The Thesis Committee for Brett Donovan Baker Jr.
Certifies that this is the approved version of the following thesis:

The Role of Cross-Training in Swim-Related Injuries in Master's Swimmers

APPROVED BY
SUPERVISING COMMITTEE:

Supervisor:

____
Hirofumi Tanaka

____
Darla Castelli

The Role of Cross-Training in Swim-Related Injuries in Master's Swimmers

by

Brett Donovan Baker Jr., B.S. Kin. Health

Thesis

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Kinesiology

The University of Texas at Austin

May 2017

Acknowledgements

I would like to thank my family and friends for supporting me on my journey back to graduate school. I would also like to thank both Dr. Tanaka and Dr. Castelli for guiding me on my way to my Thesis. In addition, I would like to thank all of my lab members and all the other professors and peers I've interacted with that have helped me.

Abstract

The Role of Cross-Training in Swim-Related Injuries in Master's Swimmers

Brett Donovan Baker Jr., M.S. Kin.

The University of Texas at Austin, 2017

Supervisor: Hirofumi Tanaka

Orthopedic injuries often interfere with Masters athletes' pursuit of better performance and might place economic burden on these athletes. **PURPOSE:** We determined if the incidence of injuries increases with age and the economic burden associated with these injuries and whether the participation in cross-training (running, cycling, dryland resistance training) would reduce swim-related injuries in Masters swimmers. **METHODS:** An online, comprehensive questionnaire was sent to members of United States Masters Swimming (USMS). Response was received from 499 swimmers (294 females, 20-86 years). Economic burden was determined by total healthcare costs. Binary logistic regression was used to compute the odds ratio (OR) of having an injury, using age as a predictor. Linear regression was used to determine the relationship between injury length and healthcare costs. **RESULTS:** Participants had been swimming for 13.3±11.5 years, and 47%, 35%, and 40% participated in dryland resistance training, running, and cycling, respectively. For every 1 year increase in age, the odds of having an injury increased by 1.6% (OR=1.016, 95% CI= 1.001-1.030; $p<0.05$). For every 1 month increase in the length of swim-related injury, healthcare costs increased by 7.4% ($p<0.05$). The OR for having a swim-related injury were significantly less for individuals who participated in each form of cross-training compared with those who did not (p<0.05 for all). The OR for having a swim-related injury was significantly less for those who reported participating in any number of cross-training activities compared with those who did not participate in any (p<0.05 for all). **CONCLUSIONS:** Swim-related injuries increased with advancing age; with longer injuries leading to higher healthcare costs. Participating in any form or any number of cross-training activities attenuated the odds of having an injury in Masters swimmers.

Table of Contents

List of Tables

List of Figures

Review of Literature

Introduction

Over the last few decades, physical activity (PA) has been extensively researched as it has been shown to elicit numerous health benefits [1-5]. Being active even to a modest level, is preferable to being inactive or sedentary [6]. Recently, much interest has been focused on the master's athlete as this group of participants has grown by staggering numbers over the past few decades. As one ages, systemic changes happen that include a gradual impairment of organ systems such that functional reserves are gradually eroded, leaving one progressively more vulnerable to metabolic disturbances, environmental stresses, and disease [7]. Even though PA can't completely reverse the systemic changes that happen as one ages, PA might be able to slow down these changes.

The majority of research on master's athletes has been focused on masters running and to a lesser extent, master's swimmers, as these two sports have a very large participation rate. Endurance activities such as running and swimming have shown to maintain and improve the cardiocirculatory fitness of individuals. Having good cardiocirculatory fitness can decrease both systolic and diastolic blood pressure, decrease risk for cardiovascular disease, and decrease adiposity [8], all important variables that could increase with advancing age.

However, with all the benefits associated with regular PA, there are also risks of musculoskeletal injuries. Musculoskeletal injuries and their associated economic impact (healthcare costs) are very important outcomes to look at when it comes to the master's athlete. As one ages, healthcare costs typically become increased due to the physiological changes associated with aging and the increased risk for injury. Therefore, the prevalence of injuries and their healthcare costs become a very intriguing topic for the master's athlete.

The purpose of this review is to 1) discuss the physiological changes associated with aging, 2) discuss common injuries of swimmers, 3) discuss the non-swim training activities used by master's swimmers and 4) highlight the prevalence of injuries in master's swimmers and what could be looked at for future research.

PHYSIOLOGICAL CHANGES ASSOCIATED WITH AGING

As one ages, bones undergo structural changes that could lead to deformation. Healthy bone consists of a combination of organic and inorganic materials that are capable of withstanding incredible forces. Aging brings about an increased risk of developing osteoporosis due to changes in bone mass. Bone mass reflects a balance between bone formation and bone resorption. In young age, the rate of bone formation exceeds the rate of bone resorption and therefore bone mass increases. However, as one ages, the rate of bone resorption exceeds the rate of bone formation and therefore bone mass decreases. The rate of bone loss is different based on the sex of the individual; men lose bone mass at approximately 0.4% per year after the age of 50, whereas women lose bone mass at a rate of 0.75-1% per year beginning in their early 30's. The rate of bone loss for women may even triple during menopause and could remain elevated for several years after [9-10]. The start of osteoporosis is individualized depending on hormones, calcium intake, level of physical activity, and genetics playing major roles for the rate of bone loss. However, it appears that no matter what age, bone responds positively to muscular traction (pull on a bone by a muscle contraction) and gravitational loading- by increasing in strength and calcium levels [9,11]. Because of this, maintaining PA levels into adulthood are preferred as PA has been shown to not only prevent osteoporosis but may be able to reverse the process.

Collagen plays a major role in the structural changes that are seen in the aging tendons and ligaments. Tendons and ligaments are made up of several structures, with collagen being the most abundant. Collagen is one of the most prevalent proteins in the body, accounting for 30% of the body's total protein volume [12]. The strength of collagen comes from the cross-links it forms and it is these cross-links that have been found to change with advancing age. Aging tendons and ligaments are associated with an increase in collagen maturation which leads to an increase in the number of cross-links formed [13]. Maturation of collagen leads to a decrease in the collagen turnover rate which leaves the collagen fibers less compliant. As a result, the aging tendons and ligaments are less elastic and more prone to injury [14].

With advancing age, there are noticeable changes that occur to skeletal muscle, such as atrophy, reduced flexibility and ability to produce force, decrease in mitochondrial volume, and an increase in collagen content [15]. Aging results in sarcopenia, the natural loss of muscle mass. This is due to both a reduction in muscle fibers and fiber volume [15]. Thus, the loss of muscle mass, both the number of muscle fibers and the size of the muscle fibers will directly affect the ability of the aging musculature to produce force. A decrease in mitochondrial volume will act to impair performance as they will be less efficient at producing ATP. The increased collagen acts to stiffen the musculature and decreases flexibility.

POTENTIAL RISK FOR INJURIES IN MASTERS SWIMMERS

Potential risks for injuries in master's swimmers are due to several factors. Firstly, they are at a potential risk due to the commonly seen injuries in their respective sport. Swimmers are at a large risk for shoulder pain and developing an upper extremity injury. Secondly, these athletes have a potential risk for injury due to the physiological changes associated with aging. Changes to the musculoskeletal system would also seem to enhance potential risks for injuries: aging leads to decreased bone mass, increased collagen content in both ligaments and tendons which decreases their elasticity, and a loss of muscle mass which decreases flexibility.

COMMONLY SEEN INJURIES IN SWIMMERS

The majority of injuries in swimmers occur in the shoulder while other common problem areas include the knees and the feet. In most studies reported in the literature, the incidence of shoulder pain ranged from 40 to 80% [16-20]. This shoulder pan is typically due to impingement of the supraspinatus muscle or the biceps tendon against the scapula. Most shoulder pain is seen in swimmers who swim the freestyle, backstroke, and butterfly as much of the speed from these strokes comes from the propulsion of the arms. However, in swimmers who perform the breastroke, the majority of the speed achieved comes from the knees. Because of this, knee pain in swimmers has been termed "breastrokers knee". Breastroker's knee is thought to be due to incorrect mechanics of the whip kick [21]. Tendinitis of the foot and ankle is another common injury seen in swimmers. Swimmers need good ankle strength in order to develop maximal plantar flexion and dorsiflexion, which places the foot in a better position to push the water backward during a flutter kick [22]. Dorsiflexion and plantar flexion are achieved through stretching the muscles of the anterior compartment of the leg and supporting ligaments of the ankle. This repetitive motion may lead to inflammation of the extensor tendons [19].

PREVALENCE OF INJURIES IN MASTERS SWIMMERS

Although master's swimmers start from age 25+ years of age, the majority of studies have been done in collegiate-aged swimmers. Kerr et al. performed a study on male and female collegiate swimmers from 2009-2014, in which they determined the prevalence of injuries per 1000 athlete exposures. An athlete exposure (AE) was defined as one student-athlete participating in one practice or competition in which he or she was exposed to the possibility of athletic injury. For the 207 males, there were a total of 124 injuries during 83,829 AEs, for an injury rate of 1.48 injuries/1000 AEs. For the 286 females, there were a total of 171 injuries during 105,121 AEs, for an injury rate of 1.38 injuries/1000 AEs [23]. Another study followed 34 collegiate swimmers (16 males, 18 females) over the course of an 8-month season. They also determined the prevalence of injuries per 1000 AEs. For the 16 males, there were a total of 13 injuries during 2614 AEs, for an injury rate of 4.97 injuries/1000 AEs. For the 18 females, there were a total of 18 injuries during 2971 AEs, for an injury rate of 6.06 injuries/1000 AEs [24].

While those studies focused on injuries related to swim training alone, others have looked at the prevalence of injuries as also occurred by cross training and dryland training. McFarland et al., 1996 followed a group of female collegiate swimmers for 7 years and documented their injury prevalence due to swim training, cross training, and dryland training. During the 7 year follow up, there were 125 injuries; 45% of these were due to swim training, 20% due to cross training, 24% due to dryland training and 11% unrelated to training [25].

A few other studies have looked at the role dryland training plays in preventing the prevalence of injuries. Dominguez (1978) utilized a questionnaire and asked swimmers about their shoulder pain after they had implemented a dryland training program; they reported a significant decrease in shoulder pain [17]. Hawkins and Kennedy (1980) implemented a dryland training program in swimmers and their questionnaire results found that the dryland training decreased any shoulder pain and also reported that the swimmers felt they could continue dryland training throughout the season without adverse effects [26].

The prevalence of injuries in master's swimmers is important as healthcare costs typically increase as one ages. In a survey of hospital emergency rooms, the U.S. Consumer Product Safety Commission found that between 1990 and 1996, sports-related injuries increased by 18% in people 25-64 years of age and by 54% in people aged 65 and over [27].

To date, there has only been one study that has looked at the prevalence of injuries and their economic impact (healthcare costs) in master's athletes. Last year, Hespanhol et al., conducted a prospective cohort study that followed 53 master's runners and documented their prevalence of injuries and the associated economic impact of those injuries over the span of 18 weeks. This study allowed them to determine the prevalence and 'economic burden' (healthcare costs) of musculoskeletal injuries in their sample of master's runners. Direct costs were money that was spent on a doctor's visit and indirect costs were from salary they missed out on due to absenteeism from paid work. They determined that the overall injury rate was .80 injuries/participant over the 18 weeks. Directly, each injury cost on average $57.97 and indirectly cost $115.75 [28].

NON-SWIM TRAINING ACTIVITIES

In order to maintain and improve performance, swimmers participate in non-swim training activities, both aerobic and anaerobic. Predominantly, running and cycling for aerobic training and dryland training (weight training) for anaerobic training. These three forms of training are commonly grouped together as cross-training.

Cross-training aims both to increase an athlete's overall fitness, and to develop specific muscle groups for enhanced performance through increased speed, power, or endurance. Through a combination of cross and sport specific training, the total volume of training may be increased without increasing the constant repetitive stress of sport specific training alone [29]. Swimmers utilize running and cycling as ways to maintain cardiovascular fitness without having to undergo the stresses of swim training. In contrast, the proposed benefits of dryland training include performance enhancement and injury prevention [30]. Several studies suggest a positive effect on performance, including increased stroke length and reduced stroke rate [31-32].

Cardiovascular fitness decreases linearly with age directly because of the reduction of max attainable HR which subsequently decreases VO2max. In order to confound this, master's swimmers dedicate increased amounts of time to swim-training and cross-training. Not only does the amount of practice change as the swimmers age, but also their patterns of activity change such that dryland training is neglected for respiratory-endurance training. Presumably, this change in practice helps counter the respiratory declines associated with aging [33]. The benefits of endurance training for older adults have been demonstrated quite convincingly in a number of studies that have shown that older adults can achieve the same 10-30% increase in VO2max that is enjoyed by younger athletes for training endurance [34-36].

Many individuals utilize dryland training as a means to increase muscular strength and hypertrophy. However, an often-overlooked benefit of dryland training is the prevention of injury. Physiological adaptation brought about by dryland training that could aid in prevention of injury include increased strength of connective tissue and bone. Increased strength of particular muscles or muscle groups may aid in the prevention of overuse injuries such as swimmers shoulder [37]. Examples of the increased strength in connective tissues include hyaline cartilage (cartilage that lines the joints), connective tissue membranes around muscle and bone. Hyaline cartilage is permeable to water and other small molecules such as oxygen and carbon dioxide. When the joint is loaded, as in PA, synovial fluid is forced into the cartilage surfaces. After cessation of loading, water is again drawn into the cartilage. This pumping of synovial fluid and alternate compression and decompression of the cartilage due to PA is in part responsible for nutrition and strength of the cartilage [38]. There are also sheaths of connective tissue within and around the muscle itself. These connective tissue sheaths are a major component in the tensile strength and passive properties of muscle and provide the framework that supports overload of the muscle. The major component of these sheaths is collagen. Undergoing weight training in rats has shown to increase hypertrophy of the lower extremity muscles and has shown to increase the collagen content of those muscles, indicating that dryland training can increase collagen content and the strength of connective tissues [39-40]. As mentioned earlier, with PA, bone formation ensues due to the gravitational loading and mechanical forces distributed onto the bone.

Cross-training or non-swim training activities elicited from swimmers have several benefits for performance. Running and cycling are non-sport specific way to increase cardiovascular fitness without the repetitive nature of swim training, whereas dryland training is a means to increase strength of numerous tissues and prevent against injury.

WHAT NEEDS TO BE STUDIED?

Since there are very few studies looking at the prevalence of injuries in older populations of swimmers, that area of research could be vastly expanded on. As mentioned earlier, there has only been one study looking at both the prevalence of injuries and their associated economic impact in master's athletes. Because both running and swimming elicit similar cardiocirculatory improvements, it would be beneficial to measure those outcomes in a sample of master's swimmers.

Introduction

The numerous health benefits associated with regular exercise have been well established [1-5]. As one matures, systemic physiological changes occur including a gradual impairment of organs such that functional reserves gradually decline leaving one progressively more vulnerable to metabolic disturbances, environmental stresses, and disease [7]. Being even moderately active is preferable to leading a sedentary lifestyle [6]. In contrast to the high prevalence of sedentary lifestyle in the overall aging population, master's athletes (MA) comprise a highly small portion of older adults [41]. These groups of athletes are challenging the prevalent notion that aging is an inevitable process of decline and that not much can be done to change it [41]. Recently, much interest has focused on MA's, as this group of participants has grown significantly over the last decade. The majority of research on MA's has been focused on master's runners and master's swimmers, as those sports have high participation rates.

To maintain and improve performance and overall fitness, many master's swimmers participate in cross-training or non-swim training activities. By adding cross-training, the total volume of exercise may be increased without overloading from the constant, repetitive stress of sport specific training [29]. Endurance activities such as running and swimming have been shown to maintain and improve cardiovascular fitness. Many individuals incorporate dryland training (resistance training) because it has been reported to enhance performance and increase muscular strength and hypertrophy; however, an often-overlooked benefit of dryland training is injury prevention [30]. Dryland training can induce physiological adaptations that may help prevent injury including increased strength of connective tissue and bone and correcting antagonist muscle imbalances [30].

Despite the numerous benefits associated with regular exercise, exercise could increase the risk of musculoskeletal injuries [27], as well as their associated healthcare costs. The relationship between aging, musculoskeletal injuries, and healthcare costs in master's athletes has only been looked at once, in a sample of master's runners [28]. To date, no study has yet investigated the relationship between the prevalence of injuries and the associated economic impact of those injuries in master's swimmers. Therefore, the aims of our study were 1) to determine the prevalence of swim-related injuries and their healthcare costs, 2) determine if swim-related injuries increase with increasing age, 3) determine the association between age and participation in cross-training activities, and 4) determine if there is an association between swim-related injuries and participation in cross-training activities.

Methods

Subject Recruitment

Masters swimmers were recruited from the United States Masters Swimming database (USMS) through the USMS database's monthly newsletter and the announcement at the USMS annual conference. The questionnaire was administered electronically through Qualtrics (an online survey platform). A total of 499 completed questionnaires were received.

USMS Questionnaire

The comprehensive questionnaire included questions on demographics (age, sex, ethnicity, self and family medical history) and training history. Training history questions allowed us to determine how long they had been swim-training as master's swimmers, whether they had sustained a swim-related injury, their healthcare costs due to the injury and whether they had participated in cross-training or non-swim training activities. The first page was an informed consent; clicking the next page to begin the questionnaire was an acknowledgement that they had agreed to participate. This questionnaire was approved by the institutional review board of the University of Texas at Austin.

Data Analysis

All data analysis was conducted in IBM SPSS Statistics, version 24. Odds ratios (OR) and 95% CI for injury prevalence using age as a predictor were computed by binary logistic regression. For those that had an injury, linear regression tests were run to determine the association between injury length and healthcare costs. OR and 95% CI of participation in non-swim training activities using age as a predictor were computed by binary logistic regression in separate models for running, cycling and dryland training. Participants who did not participate in those training activities were used as controls.

OR and 95% CI for the associations between swim-related injury prevalence and participation in non-swim training activities were computed by binary logistic regression in separate models for running, cycling and dryland training; covariates were age and sex. Participants who did not participate in those non-swim training activities were used as controls. Some individuals (39%) reported participating in more than one activity. Therefore, we grouped all individuals based on the number of non-swim training activities. A multinomial logistic regression was run to compute the association between swim-related injury prevalence and number of non-swim training activities. For this, individuals who participated in zero activities served as the referent category for OR calculations.

Results

Out of the 499 master's swimmers surveyed, 32% reported a swim-related injury (**Table 1**). Of those who reported an injury, the average length of the injury was 6.6 months, with 82 individuals seeking healthcare. There was a positive relationship ($r=0.1$, $p<0.05$) between age and swim-related injury prevalence, as well as between injury length and healthcare costs ($r=0.35$, $p<0.05$). For every 1 year increase in age, the odds of having an injury increased by 1.6% (OR=1.016, 95% CI= 1.001-1.030; $p<0.05$). For every 1 month increase in the length of swim-related injury, healthcare costs increased by 7.4% (**Figure 1**).

There was a negative relationship between age and participation in cross-training activities ($r=0.2$, $p<0.05$). For every 1 year increase in age, participation in running, cycling, and dryland resistance training decreased by 5.6%, 2.5%, and 2.4%, respectively ($p<0.05$ for all) (**Table 2**).

The odds of having a swim-related injury were significantly less for individuals who participated in each non-swim training activity compared with those who did not ($p<0.05$ for all) (**Table 3**). Since a number of swimmers (39%) reported participating in more than one cross-training activity, swimmers were grouped based on the number of non-swim training activities in which they reported participating. The OR for having a swim-related injury was significantly less for those who reported participating in any number of non-swim training activities (**Table 4**).

We found no differences in swim volume, either days per week or minutes per week, with age as a predictor. There was no relationship between swim volume and either OR of injury or healthcare costs. Also, there were no sex/gender differences between OR of injury or healthcare costs.

Discussion

Results from the present study indicate that the odds of suffering a swim-related injury increase with age and that the longer the injury lasts, the higher the healthcare costs. In master's athletes, participating in any form or any number of cross-training activities seems to lower the OR of having a swim-related injury.

The odds of reporting a swim-related injury increases with age and physiological changes associated with aging could be contributing. Aging tendons and ligaments are associated with an increase in collagen maturation which leads to an increase in the number of cross-links formed and a decrease in the collagen turnover rate. Consequently, collagen fibers become less compliant [13] and aging tendons and ligaments are less elastic and more prone to injury [14]. With advancing age, there are noticeable changes that occur to skeletal muscle, such as atrophy, reduced flexibility and ability to produce force, and an increase in collagen content [12]. The combined effects to muscle and connective tissue that occur with normal aging could contribute to the relationship between increasing injury and age in master's swimmers.

For those that reported a swim-related injury, there was a positive association between injury length and healthcare costs. The longer the length of a swim-related injury, the greater individuals paid for healthcare costs associated with that injury. As expected, the longer someone endures an injury, the greater the likelihood that he or she would see a healthcare professional to resolve the problem. Hespanhol et al. (2015) reported similar findings in their sample of master's runners. As the length of injury increased (from acute to chronic), the associated healthcare costs also increased [28]. However, they estimated healthcare costs per injury based on standardized healthcare professional visits for gender and age.

In the present study, the odds of participating in different forms of cross-training decreased with age. We attribute this to the physiological changes associated with aging, as described above, as well as longer recovery times for master's athletes. Easthope et al. found master's ultra-endurance athletes took significantly longer for muscular function to recover than their younger peered runners in a 55-km trail running event [42]. Significantly longer recovery times for peak muscle twitch were seen between master's endurance athletes and young endurance athletes [43]. The longer recovery time supports the suggestion that neuromuscular fatigue and recovery may differ in masters versus younger athletes following muscle damaging exercise which may cause a delay in overall recovery from previous exercise.

Although there were decreases in participation in cross-training with increasing age, those who did participate exhibited lower odds of reporting a swim-related injury. Further, this association remained even after separating into the number of cross-training activities. One could argue that perhaps those individuals who participate in cross-training might spend less time swim training, therefore they would have less swim-related injuries. However, the amount of time spent in the pool regarding either days per week or minutes per week was not different between groups. Without knowing the intensity of workouts performed by these individuals, it is difficult to determine the cause of this association.

It seems likely that individuals who participate in dryland training have fewer injuries because they perform shoulder and back resistance exercises that increase the strength of the skeletal muscle and its surrounding connective tissue. Increased strength of particular muscles or muscle groups may aid in the prevention of overuse injuries, such as swimmers shoulder [37]. Connective tissue sheaths are a major component in the tensile strength and passive properties of muscle and provide the framework that supports overload of the muscle. The major component of these sheaths is collagen [38]. Undergoing weight training in rats has shown to increase hypertrophy of the lower extremity muscles and increase the collagen content of those muscles, indicating that dryland training can increase collagen content and the strength of connective tissues [39-40].

Perhaps those individuals who participate in either cycling and/or running have fewer injuries because they can train less intensely in the pool. Aerobic capacity has been shown to decrease with age [44-45] and therefore, swimmers utilize running and cycling as exercise modes to maintain or increase aerobic performance and maintain cardiovascular fitness. Through a combination of cross and sport specific training, the total volume of training may be increased without increasing the constant repetitive stress of sport specific training alone [29].

This study has a few limitations. First, it is a qualitative study based on a questionnaire. Participants' responses are subject to recall bias. Second, there was considerable variability in the healthcare cost data, which limited possible associations. Because there were so few individuals who reported healthcare costs about the sample, and because the range was not normal, log transformed healthcare costs were computed and associations with it were minimal. Third, these data cannot be attributable to the general population, or even athletes or swimmers due to the very specific population we sampled. Despite the limitations, the present study exhibits several strengths. First, our sample size was large, allowing our statistical inferences to be run with power. Second, this is the first study documenting injury prevalence and associated healthcare costs in master's swimmers. Third, to the best of our knowledge this is the first study to document the association between strictly swim-related injuries and participation in cross training.

Master's athletes have become an increasingly popular population to study due to their high level of training and performance at an advanced age. Through our questionnaire, we were able to provide further evidence that the odds of having a musculoskeletal injury increase with age and that there is a direct association between length of injury and healthcare costs. In addition, participating in various forms of cross-training as one aged might offer protective effects. Regardless of the form or the number of cross-training activities, master's swimmers who cross-train had significantly lower odds of reporting swim-related injuries than their counterparts, suggesting that participation in cross-training may help to attenuate swim-related injury occurrence in master's swimmers.

Tables and Figures

Table 1. Selected Subject Characteristics

Variable	**Mean ± S.D. or n (%)**
Male/Female, n	205/294, 499
Age, years	55.3 ± 13.7
Race	
African American, n (%)	3 (.6%)
American Indian/Alaskan Native, n (%)	1 (.2%)
Asian, n (%)	4 (.8%)
Mixed, n (%)	10 (2%)
Pacific Islander, n (%)	1 (.2%)
White, n (%)	480 (96.2%)
Years as a Master's Swimmer	13.3 ± 11.5
Participation in Swim-Training, days per week	2.5 ± 1.5
Participation in Swim-Training, minutes per week	67 ± 25.3
Participation in Dryland Training, n (%)	239 (47%)
Dryland Training Experience, years	14.9 ± 12.7
Participation in Cycling, n (%)	197 (39.5%)
Participation in Running, n (%)	172 (34.5%)
Cycling and Running Experience, years	18.6 ± 14.3
Swim Training-Related Injury, n (%)	160 (32%)
Shoulder, n (%)	121 (76.1%)
Knee, n (%)	10 (6.3%)
Ankle, n (%)	9 (5.9%)
Other, n (%)	20 (12.6%)
Length of Injury, months	6.6 ± 6.4
Healthcare Visit Required, n (%)	82 (51.3%)
Healthcare Costs, dollars	450 ± 605

Table 2. Regression models and odds ratio (OR) of the participation rate in cross-training or non-swim training activities, using age as a predictor.

Model	Model p	Predictor p	Crude OR (95% CI)	Adjusted OR (95% CI)*
Running	<0.0001	<0.0001	.942 (.927-.957)	.944 (.929-.959)
Cycling	0.001	<0.001	.976 (.962-.989)	.975 (.962-.989)
Dryland	0.004	0.021	.974 (.954-.994)	.976 (.955-.996)

*Adjusted for sex

Table 3. Odds ratio (OR) of having a swim-related injury based on participation in cross-training or non-swim training activities.

Training		Injury		Adjusted OR (95% CI)*	Model p
		Yes	No		
Running	Yes	35	137	.455 (.287-.722)	0.001
	No	124	203		
Cycling	Yes	50	147	.642 (.428-.962)	0.025
	No	109	193		
Dryland	Yes	58	181	.525 (.355-.776)	0.002
	No	101	159		

*Adjusted for age and sex.

Table 4. Crude and adjusted odds ratio (OR) of the association between the number of cross-training or non-swim training (dryland, running and cycling) participation and swim-related injury prevalence.

# of Cross-Training	Injured	Injury Free	Crude OR (95% CI)	Adjusted OR (95% CI)*
Zero	73	80	1	1
One	48	103	.511 (.320-.815)	.527 (.329-.843)
Two	19	110	.189 (.106-.338)	.206 (.114-.371)
Three	19	47	.443 (.238-.824)	.491 (.258-.934)
			P for trend<.0001	P for trend<.0001

*Adjusted for age and sex.

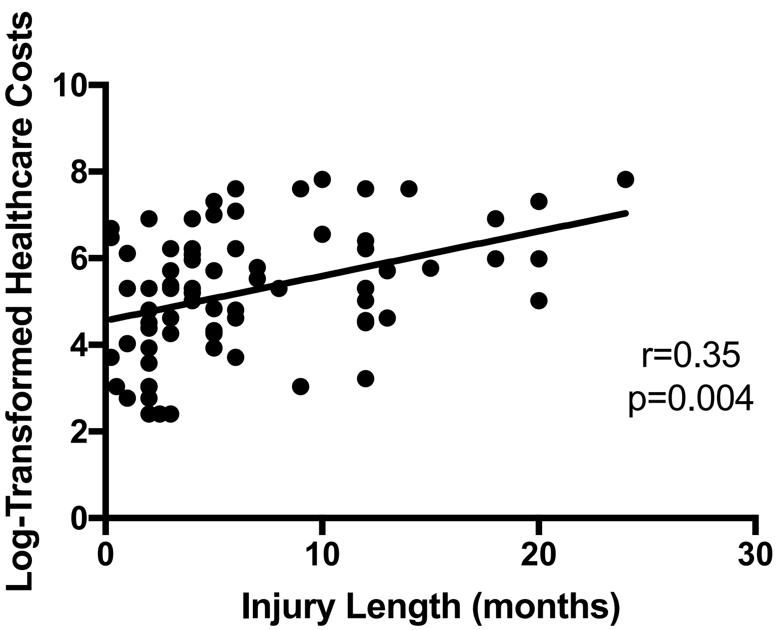

Figure 1. Linear regression of the association between the length of swim-related injuries and healthcare costs using age and sex as covariates. For every 1 month increase in the length of swim-related injuries, healthcare costs increased by 7.4%.

References

1. Durstine, J. L., Grandjean, P. W., Davis, P. G., Ferguson, M. A., Alderson, N. L., & DuBose, K. D. (2001). Blood lipid and lipoprotein adaptations to exercise. *Sports Medicine*, *31*(15), 1033-1062.

2. Durstine, J. L., Grandjean, P. W., Cox, C. A., & Thompson, P. D. (2002). Lipids, lipoproteins, and exercise. *Journal of Cardiopulmonary Rehabilitation and Prevention*, *22*(6), 385-398.

3. Leon, A. S., & Sanchez, O. A. (2001). Response of blood lipids to exercise training alone or combined with dietary intervention. *Medicine and science in sports and exercise*, *33*(6; SUPP), S502-S515.

4. Gordon DJ, Probstfield JL, Garrison RJ, et al. High-density lipoprotein cholesterol and cardiovascular disease: four prospective American studies. *Circulation*. 1989;79:8-15.

5. Petitt, D. S., & Cureton, K. J. (2003). Effects of prior exercise on postprandial lipemia: a quantitative review. *Metabolism*, *52*(4), 418-424.

6. Myers, J. (2003). Exercise and cardiovascular health. *Circulation*, *107*(1), e2-e5.

7. Siegel, A. J., Warhol, M. J., & Lang, G. (1986). Muscle injury and repair in ultra long distance runners Sports medicine for the mature athlete (pp. 35-43): Benchmark Press Indianapolis.

8. American College of Sports, M. (2004). Physical activity programs and behavior counseling in older adult populations. *Med Sci Sports Exerc, 36*(11), 1997-2003.

9. Beyer, R. E., Huang, J. C., & Wilshire, G. B. (1985). The effect of endurance exercise on bone dimensions, collagen, and calcium in the aged male rat. *Experimental gerontology, 20*(6), 315-323.

10. Smith, E. L. (1982). Exercise for prevention of osteoporosis: a review. *Phys Sports Med, 10*(3), 72-80.

11. Booth, F. W., & Gould, E. W. (1975). Effects of training and disuse on connective tissue. *Exercise and sport sciences reviews, 3*(1), 83-112.

12. Viidik, A. (1979). Connective tissues—possible implications of the temporal changes for the aging process. *Mechanisms of ageing and development*, *9*(3), 267-285.

13. Cook, J. L., Khan, K. M., & Purdam, C. (2002). Achilles tendinopathy. *Manual therapy*, *7*(3), 121-130.

14. Magnan, B., Bondi, M., Pierantoni, S., & Samaila, E. (2014). The pathogenesis of Achilles tendinopathy: a systematic review. *Foot and Ankle Surgery*, *20*(3), 154-159.

15. Chen, A. L., Mears, S. C., & Hawkins, R. J. (2005). Orthopaedic care of the aging athlete. *Journal of the American Academy of Orthopaedic Surgeons*, *13*(6), 407-416.

16. Ciullo JV. Swimmer's shoulder. Clin Sports Med. 1986;5(1):115-137.

17. Dominguez, R. H. (1978). Shoulder pain in age group swimmers. *Swimming Medicine*, 105-109.

18. Fowler, P. J., & Webster, M. S. (1983). Shoulder pain in highly competitive swimmers. *Orthop Trans*, *7*(1), 170.

19. Kennedy, J. C., Hawkins, R., & Krissoff, W. B. (1978). Orthopaedic manifestations of swimming. *The American journal of sports medicine*, *6*(6), 309-322.

20. Richardson, A. B., Jobe, F. W., & Collins, H. R. (1980). The shoulder in competitive swimming. *The American Journal of Sports Medicine*, *8*(3), 159-163.

21. Stulberg, S. D., Shulman, K., Stuart, S., & Culp, P. (1980). Breaststroker's knee: pathology, etiology, and treatment. *The American journal of sports medicine*, *8*(3), 164-171.

22. Johnson, J. E., Sim, F. H., & Scott, S. G. (1987, April). Musculoskeletal injuries in competitive swimmers. In *Mayo Clinic Proceedings* (Vol. 62, No. 4, pp. 289-304). Elsevier.

23. Kerr, Z. Y., Baugh, C. M., Hibberd, E. E., Snook, E. M., Hayden, R., & Dompier, T. P. (2015). Epidemiology of National Collegiate Athletic Association men's and women's swimming and diving injuries from 2009/2010 to 2013/2014. *British journal of sports medicine*, bjsports-2014.

24. Chase, K. I., Caine, D. J., Goodwin, B. J., Whitehead, J. R., & Romanick, M. A. (2013). A prospective study of injury affecting competitive collegiate swimmers. *Research in Sports Medicine, 21*(2), 111- 123.

25. McFarland, E. G., & Wasik, M. (1996). Injuries in female collegiate swimmers due to swimming and cross training. *Clinical Journal of Sport Medicine*, *6*(3), 178-182.

26. Hawkins, R. J., & Kennedy, J. C. (1980). Impingement syndrome in athletes. *The American journal of sports medicine*, *8*(3), 151-158.

27. Kalb, C. (1999). The Jock v. the Clock. *Newsweek, 133*(21), 76.

28. Hespanhol Junior, L. C., Mechelen, W., Postuma, E., & Verhagen, E. (2015). Health and economic burden of running-related injuries in runners training for an event: A prospective cohort study. *Scandinavian journal of medicine & science in sports*.

29. Stamford, B. (1991). Exercise adviser: Task-Specific Training Vs Cross Training. *The Physician and Sportsmedicine*, *19*(7), 113-114.

30. Wanivenhaus, F., Fox, A. J., Chaudhury, S., & Rodeo, S. A. (2012). Epidemiology of injuries and prevention strategies in competitive swimmers. *Sports health*, *4*(3), 246-251.

31. Pichon, F., Chatard, J. C., Martin, A., & Cometti, G. (1995). Electrical stimulation and swimming performance. *Medicine and science in sports and exercise*, *27*(12), 1671-1676.

32. Girold, S., Maurin, D., Dugué, B., Chatard, J. C., & Millet, G. (2007). Effects of dry-land vs. resisted-and assisted-sprint exercises on swimming sprint performances. *The Journal of Strength & Conditioning Research*, *21*(2), 599-605.

33. Weir, P. L., Kerr, T., Hodges, N. J., McKay, S. M., & Starkes, J. L. (2002). Master swimmers: How are they different from younger elite swimmers? An examination of practice and performance patterns. *Journal of Aging and Physical Activity*, *10*(1), 41-63.

34. Hagberg, J. M., Graves, J. E., Limacher, M., Woods, D. R., Leggett, S., Cononie, C., ... & Pollock, M. L. (1989). Cardiovascular Responses Of 70-79 Year Old Men And Women To Endurance And Strength Training. *Medicine and Science in Sports and Exercise*, *21*(2), S95.

35. Kohrt, W. M., Malley, M. T., Coggan, A. R., Spina, R. J., Ogawa, T. A. K. E. S. H. I., Ehsani, A. A., ... & Holloszy, J. O. (1991). Effects of gender, age, and fitness level on response of VO2max to training in 60-71 yr olds. *Journal of applied physiology*, *71*(5), 2004-2011.

36. Seals, D. R., Hagberg, J. M., Hurley, B. F., Ehsani, A. A., & Holloszy, J. O. (1984). Endurance training in older men and women. I. Cardiovascular responses to exercise. *Journal of applied physiology*, *57*(4), 1024-1029.

37. Fleck, S. J., & Falkel, J. E. (1986). Value of resistance training for the reduction of sports injuries. *Sports Medicine*, *3*(1), 61-68.

38. Staff, P. H. (1982). The effects of physical activity on joints, cartilage, tendons and ligaments. *Scandinavian journal of social medicine. Supplementum*, *29*, 59.

39. Turto, H., Lindy, S., & Halme, J. (1974). Protocollagen proline hydroxylase activity in work-induced hypertrophy of rat muscle. *American Journal of Physiology--Legacy Content*, *226*(1), 63-65.

40. Laurent, G. J., Sparrow, M. P., Bates, P. C., & Millward, D. J. (1978). Turnover of muscle protein in the fowl. Collagen content and turnover in cardiac and skeletal muscles of the adult fowl and the changes during stretch-induced growth. *Biochemical Journal*, *176*(2), 419-427.

41. Tanaka, H. (2012). Aging athlete. *Encyclopedia of Exercise Medicine in Health and Disease*, 43-43.

42. Easthope, C. S., Hausswirth, C., Louis, J., Lepers, R., Vercruyssen, F., & Brisswalter, J. (2010). Effects of a trail running competition on muscular performance and efficiency in well-trained young and master athletes. European journal of applied physiology, 110(6), 1107-1116.

43. Bieuzen, F., Hausswirth, C., Louis, J., & Brisswalter, J. (2009). Age-related changes in neuromuscular function and performance following a high-intensity intermittent task in endurance-trained men. Gerontology, 56(1), 66-72.

44. Heath, G. W., Hagberg, J. M., Ehsani, A. A., & Holloszy, J. O. (1981). A physiological comparison of young and older endurance athletes. *Journal of Applied Physiology*, *51*(3), 634-640.

45. Pimentel AE, Gentile CL, Tanaka H, Seals DR & Gates PE (2003). Greater rate of decline in maximal aerobic capacity with age in endurance-trained vs. sedentary men. *J Appl Physiol* **94**, 2406–2413.