weight group. At the end of eight weeks, no significant differences were found in VO_2 max. or body composition between the two groups. However, a significant increase in VO_2 max. was found within each group. They concluded that aerobic dance does not modify body weight or body composition but does promote cardiovascular fitness. Similarily they did not feel that a one pound weight had any measurable effect on body composition. It should be noted that they started the hand-held weight group at five minutes and added five minutes per week until twenty minutes was reached. This in effect meant that the hand-held weight group used the weights for a full twenty minutes for only four weeks which might not have been long enough to allow a change to take place. Other than increased arm fatigue and upper body muscle stiffness, they did not find an increase in injury rate due to the weights in the hand-held group and concluded that they were safe to use.

Eickhoff et al. (1983) examined the psychological as well as the physiological benefits of aerobic dance. They randomly assigned 39 women to an experimental and control group. The experimental group participated in three, 30 minute aerobic dance classes per week, for 10 weeks. All subjects were examined for sum of skinfolds, resting heart rate, submaximal exercise heart rate, a Total Positive Test (measuring self-esteem) and a Physical Self Test (measuring how each subject viewed their body). They found a statistically significant improvement in resting heart rate and contrary to others (Blessing et al., 1987; Dowdy et al., 1985) in sum skin folds. There was no statistically significant difference in the psychological scores. When the subjects were further subdivided into low fit and high fit subgroups, a statistically significant difference was found for the psychological tests in the low fit exercising group. The sum of skin folds test was only significant for the low fit exercise group. They felt that participation in aerobic dance classes had beneficial cardiovascular effects for all subjects but had the greatest effect on low fit individuals in both a physiological (body shape) and psychological (improved self esteem and body image) manner.

As reviewed, the majority of the research into aerobic dance has focused on the cardiovascular effects but did not examine the injury potential of this form of activity. All authors agreed that aerobic dance can be classified as a true aerobic activity that can produce beneficial cardiovascular changes but did not appear to alter body composition.

Injury Potential

Controversy arises when the safety of aerobic dance is examined (Garrick et al., 1986; Legwold, 1982; Ritchie et al. 1985; Wood, 1986).

Kerr (1984) addressed the qualifications of aerobic dance instructors as a guide for prospective students. She felt that the instructors should be trained to avoid hazardous exercises such as straight leg sit-ups and should understand proper body alignment. She advised a warm-up period including stretching to allow the muscles to prepare for the vigorous exercise to follow. The aerobic exercise should be uniformly paced, allow for individual control and pulse monitoring, followed by a slow cool-down period. Benjamin (1980) agreed and emphasized a proper warm-up with stretching, proper technique and knowing one's limits to prevent injury.

Klemp & Learmouth (1984) in a study of hypermobility in professional ballet dancers concluded that when forward flexion was eliminated as a criterion, the professional dancers were not significantly different from a control group and in fact, had to do warm-up exercises to demonstrate the increased forward flexion with ease. They found that the injury rate was "suprisingly low" in spite of the physical demands.

A proper warm-up and cool-down to prevent injuries, was also strongly advocated by Clippinger-Robertson (1986) . She felt that "too much too soon" was one of the most common causes of injury in dance.

Vetter et al. (1985) suggested that vigorous exercise after a period of inactivity could be a cause of injury. They examined 61 overuse injuries, that occurred over an 18 month period. The subject group was composed of 24 instructors and 37 participants. The amount of dancing per week varied from a mean of 2.8 hours in the participants group to 7.8 hours in the instructors' group. Over 80% of the injuries involved the lower limbs with the highest incidence of injury being diagnosed as plantar fasciitis. Shin splints ranked second, followed by patello-femoral joint pain, stress fractures of the tibia and low back pain respectively. All but seven of the injuries were classified as overuse injuries attributed to accumulated microtrauma without sufficient time to heal. The average delay between injury and the seeking of medical care was 4.8 months. Training errors were attributed to over 50% of the injuries. The main error was starting too active a program following a period of inactivity or in the instructors' case, increasing the amount of teaching time too quickly. They also found a high incidence of abnormal lower leg alignment in the patients with stress fractures and shin splints. The chief deformity was rearfoot valgum - forefoot varus. Aerobic dance injuries comprised less than 1.3% of the injuries treated at this clinic over the 18 month period. The authors felt that with attention to training errors, aerobics was a safe method of achieving fitness.

The repetitive movements inherent in aerobic dance could leave the participant susceptible to overuse injuries. Read (1984) in a case report, discussed a stress fracture of the fibula due to aerobic dance. He attributed it to the excessive amount of the exercise "jumping jacks" that the dance instructor was doing as a part of her aerobic routine. Seder (1987) felt that heel spur syndrome can be attributed to excess running or walking resulting in trauma to the heel. Nigg & Morlock (1987) felt that impact forces were responsible for fatigue fractures and tendonitis.

Richie et al. (1985) found a high injury rate among aerobic dancers and instructors. They surveyed 1,223 students and 58 instructors requesting information regarding personal physical data, shoes, participation level, floor surface, alternate exercise activities and site, severity, disability and treatment of injuries. They defined injury as "any condition causing significant pain and/or limiting participation". They found an injury rate of 43.3% in the students and of 75.9% in the instuctors. Forty-nine percent of the student injuries and 44.8% of the instructors injuries involved the shin, foot and ankle respectively. The severity of the injuries was low with only 9.3% of the students'injuries requiring treatment. Twenty-three percent of the students and 34% of the instructors had to miss classes due to their injury. Analysis of the factors affecting injury revealed a significant relationship between injury and amount of participation per week. They also reported a significant realtionship between injury and length of participation. They felt that the longer one participated in aerobic dance the greater the chance of injury.

Vetter et al. (1985) however, felt that an early, vigorous participant also had a higher chance of injury. A hard floor surface such as carpet over concrete produced the highest injury rate while padded or wood suspension floors produced the lowest injury rate. The use of shoes produced a lower injury rate than barefoot dancing. No relationship could be found between other activity levels such as jogging and injury rate in aerobic dance. They concluded that aerobic dance had a relatively high injury rate and felt injury rate increased with an increase in participation, inadequate shoes and poor floor surfaces.

Francis et al. (1985) also found a high incidence of injuries in 135 aerobic dance instructors that they surveyed with a questionnaire. They did not state their definition of an injury. They found that 76.3% of the instructors had suffered an injury. The shin, foot and back respectively, were the most frequently injured. Thirty-six per cent of the injuries were felt to be an aggravation of an existing problem while 64% were new injuries. When asked to estimate what areas were most commonly injured, the shin, back and knee were the areas most frequently cited. The researchers felt the injury rate could be attributed to poor floor surfaces, footwear, and body mechanics as well as inadequate strength and flexibility, improper warm-ups and too rapid a progression into the program. The instructors taught an average of 7.14 classes per week on a variety of surfaces. It was felt that the high injury rate among instructors may mean that there was a higher than suspected injury rate among participants. They included a number of recommendations concerning floor surface, footwear, warm-ups, instructor education and special classes for deconditioned athletes.

The findings of a high injury rate were contrary to those of Garrick et al. (1986). They followed 351 students and 60 instructors from six facilities for 16 weeks and found only 327 complaints in 29,924 hours of aerobic dance activity. Of the complaints, medical attention was required by only 2.1%. The subjects first completed a questionnaire asking age, height, weight, medical history and activity level. They wre then interviewed weekly, by telephone, to ascertain their activity level and whether they had sustained an injury. Garrick et al. classified an injury in four levels. Grade I was discomfort without alteration of activity level which they interpreted as a complaint rather than an injury. A Grade II injury required the subject to stop aerobic dancing. Subjects with Grade III injury had to stop aerobic dancing as well as alter their daily activity. A Grade IV injury required medical intervention.

Complaints of injuries were voiced by 48.7% of the participants yet almost 75% of these complaints did not cause an alteration of the subjects' activity (Grade I). This incidence was further calculated to be a rate of one student complaint for every 86.2 hours of activity and one instructor complaint for every 107.5 hours of activity. A previous orthopaedic injury was reported by 24.8% of the students and by 28.3% of the instructors. This group had a subsequent injury rate of 57.5% for the students and 70.6% for the instructors. The students with previous foot, ankle, knee or shin injuries were twice as likely to reinjure the same area as the students with no previous history of injury. However, the degree of injury was not different between the two groups. The shin, foot, knee and ankle were the most commonly injured areas for both students and instructors.

There was no significant difference between the types of shoes worn and the injury rate. In spite of a variety of floor surfaces, ranging from carpet over concrete to cushioned wood floors, there was no difference between flooring surface and injury rate. There was a significantly higher injury rate for those who only did aerobic classes when compared to the subjects who had multiple fitness activities.

Garrick et al. classified the injury rate to reflect the difference between complaints which did not alter activity level and an injury that required an alteration or cessation of activity. The injury rate was much lower than that found by Francis et al. (1985) and Richie et al.(1985). By further classifying injury rate as a function of time at risk, the injury rate became quite low; 0.29 per 100 hours of activity for students and 0.26 per 100 hours for instructors.

The main factors that Garrick et al. (1986) were able to identify that led to an increased injury rate were previous orthopaedic injury, attending aerobic classes as the subject's only exercise program and having a minimal attendance of once a week. It was felt that given the cardiovascular benefits and the fact that 39% of their subjects only did aerobics, the injury rate was minimal.

Garrick (1986) offered guidelines for a safe aerobic program. He recommended a gradual, alternate day of exercising, start-up for beginners. Clothing should be sensible and comfortable. Correct shoes should be worn, particularily those offering cushioning across the ball of the foot. The type of floor was not as important as the quality of the instructor who should be knowledgable and should supervise the participants. He also recommended stretching classes to increase flexiblity and no-bounce classes for those wishing to avoid shin splints. He felt most injuries could be managed by a modification of the dance program such as lowering the height of the kicking to lessen hamstring injury. Finally he advised that participants with a history of previous injury and the unfit were more likely to be injured.

An attempt to reduce the injury factor in aerobic dance has led to the introduction of low-impact classes. These are sometimes referred to as non-impact or standing cardio classes. In this type of class, the participant is instructed to keep one foot on the floor at all times. The main goal of the class is to stress the cardiovascular system without the bounce or jumping steps found in regular aerobic dance (Koszuta 1986). To achieve the elevated heart rate throughout the cardiac session, the arms are used more while one foot is always touching the floor. The reduced muscle work of the lower limbs is compensated for by larger and more frequent upper body motion. This type of class is recommended for those participants with poor lower body alignment, sedentary lifestyles, a history of previous injury, and low strength and flexibility levels. It is believed that the decreased impact and time spent on the ball of the foot will reduce strain on the various joints and ligaments and thereby reduce the risk of injury.

Cavanagh, Rodgers & Iiboshi (1987) found pressures under the ball of the foot in standing, were 2.5 times lower than those under the heel. The increased forces were not absorbed by the muscular system. Ericson, Nisell & Elkholm (1986) found the greatest activity of the triceps surae occurs at the beginning of toe-off. Theoretically, a no-bounce class would reduce the forces and strain on this muscle group by eliminating the push-off phase of gait.

Koszuta (1986) questioned this assumption of reduced injury risk. He felt that the types of movement required may simply expose the participant to a different type of injury. Dance steps that incorporated movement patterns that were not natural may predispose the participant to hyperextension injuries or place undue strain on vulnerable areas, such as the patello- femoral joint in the knee. In addition, the different twisting motions may cause individuals with pre-existing low back pain to reinjure themselves.

Incorporating weights in these classes as is commonly found in "strength and tone" classes can expose the participant to a different risk. Koszuta pointed out that adding a two pound weight to the ankle exerted a force that was up to three times greater than the weight on the limb. This could increase pronation and the incidence of muscule strain, could reduce flexibility and could cause muscle imbalance. Martin (1985) found that adding a 1.00 kg weight to the feet of runners increased four temporal and kinematic variables including swing time and peak velocity of the ankle. Correct body mechanics and well trained instructors were necessary to prevent injuries in low- impact aerobics.

In a letter to the editor, Feuerborn & Crockett (1986) drew attention to the problem of elevated blood pressure when exercising with the arms above the head as is frequently found in low-impact aerobics. They pointed out that low-impact classes were targeted at the sedentary, overweight, elderly and pregnant women yet this population may be the one that was at greatest risk for high blood pressure problems. This problem could be aggravated by an increase in heart rate without a corresponding increase in oxygen uptake. They recommended careful monitoring of subjects with cardiovascular problems. They also advised that proper body mechanics and alignment were necessary in both low-impact and regular bounce classes to prevent injury.

Legwold (1982) addressed the safety of aerobic dance and found the dangers were overstated. He pointed out that there were low injury rates associated with aerobic dance provided a few rules were followed. Participants could avoid the competitive aspects found in other forms of exercise and work at their own pace. Properly trained instructors in well planned programs could lower the risk. In spite of the fact that the varied floor surfaces and warm-ups can lead to injury, there was not a great injury rate . He quoted a rate of less than one per cent per year at one company. Cardiac problems were rare due to the fact that the vast majority of participants were young women who are not a high risk group.

Discussion

The literature review supported the cardiovascular benefits of aerobic dance. All studies surveyed that examined physiological parameters, found a significant increase in cardiovascular performance (Blessing et al., 1987; Cearly et al., 1984; Dowdy et al., 1985; Eickhoff et al., 1983; Foster, 1975; Igbanugo & Gutin, 1978; Lowdon & Ross, 1985; Milburn & Butts, 1983; Rockerfeller & Burke, 1979). A program that incorporated 15 to 30 minutes of intense exercise at 60 - 80% of age related estimated maximum heart rate, three times a week will produce improved cardiac function.

Injury rates in aerobic dance were a much more controversial issue. Richie et al. (1985), and Francis et al. (1985) quoted high injury rates. Richie et al. (1985) found 43.3% for students and 75.9% for instructors. Francis et al. (1985) found an injury rate of 76.3% in instructors. This is in contrast to Garrick et al. (1986) who found only 2.1% of participants had to seek medical attention.

Garrick et al. (1986) was the only study to grade the degree of injury. Their Grade I was treated as "complaints" rather than injury and was classified as discomfort without alteration of activity level. If Grade I had been included in the overall injury rate, the rate would have been 48.7%. which was comparable to Richie et al. (1985).

Richie et al. (1985) used a broad definition of injury that would include virtually any discomfort. An injury was defined as "any condition causing significant pain and/or limiting participation" (p.132). If the same grading system that was used by Garrick et al. (1986) was applied, it may be that the injury rate would have been lower. Richie et al. (1985) used a definition of pain that may be too broad to be meaningful. The study used a subjective questionnaire answered by the subjects. A sore muscle that disappeared after 12 hours could have qualified as an injury even though this might not affect the subjects' activity level.

Francis et al. (1985) failed to define their definition of an injury. It was not clear exactly what they were measuring. The researchers not only failed to define injury, they failed to give a time period over which the injuries occurred. The study found that 60% of the participants had taught aerobic dance classes for two years or more but offered no furthur clarification. Garrick et al. (1986) pointed out, if 95% of 10 year veterans of the N. F. L. had sustained an injury , no one would be suprised. It is injuries per time period that illustrate the true risk .

Legwold (1982), pointed out the shortage of research on aerobic dance, particularily so on injury rates. All authors recommended a common sense approach to aerobic dance. A good warm-up, work at your own pace, an adequate cool-down, sensible clothing, shoes and floor surfaces and qualified instructors should produce a low risk exercise program.

In summary, aerobic dance is a relatively new form of exercise that has not had the benefit of adequate scientific research to investigate the safety of the program to the participants. The research to date has been able to demonstrate a significant cardiovascular benefit but has not been able to substantiate claims of weight loss. Investigations into the injury risk of aerobic dance are mainly antecdotal or descriptive in nature.

Normal Biomechanics of the Foot and Ankle

The foot and ankle have 28 bones, over 30 joints, and numerous muscles and ligaments maintaining its structural integrity (Engsberg & Andrews 1987). It has evolved to form a dynamic structure that allows upright movement, is adaptable to varying ground surfaces, and is able to convert the rotational forces of the body into rapid motion in all directions (Inman 1976). The major evolutionary changes that have occurred are the development of an enlarged and elongated hallux and well developed arches (Olsen & Seidal, 1983), and the migration of the talus to a position over the calcaneum (Conroy & Rose, 1983).

This study will examine the foot in terms of three functional units; the rearfoot (talus and calcaneus), the midtarsal area (navicular, cuboid, first, second and third cuneiform), and the forefoot (the first through fifth metatarsals and the phalanges) (Cracchiolo, 1982; Duckworth, 1983). The three functional units will be followed through the normal stance phase of the gait cycle ; heel strike, mid- stance, and toe-off (Tiberio 1987b). Abnormal biomechanics will then be discussed.

When the foot passes through the gait cycle, a number of forces passing down through the body have to be balanced with ground reaction forces passing up from the walking surface (Donatelli 1985b). As this occurs, the foot has to become a loose adapter for shock absorption on an ever changing surface and then turn into a rigid lever arm to allow forward propulsion of the body (Barry & Scranton, 1983; Doxey, 1985; Drez, 1980).

The foot does this by two complex joint movements; supination and pronation. These are triplane motions ocurring in the transverse, sagittal, and frontal planes. Root et al (1977) described five triplane joints in the foot; the talocrural, the subtalar, the midtarsal, the first ray, and the fifth ray. Having oblique axes allows the three separate motions of abduction, eversion and dorsiflexion to occur simultaneously as pronation. Similarily, adduction, inversion and plantarflexion occur as supination. When the foot is in the pronation cycle, it is a mobile structure and the joint surfaces are not in maximum congruence. When the foot is supinated, it becomes a rigid structure where the joint surfaces are in maximum congruence (Donatelli 1985b).

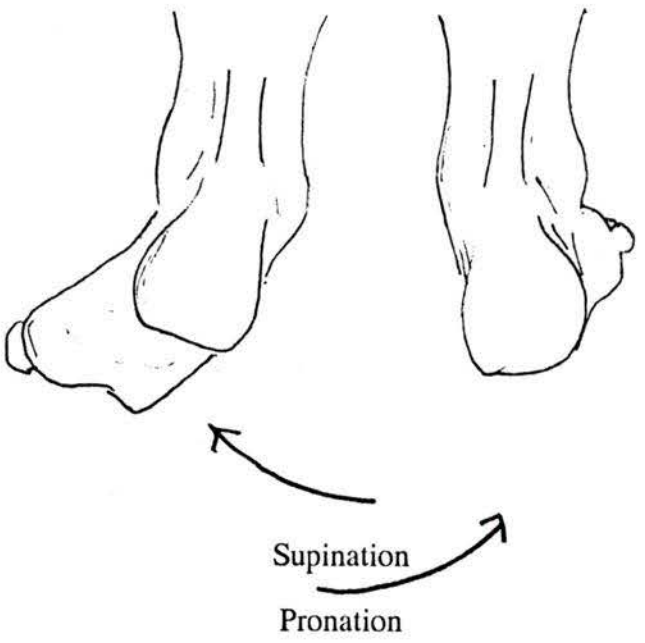

Figure 4: Illustration of Supination and Pronation

Normal Gait

The heel strike phase of the gait cycle begins as the heel strikes the ground and ends when the forefoot becomes fully weight borne (Brown & Yavorsky 1987) and the toes of the opposite foot leave the ground (Taunton, 1979; Wright, Desai, & Henderson, 1964). This consumes approximately 27% of the total stance phase (Brown & Yavorsky 1987). When the foot strikes the ground, it is slightly supinated and begins to pronate upon contact (Heckman, 1980; James et al, 1978; Mann, 1980).

The foot must be a mobile adapter to allow for surface changes, shock absorption of the decelerating body, and to maintain balance (Bordelon, 1983). It is only during the heel strike phase that normal pronation occurs (Ramig, Shadle, Watkins, Cavolo & Kreutzberg, 1980; Root et al., 1977). Compression forces and ground reaction forces rise throughout this phase, peaking at the end of heel strike. As the foot continues through the heel strike phase, the forefoot becomes weight bearing thus spreading the force between the calcaneous and the metatarsals. The forward movement of the body produces an anterior shear of the tibia on the talus (Donatelli, 1985b). This movement is decelerated by the action of the gastrocnemius and soleus muscles (Mann & Hagy, 1979).

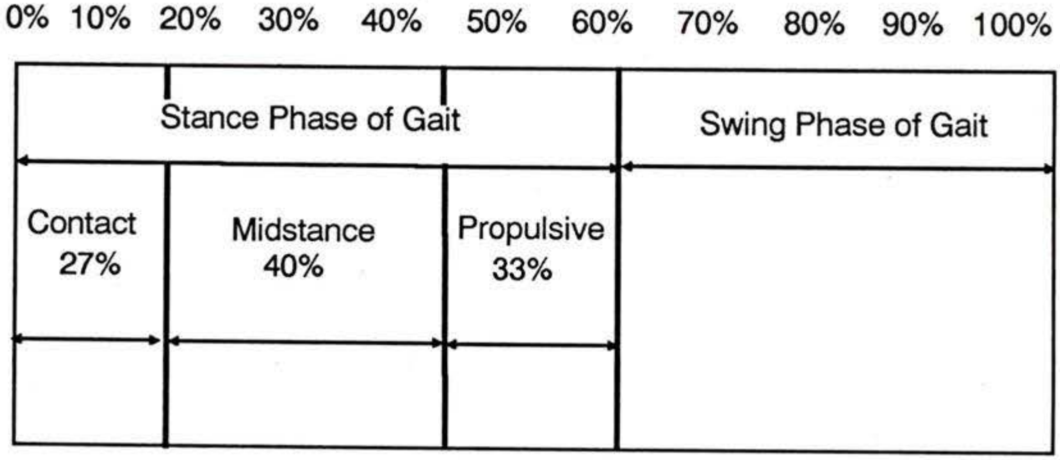

Figure 5: Illustration of Gait Cycle

The tibia is internally rotating on the talus causing a medial shear on the foot. The subtalar joint responds to this shear by causing the calcaneus to move laterally or into eversion (Perry 1983) causing rapid pronation. The talus responds to this by moving in a medial direction (plantarflexes and adducts) to fully articulate with the sustentaculum tali. This movement of the talus and the calcaneum has been described as the torque convertor of the lower limb (Beckman, 1980; Inman, 1976; Root et al., 1977). The transverse rotations of the lower limb are converted by the subtalar joint into the triplane motions of pronation and supination.

As the subtalar joint pronates, the midtarsal joint follows and pronates (Inman 1976). The foot becomes unlocked thus allowing it to become a mobile adapter to the ground surface. The unlocking of the midtarsal joint is evidenced by the lowering of the medial arch (Barry & Scranton, 1983; DeLacerda, 1980a, 1980b). Root et al. (1976) stated normal motion available at the subtalar joint is twice as much inversion as eversion of the calcaneus from subtalar neutral.

As the foot moves from the heel strike to the mid- stance phase, it prepares to become a rigid lever for forward propulsion during the toe-off phase. The mid-stance phase consumes approximately 40% of the stance phase (Brown & Yavorsky 1987). This is acomplished by supination of the subtalar joint initiated by the supinating action of the soleus, gastrocnemius, tibialis posterior, flexor digitorum longus, and flexor hallucus longus muscles (Donatelli, 1985a) and the stabilizing effect of the intrinsics on the midtarsal joint (Mann & Inman, 1964).

The lower limb begins to externally rotate as the body moves over the foot and the contralateral limb swings forward. This action causes a lateral shearing force promoting a supination motion. Supination is initiated by the calcaneus moving into inversion, locking the subtalar joint. As the subtalar joint is locking, the midtarsal joint moves into supination (Mann & Inman, 1964). Locking of the midtarsal joint stabilizes the cuboid and navicular allowing a more efficient action of the peroneous longus and tibialis posterior which in turn helps to stabilize the first ray.

During the midstance phase, as the foot passes from pronation to supination, all of the body weight is borne by the stance foot. The foot should be in a neutral position just before heel lift (Subotnick 1980). Green, Sgarlato, & Wittenberg (1975) note that as the foot moves to the more neutral position and on to supination, the first ray becomes plantarflexed on the talus and navicular. As body weight continues forward, the first metatarsal phalangeal joint begins to dorsiflex producing tension on the plantar fascia (Sarrafian 1987) thus furthur assisting supination (Katoh, Chao, Morrey & Laughman, 1983). This effect has been termed the windlass effect (Boissonnault & Donatelli, 1984; Mann & Hagy, 1979).

At the toe off phase, which consumes 33% of the stance phase (Brown & Yavorsky, 1987), the heel begins to rise off the ground. Supination continues to increase the efficiency of the foot to serve as a rigid lever arm for propulsion. Vertical ground reaction forces peak at the end of this phase as the weight of the body is borne by the ball of the foot and the toes (Bojsen- Möller, 1979; Root et al. 1977). Body weight shifts from the lateral border of the forefoot to the medial side causing the weight to be relieved from the fifth metatarsal head at the start of toe off and to shift to the head of the first metatarsal at the end of this phase. The intrinsic muscles work strongly during this period to maintain the structural integrity of the rigid lever arm (Mann & Inmann 1964). Flexor hallucis plantarflexes the first ray and maintains it strongly against the sesamoids in preparation for push off. The other toes also plantarflex and stabilize against the ground. The body weight continues to move medially toward the contralateral limb.

In summary, a number of factors are necessary in each part of the stance phase for normal biomechanics of the foot to occur. In the heel strike phase the foot lands slightly supinated and then rapidly pronates to absorb the compressive and shear forces and attenuate them with the rotational forces from the body. It does this through pronation of the subtalar joint and eccentric muscle contractions of the supinating muscles. In midstance the foot must move from a pronating cycle to neutral in preparation for a supination cycle. In toe-off the foot moves into supination therby locking the midtarsal, and first ray in preparation for propulsion as all of the body weight passes off the first metatarsal head.

Abnormal Biomechanics of the Foot and Ankle

Pronation of the foot is a necessary part of gait. However, pronation that is in excess of the normal motion is felt to be a major cause of abnormal biomechanics (James et al., 1978). Root (1977) stated that pronation should only occur in the contact (heel strike) period which occupies the first 27% of the stance phase. Subotnick (1980) stated that pronation should occur in the first 14-15% of the time that the foot is on the ground and the foot should be close to neutral by the middle of midstance. Taunton, Clement, Smart, Wiley & McNicol (1985) used the term compensatory overpronation, while other authors used the term excessive pronation (Bates et al. 1979; Sperryn & Restan, 1983; Vogelbach & Combs, 1987) to describe an abnormal amount of pronation.

Ground reaction forces are greatest at heel strike and at toe-off (Doxey, 1987; Root et al., 1977).

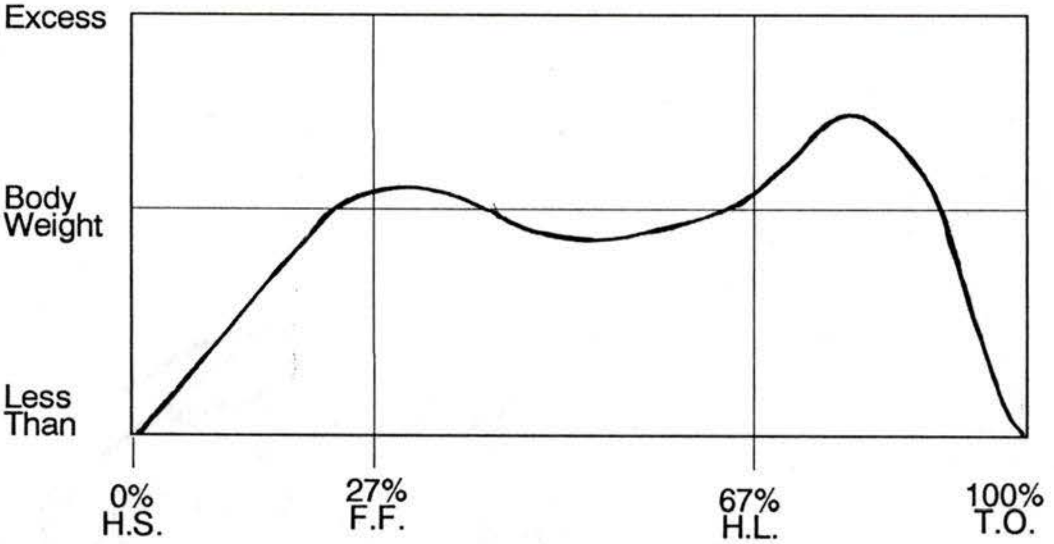

Figure 6: Ground Reaction Forces

Robbins and Hanna (1987) stated that sudden loading of the foot due to ground contact can produce forces up to 2.5 times one's body weight. Any abnormality in the biomechanics of the foot and ankle, such as excessive pronation, would leave the musculo-tendonous-ligamentous structures vulnerable to forces that they could not attenuate.

Pronation that occurs beyond the heel strike period causes a number of common deformities in the foot such as hallux valgus and neuromas (Root, 1977), tarsal tunnel syndrome (Radin, 1983), shin splints (Vogelbach & Combs, 1987) and achilles tendinitis (Taunton, 1979).

James et al. (1978) found the most common abnormalities that contribute to excessive pronation were decreased dorsiflexion, tibial varum, subtalar varus and forefoot supination. Bates et al. (1979) agreed with these findings and felt that excessive pronators have two or more of these conditions. Sperryn & Restan, (1983) cited overpronation to be a factor in 46% of athletes examined with resistant symptoms. They found the most common abnormalities to be calcaneal inversion (42%), forefoot malalignment (38%), tibial varus (14%), and leg length discrepancies (16%).

Taunton et al. (1985) used the term varus alignment (tibial varum, subtalar and/or forefoot varus) to describe findings in compensatory overpronation. Root (1977), and Donatelli (1985a) cited forefoot varus as the most common deformity compensated for by excessive pronation. Hughes (1985), in a retrospective examination of stress fractures in excessive pronators, found forefoot varus and decreased dorsiflexion to have a significant effect on developing the injury. Nigg, Luethi, Stacoff & Seguesser (1984) felt the pain may be due to a misalignment of the forces acting on the heel and leg.

Abnormal Gait

Normal movement in the foot requires at least 10 degrees of dorsiflexion at the talocrural joint (Donatelli, 1985b, Perry, 1985; Root et al., 1971; Root et al., 1977; Tiberio, 1987a; Vogelbach & Combs, 1987). Dorsiflexion can be limited by a tight gastrocnemus-soleus complex (Bates et al. 1979) or a loss of joint motion at the talo-fibular and or talo- tibial articulations (Kaumeyer & Malone 1980). Inman (1976) describe the talus as being wedge shaped thus necessitating a spreading of the mortice to allow the talus to dorsiflex. This movement allowed the tibia to move forward over the talus at mid stance as the foot prepared to supinate. The lack of dorsiflexion caused the motion to be compensated for anterior to the talocrural joint in either the subtalar joint through prolonged eversion or in the midtarsal joint by dorsiflexion of the first metatarsal on the firstt cuneiform (Donetelli, 1985a; Tiberio, 1987a). Taunton et al. (1985) stated the greatest motion occuring between heel strike to midstance was eversion. The eversion was one of the three components of pronation and was used by some authors (Bates et al., 1979) to approximate the true action of pronation.

A foot that stays in eversion beyond midstance delays the onset of supination and does not allow locking of the foot for propulsion. James et al. (1978) stated subtalar pronation was required to compensate for lack of ankle dorsiflexion. Compensatory pronation at the subtalar joint may provide up to 10 degrees of apparent dorsiflexion thereby maintaining pronation into the supination phase of the gait cycle (Hughes, 1985).

Similarily, if the compensation occurs through dorsiflexion of the midtarsal area, the first ray cannot become a rigid lever arm as body weight moves on to it. Supination of the foot requires plantarflexion of the first ray with stabilization of it by the peroneus longus using the cuboid pulley, and by the tibialis posterior, using the medial malleolus, to lock it into the midtarsal joint. Failure to stabilize the first ray maintains the foot in pronation. If there is not enough available movement in eversion or dorsiflexion of the first ray, the foot responds by abducting to allow the body to move over it. Green et al. (1975) noted this in a study of forefoot varus.

Rearfoot varus contributes to overpronation during the heelstrike and midstance phase of gait. To compensate for this deformity, the calcaneus must evert from its inverted subtalar neutral position (Root et al. 1977; Vogelbach & Coombs, 1987) to try to position the calcaneus as near to vertical as possible. Subtalar pronation is the only mechanism that can accomplish this. If the rearfoot varus deformity can be compensated by calcaneal eversion to vertical, no further pronation is required. As long as the heel is on the ground, the subtalar joint remains pronated to maintain vertical heel alignment. The subtalar joint must remain pronated until the heel is lifted off the ground, delaying the onset of supination and leaving the forefoot vulnerable to weight-bearing before it has fully locked.

Once the heel has left the ground the foot is free to function normally. Root et al. (1977) felt this type of deformity yielded only mild symptomatology. Taunton et al. (1985) felt a rearfoot varus under three degrees was unremarkable. The amount of calcaneal eversion possible from subtalar neutral and the degree of rearfoot varus present determine the length of time required for pronation of the subtalar joint and the delay of supination necessary.

A forefoot varus deformity creates overpronation in the foot in two different manners. The rearfoot may function normally but a forefoot varus deformity may still exist (Jahss, 1983). As the foot moves into midstance, the first ray is off the ground and unable to take weight. The subtalar joint compensates for this by maintaining pronation (Donatelli, 1985a). Excessive pronation causes the midtarsal joint to stay unlocked. The first ray then becomes hypermobile as it depends on the chain of locking from the subtalar joint to fix it snugly against the navicular. The efficiency of the peroneus longus, using the cuboid pulley, to stabilize the first ray in a posterior and lateral direction is decreased. Instability of the first ray decreases the ability of the foot to propel the body forward in the toe-off period, and causes the first ray to dorsiflex further adding to its instability. Compensation by the subtalar joint causes the calcaneus to move into eversion. This untwisting of the interconnecting ligaments of the rearfoot and forefoot causes the medial arch to lower to the ground (Franco, 1987). This further adds to stress on the medial structures of the foot and over time leads to a planus foot (Root et al., 1977).

If the calcaneus is unable to evert enough to compensate for the forefoot varus, the talus remains pronated and weight stays on the lateral aspect of the foot. As the heel begins to lift, the foot rotates into an abducted position by spinning on the fifth metatarsal head and the weight rolls off the medial aspect of the hallux (Donatelli, 1987; Root et al., 1977). The first ray does not bear weight in either compensated or uncompensated forefoot varus.

Subotnick (1975) attributed "overuse" syndromes to prolonged pronation. The emphasis of his approach was placed on rearfoot control. In an article on leg length Subotnick (1981) felt pronation of both feet can cause an excessive lumbar lordosis leading to low back pain. Kosmahl & Kosmahl (1987) felt abnormal pronation led to the development of calcaneal traction spurs and plantar fasciitis due to an increased traction force.

James et al. (1978) in a study of 232 running injuries stated:

> "(1) There is a position in which the foot will function most efficiently and with the least amount of stress being exerted on the joints, ligaments, and tendons. (2) With weight bearing, the foot should functionally be positioned such that the vertical axis of the heel is parallel to the longitudinal axis of the distal one-third of the tibia and the plane of the metatarsal heads is perpendicular to the heel. (3) These relationships should exist with the subtalar joint in 'neutral position' " (p 41).

They used the term pronation to describe motion at the subtalar joint and felt it was caused as a compensation for anatomical conditions such as subtalar varus and forefoot supination (varus). They could not find a correlation between any single anatomical variation and any specific diagnosis of injury, yet all of the feet in the study demonstrated forefoot supination. Fifty-six per cent of their study presented with subtalar varus. Subtalar varus and forefoot supination were treated with orthotic devices and reduced dorsiflexion was treated with stretching. James et al. did not offer a breakdown of success rates by specific anatomical variation.

Bates et al. (1979) offered a follow-up study to James et al. where six runners were filmed running barefoot, with shoes, and with shoes and orthotic devices. Bates et al. defined pronation as "eversion of the calcaneus relative to the midline of the lower leg". (p 339). They found a significant difference between running barefoot and with shoes plus orthotic devices for maximum pronation, occurrence of maximum dorsiflexion later in the support phase, and reorientation of the heel. They also found a strong relationship between reduced ankle dorsiflexion and pronation. Significant differences were found for this variable between running barefoot and running with shoes but not between shoes and shoes plus orthotics. A shoe with a low heel (8 mm) was found to reduce the period of pronation, amount of maximum pronation and maximum ankle dorsiflexion. There is not a breakdown of anatomical variations that caused the excess pronation problem.

Drez (1980) recommended allowing the foot to function as nearly as possible to a subtalar neutral position thereby preventing or reducing abnormal compensatory motions. Ramig et al. (1980) stated forefoot varus was a frequent cause of overpronation.

Lutter (1982) cited pronated feet that showed a pattern of injuries such as metatarsalgia, medial tibial syndrome, and plantar fasciitis. He recommended orthoses for an anatomic abnormality in conjunction with over-use injuries and for controlling pronation.

Taunton et al. (1982) found, in 40 cases of plantar fasciitis, 32 biomechanical foot faults related to poor dorsiflexion, forefoot varus, rearfoot varus or a combination of them. The most common cause of excessive pronation was combined forefoot and rearfoot varus.

Sperryn & Restan (1983) did a retrospective study on 50 athletes treated for foot deformities. Their initial findings were that 42% had subtalar varus, and 24% had forefoot varus. Doxey (1985) advocated correction of forefoot problems by establishing normal biomechanical function. Burkett, Kohrt & Buchbinder (1985) were unable to find a significant difference in linear displacement of the knee between barefoot running, running with shoes or running with shoes plus orthotics.

Taunton et al. (1985) examined overpronation in 10 runners. They felt compensatory overpronation was due to a varus alignment consisting of a notable degree of tibial varum, subtalar and/or forefoot varus, examined in a non weight-bearing position. They felt a subtalar varus of 3 degrees and forefoot varus of 2 degrees was unremarkable while a subtalar varus or forefoot varus of 4 to 6 degrees represented mild varus alignment. Forefoot or subtalar varus alignment of 7 to 10 degrees represented a moderate varus alignment while forefoot or subtalar varus alignment of 10 degrees or greater represented severe varus alignment.

Summary of Biomechanics

The review of literature demonstrated three common findings in overpronation, limited dorsiflexion, subtalar varus and forefoot varus, but little agreement on which variation in the normal biomechanics is the most significant in compensatory overpronation. Pronation is composed of three motions; eversion, abduction and dorsiflexion. Rearfoot control as afforded in most sport shoes would only limit eversion, effectively stabilizing the subtalar component. It would not correct a forefoot varus deformity but would only stop the forefoot rolling down to the ground. This would produce either an uncompensated forefoot varus deformity evidenced by an increase in abduction of the forefoot (Root et al. 1977) or would necessitate an increase in dorsiflexion at the metatarsal first cuneiform joint. Overpronation prevents locking of the foot and should have an effect on performance due to the inefficient propulsion at toe-off. Specific measurements for each component will be used in an attempt to discern if one component is more important than the others.

Flexibility

Flexibility of the muscles and joints of the lower limb has been advocated as a preventative measure to limit the occurance of overuse injuries (Bates 1985, Taunton et al. 1982). James et al. (1978) felt that the use of stretching of the calf and hamstring muscle groups was a significant prophylactic treatment for injuries in runners. Mckenzie et al. (1986) agreed and recommended stretching before and after running to help prevent overuse injuries. Hughes (1985) stated that tight calf muscles may cause the foot to overpronate due to a loss of normal dorsiflexion.

In a study of the first metatarsophalangeal joint, Creighton & Olson (1987) found a significant loss of extension in runners with plantar fasciitis. They advocated the examination of this joint in all prerunners'evaluations. Warren & Jones (1987) found dorsiflexion ability and ankle flexibility were factors in predicting runners with plantar fasciitis.

Tiberio (1987a) felt that many subjects did not have a normal dorsiflexion of 10 degrees and relied on the height of their shoes' heels to compensate. Lindsjöm, Danckwardt-Lillieström & Sahlstedt (1985) felt 20 - 30 degrees of dorsiflexion was necessary for athletic activities.

Clippinger-Robertson (1986) felt that most dance injuries were caused by "too much too soon" and felt that lack of flexibility was a cause of injury. Gans

(1985), in a study of shin splints in ballet dancers, recommended stretching as a preventative measure. Benjamin (1980) agreed and stated that lack of stretching could cause muscle tears. He felt that well stretched out muscles offered a degree of protection against injuries.

Francis et al. (1985) found that all aerobic dance instructors in their survey used stretching as a part of their classes with a mean of 9.6 minutes prior to dancing. They recommended static stretching before and after the aerobic exercise. Kerr (1984) also recommended static type stretches for aerobic dancers and cautioned against ballistic or jerky movements. Garrick (1986) cautioned that increases in flexibility were slow and participants in stretch classes should exercise prudence.

Condon & Hutton (1987) examined four types of stretching techniques for the ankle plantar flexors. They examined the differences among static stretch, hold - relax, agonist contract and hold - relax agonist contract types of stretching. They did not find a significant difference between the four groups and felt that complicated stretching programs utilising muscle relaxation were unnecessary. Wilford, East, Smith & Barry (1986) found that flexibility could increase with a stretching program but that a prior warm-up by jogging did not have a significant increase in movement when compared with stretching alone.

Hornsby, Nicholson, Gossman & Culpepper (1987) examined the difference in isometric plantar flexion muscle torque in 61 women. They found that the tight plantar flexion group was able to produce a significantly greater torque than the loose plantar flexion muscle group. This finding was consistent with the knee flexed and extended. Their normative data found a mean passive dorsiflexion of

-3.7 degrees (SD 4.3) with the knee extended. This could imply that tight muscles producing a greater force may contribute to injury.

Henricson, Larsson, Olsson & Westlin (1983) studied the relationship between a stretching program for the calf muscles and achilles tendinitis. They did not find a significant difference between the subjects and a control group. They concluded that a tight or loose calf muscle had no relationship on a subsequent achilles tendon injury in badminton players. Gould (1983) however, felt that a well stretched achilles tendon allowed adequate dorsiflexion leading to correct balancing of the medial arch.

Powell et al. (1986) in an epidemiological study of the causes of running injuries did not feel that stretching was a factor in injury prevention. They pointed out that most injured runners were told to stretch and this may have influenced the analysis. Similarily, McQuade (1986) in a comparison of 250 injured and non-injured runners failed to find statistical significance between those runners who stretched and those who did not. The difference was not apparent for those who stretched before only, before and after, after only or did not stretch at all. Only when statistical adjustment for a larger sample size was applied, did any importance of stretching become significant. The relative risk of injury for the subject groups was greatest for those groups that did not stretch after. He questioned whether the effect of stretching may not be due to the stretching itself but rather whether a runner who stretches might be more conscientious about his running in general and therefore avoid injury.

Klemp & Learmouth (1984) examined hypermobility in professional dancers. When forward flexion was excluded they could not find a significant difference between the dancers and a control group in overall flexibility. They noted that although forward flexion was greater in the dancers, a warm-up period was required by the dancers in order to do this movement with ease.

The effect of stretching on injury prevention appears to be antecdotal. Although virtually all aerobic dance programs advocate the use of stretching, research into the causes and prevention of injuries in dancers has not been able to demonstrate a cause - effect relationship.

Methodology

Limitations

This study only examined the relationship between injury rate and the biomechanical risk factors of abnormal dorsiflexion, abnormal rearfoot motion, abnormal forefoot motion and general lower limb flexibility as measured by a sit and reach test in a subject group of 212 female participants in aerobic dance classes. The results are only applicable to the subject group tested; female, volunteer, aerobic dance participants in the city of Victoria.

Measurement System

All measurements of ankle dorsiflexion, rearfoot and forefoot position were done with a medical goniometer using standard measurement technique described by Root, Orien, Weed & Hughes (1971). In order to eliminate instrument error, an error margin of 4 degrees was added to all subjects' goniometer readings used in the testing.

Measurement Procedure

The following measurement procedure favored by Root et al (1971) was used;

Subtalar Neutral: The subject was prone with the knees extended and feet over the end of the table. The tibia was placed so that its borders were equidistant from the table. The medial and lateral borders of the calcaneus were palpated and a line was drawn bisecting them. The distal one third of the leg was bisected and a line was drawn. The calcaneus was first inverted and the angle produced was measured. The calcaneus was then everted and the angle produced was measured. The subtalar neutral position was then calculated using the following formula.

Rearfoot Formula:

1. Total Range / 3 x 2 = Inversion from neutral
2. Inversion from leg - Inversion from neutral = Neutral Position

If inversion from the leg was greater than inversion from neutral, a rearfoot varus deformity was present.

If inversion from the neutral position was greater than inversion from the leg, a rearfoot valgus was present.

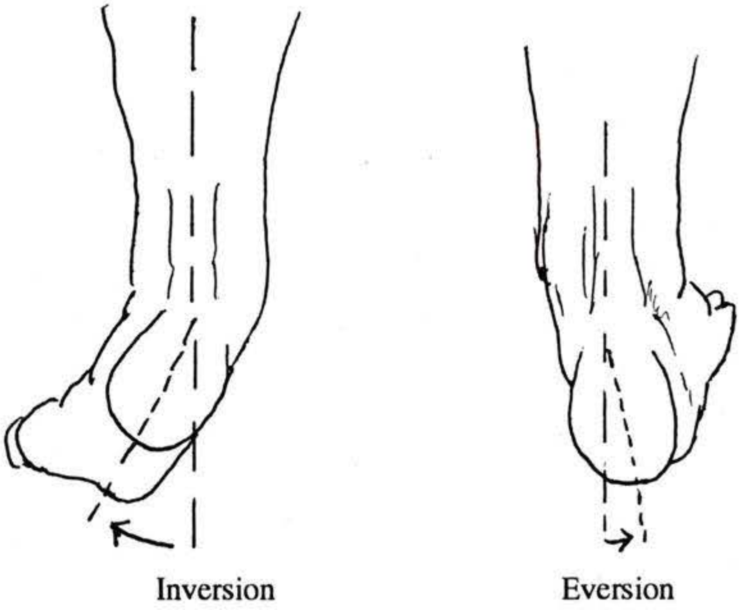

Figure 7: Rearfoot Measurement

Dorsiflexion: The subject was prone with the knee extended and the feet over the end of the table. The subtalar joint was placed in neutral. The subject's ankle joint was passively dorsiflexed to maximum while maintaining subtalar neutral. The angle between the plantar aspect of the foot and a line from the musculotendinous junction of the triceps surae to just proximal to the lateral malleolus was measured.

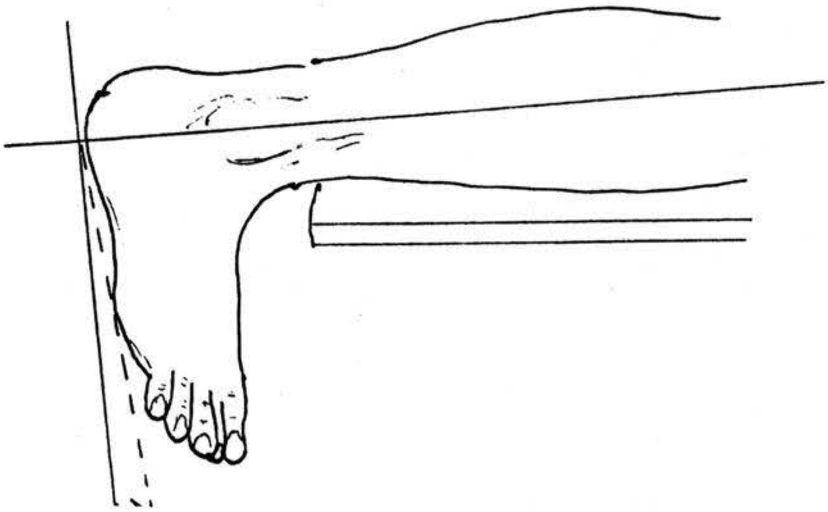

Figure 8: Measurement of Dorsiflexion

Forefoot: The subject was prone with the subtalar joint in neutral (Mann, 1982). The forefoot was passively dorsiflexed to resistance, without allowing any calcaneal motion, by pressure on the neck of the fifth metatarsal (McPoil, Knecht & Schuit, 1988). The angulation between the forefoot and rearfoot was measured.

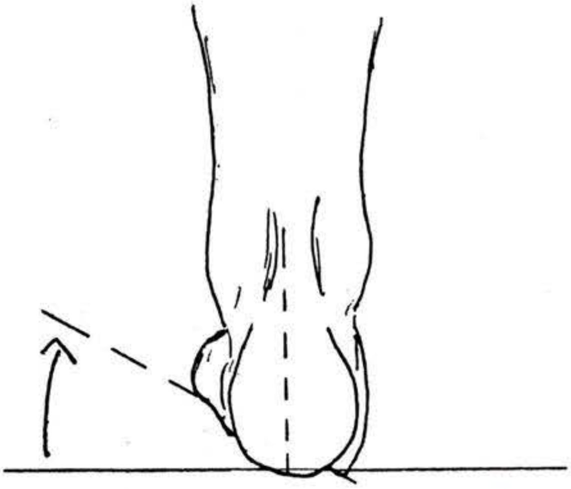

Figure 9: Measurement of Forefoot

Instrumentation

All measurements of true dorsiflexion, subtalar varus and forefoot varus were done with a standard 360 Degree Universal Goniometer made of clear plastic calibrated in 1-degree increments. The goniometer was validated against known angles of 0, 45, 90, 135, & 180-degrees. All measurements were taken using a standard method and bony landmarks were marked on each subject with ink. The scale on the goniometer was shielded until the measurement had been taken.

Goniometer Reliability

The universal goniometer is one of the main tools used in physiotherapy to assess movement. Fish & Wingate (1985) examined the accuracy of goniomteric measurements with 46 untrained subjects and compared the readings to photographic measurement. They found a standard deviation of +/- 2.8 degrees. They concluded that accuracy of photographic measurement was greater than by standard goniometry and that labeling of bony landmarks and use of goniometers that permit raters to view the joint axis of rotation (clear plastic) enhanced standardization.

Henricson et al. (1983) found the error from repeated measurements of dorsiflexion to be 1.5 degrees. Mayerson & Milano (1984) using two examiners, found repeated measurements under controlled conditions can be expected to fall within 4 degrees of each other. They studied a variety of joints and attributed error to instrument placement and readings. Olerud & Berg (1984), in a study of the Q angle of the knee, found, when the foot position was standardized, there was no difference between photographic and direct measurement methods.

Pandya et al. (1985) found, in a study of intratester and intertester reliability, that intratester reliability for all measurements of the ankle joint was high (ICC = .90). Gogia, Braatz, Rose & Norton, (1987) had intertester reliability of r = .98 and validity of r = .97-.98 in a study of goniometric measurements at the knee. Walker, Sue, Miles-Elkousy, Ford, & Trevelyan (1984) in a study of multiple joint measurement with four investigators, found all Pearson correlation coefficients for intratester reliability to be above .81. They used a 360 degree universal clear plastic goniometer validated against known angles.

Stratford, Agostino, Brazeau, & Gowitzke (1984) developed strategies for accurate goniometer measurement. They suggested a uniform method and the use of universal landmarks. The major divisions on each side of a 360 degree goniometer were to be checked with the value lying in between the two. The instrument had one degree increments and the scale on the goniometer was to be shielded until the measurement had been taken.

Sit and Reach Test

The sit and reach test is an indirect method of assessing flexibility of the low back - hamstrings. It is commonly used in fitness assessments of athletes (Minister of State, Fitness and Amateur Sport, 1986).

The test was first described by Wells & Dillon (1952). The subject sat on the floor with the legs slightly apart and knees extended and feet placed against an immoveable board. The subject then reached forward with the hands toward a scale on the testing apparatus. The subject held the maximum reach position after bobbing forward four times. The distal point reached was recorded on a scale on the testing apparatus. Wells & Dillon (1952) stated a high reliability with a correlation coefficient of 0.98.

The exact procedure has been modified by various authorities. The Canadian Standardized Test of Fitness recommended a 20 second per leg stretch warm-up, a slow reach and holding the farthest position for two seconds. Two trials were taken and the participant was allowed to lower the head forward (Minister of State, Fitness and Amateur Sport, 1986). Mathews, Shaw & Woods (1959) instructed the participant to slowly reach forward and allowed only one attempt.

Docherty & Bell (1985) used the mode of three trials and instructed the subjects not to strain to reach the end point.

Cotten (1972) in a review of trunk flexibility tests felt that leg length was not an important factor. He found a reliability of 0.95 for women and 0.98 for men on the Wells sit and reach test. The subjects were allowed a two minute warm-up, were allowed to bob three times and then hold the fourth attempt.

Smith & Miller (1985) examined the effect of head position on the sit and reach test. They allowed a standardized warm-up and four attempts at reaching, holding on the last attempt. They found that keeping the head up produced a small but significant difference in improved performance. Patton & Newby (1987) instructed their subjects to bend forward as far as possible with the head down when reaching. They used the best score from three trials. Subjects were instructed to place one middle finger on the other to assure a uniform measure.

Fieldman (1968) felt that the warm-up affects the ability of the hamstring muscles to contribute to hip joint flexion in a toe-touch test. Jackson & Baker (1986) found a moderate relationship (r=.64) between the sit and reach test and hamstring flexibility.

Although the test did not offer a precise measure of total range of motion, Hubley (1982) felt that it could be used for within-subject comparisons. Cotten (1972) stated that the sit and reach test required a minimum of equipment and time.

General flexibility including hamstring stretching is usually a part of the cool-down phase of an aerobics class. In addition, the commonly used aerobic dance step known as high kicks require a flexible hamstring muscle. A participant who has attended on a regular basis should be able to demonstrate an improved flexibility of their hamstrings which should be demonstrated on a sit and reach test. This test was used as a general assessment of the subject's lower limb flexibility as it involves muscle groups that play a major role in aerobic dance.

As activity level before the examination might affect the measurement results, all subjects were allowed a short warm-up prior to administration of the test. The test was administered by the three trials of non-jerking movements followed by a fourth attempt which the subject held for two seconds. The head was looking up at the scale of the flexometer.

Research Design

All subjects were informed of the nature of the study and participation was on a voluntary basis. A consent form was issued prior to each test (see Appendix 2). The subject population was comprised of 212 females who participated in conventional aerobic classes. The subjects were followed for a 12 week period following initial examination. All subjects were contacted on a bi-weekly basis to report on their activity level and injury status. If an injury was present, the location and type of injury was ascertained

For this study, the level of injury was based on a scale of four grades. Grade I through IV were based on rankings similar to those used by Garrick et al. (1986). Grade I was a problem that resulted in discomfort but did not alter either aerobic dance or other daily activities. Grade II was a problem that resulted in alteration or cessation of aerobic dance activities only. Grade III was a problem that resulted in in alteration or a cessation of aerobic dance and alteration of normal daily activities. Grade IV was a problem that required medical intervention. For the purpose of this study, an injury only referred to grades II to IV. Grades I to IV were viewed as the apparent, plus the real injury rate. Grade I was therefore viewed as a complaint only.

Three major components of overpronation were examined at the commencement of the study. The major components were 1) dorsiflexion of the ankle joint, 2) rearfoot varus or valgus, 3) forefoot varus.General lower limb flexibility was measured by a sit and reach test.

Descriptive data were collected from the subject pool by use of a questionnaire. Subjects were asked to provide information which included their age, height (in), weight (lb), history of previous injury, degree of injury, history of aerobic dance activity, level of aerobic dance activity and weekly leisure activity level.

Tester Reliability

Tester reliability for passive foot position was determined by two different measurements of five subjects for each position of dorsiflexion, passive rearfoot motion and passive forefoot motion. Pearson product-moment correlation coefficients (r) for intertester reliability were .826 for passive dorsiflexion, .829 for passive rearfoot motion and .933 for passive forefoot motion. The sit and reach test was administered by a graduate in Human Performance from the

School of Physical Education at the University of Victoria. The tester performed fitness evaluations in her occupation. Three attempts were allowed and a fourth attempt was recorded.

Statistical Analysis

Means and standard deviations were calculated for the normative data and biomechanical and flexibility measurements. Correlation coefficients were calculated for the sit and reach test and degree of dorsiflexion.

Scatterplots and histograms drawn for age, height and weight demonstrated that the subject group was a normal population.

Previous studies of goniometric error for intertestor reliability have recorded a variance of from 1.7 to 5 degrees (Fish & Wingate, 1985; Mayerson & Milano, 1985; Walker et al., 1984). Mayerson and Milano (1984) in a study of 22 different joints suggest that "repeated measurements can confidently be expected to fall within 4 degrees of each other" (p.93). Therefore to allow for intertester error, a four degree margin of error was incorporated into the classification system for analysis.

As 10 degrees of dorsiflexion is necessary for normal gait (Root et al., 1977), for statistical analysis, dorsiflexion was grouped into those subjects having 6 degrees or less and those subjects having 7 degrees or more.

Normal rearfoot motion has twice as much inversion as eversion; the rearfoot should be in neither varus nor valgus (Root et al., 1971). Rearfoot movements were grouped into those subjects having an inversion to eversion ratio of 2 / 1, (+/-) 2 degrees or less (2 degrees or less of either varus or valgus) and those subjects having an inversion eversion ratio of 2 / 1 (+/-) 3 degrees or more (3 degrees or more of either varus or valgus).

Forefoot movements were grouped into those subjects having forefoot varus of 4 degrees or less, and those subjects having a forefoot varus of 5 degrees or more. As previous studies have noted a difference between the right and left leg (Rogers & Leveau, 1982; Taunton et al, 1985), for statistical purposes, the 212 subjects were treated as 424 limbs.

Injury rates were analyzed by a Chi-square test to determine if there was a relationship between each measure of biomechanical analysis and general lower limb flexibility and between injury rate. The Chi-square analysis was done for both apparent injury rate (Grades I-IV) and for actual injury rate (GradesII-IV). A Yates' correction was employed for cells of less than five.

Results

The study included 212 female subjects and had a drop-out of 17 subjects over the 12 week period. Anyone who had less than four weeks of aerobic dance was considered to be a drop-out. The reasons for the drop- outs may be found in Appendix 1.

A total of 8115 hours of aerobic dance was recorded. When the drop-outs were eliminated, this total was reduced to 7969 hours of which 5321 were of a bounce type of class (66.77%) and 2648 were of a low bounce type (33.22%). It was not possible to separate the subjects into bounce and low bounce groups as most participants took part in both types of class. The mean aerobic participation over the 12 weeks was 40.86 hours (standard deviation 23.26) for an average of 3.40 hours per week. The minimum number of hours in the subject group was five (less than one per week) while the maximum number was 199 (16.58 hours per week).

Descriptive data for the variables of age, height, weight and sit and reach test appear in Table 1.

Table 1

Means and Standard Deviations for Age Height weight and Sit and Reach Test for all Subjects

Measurement	*N*	*M*	*SD*
Age	212	28.69	7.89
Height *	212	164.80	6.09
Weight **	212	59.25	7.96
Sit & Reach *	210	37.94	6.98

* in centimeters, ** in kilograms

The Means and Standard Deviations for the subject group are found in Table 2. This group does not include the 17 drop-outs. There was a strong correlation between height and weight (*r* =.477, *p*.01) and very weak correlations between age and weight (*r* =.03, *p*.05).

Table 2

Means and Standard Deviations for Age Height Weight and Sit and Reach Test for Subject Group

Measurement	N	M	SD
Age	195	28.61	7.66
Height *	195	164.79	6.05
Weight **	195	59.39	7.96
Sit & Reach *	193	38.11	6.96

* in centimeters, ** in kilograms

Pearson product-moment correlation coefficients (r) for intertester reliability were .826 for passive dorsiflexion, .933 for passive forefoot position and .829 for passive rearfoot position.

A correlation between degree of passive dorsiflexion and the sit and reach test was not significant, r(193) =.122, p.05 for the left limb and r(193) =.132, p.05 for the right.

Group descriptive foot biomechanical measurements appear in Table 3.

Table 3

Group Descriptive Foot Biomechanical Measurements in Degrees for all Subjects

		Foot			
		Left		Right	
Measurement	N	M	SD	M	SD
Dorsiflexion	211	4.597	2.651	5.090	2.349
Forefoot	211	5.436	2.937	4.834	3.278
Rearfoot	211	-0.052	1.885	-0.796	2.142

Group descriptive foot biomechanics for the subject group which did not include the 17 drop-outs are found in Table 4.

Table 4

Group Descriptive Foot Biomechanical Measurements in the Subject Group in Degrees

		Foot			
		Left		Right	
Measurement	N	M	SD	M	SD
Dorsiflexion	195	4.620	2.600	5.097	2.380
Forefoot	195	5.456	2.948	4.907	3.269
Rearfoot	195	-0.076	1.860	-0.789	2.185

There was a total of 81 injuries received by 54 subjects in the subject group during the course of the study. This represented at least one injury to 27.5 % of the subject group over the 12 week period. When broken down by the grading system employed in the study, there were 56 Grade I injuries (69.13 %), 20 Grade II injuries (24.69 %), three Grade III injuries (3.7 %) and two Grade IV injuries (2.46 %). This is a total of 56 complaints and 25 injuries in 195 subjects (390 limbs) in 7957 hours of aerobic dance. The 25 injuries that were Grade II or higher were suffered by 19 of the subjects (9.6 %).

There were eight areas of complaint or injury cited by the subjects. An injury to two limbs at the same time was counted as two injuries e.g. shin splints was two injuries; shin splint was one injury. Ten subjects had injuries to both sides of the body at the same time. If a subject suffered more than one injury, each injury was counted separately. There were eight subjects who suffered injuries to more than one area of the body. Seven subjects suffered repeat injuries during the course of the study. A breakdown of the injury rate by site is found in Table 5.

Table 5

Area and Grade of Injury Cited by Subjects

		Grade				
Area	I	II	III	IV	Total	%
Foot	6	4	1	-	11	13.5
Ankle	5	3	-	-	8	9.8
Shin	17	6	-	-	23	28.4
Calf	6	-	-	-	6	7.4
Knee	12	3	1	-	16	19.7
Quads	1	-	-	-	1	1.2
Hip	2	2	-	-	4	4.9
Back	7	2	1	2	12	14.8
Total	56	20	3	2	81	99.7
Per-cent	68.4	23.7	5.3	2.6		

The Grading system employed had an increasing order of severity and Grade I injuries were recorded as complaints. When all four Grades were included, the shin (28.4 %), knee (19.7 %), the back (14.8 %) and foot (13.5 %) were the greatest areas of complaint. When the Grade I complaints were excluded, the areas of most severe injury were the back (21.7 %), shin (21.7 %) knee (17.4 %), and foot (17.4 %) respectively. (see Table 6).

Table 6

Area and Grade of Injury Above Grade I Cited by Subjects

	Grade				
Area	II	III	IV	Total	%
Foot	4	1	-	5	13.5
Ankle	3	-	-	3	9.8
Shin	6	-	-	6	28.4
Calf	-	-	-	-	7.4
Knee	3	1	-	4	19.7
Quads	-	-	-	-	1.2
Hip	2	-	-	-	4.9
Back	2	1	2	5	14.8
Total	20	3	2	23	99.7
Per-cent	80	12	8		

Statistical analysis was done using a Chi Square test for injury grades two to four inclusive and subsequent injury rate. Grade II or higher injuries to the back were not included in the analysis as it was not possible to determine which foot and ankle complex i.e. left or right, could be related to the lower back injury. There were 17 drop-outs and four back only injured subjects who were excluded leaving a 191 subjects.

There was not a significant relationship between (1) ankle dorsiflexion and subsequent injury rate, X^2 (1, $\underline{N}$ = 382) = .949 $\underline{p}$.15; (2) rearfoot motion and subsequent injury rate, X^2 (1, $\underline{N}$ = 382) = .136, $\underline{p}$.35 (Yates correction); (3) forefoot varus and subsequent injury rate, X^2 (1, $\underline{N}$ = 382) = 2.613 $\underline{pg}$.06 (Yates correction). The findings are summarized in Table 7.

A Chi square test was also used to see if a relationship existed between the four grades of injury and the three biomechanical measurements. When the back injuries and the drop-out group were eliminated, 188 subjects (376 limbs) were included in the study.

There was not a significant relationship between (1) ankle dorsiflexion and subsequent injury X^2 (1, $\underline{N}$ = 376) = .848, $\underline{p}$.15; (2) rearfoot motion and subsequent injury, X^2 (1, $\underline{N}$ = 376) = 1.386, $\underline{p}$.10; (3) forefoot varus and susequent injury rate, X^2 (1, $\underline{N}$ = 376) = .214, $\underline{p}$.25.

Table 7

Relationship Between Subsequent Injury Rate And Biomechanical Measurement *

Measurement	N	Grades I-IV	N	Grades II-IV
Forefoot Varus	376	.214	382	2.163**
Dorsiflexion	376	1.268	382	.949
Rearfoot	376	1.386	382	.136

* Chi-square test, ** $p > .06$

In addition to the 17 drop-outs, two subjects did not complete a sit and reach test. This left 193 subjects in this section. The mean result of the sit- and-reach test (38.1 cms) was used to separate the subject groups into their respective cells for analysis. There was not a significant relationship between those reporting Grades II-IV injury rates and flexibility as measured on the sit and reach test, X^2 (1, N = 193) = 2.213, p.05. In addition, there was not a significant relationship between flexibility as measured by a sit and reach test and injury rate when all grades of injury were examined, X^2 (1, N = 193) = 2.213, p.05. The results are summarized in Table 8.

Table 8

Relationship of Injury Rate And Flexibility as Measured by a Sit and Reach Test

Measurement	N	Grades I-IV	Grades II-IV
Flexibility	193	2.213	2.049*

* not significant

The results of this study were not able to support any of the four hypotheses.

Discussion

Previous studies have implicated decreased dorsiflexion, rearfoot varus or valgus and forefoot varus as probable causes of injuries of the lower limbs (James et al, 1978; McKenzie et al, 1986; Sperryn & Restan, 1983; Taunton et al, 1982). With the exception of the pilot study (Iles & Collis, 1988), a literature review failed to find a study that implicated abnormal biomechanics where the biomechanical assessment was done prior to the injury. This prospective study was unable to demonstrate a relationship between forefoot deformity, rearfoot deformity, or abnormal dorsiflexion and subsequent injury rate in women's aerobic dance classes.

Excessive motion in the foot has been collectively referred to as overpronation (Sperryn & Restan, 1983), excessive pronation (Rogers & Leveau, 1982), excessive foot pronation (Bates et al, 1979; James et al, 1978) or simply pronation in the non-scientific literature. These terms described abnormal biomechanics caused by a reduction in ankle motion, subtalar varus or valgus and forefoot varus, but more correctly described the result of these factors.

Taunton et al. (1985) used the term varus alignment to describe a notable degree of tibial varum, subtalar and/or forefoot varus that necessitated a functional overpronation during weight bearing. Their clinical impression was that a subtalar varus of less than three degrees and forefoot varus of less than two degrees was unremarkable. They required a subtalar or forefoot varus of four degrees or more to represent varus alignment that may require correction. The results of this study were unable to find a significant relationship between forefoot varus, rearfoot varus /valgus when considered as sole factors. It should be noted that Taunton et al. (1985) based their data on runners and not aerobic dancers.

Most authorities felt that abnormal biomechanics were a major factor in injury. Root et al. (1977) felt a forefoot varus deformity would cause instability in the forefoot. Boissonault & Donatelli (1984) felt that forefoot varus would lead to a loss of stability of the medial side of the foot and the loss of normal motion at the first metatarsalphalangeal joint. This led to subsequent development of halluxvalgus or other injuries to the foot. Creighton and Olson (1987) found a significant loss of dorsiflexion in the first metatarsophalangeal in a group of runners with plantar fasciitis. Hughes (1985) demonstrated a significant relationship between forefoot varus and stress fractures of the metatarsals. James et al. (1978) found 58% of their sample to have pronated feet.

An exception was a study by Warren and Jones (1987). They examined a number of anatomical and training variables including rearfoot deformity and ankle dorsiflexion in a study to predict plantar fasciitis. Using a factor analysis they concluded that variables often implicated in the onset of plantar fasciitis were not able to predict runners with plantar fasciitis. All of the studies cited that examined the influence of limited dorsiflexion, rearfoot varus/valgus and/or forefoot varus dealt with subjects who had running as their principle activity (Bates et al., 1979; Creighton & Olson, 1987; Hughes, 1985; Iles & Collis, 1987; James et al., 1978; McKenzie et al., 1986; Sperryn & Restan, 1983; Taunton, 1982; Taunton et al., 1985; Warren & Jones, 1987). The biomechanics involved in running may be a crucial variant in comparing the results of injury rates and biomechanical function with other activities. This may explain why there was not a relationship between any of the variables and injury rate in aerobic dance. Running requires a prolonged repetition of the same movements with the principle variants being speed of movement, type of terrain and distance run.

The subjects in this study did aerobic dance. Although there may be a "running" type of movement in part of an aerobic dance class, the principle components of the class are a variety of body movements that do not necessarily continually stress the same musculoskeletal tissue and do not continue for a prolonged period of time. In addition, participants are free to modify the type of motion and pace of any part of the class to suit themselves. This principle was stressed by all of the instructors that were observed during the course of the study. A subject who reported a Grade 1 knee pain for example, could still participate in an aerobics class by modifying her pattern of movement to remove stress from the knee. This type of modification would not be as easily accomplished if the subject was a runner. Varied movements would not produce a constant repetitive stress on the tissues involved. Different foot and ankle biomechanics would be required for the unusual movements in an aerobic dance type of activity. This in turn could lead to a altered pattern of injury due to different combinations of variables. A comparison with the mechanism of runners' injuries may not be valid.

The fact that all the subjects in this study wore sports shoes may have influenced the results. Most sport shoes on the market have a heel and some form of rearfoot control. If these shoes maintain correct motion, as the manufacturers claim, the importance of abnormal rearfoot deformity and loss of dorsiflexion may be negated by the shoe. This would also explain Taunton's et al. clinical observation that rearfoot varus of under 2 degrees is unremarkable. A sports shoe may also have the ability to decrease the influence of a specific deformity by increasing the functional motion available at the joint. A shoe with a heel will compensate for a stiff talocrural joint by decreasing the amount of dorsiflexion required for normal motion. The terrain that a runner uses has been cited (Bates, 1985; Brody, 1980; McKenzie et al., 1986; Renstrom & Johnson, 1985; Taunton, 1979) as a factor in the onset of runners' injuries. All of the subjects in this study performed on a surface that was suitable to their activity. Three of the centres had a type of cushion floor specific to aerobic dance and the other two used a wooden gymnasium floor. This would be in contrast to the variety of surfaces that runners use.

The fact that there were only a small number of injuries in this study may have influenced the results. There were only 15 subjects (back injuries excluded) that suffered a Grade II-IV injury over a 12 week time period. A longer time period may be required to demonstrate a greater number of overuse type of injuries.

The level of instruction in aerobic dance was of a high calibre. All instructors that taught classes in the study had completed an instructors course that featured the importance of injury prevention. The fact that only 15 subjects had an injury may be related to this fact. Kerr (1984) felt that properly trained aerobic dance instructors would avoid hazardous movements.

Although empirically, increased flexibility should be related to a lower injury rate, the study was not able to demonstrate such a relationship in aerobic dance participants. Numerous authors have advocated a proper warm-up to prevent injury (Benjamin, 1980; Clippinger-Robertson, 1986; Garrick, 1986; Kerr, 1984; Klemp & Learmouth, 1984). Proper instruction might decrease injuries due to poor flexibility. As well the subject group was all female. Bell & Hoshizaki (1981) found females had greater flexibility than males throughout their life. This may explain the lack of a relationship between flexibility as measured by the sit and reach test and injury rate.

Aerobic dance may also be a low injury activity. The injury rate in this study is comparable to that found by Garrick et al. (1986). They had only 327 complaints and injuries among 411 subjects in a total of 29,924 hours of aerobic dance activity. Only 2.1% required medical attention. Legwold (1982) felt the dangers of aerobic dance were overstated and cited a rate of injury of less than one per cent per year at one dance company. In this study, there were 81 complaints and injuries among 195 subjects in a total of 7969 hours of activity. Only 1.02% required medical attention (Grade IV injury).

The literature review failed to find a study of foot and ankle biomechanics and injury rate in aerobic dance. This study did not deal with combinations of variables but rather looked at each biomechanical variable as a separate entity. The study does not support a contention that correcting one of the deformities would decrease injury rates in aerobic dance. It is possible that injury rates in this activity are due to a variety of variables that interact to produce stress on the musculoskeletal system resulting in failure.

This study implies that a direct relationship between specific foot and ankle deformities and subsequent injury rate in aerobic dance can not be supported.

Conclusion

This study did not demonstrate a relationship between the three biomechanical variables of limited dorsiflexion, rearfoot varus/valgus and forefoot varus and subsequent injury rate. It was also unable to demonstrate a relationship between lower limb flexibility, as measured by a sit and reach test, and subsequent injury rate.

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Appendix 1. Drop-outs:

Anyone who had less than four weeks of aerobic dance will be considered a drop-out. There were 17 women who were placed in this category.

Reasons for dropping out:

	Subject Number	Reason
1.	#4	Subject pregnant
2.	#7	Not motivated
3.	#30	Not motivated, too expensive
4.	#33	Hurt knee in other activity
5.	#36	Moved
6.	#40	Poor attendance
7.	#41	Moved
8.	#49	Switched clubs and didn't restart
9.	#73	Too busy
10.	#112	Hurt knee skiing
11.	#113	Switched activities
12.	#125	In hospital / Moved
13.	#150	Unknown - Death in family ?
14.	#151	Unknown - Death in family ?
15.	#193	Holidays for 8 weeks
16.	#195	Unable to contact after initial form
17.	#208	Holiday / Moved

This left an effective n of 195 subjects.

Appendix 2. Survey Form

AEROBICS INJURY STUDY

This study will be examining the risk factors in aerobic dance in an effort to identify areas where improvement in aerobic dance programs can be made. It is part of the requirement for a Master of Arts degree at the University of Victoria and is under the supervision of Drs. M. Collis, R. Bell and R. Backus of the School of Physical Education. All participation is voluntary and ALL PERSONAL INFORMATION WILL BE KEPT CONFIDENTIAL.

You will be required to fill in this form at the start of the study and will be phoned on a regular basis over the following 12 weeks to inquire about the number of classes you have attended and if you have sustained an injury. You will be measured for hamstring flexibility using a sit and reach test and have your feet measured for normal biomechanical function. This will take approximately five minutes of your time.

I UNDERSTAND THE PURPOSE OF THE STUDY AND I CONSENT TO BE IN THE STUDY OF AEROBIC INJURY RATES SUPERVISED BY DAVID ILES.

Signed _ _ _ _ _ _

NAME _ _ _ _ _ _ _ _ _ BIRTHDATE / / /

d m y

Address _ _ _ _ _

TELEPHONE (W)____-______ (H)____-________

Height ( ) Weight ( ) Age ( )

1.Have you suffered an injury in the past year that

a) Caused discomfort but did NOT stop your regular activities?

Y( ) N( )

b) Caused you to alter or stop ONLY your aerobic dance?

Y( ) N( )

c) Caused you to STOP aerobics AND ALTER your normal activities

for at least one week? Y( ) N( )

d) Has required medical care? Yes( ) No( )

If yes, what was your injury and to what part of the body did it occur?

2. How many classes (in hours) of aerobic dance do you attend

per week? _____ Level? Mod. ( ) Intense.( )

3. What type of aerobic class do you attend?

Low-Bounce Regular (Bounce)

4. Do you participate in any other sports eg. Running, Squash, Swimming? Y( ) N( ). If yes, what?

5. Do you stretch at least once a day? Y( ) N( )

Only during aerobics class? Y( ) N( )

6. How long have you been going to aerobics? (months)

7. Do you wear orthotic inserts in your shoes at aerobics?

Y ( ) N ( )

8. What type of shoes do you wear? _ _ _ _ _ _

DO NOT WRITE BELOW THIS LINE

Facility Floor

	TR 1	TR2	TR3
Sit & Reach	cm	cm	cm

	Left		Right	
–			–	
Dorsiflex.				
–			–	
Rearfoot	In	Ev	In	Ev
–			–	
Forefoot				

VITA

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Title of Thesis/Dissertation

BIOMECHANICS OF THE FOOT AND ANKLE
AND INJURY RATE IN WOMEN'S
AEROBIC DANCE

Author [redacted]
(Signature)

DAVID M. ILES
(Name in block letters)

August 22, 1988
(Date)