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Association of Running Biomechanics and Injury in Middle School Cross Country Runners

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ASSOCIATION OF RUNNING BIOMECHANICS AND INJURY IN MIDDLE SCHOOL CROSS COUNTRY RUNNERS

SENIOR HONORS PROJECT

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ASSOCIATION OF RUNNING BIOMECHANICS AND INJURY IN MIDDLE SCHOOL CROSS COUNTRY RUNNERS

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Honors Research Project

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Abstract

INTRODUCTION: While associations between running biomechanics and injury incidence have been fairly well investigated in the adult population, few studies have targeted the adolescent population. Since the adolescent developmental stage places certain vulnerabilities on athletes, adolescents typically sustain injuries that differ from those of adults (DiFiori J.P., et al, 2014). Due to these vulnerabilities, it would be relevant to investigate the biomechanics-injury relationship specifically in this population. **PURPOSE:** The purpose of this study was to investigate the associations that exist between running gait characteristics and incidence of injury for middle school cross country runners **METHODS:** The running gait of 19 middle school cross country runners was analyzed at the beginning of the cross country season. Participants reported all injuries that were acquired prior to and throughout the season. The biomechanics of participants were compared in order to determine any gait consistencies between runners with similar injuries. **RESULTS:** The injuries presented by participants in this study were knee injuries, tibial stress fractures, and Achilles' tendon injuries. Several gait characteristics were found to be shared between participants presenting with similar injuries. **CONCLUSION:** Within this study, participants with injuries to the same anatomical location shared several corresponding biomechanical characteristics. Many of these characteristics had previously been correlated with the same injuries in other studies. As research continues to identify consistent relationships between running biomechanics and injury, healthcare professionals and coaches will gain a better understanding of how to approach injury prevention in adolescent runners.

Acknowledgements

As a runner, cross country coach, and future physical therapist, I have been intrigued to learn more about running gait analysis and injury prevention. However, due to my limited research experience and knowledge of gait analysis, I would not have been able to conduct this project without a few key people. I would first like to thank Trayce Krauth, who amidst her busy life as a physical therapist, mom, and marathoner, generously gave hours of her time to analyze the gait of 19 runners. Thank you for showing me the ropes of running gait analysis and sharing your resources with me. Secondly, I would like to thank Dr. Ronald Otterstetter, who, as my sponsor, gave me both freedom and guidance through the design and implementation of this project. To my advisor, Laura Richardson, and project readers Rachele Kappler and Stacey Buser – thank you for your guidance and time. Lastly, thank you to the coaches, parents, and athletes of the Field Middle School, Tallmadge Middle School, Mogadore Middle School, and Running Tigers Cross Country Teams for taking interest in this study and making time to come to the lab.

Literature Review

Running Injury Epidemiology

In 2008, roughly 60 million U.S. children ages 6-18 participated in organized sports (DiFiori et al., 2014). As popularity of youth sports has increased and early specialization has become common, young athletes are training longer and harder than in the past. With this increase in intensity, the incidence of overuse injuries in young athletes has risen as well (Lord & Winell, 2004). Adolescent runners are of particular interest to clinicians, coaches, and researchers, because running serves as one of the top injury-contributing sports for this population (Kennedy, Hodgkins, Sculco, Carter, & Robinson, 2006). Although improper training has been identified as the most likely cause for a running injury, Lysholm & Wiklander (1987) found that 40% of running injuries were related to biomechanical errors. Additional studies have drawn further correlations between gait abnormalities and injuries (Taunton et al., 2002; DiFiori et al., 2014). While associations between running biomechanics and injury incidence have been fairly well investigated in the adult population, few studies have targeted the adolescent population. Since the adolescent developmental stage places certain vulnerabilities on athletes, adolescents typically sustain overuse injuries that differ from those of adults (DiFiori et al., 2014). Because of this, it would be relevant to investigate the biomechanics-injury relationship specifically in the adolescent population.

Studies reviewing the prevalence of running injuries over the past thirty years have come to an agreement regarding the most common injuries and injury sites in adults and adolescents. According to a study conducted at the Allan McGavin Sports Medicine Center (AMSMC) reviewing a total of 2002 patients with running injuries, the most common running injuries are patellofemoral pain syndrome (PFPS), iliotibial band syndrome (ITBS), plantar fasciitis, meniscal injuries, and patellar tendinopathy. The most common anatomical site for injury is the knee, followed by the foot/ankle, lower leg, hip/pelvis, Achilles/calf, upper leg, and low back (Taunton et al., 2002). A 2007 review of articles regarding running injuries confirmed that the most common site for injury in runners is the knee, followed by the lower leg, foot, and upper leg (van Gent et al., 2007). In a study involving solely adolescent runners, the majority of observed injuries were present in the knee, with PFPS and ITBS as the top culprits (Paty & Swafford, 1984).

Evaluation of Running Biomechanics

Research has shown that running gait is broken up into two main stages: the stance phase and swing phase. There is no point in which both feet are in contact with the ground, and there is a flight phase present in which neither foot is in contact with the ground. The stance phase, which constitutes approximately one third of the running gait cycle, is the highest energy portion of the cycle. During this time, the legs are subject to forces that are 2-6 times the individual's body weight, contributing to increased risk for injury due to force. The sequence of the stance phase is initial contact, loading response, mid-stance, terminal stance, and pre-swing. The movements of the hip, knee, subtalar, and talocrural joints during the stance phase are summarized in Table 1 (Starkey & Brown, 2015).

As the leg leaves the ground after push-off, it enters the swing phase. Although ground reaction forces are eliminated, injury of the muscles that decelerate the leg can occur. The sequence of the swing phase is initial swing, mid-swing, and terminal swing. The movements of the hip, knee, and talocrural joints during the swing phase are summarized in Table 2 (Starkey & Brown, 2015).

Table 1

Summary of Stance-phase Movements in Major Joints during the Running Gait Cycle

Joint	Initial Contact	Loading Response	Mid-Stance	Terminal Stance	Pre-Swing/Push-off
Hip	50° flexion (max flexion)	Moves toward extension	Moves toward extension	Moves toward extension	0-5° extension
Knee	30° flexion	50° flexion (max flexion)	Moves toward extension	Moves toward extension	Maximum extension
Subtalar joint	Supination	Pronates toward neutral	Neutral	Moves toward supination	Supination
Talocrural joint	25° dorsiflexion (max dorsiflexion)	Moves toward 5-20° dorsiflexion	5-20° dorsiflexion	Moves toward plantarflexion	Plantarflexion

Note. Degree measurements are approximate. Cited from Starkey & Brown, 2015.

Table 2

Summary of Swing-phase Movements in Major Joints during the Running Gait Cycle

Joint	Initial Swing	Mid-Swing	Terminal Swing
Hip	10° extension	Moves toward flexion	50-55° flexion
Knee	Full extension	Maximum flexion (can reach up to 125° flexion, but less in distance runners)	Moves toward extension
Talocrural joint	25° plantarflexion	Moves toward dorsiflexion	20° dorsiflexion

Note. Degree measurements are approximate. Cited from Starkey & Brown, 2015.

While individual differences in running gait can occur without consequence, some variations from the normal gait can alter the forces absorbed up the kinetic chain which may lead to injury. Running gait analysis is helpful for identifying any deviations from normal running gait. The most comprehensive way to do so is by viewing the gait from multiple planes – anterior, lateral and posterior. In addition, utilization of a video recording helps to increase accuracy of the evaluation by allowing the evaluator to watch the video in slow motion and draw in angles if analysis software is used (Plastaras, Rittenberg, Rittenberg, Press, & Akuthotha, 2005). Treadmills are useful tools for gait analysis because they allow for speed control and the use of a stationary camera. Though gait on a treadmill may slightly differ from gait on the ground, the difference is within 1 standard deviation. Therefore, treadmill results can often be applied to ground running (Riley et al., 2008).

Important Biomechanical Factors

When analyzing a runner's gait, there are certain parameters that are most important to examine. According to literature, running gait characteristics that have been most widely associated with injuries are over-striding, bounce, and compliance. There are several reasons that each of these characteristics should be avoided.

Over-striding: When the foot's initial contact is further away from the body anteriorly, the braking impulse of the leg is increased, which in turn increases the force being absorbed by the lower leg. Thus, over-striding is often related to bone stress injuries to the lower leg (Souza, 2016; Heiderscheit). Over-striding is analyzed by evaluating foot inclination angle, heel to center-of-mass (COM) distance, knee flexion angle, and tibial angle at initial contact in the sagittal plane (Heiderscheit).

Bounce: Bounce, or COM Vertical Displacement, is the difference between the body's maximum and minimum heights reached throughout the gait cycle. Excessive bounce is associated with calf and Achilles injuries (Souza, 2016; Heiderscheit).

Compliance: Compliance is defined as lack of proper alignment between the hip, knee, and ankle. It is analyzed by evaluating joint center alignment, lateral pelvic tilt, knee separation, and foot-COM placement in the frontal plane. Excessive compliance has been associated with PFPS, ITBS, Greater Trochanteric Syndrome, and Piriformis Syndrome. With this in mind, it is apparent how important it is to evaluate the entire kinetic chain, noticing how joint biomechanics on the opposite end of the chain can contribute to an injury (Souza, 2016; Heiderscheit). As shown in Table 3, several additional biomechanical factors have been associated with specific running injuries.

Table 3

Orthopedic injuries and their associated biomechanical risk factors.

Injury	Associated Biomechanical Risk Factors
Iliotibial band syndrome (ITBS)	Joint center misalignment (knee varus, excessive pronation, increased internal tibial rotation), lateral heel strike, excessive lateral pelvic tilt
Popliteus tendinopathy	Excessive pronation
Patellofemoral Pain Syndrome (PFPS)	Joint center misalignment (knee valgus, excessive hip adduction and internal rotation, excessive pronation, increased internal tibial rotation), excessive lateral pelvic tilt
Achilles tendinitis	Toe-only gait, rearfoot varus or valgus, excessive bounce
Calcaneal apophysitis (Sever's disease)	Forefoot varus/valgus, rearfoot varus/valgus
Tibial stress syndrome	Excessive pronation, over-striding, narrow step width
Leg stress fractures	Excessive hip external rotation, pes cavus
Chronic Exertional Compartment Syndrome	Excessive pronation
Plantar fasciitis	Pes cavus, pes planus, forefoot valgus, excessive pronation
Tarsal Tunnel Syndrome	Rearfoot varus with excessive pronation, increased internal tibial rotation
Metatarsal stress fractures	Forefoot valgus, rearfoot varus/valgus, pes planus, pes cavus
Greater Trochanter Syndrome	Joint center misalignment, excessive lateral pelvic tilt
Piriformis Syndrome	Joint center misalignment, excessive lateral pelvic tilt

Note. Cited from Heiderscheit; Souza, 2016; Starkey & Brown, 2015

Research Question and Rationale

The purpose of this study was to investigate the associations that exist between certain deviations in running gait and incidence of injury for middle school cross country runners. My hypothesis was that biomechanical characteristics would correlate with specific injuries. This project is significant because the results may contribute to the understanding of injuries that often affect middle school cross country runners specifically, and will hopefully provide insight into the influence of biomechanics on injury. A better understanding of factors that contribute to injury may aid healthcare professionals and coaches to take steps toward prevention. If gait deviations are consistently associated with specific running injuries, it would be warranted to take steps to correct these deviations before injury occurs.

Methodology

Prior to implementation of this study, all recruiting and data collection procedures were approved by The University of Akron Institutional Review Board. Permission was granted from each involved school district prior to any data collection regarding the students of that district.

Participant Demographics

The study population consisted of 19 apparently healthy middle school cross country runners; 10 females and 9 males with a mean age of 12.3 years. At the time of the gait analysis, participants had been involved with a running program for an average of 1.6 years, ranging from 1 month to 5 years of experience. Participants were eligible for the study if they were able to run at a self-selected pace for at least 10 minutes without stopping, planned to complete the 2015 cross country season, and had no contraindications to exercise such as musculoskeletal injuries that were exacerbated with running. In order to participate, all runners were required to have a parent or guardian transport them to The University of Akron to record a video of their running gait. Detailed demographic information is available in Table 4.

Table 4

Participant Demographics

Demographic	Mean (Standard Deviation)
Age (yrs)	12.3 (0.8)
Weight (lbs)	100.9 (15.5)
Height (in)	62.8 (2.5)
Time Running (yrs)	1.6 (1.4)

Recruiting Procedures

Participants were recruited from the Field, Tallmadge, and Mogadore Middle School cross country teams, as well as the Running Tigers cross country club. Recruiting was administered through email and word of mouth prior to and during the 2015 cross country season. Parents and guardians were instructed to schedule a time for the gait analysis by contacting the Principle Investigator if their child was interested in participating in the study. At this time, participants were instructed to wear athletic shorts, a t-shirt, and running shoes on the day of the evaluation. Before participation, each subject was required to have a parent or guardian read and sign a consent form (Appendix A) that informed them of the subject's role in the study, his or her ability to discontinue at any time, testing protocols, and all other appropriate information. Participants were required to read and sign an assent form (Appendix B) that contained the same information as the consent form, but at an appropriate reading level for their age.

Experimental Protocols

Upon arrival to the University of Akron, the experimental protocol was verbally explained to the participants and their parents or guardians, and all questions were addressed. Following collection of demographic information (Table 4), participants were asked to complete a pre-season injury questionnaire (Appendix C). Next, the participants were asked to step onto the treadmill to begin the 2-D video gait analysis. Participants ran on a treadmill for 6 minutes at a self-selected pace before videotaping was begun in order to normalize their gait to the treadmill. Participants continued to run at a self-selected pace while anterior, lateral, and posterior views were recorded by the Principal Investigator, each for 1 minute. The camera recorded from head to toe in order to achieve the most comprehensive view of each participant's running gait. After a 3-minute recovery consisting of walking, the belt of the treadmill was stopped. At this time, participants and their parent or guardian were free to leave.

Following each recording, a Licensed Physical Therapist who is experienced with running gait analysis assisted the Principal Investigator in analyzing the running biomechanics of each participant via video using the *Hudl Technique* (formerly known as *Ubersense*) gait analysis app. *Hudl Technique* is an app designed for coaches to analyze athlete biomechanics. After recording with the app, the 240 frames-per-second videos can be viewed in slow motion, and angles can be drawn directly on-screen to analyze the athlete’s movement. The videos can also be compared side-by-side, and shared with athletes and their parents. Observations for each participant were recorded on a gait analysis evaluation form (Appendix D), which was collected by the Principal Investigator upon completion.

At the conclusion of the cross country season, participants were asked to complete a post-season questionnaire reporting any injuries they encountered over the course of the season (Appendix E). For the purpose of this study, an injury was defined as "running-related (training or competition) musculoskeletal pain in the lower limbs that causes a restriction on or stoppage of running (distance, speed, duration, or training) for at least 7 days or 3 consecutive scheduled training sessions, or that requires the runner to consult a physician or other health professional" (Yamato, Saragiotto, & Lopes, 2015).

Data Analysis and Results

Gait analysis results as well as the pre- and post-season injury questionnaires were collected from the original 19 participants. No participants dropped out of the study. When all of the injury questionnaires were collected at the conclusion of the season, the type of each reported injury from the pre- and post-season questionnaires was recorded. If the same type of injury occurred bilaterally in an individual, this was counted as two separate injuries. The diagnosed running injuries observed were as follows: tibial stress fracture (3), plantar fasciitis (1), Sinding Larsen Johanssen Syndrome (SLJ) (1), Patellofemoral Pain Syndrome (PFPS) (1), and Achilles tendonitis (1). Reported injury locations including diagnosed and non-diagnosed injuries were as follows: hip (1), knee (7), lower leg (3), calf/Achilles (2), and foot (1). Because most injuries were not given an official diagnosis, injuries were grouped according to their anatomical location for data analysis. Gait analysis reports of participants with injuries to the same body part (e.g. knee, shin, etc.) were compared in order to identify any biomechanical characteristics that were consistent within the injury group. When matching the injury to a participant's biomechanical characteristics, the biomechanics on the same side as the injury were used. For example, if an injury occurred in a participant's right knee, the biomechanics on the right side of her body were taken into account in data analysis. If an injury occurred bilaterally in a single participant, his right-sided biomechanics were matched to his right-sided injury, and his left-sided biomechanics were matched to his left-sided injury. Criteria for classifying gait characteristics are outlined in the Gait Analysis Evaluation Form (Appendix D).

Knee Injuries

From the population of 19 middle school cross country runners, 7 knee injuries were reported in this study. Because two participants reported bilateral knee injuries, there were 5 participants with knee injuries, but 7 total knee injuries. The gait analysis results corresponding to the 7 knee injuries were compared, and any gait characteristics that were shared between the majority of the knee injury group were identified. Of the seven knee injuries, six occurred in conjunction with contralateral pelvic tilt, narrow step width, and hip adduction on the injured side, as well as COM vertical excursion increase. Five knee injuries occurred in conjunction with foot pronation and increased tibial inclination at contact on the injured side. Four knee injuries occurred in conjunction with medial heel whip, decreased knee flexion angle at contact, and increased knee flexion angle at mid-stance on the injured side. Table 5 presents the biomechanical characteristics that were shared between the majority of participants presenting with a knee injury.

One knee injury was diagnosed by a Certified Athletic Trainer as PFPS, and another was diagnosed as SLJ. All other injuries were never diagnosed by a medical professional. One of the participants reporting post-season bilateral knee injuries reported a knee sprain to one knee in the pre-season survey. Another participant reporting a post-season unilateral knee injury reported knee pain in the same knee on the pre-season survey. The participant diagnosed with SLJ had been diagnosed prior to the season, and reported pain due to SLJ in the pre- and post-season surveys.

Shin Injuries

From the population of 19 middle school cross country runners, 3 shin injuries were reported in this study. All 3 shin injuries were diagnosed by a physician as tibial stress fractures.

Because one participant reported bilateral tibial stress fractures, there were 2 participants with tibial stress fractures but 3 total tibial stress fractures. The gait analysis results corresponding to the 3 injuries were compared, and any gait characteristics that were shared between all 3 tibial stress fracture injuries were identified. All three tibial stress fractures occurred in conjunction with narrow step width, hip adduction, medial heel whip, contralateral pelvic tilt, COM vertical excursion increase, heel strike, foot anterior to COM at initial contact (IC), tibial inclination at IC, and decreased knee flexion angle at IC. Table 6 presents the biomechanical characteristics that were shared between the participants presenting with a tibial stress fracture. The participant with a unilateral tibial stress fracture also displayed ipsilateral trunk movement toward the injured side, bilateral hip internal rotation, knee valgus on the injured side, and bilateral pronation – factors that would be expected to increase force on the tibia. This participant had experienced tibial pain prior to the season, which worsened as the season continued.

Calf/Achilles Injuries

From the population of 19 middle school cross country runners, 2 calf/Achilles injuries were reported in this study. Gait analysis results of the 2 participants presenting with calf/Achilles injuries were compared, and any gait characteristics that were shared between the 2 participants were identified. The 2 calf/Achilles injuries occurred in conjunction with narrow step width, hip adduction, contralateral pelvic tilt, pronation, COM vertical excursion increase, heel strike, increased tibial inclination at IC, decreased knee flexion angle at IC, and increased knee flexion angle at mid-stance. Table 7 presents the biomechanical characteristics that were shared between both of the participants presenting with a calf/Achilles injury. One of the calf/Achilles injuries was diagnosed by a medical professional as Achilles tendonitis, and the other was never diagnosed.

Table 5

Biomechanical Characteristics Associated with Knee Injuries

n=7

Biomechanical Characteristic	Number of Participants with a Knee Injury Presenting with the Biomechanical Characteristic
Frontal Plane	
Hip Adduction	6
Contralateral Pelvic Tilt	6
Narrow Step Width	6
Foot Pronation	6
Medial Heel Whip	4
Lateral Plane	
COM Vertical Excursion Increase	6
Initial Contact	
Knee Flexion Angle Decrease	4
Tibial Inclination Increase	5
Midstance	
Knee Flexion Angle Increase	4

Table 6

Biomechanical Characteristics Associated with Tibial Stress Fractures

n=3

Biomechanical Characteristic	Number of Participants with a Tibial Stress Fracture Presenting with the Biomechanical Characteristic
Frontal Plane	
Hip Adduction	3
Contralateral Pelvic Tilt	3
Narrow Step Width	3
Medial Heel Whip	3
Lateral Plane	
COM Vertical Excursion Increase	3
Initial Contact	
Heel Strike	3
Foot Anterior to COM	3
Knee Flexion Angle Decrease	3
Tibial Inclination Increase	3

Table 7
Biomechanical Characteristics Associated with Calf/Achilles Injuries
n=2

Biomechanical Characteristic	Number of Participants with a Calf/Achilles Injury Presenting with the Biomechanical Characteristic
Frontal Plane	
Hip Adduction	2
Contralateral Pelvic Tilt	2
Narrow Step Width	2
Foot Pronation	2
Lateral Plane	
COM Vertical Excursion Increase	2
Initial Contact	
Heel Strike	2
Knee Flexion Angle Decrease	2
Tibial Inclination Increase	2
Midstance	
Knee Flexion Angle Increase	2

Conclusion

Within this study, participants with injuries to the same anatomical location shared several corresponding biomechanical characteristics. Many of these characteristics had previously been correlated with the same injuries in other studies. This data provides further evidence of the relationship between biomechanics and running injuries, specifically in cases of knee injuries, tibial stress fractures, and calf/Achilles injuries. As research continues to identify consistent relationships between running biomechanics and injury, healthcare professionals and coaches will gain a better understanding of how to approach injury prevention in adolescent runners.

Limitations and Future Studies

A few limitations were present in this study. First, several of the participants did not tuck in their shirts during the video recording, making it difficult or impossible to evaluate hip biomechanics. For future running gait analysis studies, it would be advantageous to require all participants to tuck in their shirts during the analysis. Secondly, the pre- and post-season injury questionnaires required the participants to recall incidences of injury over an extended period of time. This method was problematic because many of the athletes had difficulty remembering how long their running was inhibited by pain or discomfort, the extent to which their running was affected by the pain or discomfort, and the exact location of the injury. For future studies, a weekly injury log, while more time consuming, would help to improve the accuracy of the participants' injury reports. Additionally, the short duration of the study puts limitations on the conclusions that can be drawn. Several runners presented with biomechanics that were characteristic of certain injuries, but were able to complete the season injury-free. In future studies, it would be beneficial to follow a group of adolescent runners for an extended period of time, perhaps throughout their entire middle and high school running careers, to help determine if their gait predisposes them to an injury.

Discussion

It is important to note that there are several contributing factors to injury besides biomechanics. An athlete's training program (volume, intensity, and rest periods), training surface, nutrition, running shoes, and genetic factors all play into the likelihood of injury. The scope of this project was to evaluate only the biomechanics of athletes. By not considering other injury-contributing factors, the conclusions drawn from this study can be generalized across the population.

This study provides tangible evidence that deviations in running gait may increase the risk for injury in adolescent runners. With this knowledge available, coaches and healthcare providers are supplied with a reason to advocate for running gait training and correction for all young cross country teams. The goal of reducing injury incidence through biomechanical interventions is to help the body receive the forces of running in the most efficient way possible. Gait retraining is often included in rehabilitation programs in order to prevent injury recurrence (Agresta & Brown, 2015). Rather than waiting for runners to become injured, risky biomechanical characteristics should be addressed early on in order to prevent the primary occurrence of injuries. Including a running gait analysis in pre-season participation screenings could help to identify these biomechanical factors, and allow coaches to begin addressing them early on. While many school sports teams do not have access to a sports medicine physician, physical therapist, or athletic trainer to analyze the gait of the entire team, an educated coach could perform this task. To make productive use of the data collected in this study, the next step would be to develop a running biomechanics education program for coaches. By developing an education program of this nature, it may be possible to minimize injuries such as those highlighted by the findings in this study.

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APPENDIX A

Parental Consent Form – Running Biomechancis Study

Title of Study: *Association Between Running Biomechanics and Injury Incidence in Middle School Cross Country Runners*

Introduction: Your child is invited to participate in a research project being conducted by Rachel Salberg, a student in the School of Sport Science and Wellness Education, at The University of Akron. Dr. Ronald Otterstetter, a professor in the School of Sport Science and Wellness Education, at The University of Akron will be overseeing the project.

Purpose: The purpose of this study is to investigate what correlations exist between running biomechanics and specific injuries for middle school cross country runners. 15-20 male and female middle school cross country runners will be recruited for participation.

Procedures: For this study, we will be using 2-D video gait analysis to look at the running form of all participants. Your child will be asked to come to InfoCision Stadium at The University of Akron, accompanied by a parent or guardian, to run on the treadmill and have their running form video recorded. On the day of the video recording, please have your child arrive wearing shorts, a t-shirt, and running shoes. Upon arrival, you will be asked to sign this parental consent form, and your child will be asked to sign an assent form. Please read through these forms to learn what the study entails, and please direct any questions to Rachel Salberg. After the forms have been signed, your child will be asked to report his/her age, gender, team name, and length of time running. His/her weight and height will be measured. Next, your child will fill out a questionnaire asking about their injuries before the season starts. Then, your child will be instructed on how to safely use the treadmill. He/she will then do a 6 minute warm up run on the treadmill at a self-selected pace. After the warm up, your child will continue running, and Rachel Salberg will record him/her running on the treadmill from the front, side, and back, each for 1 minute. Your child will be recorded from head to toe in order to achieve the most comprehensive view of his/her gait. Your child will then perform a walking cool down for 3 minutes, and then stop the belt of the treadmill before stepping off. At this time, you and your child will be free to go. Your child's video will be analyzed by Rachel Salberg with the assistance of a Licensed Physical Therapist who is experienced with running gait analysis. At the end of the cross country season, your child will be asked to fill out a questionnaire to report any injuries he/she encountered over the course of the season.

Your child is eligible for the study if he/she has no contraindications to exercise such as musculoskeletal injuries that are worsened with exercise, are able to run at a self-selected pace for at least 10 minutes without stopping, and plan to complete the 2015 cross country season. In order to participate, your child must also be able to come with a parent or guardian to InfoCision Stadium at The University of Akron for 20 minutes on 1 day in order to have his/or running gait video recorded.

Risks and Discomforts: Risks associated with this study are those involving loss of balance or footing on the treadmill. Loss of balance or footing on the treadmill can cause falling, leading to various degrees of injury. Because your child will be instructed on how to safely use the treadmill, the likelihood for a fall is minor. While it is possible to incur injuries from running, the short time interval and low intensity at which the participants will be performing does not warrant concern for a running-induced injury**.**

If a participant does happen to fall or become injured in any way, first aid care will be offered by Rachel Salberg as well a call for additional medical attention if warranted.

Benefits: The benefits to your child for participating in this study may be acquiring knowledge about how a running gait analysis is performed, and how running biomechanics may be associated with certain injuries. If desired, your child and his/her parents or guardians may have access to the results of the biomechanical evaluation. Knowing about your child's running form may help them make improvements to their form later on. However, there may be no direct benefit from participating in this study.

Right to Refuse or Withdraw: Following your consent, participation of your child in this study remains voluntary. Your child will also be asked to provide assent to participate and may refuse even if you consent. Your child can also refuse to answer any questions and may withdraw from the study at any time without penalty.

Confidential Data Collection: The video recordings of your child's running form will be kept on an iPad that only Rachel Salberg, and Dr. Ronald Otterstetter (project advisor) will have access to. Hard copy results of the gait analysis and questionnaires will be stored in a locked cabinet in InfoCision Stadium 307J at the University of Akron. Only the study investigators will have access to this information. Participants will not be individually identified in any publication or presentation of the research results. Only aggregate data will be used. Your signed consent form and your child's assent form will be kept separate from the data, and nobody will be able to link their responses to them.

Confidentiality of Records: All participants will be assigned a code number, and names and code sheets will be stored separately from the data sheets in which all data will be recorded. Code sheets and data sheets will be stored in a locked cabinet being accessible only by Rachel Salberg and Dr. Ronald Otterstetter. Data will then be stored in Infocision Stadium 307J for 3 years. Gait analysis videos will be stored on the designated iPad for the duration of the study, and will only be accessible by Rachel Salberg, and Dr. Ronald Otterstetter. All videotapes will be deleted at the conclusion of the study unless requested otherwise by a parent or guardian of the participant. If you agree to have your child's information used as part of the research data, you will be asked to sign this parental consent document.

Who to Contact with Questions: If you have questions at any time, you may contact any of the following. Please contact Rachel Salberg to schedule a time for your child's video recording.

Rachel Salberg: 330-612-2927 or rms134@zips.uakron.edu

Dr. Ronald Otterstetter: 330-972-7738 or ro5@uakron.edu
Advisor

This project has been reviewed and approved by The University of Akron Institutional Review Board. If you have any questions about your rights as a research participant, you may call the IRB at (330) 972-7666.

I have read the information provided above and all of my questions have been answered. I voluntarily agree to the participation of my child in this study. I will receive a copy of this consent form for my information.

Parent/Legal Guardian Signature: ________________________ Date: _________________

Name of Child: __________________________________

APPENDIX B

Child Assent Form – Running Biomechanics Study

Title of Study: Association Between Running Biomechanics and Injury Incidence in Middle School Cross Country Runners

My name is Rachel Salberg. I am a student in the School of Sport Science and Wellness Education at The University of Akron being advised by Dr. Ronald Otterstetter.

I am asking you to take part in a research study because I am trying to learn more about the relationship between running form and injuries in middle school cross country runners.

You can participate in this study if you…

- ✓ Do **not** have any current injuries or conditions that are made worse with exercise
- ✓ Can run for 10 minutes without stopping
- ✓ Plan to complete the 2015 cross country season
- ✓ Are able to come to InfoCision Stadium at The University of Akron with a parent or guardian for 20 minutes to record a video of your running form in August.

What is involved in participating in this study?

You will be asked to run on a treadmill. As you run, I will videotape your running form. Please wear shorts, a t-shirt, and running shoes when you show up for your recording. When you arrive, you will be asked to read and sign this assent form. If you have any questions, please ask me! After you sign the form, I will ask you to tell me your age, gender, team name, and length of time you have been running. I will also measure your height and weight. Next, you will fill out a questionnaire asking about your injuries before the season starts. Then, I will teach you how to safely use the treadmill, and you will do a 6-minute warm up run on the treadmill at a pace comfortable for you. After your warm up, you will continue running and I will record a video of you from the front, side, and back, each for 1 minute. Then, you will walk for 3 minutes to cool down. You can then press the stop button on the treadmill and step off. At this time, you will be free to go. At the end of the cross country season, I will ask you to fill out a questionnaire asking about any injuries that you experienced during the season.

Are there any risks to participating?

While running on the treadmill, it is possible to lose your balance or footing, which may cause you to fall. Because I will teach you how to safely use the treadmill, it is not very likely that this will happen. You must also be sure to remain focused throughout your run in order to decrease your risk of falling. If you do fall, first aid care will be offered.

What are the benefits to participating?

You may benefit from participating in this study by learning more about running form, how it is analyzed, and how it may be related to certain injuries. If desired, you may have access to the results of your analysis. Knowing about your personal running form can help you make improvements to it in the future.

Please talk this over with your parent(s)/guardian(s) before you decide whether or not to participate. I will also ask your parents to give their permission for you to take part in this study. But even if your parents say "yes" you can still decide not to do this.

What if I do not want to participate or want to stop participating?

If you don't want to be in this study, you don't have to participate. Remember, being in this study is up to you and no one will be upset if you don't want to participate or even if you change your mind later and want to stop.

You can ask any questions that you have about the study. If you have a question later that you didn't think of now, you can call me, Rachel Salberg, at 330-612-2927 or Dr. Ronald Otterstetter at 330-972-7738.

This project has been reviewed and approved by The University of Akron Institutional Review Board. If you have any questions about your rights as a participant, you can call the IRB at (330) 972-7666.

Signing your name at the bottom means that you agree to be in this study. You will be given a copy of this form to keep.

___________________________________	__________
Print First and Last Name	Age
___________________________________	___________
Signature	Date

APPENDIX C

Pre-Season Injury Questionnaire

Please answer the questions below as honestly and accurately as possible.

1. At any point in the last 3 months, did you stop running due to leg or back pain for 3 or more days in a row?

(a) Yes
(b) No

2. If you answered **YES** to #1, which best describes the location of your pain?

(a) low back
(b) hip/pelvis
(c) upper leg
(d) knee
(e) lower leg
(f) calf/Achilles
(g) ankle
(h) foot
(i) other _______________

3. At any point during the last 3 months, did you stop running due to leg or back discomfort for 3 or more days in a row?

(a) Yes
(b) No

4. If you answered **YES** to #3, which best describes the location of your discomfort?

(a) low back
(b) hip/pelvis
(c) upper leg
(d) knee
(e) lower leg
(f) calf/Achilles
(g) ankle
(h) foot
(i) other _______________

5. At any point during the last 3 months, were you forced to decrease your running distance or speed due to leg or back pain for 3 or more days in a row?

(a) Yes
(b) No

6. If you answered **YES** to #5, which best describes the location of your pain?

(a) low back
(b) hip/pelvis
(c) upper leg
(d) knee
(e) lower leg
(f) calf/Achilles
(g) ankle
(h) foot
(i) other _______________

7. At any point during the last 3 months, were you forced to decrease your running distance or speed due to leg or back discomfort for 3 or more days in a row?

(a) Yes
(b) No

8. If you answered **YES** to #7, which best describes the location of your discomfort?

(a) low back
(b) hip/pelvis
(c) upper leg
(d) knee
(e) lower leg
(f) calf/Achilles
(g) ankle
(h) foot
(i) other _______________

9. At any point during the last 3 months, did you consult a doctor or other health professional due to leg or back pain or discomfort?

(a) Yes
(b) No

10. If you answered **YES** to #9, which best describes the location of your pain or discomfort?

(a) low back
(b) hip/pelvis
(c) upper leg
(d) knee
(e) lower leg
(f) calf/Achilles
(g) ankle
(h) foot
(i) other _______________

11. If you consulted a doctor or other health care professional due to your pain or discomfort, was a diagnosis made?

(a) Yes
(b) No

12. If you answered **YES** to #11, which best describes the diagnosis?

a	Adductor injury
b	Abductor injury
c	Achilles tendonitis
d	Ankle inversion injury
e	Compartment syndrome
f	Calcaneal apophysitis
g	Chondromalacia patella
h	Gastrocnemius (calf) injury
i	Gluteus medius injury
j	Greater trochanteric bursitis
k	Hamstring injury
l	Iliopsoas injury
m	Iliotibial band syndrome (ITBS)
n	Meniscus injury
o	Metatarsalgia
p	Morton’s neuroma
q	Osgood-Schlatter's disease
r	Patellofemoral Pain Syndrome (PFPS)
s	Patellar tendonitis
t	Piriformis sydrome/strain
u	Peroneal tendonitis

v	Plantar fasciitis
w	Sacroiliac injury
x	Spinal injury
y	Stress fracture – femur
z	Stress fracture - metatarsal
aa	Stress fracture - tibia
bb	Stress fracture - vertebrae
cc	Stress fracture – other ____________
dd	Tibial stress syndrome
ee	Tibialis posterior injury
ff	Other ______________________

APPENDIX D
Gait Analysis Evaluation Form

Name: [redacted] Date: ______________

Diagnosis: ____________________ Symptoms: ________________

Left	Frontal Plane	Right
Narrow Neutral Wide	*Step width*	Narrow Neutral Wide
Abducted Cross-over In-line	*Arm movement*	Abducted Cross-over In-line
Ipsilateral Neutral Contralateral	*Trunk*	Ipsilateral Neutral Contralateral
ADD ABD Neutral ↑IR ↑ER	*Hip stability*	ADD ABD Neutral ↑IR ↑ER
Valgus Neutral Varus	*Dynamic knee alignment*	Valgus Neutral Varus
Supinated Neutral Pronated	*Midstance pronation*	Supinated Neutral Pronated
	Cadence (180 strikes per min)	
MILD EXCESSIVE	HEEL WHIP medial	MILD EXCESSIVE
	Lateral Plane	
<4cm 4-6cm >6cm	*Vertical displacement*	<4cm 4-6cm >6cm
↑anterior neutral ↑posterior	*Arm movement*	↑anterior neutral ↑posterior
Forward tilt Neutral	*Torso orientation*	Forward tilt Neutral
Lordosis neutral flat	*Lumbopelvic posture*	Lordosis neutral flat
15-20deg 5-15 <5 <0	*Hip extension*	15-20deg 5-15 <5 <0
>25deg 20-25 <20	*Knee excursion @ stance*	>25deg 20-25 <20
Heel Midfoot Forefoot neutral contact anterior to COM	*Foot strike pattern*	Heel Midfoot Forefoot neutral contact anterior to COM
	Notes:	

Sagittal plane

	Left	Right
Initial Contact		
Foot-Strike Pattern	Heel Strike Rear Foot Mid-Foot Forefoot Toe-Strike	Heel Strike Rear Foot Mid-Foot Forefoot Toe-Strike
Tibial Inclination (vertical or mild inclination)	Vertical Mild Inclination Excessive Inclination	Vertical Mild Inclination Excessive Inclination
Knee Flexion Angle (~20°)	Excessive Decrease Mild Decrease Appropriate Mild Increase Excessive Increase	Excessive Decrease Mild Decrease Appropriate Mild Increase Excessive Increase
Mid-Stance		
Knee Flexion Angle (~40°)	Excessive Decrease Mild Decrease Appropriate Mild Increase Excessive Increase	Excessive Decrease Mild Decrease Appropriate Mild Increase Excessive Increase
Ankle Dorsiflexion Angle (5-20°, relative to WB)	Appropriate Mild Inclination Excessive Inclination	Appropriate Mild Inclination Excessive Inclination
Pushoff		
Hip Extension Angle (0-5°)	Excessive flexion Mild flexion Appropriate Mild extension Excessive extension	Excessive flexion Mild flexion Appropriate Mild extension Excessive extension
Pelvic Tilt (5-10°)	Excessive anterior Mild anterior Appropriate Mild posterior Excessive posterior	Excessive anterior Mild anterior Appropriate Mild posterior Excessive posterior
Lumbar Lordosis (slight extension)	Excessive flexion Mild flexion Appropriate Mild lordosis Excessive lordosis	Excessive flexion Mild flexion Appropriate Mild lordosis Excessive lordosis
Full Gait Cycle		
COM Vertical Excursion (6-8 cm)	Appropriate Mild increase Excessive increase	Appropriate Mild increase Excessive increase
Forward Trunk Lean (5-10° forward)	Excessive Backward Mild Backward Appropriate Mild Forward Excessive Forward	
LATERAL PELVIC TILT (3°-5° male) (5°-7° female)	MILD CONTRALATERAL NORMAL EXCESSIVE CONTRALATERAL	MILD CONTRALATERAL NORMAL EXCESSIVE CONTRALATERAL

APPENDIX E

Post-Season Injury Questionnaire

Please answer the questions below as honestly and accurately as possible.

1. At any point during the season, did you stop running due to leg or back pain for 3 or more days in a row?

(a) Yes
(b) No

2. If you answered **YES** to #1, which best describes the location of your pain?

(a) low back
(b) hip/pelvis
(c) upper leg
(d) knee
(e) lower leg
(f) calf/Achilles
(g) ankle
(h) foot
(i) other _______________

3. At any point during the season, did you stop running due to leg or back discomfort for 3 or more days in a row?

(a) Yes
(b) No

4. If you answered **YES** to #3, which best describes the location of your discomfort?

(a) low back
(b) hip/pelvis
(c) upper leg
(d) knee
(e) lower leg
(f) calf/Achilles
(g) ankle
(h) foot
(i) other _______________

5. At any point during the season, were you forced to decrease your running distance or speed due to leg or back pain for 3 or more days in a row?

(a) Yes
(b) No

6. If you answered **YES** to #5, which best describes the location of your pain?

(a) low back
(b) hip/pelvis
(c) upper leg
(d) knee
(e) lower leg
(f) calf/Achilles
(g) ankle
(h) foot
(i) other _______________

7. At any point during the season, were you forced to decrease your running distance or speed due to leg or back discomfort for 3 or more days in a row?

(a) Yes
(b) No

8. If you answered **YES** to #7, which best describes the location of your discomfort?

(a) low back
(b) hip/pelvis
(c) upper leg
(d) knee
(e) lower leg
(f) calf/Achilles
(g) ankle
(h) foot
(i) other _______________

9. At any point during the season, did you consult a doctor or other health professional due to leg or back pain or discomfort?

(a) Yes
(b) No

10. If you answered **YES** to #9, which best describes the location of your pain or discomfort?

(a) low back
(b) hip/pelvis
(c) upper leg
(d) knee
(e) lower leg
(f) calf/Achilles
(g) ankle
(h) foot
(i) other ______________

11. If you consulted a doctor or other health care professional due to your pain or discomfort, was a diagnosis made?

(a) Yes
(b) No

12. If you answered **YES** to #11, which best describes the diagnosis?

a	Adductor injury
b	Abductor injury
c	Achilles tendonitis
d	Ankle inversion injury
e	Compartment syndrome
f	Calcaneal apophysitis
g	Chondromalacia patella
h	Gastrocnemius (calf) injury
i	Gluteus medius injury
j	Greater trochanteric bursitis
k	Hamstring injury
l	Iliopsoas injury
m	Iliotibial band syndrome (ITBS)
n	Meniscus injury
o	Metatarsalgia
p	Morton’s neuroma
q	Osgood-Schlatter's disease
r	Patellofemoral Pain Syndrome (PFPS)
s	Patellar tendonitis
t	Piriformis sydrome/strain
u	Peroneal tendonitis

v	Plantar fasciitis
w	Sacroiliac injury
x	Spinal injury
y	Stress fracture – femur
z	Stress fracture - metatarsal
aa	Stress fracture - tibia
bb	Stress fracture - vertebrae
cc	Stress fracture – other ____________
dd	Tibial stress syndrome
ee	Tibialis posterior injury
ff	Other ______________________