EVALUATING THE EFFECTIVENESS OF KINESIO® TAPE AS AN INTERVENTION FOR RECREATIONAL RUNNERS WHO PRONATE

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MASTER OF SCIENCE

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ABSTRACT

Kinesio® Tape could potentially be an intervention to improve excessive pronation of the foot. This research project investigated the effect Kinesio® Tape has on the navicular drop test and joint kinematics through 3D motion analysis in recreational runners. Twenty volunteers with an NDT greater than 10 mm ran two separate half-miles, one receiving a mechanical Kinesio® Tape technique and the other with a sham Kinesio® Tape technique. NDT measurements were taken immediately on arrival, immediately after Kinesio® Tape application, and immediately after the half-mile with Kinesio® Tape still applied. 3D motion analysis measured gait kinematics during the half-miles. NDT scores for the tension trials were statistically significantly lower when compared to the sham trials. 3D motion analysis captured six cases of statistical significance, however tape did not change the joint angles. Therefore, Kinesio® Tape improved the amount of pronation of the foot but only slightly improved gait kinematics.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

CHAPTER 1. INTRODUCTION

1.1. Overview of the Problem

Excessive pronation of the foot is a common pathomechanic that often leads to lower extremity injuries, such as medial tibial stress syndrome and patellafemoral pain syndrome. Pronation is a necessary movement during gait, but when an excessive amount occurs, musculoskeletal injuries may occur. Not only does an overly pronated foot place excessive amount of stress on the foot, but it also creates a mechanism to affect superior portions of the kinetic chain.[1] To help decrease the amount of pronation, clinicians have used multiple interventions such as athletic tape and orthotics. Clinicians continue to search for ways to improve patient outcome measures not only to decrease the amount of pronation, but ultimately decrease related lower extremity injures.

Kinesio® Tape is an intervention increasing in popularity that is proposed to have multiple benefits. One way Kinesio® Tape is theorized to aid a joint is by providing a Mechanical Correction. When applied with 75 - 100% tension, Kinesio® Tape is thought to provide an overstimulation to joint receptors and mechanoreceptors to limit the amount of mobility.[2] By applying Kinesio® Tape with this method, a decrease in the amount of pronation of the foot may occur, therefore improving the alignment of the lower extremity kinetic chain.

To analyze joint kinematics, three-dimensional (3D) motion analysis has been proven to be a reliable and valid intervention for detecting gait defects. Specific body parts can be analyzed during dynamic movements through a camera and marker system. Three-dimensional motion analysis is considered the gold standard being it is reliable and accurate in measuring functional tasks and joint kinematics in multiple planes. Excessive pronation has been analyzed in its relationship of altering proximal segments in the kinetic chain. However the use of Kinesio®

Tape on an overly pronated foot has not been extensively investigated nor its potential to improve joint and gait kinematics.[3,4]

1.2. Statement of Purpose

The purpose of this study is to use three-dimensional (3D) motion analysis to evaluate the effect Kinesio® Tape has on pronated feet and superior kinetic chain angles in recreational runners.

1.3. Research Questions

1. When comparing across the two protocols (i.e., Kinesio® Tape applied with or without tension), what changes occur in NDT scores with measurements conducted on participant's bare feet immediately on arrival, immediately after Kinesio® Tape application, and immediately after the half-mile with Kinesio® Tape still applied.
2. What with-in subject differences are observed in joint angles (hip, knee, ankle, and pelvis in the sagittal, frontal, and transverse planes) when Kinesio® Tape is applied with and without tension?

1.4. Dependent Variable

The focal dependent variable in this study will be joint angles (foot pronation, tibial internal rotation, knee valgus, hip internal rotation, and anterior pelvic tilt) measured with 3D motion analysis. In addition, navicular drop test (NDT) scores will also be a dependent variable.

1.5. Independent Variable

The independent variable of this study will be the application of Kinesio® Tape.

1.6. Limitations

This research study will have its limitations. First a treadmill will be used in this study. Running on a treadmill cannot be generalized to outdoor running. A convenience sample will be used with participants between the ages of 18 and 45 years limited to the surrounding Fargo/Moorhead communities. Finally, participants are running two, half mile intervals; thus, the researchers cannot generalize the results beyond a half mile in length.

1.7. Delimitations

After a thorough analysis of previous research as well as consideration of participant comfort, participants will wear their typical running shoes for the data collection period. It is recognized each participant will wear a different brand and model of shoe; however, it is beyond the scope of this project to control the shoe. In addition to 3D motion analysis, the researchers are choosing to include measurements associated with the NDT as opposed to other possible foot measurements. The NDT is a skill within the scope of practice for Athletic Trainers and Physical Therapists. It is commonly used in a clinic setting because of the ease in conducting the test as well as the immediate results. Thus, the NDT will be conducted on all participants for the purposes of drawing conclusions about clinical significance.

1.8. Assumptions

It will be assumed each participant will be able to run two separate half-mile runs without stopping. Participants will also be expected to honestly report their health status. Finally, it will be expected for participants to maintain their normal running mechanics and not change their mechanics due to the Kinesio® Tape and knowing the purpose of the study.

1.9. Significance of Study

Lower extremity injuries are common in recreational runners due to extreme amounts of pronation during gait. Excessive pronation can cause stress on the kinetic chain as well as alter gait kinematics. Kinesio® Tape is an intervention used by many clinicians but it remains controversial because of the lack of evidence for specific applications. By using Kinesio® Tape to decrease the amount of pronation in recreational runners, clinicians may also be able to avoid the amount of lower extremity injuries. The results of this study will be used to determine if Kinesio® Tape is a viable treatment option in recreational runners who present with excessive pronation.

1.10. Definitions

Pronation: A flattened medial longitudinal arch. An excessively pronated foot occurs from adduction and plantarflexion of the talus and eversion of the calcaneus[1]

Kinesio® Tape: A uniquely designed elastic tape that enhances the function of many different tissues and physiologic systems[2]

Three-dimensional Motion Analysis: Movement analysis that uses camera systems to analyze markers placed on specific body parts during dynamic movements to analyze joint kinematics[3]

Recreational Runner: For this study a recreational runner was defined as someone who runs an average distance of 10 miles per week in the last three months[5]

Running Related Injury: A musculoskeletal ailment attributed to running that causes a restriction of running speed, distance, duration, or frequency for at least one week[5]

CHAPTER 2. LITERATURE REVIEW

Lower extremity injuries are commonly reported in runners accounting for 79-90% of all running-related injuries. Those who develop running-related injuries in the lower extremity, such as medial tibial stress syndrome and patellafemoral pain syndrome, often present with a pronated foot type. Pronation of the foot, or decreased arch height, places stress and force along superior portions of the kinetic chain, influencing the alignment of the tibia, femur, and pelvis. In order to decrease the risk of running related injuries, as well as biomechanical errors throughout the kinetic chain, clinicians have used a variety of interventions. Athletic tape and orthotics are just a few of the therapeutic interventions clinicians have used to decrease pronation.

A type of intervention to treat a variety of musculoskeletal injuries that is gaining popularity is Kinesio® Tape. According to the literature, Kinesio® Tape can support joints by providing a biomechanical correction to increase the function of the joint. However, little research has been conducted on Kinesio® Tape's effect on altering pronation. By using three-dimensional (3D) motion analysis, joint kinematics can be collected to investigate if Kinesio® Tape is able to correct excessive pronation, as well as lower extremity alignment. The purpose of this literature review is to examine previous research on how pronation affects the kinetic chain, how Kinesio® Tape can affect foot mechanics, and the reliability and accuracy of 3D motion analysis.

2.1. Pronation

A common pathomechanic during the weight-bearing phase of gait is excessive pronation, or a flattened medial longitudinal arch. An excessively pronated foot occurs from adduction and plantarflexion of the talus and eversion of the calcaneus. Pronation of the foot is essential during initial foot contact, but when an excessive amount occurs, it can lead to lower leg pain and injuries. These mentioned motions of the foot can be caused by weak or inhibited hip abductors and external rotators, as well as a more centralized heel contact.[1] Understanding how these motions take place is crucial for health care providers in order to establish an intervention to solve the impairment. The following section provides a description of involved anatomical structures and how excessive pronation can alter the kinetic chain.

2.1.1. Navicular

The navicular is the most important bone in the shock-absorbing midfoot. Being the crown of the arch, it helps support the rest of the bones of the midfoot, which include the three cuneiforms and the cuboid. The navicular bone also serves as an insertion site for the tibialis posterior muscle.[6] Measuring the height of the navicular is helpful in evaluating the alignment of the midfoot. By measuring the amount of navicular height, the mobility of the midfoot can be determined. The lower the navicular height, the less mobility there is at the midfoot, which is also indicative to an over pronated foot.[7] Due to this biomechanical error, individuals are more susceptible to lower extremity injuries caused by the increased strain from the low navicular height, or over pronated foot.

2.1.2. Calcaneus

Forming the heel of the rearfoot, the calcaneus is the first bone to make contact during gait. Three key landmarks located on the calcaneus are the calcaneal tuberosity, sustentaculum tali, and peroneal trochlea. On the posterior side of the calcaneus, the projecting calcaneal tuberosity serves as an attachment site for the gastrocnemius and soleus via the Achilles tendon. Located on the medial aspect of the calcaneus is the sustentaculum tali, which helps stabilize the talus. Lastly, the peroneal trochlea is set on the lateral side to support the peroneal muscles.[6] During running gait, the heel is first to strike the ground >75% of the time in distance runners.

With pronation occurring between the heel-strike phase and midstance phase of gait, non-rearfoot running is becoming popular. Using a forefoot running technique allows runners to cycle energy from the impact of the ground to give a recoil effect to tendons and ligaments. By avoiding rearfoot striking, running related injuries may reduce as well as excessive pronation.[8,9,10] However, due to the tendency of recreational or inexperienced runners having a heel strike technique, they are prone to injury.

2.1.3. Tibialis Anterior

The tibialis anterior is a large, visible muscle in the anterior portion of the leg that acts to invert the foot, as well as dorsiflex the ankle. Lying lateral to the tibial shaft, the tibialis anterior originates on the lateral condyle of the tibia. The tendon then crosses beneath the ankle on the medial side to insert on the medial cuneiform.[6] As it crosses the middle of the foot, the tibialis anterior helps to pull the foot into dorsiflexion. Due to this formation, it plays a significant role in supporting the medial longitudinal arch. A strong tibialis anterior muscle is critical to sustaining posture to decrease the chances of a flat foot.[11]

2.1.4. Tibialis Posterior

Lying deep to the gastrocnemius and soleus, the tibialis posterior is a primary plantar flexor and inverter of the ankle and foot. The tibialis posterior originates on the proximal, posterior shafts of the tibia and fibula. As the tendon travels behind the medial malleolus, the tibialis posterior inserts on all five tarsal bones as well as the bases of the second, third, and fourth metatarsals.[6] A key component of this muscle is its relationship to pronation. The tibialis posterior helps control pronation as it assists in supinating the foot. Due to this effort in controlling pronation, a large amount of force is created by the tibialis posterior during running.

The weaker the tibialis posterior becomes, the more at risk individuals are to develop pain and lower extremity injuries.[7,12]

2.1.5. Flexor Hallicus Longus

Another muscle located in the deep posterior portion of the lower leg, the flexor hallicus longus, is a primary flexor of the first toe. The flexor hallicus longus also assists in plantar flexion of the ankle, inverting the foot, and supinating the foot. This small muscle originates on the middle half of the posterior fibula and inserts on the distal phalanx of the first toe.[6] The flexor hallicus passes the posterior portion of the medial malleolus and is susceptible to irritation and inflammation from repetitive motion.[12] Due to its action in supinating the foot, strengthening this muscle can decrease the amount of pronation. Developing exercises that target the flexor hallicus longus can be advantageous in decreasing lower extremity injuries associated with excessive pronation.[13]

2.1.6. Peroneals

The peroneus longus and peroneus brevis muscles are slender muscles whose primary action is to evert the foot. Running down the lateral aspect of the lower leg, the tendons pass behind the lateral malleolus to also assist in plantar flexion. Originating on the head of the fibula, the peroneus longus travels distally to insert on the base of the first metatarsal. The peroneus brevis originates on the distal two-thirds of the lateral fibula and inserts on the tuberosity of the fifth metatarsal. The peroneus longus is more superficial than the peroneus brevis however the tendons are both clearly visible.[6] Similar to the tibialis anterior, the peroneus longus pulls the midfoot upward.[11] The two peroneal muscles protect the ankle joint from movements that cause inversion. Strong peroneal muscles are able to resist these movements, thus helping to stabilize the ankle and prevent injury.[14]

2.1.7. Arches

The primary job of the three arches of the foot is to absorb shock, which aids the foot in dispersing forces as well as increasing its flexibility. The arches of the foot include the medial longitudinal arch, lateral longitudinal arch, and the transverse metatarsal arch. During non-weight bearing activities, the arches are more visible than weight-bearing situations as there is more pressure on the foot. During contact on uneven grounds, the arches are able to adapt to help the plantar surface. With the arches ideally coming together at the center of the foot, an even amount of weight can be distributed and absorbed.[6]

The most common difference that alters a runner's kinematics is the arch height. Runners who have supination are more susceptible to bone injuries, whereas those with pronation are more inclined to develop soft tissue injures. The amount of eversion occurring in the rearfoot is the prime dictator in the amount of arch height. The more eversion occurring at the rearfoot, the lower the arch, and vice versa.[15,16] Also playing a major role in the amount of arch height is the tibialis posterior. Moving from the rearfoot to the midfoot during normal gait, the medial longitudinal arch starts to become flat. The amount of eversion and activity of the tibialis posterior determines the arch retaining its integrity.[7] Without the arches working together, stresses are put on the foot that could potentially lead to pathologies.

2.1.8. Kinetic Chain

A central problem with increased pronation is the biomechanical effect it has throughout the lower limbs, or kinetic chain. Specifically relating to the pelvis, movements of this area are highly dependent on lower limb mechanics. A pronated foot causes the tibia to internally rotate, which then causes the femur to internally rotate. Under bilateral weight-bearing conditions, these movements continue to have an effect on the kinetic chain, thus creating an increase in anterior pelvic tilt. Researchers investigated the role on how pronated feet affect the motions in the sagittal, frontal, and transverse plane during unilateral weight bearing. Twenty-eight participants with 2.5°-10.0° of rearfoot eversion were included in the study. Three-dimensional motion analysis captured three conditions of unilateral standing for 10 seconds. In a randomized order, the participants stood directly on the floor, a wooden wedge creating 5° of calcaneal eversion, and a wooden wedge creating 10° of calcaneal eversion. A paired t-test was used to identify a difference of the three unilateral standing procedures ($p < 0.016$). A significant difference in calcaneal eversion, otherwise known as pronation, was produced by the three conditions. Compared to standing on a flat surface, the two eversion conditions produced a statistically significant increase in hip flexion, adduction, and internal rotation. Anterior pelvic tilt also increased during the two eversion conditions compared to the no eversion condition. Statistical analysis are represented in Table 1. The results of this study demonstrate pronated feet increase hip, pelvis, and thorax angles. Due to pronated feet, these increased angles can contribute to injuries such as patellafemoral pain syndrome, iliotibial band friction syndrome, tightened hip ligaments and capsule, and low back pain. Thus, it is recommended health care professionals examine foot alignment in individuals who experience superior kinetic chain pain or injuries.[1]

Table 1. Hip Joint, and Pelvic and Thoracic Segment Kinematics

		Normal condition (M ± SD)	5 Eversion condition (M ± SD)	10 Eversion condition (M ± SD)
Hip joint (°)	Sagittal (flexion/extension)	-1.24 ± 3.11	0.37 ± 3.95	1.71 ± 3.41
	Frontal (adduction/abduction)	3.01 ± 4.05	4.37 ± 4.19	3.19 ± 4.87
	Transverse (medial rotation/lateral rotation)	2.15 ± 3.83	9.52 ± 13.24	9.52 ± 13.32
Pelvic segment (°)	Sagittal (anterior tilt/posterior tilt)	-4.09 ± 2.56	-3.23 ± 3.10	-2.52 ± 3.13
	Frontal (lateral tilt)	6.51 ± 2.14	5.37 ± 3.04	6.77 ± 3.54
	Transverse (axial rotation)	-0.50 ± 2.97	-0.03 ± 4.63	-0.91 ± 4.20
Thoracic segment (°)	Sagittal (anterior tilt/posterior tilt)	0.10 ± 1.73	0.02 ± 2.73	0.10 ± 3.14
	Frontal (lateral tilt)	2.55 ± 1.50	4.09 ± 3.02	3.98 ± 3.72
	Transverse (axial rotation	-0.40 ± 2.31	1.34 ± 3.51	1.25 ± 3.52

2.1.9. Population Specific: Recreational Runners

Foot kinematics is widely dependent on the amount of forces and activity placed on them. Although muscles become atrophied from inactivity, abnormal kinematics can cause excessive pronation of the foot leading to lower extremity injuries. To demonstrate how pronation takes place, researchers compared the muscle morphology and kinematics of the foot in recreational runners with and without pronated feet. This study defined recreational runners as those who ran 15 km per week and have been injury-free for the last 6 months. A total of 26 recreational runners had their foot posture assessed by the Foot Posture Index (FPI). Based on the scores, 17 were categorized as having a normal foot type, while 9 were considered to have pronated feet. To analyze foot kinematics, three-dimensional motion analysis calculated forefoot, rearfoot, and hallux motions in the sagittal, transverse, and frontal planes. Diagnostic ultrasound was used as well to capture cross-sectional and thickness images of the abductor hallucis, abductor digiti minimi, flexor halluces brevis, flexor digitorum brevis, flexor digitorum longus, tibialis anterior, peroneus longus, and peroneus brevis. A one-way ANOVA was used to analyze the difference between those with a normal foot type and those with pronated feet.[17]

In the group which had pronated feet, the thickness of the abductor hallucis and cross sectional area of the flexor digitorum brevis were 7.5% and 18.7% larger than the neutral feet group. When comparing the abductor digiti minimi, the thickness and cross-sectional area in the pronated feet group were 10.3% and 12.3% lower. Lastly, the cross-sectional area of the flexor digitorum longus was 17.0% higher in the group with pronated feet. The remaining cross-sectional area and thickness values are reported in Table 2. These values support the researchers' hypothesis that the abductor hallucis and the flexor digitorum brevis would be larger in pronated feet. To counterbalance a pronated foot, these muscles produce higher forces in order to support the medial longitudinal arch. The increase in cross-sectional area of the flexor digitorum longus in the group with pronated feet was attributed to a necessary increase in inversion muscle activity to keep the foot from further eversion. Since an over-everted foot causes pronation, the invertor muscles must produce a high amount of force to keep the foot as close to normal alignment as possible.[17]

Table 2. Mean, Cross-Sectional Area, and Thickness Values of Selected Foot Muscles

Muscles	Control group	Over-pronated foot group	p-value	Mean Difference (95% CI)
AbH-CSA	262.3 (56.8)	273.7 (39.0)	0.60	-11.4 (-55.2 to 32.5)
AbH thickness	12.0 (1.2)	12.9 (0.8)	0.05	-0.9 (-1.8 to 0.0)
AbDM-CSA	211.7 (21.1)	189.8 (18.7)	0.02	21.9 (4.6 to 39.2)
AbDM-CSA	10.6 (0.8)	9.3 (0.6)	0.00	1.3 (0.6 to 1.9)
FDB-CSA	215.4 (41.6)	255.7 (35.9)	0.02	-40.3 (-74.1 to -6.4)
FDB thickness	9.5 (1.3)	10.3 (1.5)	0.20	-0.7 (-1.9 to 0.4)
FHB thickness	14.6 (1.4)	14.7 (0.6)	0.89	-0.1 (-1.1 to 0.9)
TA thickness	26.1 (3.0)	26.1 (3.3)	0.98	0.0 (-2.7 to 2.6)
PER-CSA	411.0 (88.9)	383.2 (54.0)	0.40	27.8 (-39.4 to 95.0)
PER thickness	14.1 (2.4)	13.9 (1.1)	0.83	0.2 (-1.5 to 1.9)
FDL-CSA	189.6 (27.8)	221.8 (36.4)	0.02	-32.1 (-58.5 to -5.8)
FDL thickness	11.6 (1.7)	12.9 (2.3)	0.13	-1.2 (-92.9 to 0.4)

In the three anatomical planes included in the research project, the only change in angles of heel contact, toe off, and peak dorsiflexion measured by 3D motion analysis were observed in the frontal plane. For the rearfoot, eversion was 6° ($p = 0.03$) larger in the group with pronated feet while inversion was 5° ($p = 0.01$) smaller in the group with pronated feet. In the group with pronated feet, a significant difference of 6° ($p = 0.03$) more supination was measured in the forefoot compared to the rearfoot. These values were consistent with previous studies by Levinger et al[18], Chuter et al[19], and Buldt et al[20] who all identified a greater peak eversion of the rearfoot in those with pronated feet. Since eversion of the rearfoot causes pronation, examining if an individual exhibits this motion during gait can help reduce the risk of lower extremity injuries. The remaining kinematic values are listed Table 3. The results of this study indicate rearfoot eversion and associated muscles attached to the forefoot play a major role in causing pronated feet. The pronated feet caused an increase in muscle morphology of the associated muscles in an effort to have more control in foot motion and support the medial longitudinal arch. Therefore, clinicians should establish an intervention plan to increase recruitment of counteracting muscles for those with a pronated foot.[17]

Table 3. Kinematic Values During Gait

Joint	Plane	Variable	Control Group	Over-pronated group	P-value	Mean Difference
Rearfoot/Tibia	Sagittal	Initial contact	3.03 (4.03)	3.68 (4.29)	0.70	−0.64 (−4.11 to 2.82)
		Toe off/Peak plantarflexion	-4.75 (6.34)	-4.17 (6.25)	0.82	−0.58 (−5.88 to 4.72)
		Peak dorsiflexion	14.11 (4.98)	14.44 (6.02)	0.88	−0.33 (−4.82 to 4.16)
	Transverse	Initial contact	9.00 (15.73)	12.81 (16.30)	0.56	-3.82 (-17.20 to 9.56)
		Toe-off	7.48 (17.18)	9.19 (17.54)	0,81	−1.71 (−16.25 to 12.83)
		Peak internal rotation	13.32 (15.98)	15.10 (15.79)	0.79	−1.78 (−15.16 to 11.61)
		Peak external rotation	-5.39 (15.25)	-0.19 (17.57)	0.43	−5.21 (−18.68 to 8.27)
	Frontal	Initial contact	6.11 (4.86)	0.79 (6.67)	0.03	5.32 (0.69 to 9.95)
		Toe-off	9.88 (4.54)	4.28 (6.48)	0.01	5.60 (1.19 to 10.00)
		Peak inversion	10.99 (4.30)	6.00 (5.18)	0.01	4.99 (1.12 to 8.86)
		Peak eversion	0.34 (5.80)	-5.66 (7.37)	0.03	5.99 (0.66 to 11.33)
Forefoot/rearfoot	Sagittal	Initial contact	-3.62 (6.71)	-5.93 (7.71)	0.43	2.32 (−3.60 to 8.24)
		Peak dorsiflexion	3.83 (6.85)	1.43 (7.10	0.41	2.39 (−3.43 to 8.22)
		Toe off/Peak dorsiflexion	-6.18 (8.06)	-7.63 (7.93)	0.66	1.46 (−5.28 to 8.20)
	Transverse	Initial contact	-1.58 (6.11)	-3.95 (4.22)	0.31	2.36 (−2.32 to 7.05)
		Toe off/Peak adduction	2.74 (6.38)	-0.03 (4.49)	0.26	2.77 (−2.15 to 7.68)
		Peak abduction	-3.86 (5.51)	-6.30 (4.44)	0.26	2.44 (−1.92 to 6.81)
	Frontal	Initial contact	1.84 (6.04)	9.00 (8.16)	0.02	−7.16 (−12.86 to −1.45)
		Toe-off	1.84 (6.34)	8.02 (7.10)	0.03	−6.18 (−11.73 to −0.64)
		Peak supination	3.89 (5.64)	9.89 (7.92)	0.03	−6.00 (−11.43 to −0.57)
		Peak pronation	-2.55 (5.39)	3.46 (4.64)	0.03	−6.01 (−11.50 to −0.52)
Hallux/forefoot	Sagittal	Initial contact	4.33 (6.79)	1.96 (4.64)	0.36	2.38 (−2.82 to 7.58)
		Toe-off	1.76 (6.68)	-0.15 (5.72)	0.47	1.90 (−3.47 to 7.27)
		Peak plantarflexion	-6.63 (7.47)	-6.91 (5.04)	0.92	0.28 (−5.43 to 5.99)

2.2. Kinesio® Tape

2.2.1. Purported Benefits

Taping in the medical field has many benefits that include facilitating and inhibiting muscle activity, repositioning joints, preventing injury, and improving proprioception. In recent years, a new type of tape and taping methods have garnered interest by the active population and allied health care professionals. The main difference between Kinesio® Tape and traditional athletic tape is the ability to have a lifting effect of the skin due to its elasticity, thereby creating space between tissues. This space can take pressure off joints by improving their position, allowing for changes to muscles, ligaments, and fascia. Although the effects of Kinesio® Tape are often debated, studies have been able to support the use through outcome measures, range of motion measurements, and joint position measurements.[21] Researchers continue to support these claims with scientific research, making it a more common and valuable tool to use in clinical practice.[22]

One previously mentioned benefit of Kinesio® Tape is the capability of facilitating or inhibiting muscles. By altering muscle activity, it has been suggested that functional performance may improve. In order to investigate muscle activation, researchers assessed maximum grip strength and surface electromyography (EMG) activity of the wrist extensors in 31 healthy participants. A facilitating tape procedure and inhibiting tape application were applied on the participant's dominant hand in a randomly assigned order. In the facilitation procedure, Kinesio® Tape was applied from origin to insertion of the wrist extensors with a 75% stretch. In the inhibition procedure, Kinesio® Tape was applied in the opposite direction. A control group was also created in which no taping procedure occurred. For each condition, participants squeezed a Jamar® dynamometer three times for three seconds, with one minute between each trial. After completion, participants were to return one week later to complete the next taping procedure. Researchers were able to confirm no significant difference occurred in maximal grip strength for the facilitation group (22.4 ± 16.2 kg), inhibition group (22.9 ± 15.6 kg), or no tape group (23.5 ± 16.7 kg) ($p = 0.327$). There was also no significant difference in EMG activity for the facilitation group (0.287 ± 0.117 mV), inhibition group (0.273 ± 0.148 mV), or no tape group (0.249 ± 0.104 mV) ($p = 0.276$). As a result, it was reported that Kinesio® Tape was not able to alter functional performance. The results of this study do not support the use of Kinesio® Tape in having a facilitating or inhibiting effect of wrist extensor musculature. In spite of this, a limitation to this study is the fact that the researchers applied the tape with tension at 75%, which is not the proper tension for facilitation or inhibition taping techniques. The researchers also only investigated Kinesio® Tapes use immediately after application.[23] In fact, a previous study conducted by Kuo et al[24] found there are prolonged facilitating and inhibiting effects, therefore the results by Cai et al cannot disclaim Kinesio® Tape's purported benefits

Nevertheless, Aghapour et al were able to support the findings by Kueo et al when they detected an increase in functional performance in athletes with patellofemoral pain syndrome (PFPS), suggesting an increase in muscle function. By use of isokinetic testing, a step-down test, and bilateral squatting, researchers measured knee performance in fifteen athletes with unilateral PFPS. To investigate isokinetic strength, a Biodex machine measured peak torque of the vastus medialis oblique muscle (VMO) at speeds of 60 and 180°/s. Ten repetitions were completed at both speeds; the first seven were done with sub-maximal effort and the last three were done with maximal effort. In the step-down test, athletes performed as many repetitions possible of stepping up to a 20 centimeter platform and back down in 30 seconds. Lastly, the athletes were instructed to complete as many squats possible in 30 seconds with the knee reaching 90° of flexion. Ranging from 0 to 10, athletes also recorded their pain intensity on a Visual Analog Scale (VAS) before and after the functional performance testing. These outcome measures were completed at two separate times; once with no tape, and one week later with Kinesio® Tape. To apply the tape, the athlete's leg was positioned in 30° of hip flexion and 50° of knee flexion. From origin to insertion of the VMO, the tape was placed in a Y-shape with 75% tension. Comparing the two conditions by use of a paired t-test ($p < 0.05$), significant differences were reported after the application of Kinesio® Tape, as noted in Table 4. Not only was this study able to confirm the ability to increase muscle activity, but also concluded Kinesio® Tape is able to reduce pain. That being said, the researchers also applied the tape with 75% tension like Cai et al. Although Aghapour et al found positive results, it is stated by Kase et al that 15-35% should be the proper tension to produce a facilitating affect.[2] By using Kinesio® Tape to produce a mechanical change of the VMO, reported pain decreased. With a decrease in pain, an increase in functional performance of the VMO was produced. Along with previous studies, this study supports the purported claim of Kinesio® Tape to alleviate pain, which in return, potentially enables greater muscle activity. A limiting factor of this study was the absence of a control group, or those who were not exhibiting PFPS. In conclusion, Kinesio® Tape was an effective intervention in a population with PFPS.[25]

Table 4. Pain Scale and Peak Torques for Functional Tests

Variable	No Tape	Kinesio® Tape	p-value
VAS	2.86 ± 1.76	1.6 ± 1.35	0.020
Step-down	15.6 ± 4.3	20.01 ± 5.8	<0.001
Bilateral Squat	14.9 ± 4.3	19.6 ± 5.9	<0.001
Concentric, 60	105.4 ± 43.2	137.6 ± 46.9	0.032
Concentric, 180	82.7 ± 26.8	101.4 ± 27.2	0.040
Eccentric, 60	171. ± 63.3	205.7 ± 45.1	0.017
Eccentric, 180	167.1 ± 31.9	193.7 ± 34.9	<0.001

The elasticity provided by Kinesio® Tape that is not present in traditional athletic tape provides support and stabilization to a joint while also allowing for a wide range of motion. In addition, when stabilization is provided to a joint, an increase in postural control is achieved. Due to it's elasticity, health care providers have been using Kinesio® Tape for separate neuromuscular conditions in thought of improving biomechanical function. In order to investigate the role of Kinesio® Tape on postural control and overall balance, 12 individuals who had no prior history of lower extremity injury, no vestibular disorders, and a score of ≥28 on the Cumberland Ankle Instability Tool, meaning they are considered to have functional ankle stability, were selected. At one-week intervals, participants randomly performed the Balance Error Scoring System (BESS) three times with kinesiology tape, placebo tape, or no tape. With a 30-40% stretch, four different strips were applied to the ankle, which are described in the table below.[26]

Table 5. Kinesio® Tape Procedures

Strip	Stability	Direction
1 (ABT)	Dorsiflexion (Posterior talar glide)	Wrapped from talus to calcaneus
2 (ABT)	Inversion	5 cm above medial malleoulus, through lateral calcaneus, outside of instep
3 (ABT)	Eversion	5 cm above lateral malleoulus, through medial calcaneus, inside of instep
4 (ABT)	Dorsiflexion (Posterior talar glide)	Overlaid strip 1
1 (Placebo)	None	Below medial calcaneus to middle medial lower leg
2 (Placebo)	None	Below lateral malleolus to middle lateral lower leg

Statistical analysis reported no significant differences for any of the ranges of motion of the talocrural and subtalar joints ($p > 0.05$). Values from the BESS test are listed in Table 6. While there were no errors during the double leg stances, single-leg stance, or tandem stances on a firm surface, the researchers reported a significant difference on a foam surface ($p < 0.05$). In an athletic setting, the support from the kinesiology tape may assist those athletes who are performing on a softer surface such as gymnastics or wrestling. Although the researchers reported few significant results for taping the ligaments of the ankle, it should be noted they included individuals without ankle instability. Therefore, the use of tape for this population is arbitrary. Future research should incorporate both range of motion testing and BESS scores for individuals who have ankle instability.[26]

Table 6. BESS Scores for the Three Testing Procedures

Position	No taping	Placebo	Kinesio taping	P value
SLS Firm	1.00 (3.00)	2.00 (2.00)	1.00 (2.00)	0.612
SLS Foam	6.00 (4.00)	6.00 (2.00)	4.00 (2.00)	0.003
TS Firm	0.00 (2.00)	1.00 (1.00)	1.00 (1.00)	0.739
TS Foam	4.00 (5.00)	3.00 (3.00)	1.00 (1.00)	0.029

Whereas the previous study investigated balance control on healthy tissue, researchers have also investigated this effect with Kinesio® Tape on injured tissue. Nine soccer players with a history of functional ankle instability in their dominant foot were randomly placed in one of three intervention groups. This included an ankle balance taping group, placebo taping group, and no taping group. The ankle balance taping method using Kinesio® Tape and placebo taping methods were identical to the methodology described by Lee et al mentioned previously. Subjects then performed the Star Excursion Balance Test (SEBT), a reliable test to measure balance. With the testing foot in the middle of the Y-shape, subjects stretched as far as they could with their other foot in the three directions. These distances were then measured from the middle of the Y-shape to where the toe touched the tape. Researchers discovered a significant increase in the ankle balance taping group ($p < 0.05$) for the anterior and posterolateral directions compared to the two other groups. A significant increase in the ankle balance taping group ($p < 0.05$) was also observed in the posteromedial direction when compared to untaped group. These results are described in Table 7. The results of this study support the use of Kinesio® Tape to assist balance control in those who present with functional ankle instability. In contrast to the previously discussed study, a significant improvement in balance was achieved on a firm surface. Although the measuring tool utilized in this study was different, it was able to address balance with a more complex test. By improving these qualities, a normal position of a joint can be achieved while also enhancing movements in various directions.[27]

Table 7. Star Excursion Balance Test Scores for the Three Conditions

Distance	No Tape	Placebo Tape	ABT	P value
Anterior	64.93 ± 4.74	66.07 ± 5.54	71.78 ± 3.74	0.022
Posteromedial	58.72 ± 3.76	62.42 ± 5.34	68.53 ± 5.31	0.004
Posterolateral	66.30 ±	68.81 ± 4.31	74.21 ± 3.95	0.004

2.2.2. Pronation- Specific Taping Techniques

When considering the kinetic chain, health care providers have investigated the role of pronation when recreational and competitive athletes report lower-extremity pain. Researchers have reported that by performing a taping technique to reduce pronation during weight-bearing activities, there is reduced pain reported by the athlete as well as objective, mechanical changes of the lower extremity. Mechanical changes include increased navicular height, decreased calcaneal eversion, and decreased internal tibial rotation. In order to investigate the role of mechanical changes in addition to muscle activity, researchers incorporated a Low-dye Taping Technique to five participants who were determined to have excessive pronation during the stance phase of walking. Participants were taped with the common technique in addition to further supporting taping applications referred to as "calcaneal slings" and "reverse sixes." When comparing the medial longitudinal arch height prior to and after taping, an average increase of 8 mm was recorded by use of a digital caliper. The initial increase was reduced to an average of 5 mm after participants completed 10 minutes of walking. Although the arch height was reduced, the pre-post test results still signify statistical significance (P= 0.002).[28]

In addition to the mechanical advantages of athletic tape, researchers investigated the influence of antipronation taping on lower extremity muscle activity through surface electromyography (EMG). There was a decrease in peak muscle activity of the tibialis anterior and tibialis posterior by 23.9% (P = 0.003) and 45.5% (P = 0.02), respectively with an average reduction of 7.8% (P = 0.021) and 21.1% (P = 0.047). The peroneus longus had a decrease in peak muscle activity of 5.1% (P = 0.561) and an average of -0.9% (P = 0.520) decrease in muscle activity. The reported reduction in muscle activity of the lower leg following the antipronation intervention suggests clinical significance for those individuals who suffer from chronic injuries such as Medial Tibial Stress Syndrome (MTSS) and subluxing peroneals. The results of this study support the use of antipronation taping to assist with the collapse of the medial longitudinal arch height. The researchers concluded the reduction of muscle activity in the tibialis anterior and tibialis posterior altered foot posture similar in the way a taping technique to resist an inversion ankle sprain has on the peroneus longus. In relation to EMG activity, health care providers may also want to use taping to reduce pronation on individuals who present an increase in muscle activity.[28]

Similar to both the methodology and results reported by Franettovich, an increase in medial longitudinal arch height was observed when antipronation taping was applied to joggers.[29] Seventeen participants who exhibited a difference in vertical navicular height greater than 10 mm from relaxed standing to subtalar neutral were included in the study. The same taping technique as described in Frannettovich et al[28] was applied to the foot with the greatest navicular drop, or lowest medial longitudinal arch height, while the other foot acted as a control with no tape. In order to analyze arch height, a digital video camera was used to obtain images before and after participants stood, walked, and jogged on a 12-meter runway. A three way, repeated measures ANOVA was used to measure the difference in the treatment effects before and after the procedures. The mean increases in medial longitudinal arch height of the two treatments are located in the table below. (Table 8)

Table 8. Arch Height for Intervention Condition and Exercise Task

Task	Time	Tape	Control	Condition difference
Standing	Before	0.352 (0.342 to 0.361)	0.349 (0.339 to 0.360)	0.002 (-0.007 to 0.012
	After	0.382 (0.369 to 0.395)	0.349 (0.337 to 0.361)	0.033 (0.018 to 0.048)
	Difference	0.031 (0.023 to 0.038)	0.000 (-0.005 to 0.003)	
Walking	Before	0.345 (0.335 to 0.336)	0.347 (0.335 to 0.360)	-0.002 (-0.010 to 0.006)
	After	0.371 (0.359 to 0.383)	0.347 (0.335 to 0.358)	0.024 (0.013 to 0.035)
	Difference	0.026 (0.018 to 0.033)	-0.001 (-0.004 to 0.002)	
Jogging	Before	0.329 (0.317 to 0.341)	0.330 (0.317 to 0.343)	-0.001 (-0.011 to 0.009)
	After	0.344 (0.334 to 0.355)	0.329 (0.317 to 0.341)	0.016 (0.007 to 0.025)
	Difference	0.016 (0.007 to 0.024)	-0.001 (-0.004 to 0.002)	

A post hoc test compared the effects and revealed a significant difference in arch height between the two conditions ($p < 0.002$). Similar to the results reported by Frannettovich et al, Vincenzino et al promoted the use of antipronation taping to decrease the effects of a pronated subtalar joint. These results were supported by a high intrarater (ratio = 0.98, SEM = 0.01) and inter-rater reliability (ratio = 0.94 SEM = 0.01) of arch height ratio. One potential limitation of this study is that measurements were not taken after a longer period of jogging. Thus, results cannot be generalized to running greater than 12 meters. Overall, with pronation and a low arch height playing a role in soft tissue injuries, the use of anti-pronation taping may reduce these injuries.[29]

In contrast to traditional taping, few studies have investigated whether Kinesio® Tape has an effect on pronated feet. With studies showing evidence of Kinesio® Tape being effective in providing alignment corrections, researchers believed it would have similar effects on foot position. A study conducted by Luque-Suarez et al[30] recruited 68 participants with pronated feet randomized into an experimental Kinesio® Tape group or placebo group. The participants needed to have a Foot Posture Index (FPI) score of 6 to 12, no ankle injury or pain in the previous 6 months, and between 18-40 years old. With the foot in a supinated position, researchers applied a single strip of Kinesio® Tape stretched at 100% from the lateral malleolus to the middle third of the tibia to participants in the experimental group. The description of the taping technique suggests the medial longitudinal arch would be pulled upward to decrease the amount of pronation. However, it should be noted the method used for this research is not documented in an official Kinesio® Tape textbook. The placebo group received the same direction of pull; however, the tape was applied with no tension. In order to measure pronation, an experienced podiatrist in using the FPI and rear-foot FPI obtained measurements after the tape was applied and then after 1 minute, 10 minutes, 60 minutes, and 24 hours. Researchers found there were no significant differences in FPI scores of either group. Although the results imply Kinesio® Tape has no effect on reducing pronation, the outcome measure used may not have been sufficient. Previous studies that have examined traditional taping on pronation have used a navicular drop test[31,32], plantar pressure platform[31], and high-speed film.[33] In conclusion Kinesio® Tape cannot be ruled out for correcting foot pronation without a proper outcome measure.

In the same way Lange et al used a plantar pressure platform to examine the effects of traditional taping on pronation, researchers also used this same outcome measure to discover the effect Kinesio® Tape has on pronation. Twenty participants with a history of medial tibial stress syndrome (MTSS), a leading injury due to pronation, and twenty participants with no history of MTSS were selected. A single strip of Kinesio® Tape was applied with one end at the superior, medial aspect of the tibia. With 75% tension, the tape was split into a Y-strip that was directed on each side of the medial malleolus, which ended at the medial longitudinal arch. This amount of tension was used in order to provide a ligament correction. Plantar pressure was measured five times before application, immediately after application, and 24 hours after application. The researchers' main focus was to detect a higher time-to-peak force (TTPF), or slower rate of loading, at the medial midfoot. With a slower rate of loading, less stress is placed on musculoskeletal structures A three-way ANOVA was used to compare TTPF of the three trials. As a result, a significant increase of TTPF in the MTSS group occurred at the medial midfoot ($p = 0.05$). This increase was observed before application to immediately after application ($p = 0.022$), as well as 24 hours after application ($p = 0.043$). TTPF of the two experimental groups during each condition are listed in Table 9. The results of this study suggest Kinesio® Tape has the capacity to correct excessive pronation in those suffering from MTSS. With a slower rate of loading at the medial midfoot, less strain is put on tendons that are at risk of causing MTSS. One limiting factor of this study is that the methodology included walking only as opposed to more heavy landing activities such as running or jumping. Future studies should be conducted with an appropriate outcome measure, such as a plantar pressure platform, with vigorous activities.[34]

Table 9. Time-to-Peak Force for the Three Testing Procedures

	Before Application		Immediately After		24 Hours After	
	Healthy	MTSS	Healthy	MTSS	Healthy	MTSS
LFF	0.693 ± 0.06	0.670 ± 0.07	0.698 ± 0.04	0.695 ± 0.06y	0.695 ± 0.05	0.685 ± 0.06
LMF	0.392 ± 0.11	0.418 ± 0.07	0.401 ± 0.08	0.415 ± 0.10	0.404 ± 0.12	0.419 ± 0.09
LRF	0.172 ± 0.04	0.181 ± 0.04	0.176 ± 0.04	0.172 ± 0.05	0.182 ± 0.03	0.169 ± 0.05
MFF	0.741 ± 0.04	0.746 ± 0.05	0.748 ± 0.02	0.750 ± 0.03	0.750 ± 0.02	0.750 ± 0.02
MMF	0.329 ± 0.08	0.242 ± 0.14*	0.319 ± 0.12	0.298 ± 0.10y	0.333 ± 0.10	0.287 ± 0.12y
MRF	0.173 ± 0.04	0.173 ± 0.03	0.182 ± 0.04	0.171 ± 0.05	0.179 ± 0.03	0.174 ± 0.04

2.3. Three-dimensional Motion Analysis

Three-dimensional (3D) motion analysis is used for analyzing joint kinematics. Analyzing human motion through a motion analysis system can help identify gait defects, thereby allowing professionals to assist with corrective exercise and/or injury prevention strategies. Three-dimensional motion analysis uses camera systems to analyze markers placed on specific body parts during dynamic movements. This system is often considered the gold standard as it is reliable for measuring functional tasks and can accurately measure joint kinematics in multiple planes. With 3D motion analysis, reliability and validity become essential to accurately gather and analyze data. For this reason, these variables are the primary focus in research related to 3D motion analysis. It is crucial 3D motion analysis is able to provide reliable and accurate data to avoid errors. In doing so, clinicians can be assisted to further evaluate movements and establish rehabilitation programs to improve patient care.[3,4]

2.3.1. Reliability

Three-dimensional motion analysis is considered reliable if it is able to collect consistent data during repeated trials of performance. Multiple factors can influence the reliability of 3D motion analysis including the system being used, marker placement, with-in and between-day repeatability, and movements in multiple anatomical planes. Errors in any of these factors can result in inaccurate data. With consistent and reliable data, clinicians are able to make decisions that will assist individuals in improving a specific movement. For this reason, many studies that incorporate 3D motion analysis as a tool investigate reliability as a primary focus in research. It is critical that the results of an individual's movements by use of 3D motion analysis match his/her overall every day movement otherwise there will be inconsistent data.[3,35,36,37,38]

In order to test reliability and consistency of joint kinematics, researchers created an anatomical model to explore the accuracy of 3D motion analysis. Four separate testing locations were included in order to compare and contrast between-laboratory reliability of marker placement and joint angles. Each laboratory differed in equipment including motion capture systems, which were Motion Analysis or Vicon, number and type of cameras, computational biomechanical models, as well as type of markers. The anatomical models were the same in order to investigate the reliability of the 3D motion analysis system in each laboratory. Vicon, the system of interest, met the minimum standards for testing the marker accuracy of the motion capture system and joint rotations. Overall, the four separate locations were able to collect reliable and accurate data from multiple 3D motion analysis systems. Collecting reliable and accurate data from multiple testing locations ensures the equipment captures similar data regardless of the laboratory. With Vicon being used to produce similar results to the other motion capture systems, consistent data can be collected to correct gait abnormalities and help develop intervention plans. Thus, this information supports the use of Vicon in tracking kinematics.[3]

One component of reliability, specifically related to 3D motion analysis, is the consistency of placing markers on participants for later analysis. While measuring tibial rotation, a study by Webster et al[35] used 3D motion analysis to evaluate within-day and between-day reliability of marker application. Eleven subjects were recruited and completed three sessions. Sessions 1 and 2 were completed on the same day 30 minutes apart, while session 3 was completed a week later. Markers were applied to the participant and remained throughout sessions 1 and 2. Markers were then taken off and reapplied for session 3 one week later. These markers were placed on the anterior superior iliac spines, sacrum, lateral aspects of the thigh and leg, knee joint axis, lateral malleolus, heel, forefoot. A static trial, which consisted of the participant quiet standing, was conducted to acquire a reference point for the markers to confirm their alignment. Following the reference data collection, participants descended a two-step staircase, pivoted 90 degrees, and continued to walk. Results revealed the within-day intraclass correlation coefficient (ICC) values were slightly higher than between-day, thus indicating they were more reliable. For within-day rotational excursion and peak internal rotation, the ICC values were 0.82 and 0.74, respectively. For between-day rotational excursion and peak internal rotation, the ICC values were 0.76 and 0.68, respectively. Although there were differences in the ICC values between the two conditions, they were not statistically or clinically significant. That being said, excellent reliability was demonstrated by rotational excursion for both parameters. In the case for peak internal rotation, there was fair to good reliability. The results of this study confirm reliable within-day and between-day rotational measures can be gathered from the use of marker placement by anatomical landmarks.

Both the methodology and results reported in the Webster study were later confirmed by Rast el al[36] when they incorporated anatomical landmarks to serve as the control for comparing whether a reference trial or algorithms increased reliability. Biomechanists refer to a reference trial as a standing trial in an anatomically upright position to determine a neutral position.[39] The algorithms used are known as point cloud algorithms, meaning they used a least-squares approach to determine marker position. In order to compare marker placements of the three conditions, researchers used Vicon consisting of 11 infared cameras to capture movement of the trunk via 22 anatomical landmarks on the pelvis, thorax, and spine. Between-day reliability was measured by asking participants to complete four separate movements, five times on two separate days; these included axial rotation, lateral bending, grabbing a cup to drink that was on a table and then placing it back, and walking. To process the data, five protocols were compared:

plug-in-gait, adapted plug-in-gait, adapted plug-in-gait (reference trial), point cloud, and point cloud (reference trial). When researchers compared the four movements by using the point cloud algorithm, the index dependability for lateral bending and axial rotation angles were 5.8% higher. Comparatively, anatomical landmarks were reported as having 13.7% higher index of dependability for flexion. Results indicate the use of anatomical landmarks is an appropriate method for capturing movement in the sagittal plane. Therefore, a protocol relating to marker placement is not needed in order to obtain reliable and accurate data from 3D motion analysis, thus allowing clinicians to place markers according to anatomical landmarks.

Research has shown separate protocols can be used to decrease the error related to marker application. Rather than focusing on skin markers alone, few studies have investigated the reliability of 3D motion analysis to capture normal gait movements in multiple planes. A study conducted by Kadaba et al[37] compared the within-day and between-day gait analysis reliability of motions in the sagittal, frontal, and transverse planes. Forty adults participated in a gait analysis study composed of three sessions; all sessions were one week apart. Five infrared cameras captured 3D trajectories at a distance of six meters. Markers were placed on the acromion process, anterior superior iliac spines, lateral aspect of the greater trochanter, posterior to the lateral femoral condyles, lateral malleolus, and the dorsum between the second and third metatarsals. Also, a posterior sacral wand was used to measure pelvic tilt, as well as two more markers placed at the thigh to measure rotation. Subjects were instructed to walk along the six-meter walkway and back at a self-determined pace three times. The 3D motion analysis displayed better reliability for same test day angles than those of between-day. In the sagittal plane however, results were excellent for both within-day and between-day analysis, specifically hip, knee, and ankle motions (Table 10). Compared to the sagittal plane, the frontal and transverse planes adjusted coefficients were lower due to the reapplication of the markers and wands. The outcomes of this study indicate repeated gait patterns can be measured by 3D motion analysis. This system is able to report consistent sagittal plane joint angles, especially studies conducted on the same day. Frontal and transverse plane movements are affected by between-day data collections due to marker placement.

Table 10. Coefficient of Multiple for Joint Angles

Joint Angles	CMC within a day (Left)	CMC within a day (Right)	CMC between days (Left)	CMC between days (Right)
Pelvic tilt	0.669 ± 0.134	0.643 ± 0.180	0.244 ± 0.180	0.240 ± 0.197
Hip flexion/extension	0.996 ± 0.003	0.995 ± 0.005	0.983 ± 0.012	0.978 ± 0.019
Knee flexion/extension	0.994 ± 0.005	0.994 ± 0.003	0.981 ± 0.014	0.985 ± 0.009
Ankle dorsiflexion/plantar	0.975 ± 0.018	0.978 ± 0.010	0.937 ± 0.030	0.933 ± 0.034
Pelvic obliquity	0.961 ± 0.030	0.956 ± 0.045	0.890 ± 0.096	0.883 ± 0.104
Hip abduction/adduction	0.964 ± 0.030	0.957 ± 0.088	0.885 ± 0.067	0.882 ± 0.101
Knee varus/valgus	0.942 ± 0.044	0.962 ± 0.029	0.611 ± 0.172	0.783 ± 0.159
Pelvic rotation	0.860 ± 0.090	0.878 ± 0.069	0.716 ± 0.155	0.768 ± 0.154
Hip rotation	0.893 ± 0.064	0.893 ± 0.072	0.410 ± 0.210	0.483 ± 0.236
Knee rotation	0.911 ± 0.090	0.918 ± 0.053	0.490 ± 0.191	0.534 ± 0.221
Foot rotation	0.853 ± 0.080	0.885 ± 0.053	0.582 ± 0.176	0.612 ± 0.200

2.3.2. Validity

A second component researchers must consider with the use of 3D motion analysis is validity, or the ability to correctly measure joint angles. Variables, such as joint angles and movements of a body part during a functional task, can be collected in various anatomical planes. Three-dimensional motion analysis is able to detect dysfunctions by marker locations or a xyz coordinate system to report kinematic data. With the use of camera-based analysis, a more in-depth evaluation can be completed. Clinicians can use this data as a tool in making decisions to correct a motion that may put an individual at risk for injury. Therefore, 3D motion analysis can be used to make an accurate, clinical decision to decrease the potential for injury, but also improve performance.[40,41,42]

Specific footwear technologies have been used as a correction tool to eliminate excessive pronation in runners, yet studies have had difficulty measuring foot pronation because of the morphology of the subtalar joint. By analyzing eversion and inversion, Cheung et al[43] compared and contrasted the effect of motion control versus neutral shoes on runners' rearfoot kinematics before and after fatigue. Twenty-five female, recreational runners with pronated feet who trained at least once per week for a year were recruited for the study. Motion control and neutral shoes were given to the participants to perform the running with the main feature alteration being the composite materials in the midsole. To begin, participants ran with the neutral shoes on a treadmill at 10 km/h (6.2 mph). This session was used to eliminate participants who did not have a rearfoot angle higher than 6°, as it is the average cut-off for rearfoot motion in determining a pronated foot. Data were collected for nine minutes including 25 left-footed steps before and after the nine minutes. Participants then ran on the treadmill again a week later but with the motion control shoes. Between the running trials, participants completed a fatigue technique involving left foot isometric inversion strength. Markers were placed on the left foot just above the shoe sole, center of the heel where the Achilles tendon inserts, center of the Achilles tendon at the height of the medial malleolus, and 15 centimeters above marker three. The 3D motion analysis displayed no significant difference of foot pronation with the motion control shoes before and after fatigue with a change of 0.7° (95% CI - 0.3° to 1.4°) ($p < 0.01$) after fatigue. Conversely, there was a significant change with the neutral shoes, as there was a 6.5° (95% CI –

4.7° to 8.2°) ($p < 0.01$) increase after fatigue. This study was able to conclude rearfoot angles were higher with a neutral shoe compared to a motion control shoe, exemplifying the validity of 3D motion analysis in measuring rearfoot kinematics. By being able to measure rearfoot kinematics, clinicians can use 3D motion analysis as a tool during their evaluation to correct foot issues, such as excessive pronation.

In relation to the validity for gait mechanics, Dodd et al[38] incorporated 3D motion analysis to measure the symmetry of lateral pelvic displacement. Twenty subjects were recruited to complete three trials of walking down a walkway. Markers were placed on the sacrum of S2 and the insertion site for the Achilles tendon. An xyz coordinate system was used to measure the amplitude and symmetry of lateral pelvic displacement where x was the forward motion, y was vertical motion, and z was the lateral motion of the pelvis. The mean amplitudes of lateral pelvic displacement for the three trials were 41.0 mm (SD = 12.2), 41.2 mm (SD = 14.3), and 40.5 mm (SD = 12.0), respectively. Also for the three trials, mean symmetry was 2.9 mm (SD = 7.5), 4.0 mm (SD = 8.6), and 2.0 mm (SD = 6.9). Results from this study support 3D motion analysis is able to obtain normal gait movements, such as lateral pelvic displacement. In using 3D motion analysis to observe lateral pelvic displacement, clinicians are able to detect walking patterns that may be pathomechanical and ultimately lead to injury. Clinical decisions can be based off findings from 3D motion analysis to develop a proper rehabilitation program, which will lead to improved gait performance.

2.4. Conclusion

In summary, future research is warranted to determine the effect Kinesio® Tape has on pronated feet in recreational runners. Little research has been conducted to examine if Kinesio® Tape can correct the biomechanical error that many recreational runners posses. Even though

Kinesio® Tapes capabilities are still debated, evidence has been provided to show it can, in fact, correct joint positioning. With Kinesio® Tape being able to provide this benefit, pronation is theoretically reduced and kinematics along the superior kinetic chain may also be altered. Therefore it is necessary for research to be conducted to investigate if Kinesio® Tape can be used as an intervention to decrease the risk of running-related injures due to pronation.

CHAPTER 3. METHODOLOGY

3.1. Purpose

The purpose of this study was to use three-dimensional (3D) motion analysis to evaluate the effect Kinesio® Tape has on pronated feet in recreational runners. This study will focus on changes in kinematic angles during two separate half-mile runs; one session with tension applied to Kinesio® Tape and the other session with no tension applied to the Kinesio® Tape. The goal of this study is to answer the following research questions:

1. When comparing across the two protocols (i.e., Kinesio® Tape applied with or without tension), what changes occur in NDT scores with measurements conducted on participant's bare feet immediately on arrival, immediately after Kinesio® Tape application, and immediately after the half-mile with Kinesio® Tape still applied.
2. What with-in subject differences are observed in joint angles (hip, knee, ankle, and pelvis in the sagittal, frontal, and transverse planes) when Kinesio® Tape is applied with and without tension?

3.2. Participants

Participants were recruited from the Fargo, North Dakota area by email and word-of-mouth procedures. Subjects had to be running an average distance of 10 miles per week in the last three months.[5] Subjects were between the ages of 18 and 45 years old. They also had an NDT height greater than 10 mm, as this is considered to be excessive pronation. Exclusion criteria for this study included: current lower extremity injury, which inhibited the participant from running one mile; lower extremity surgery within the past three months prior to data collection; orthopedic pain with running on a treadmill; uncontrolled asthma; and cardiovascular conditions, which prevents the volunteer from safely participating in exertional exercises. Also, any contradictions for Kinesio® Tape, including allergy to adhesive, malignancy sites, cellulitis, skin infection, open wounds, diabetes, or fragile skin were part of the exclusion criteria. Once recruited, subjects were asked to refrain from running 48 hours prior to data collection to limit confounding variables such as fatigue.

3.3. Setting

This study was conducted in the Biomechanics Laboratory in the Bentson Bunker Fieldhouse on the campus of North Dakota State University. This laboratory was used because the equipment for the study was located in this site. Participants were recruited from the surrounding area and had easy access to the location.

3.4. Instrumentation

The equipment needed for this research protocol included a treadmill, video cameras, and 3D motion analysis software. A Trackmaster TMX425C treadmill (Full Vision, Inc., Newton, KS) was used for two, half-mile runs at a self-determined tempo pace with a zero percent incline. Eight Vicon Vantage cameras at 200 Hz were used for recording 3D video. Three-dimensional motion analysis is highly reliable and accurate to measure joint kinematics and functional task in multiple planes. Normal gait movements, such as lateral pelvic displacement, rearfoot kinematics, and tibial rotation, can be analyzed in order to identify if any gait defects are present. Vicon Nexius 2.6.1 is the software that will run the cameras, while Vicon Polygon 4.3.1 is the software that will be used to analyze the motion capture data. A modified plug-in-gait model from Vicon was used.

The NDT was used to measure the degree of pronation and change in the medial longitudinal arch height. Marks were placed on an index card to compare the distance from the ground to the navicular tuberosity in a non-weight-bearing and weight-bearing position. These marks were made at the navicular tuberosity in both positions. If the difference is more than 10 mm, then a foot is considered over pronated. The NDT has been considered a reliable and valuable measurement in determining over-pronation.[44]

Kinesio® Tex Tape was used as the elastic tape to, in theory, decrease the amount of pronation at the subtalar joint. Kinesio® Tape can help decrease stress on tissue by providing a positional stimulus to influence a desired resting position. This position can "inhibit" an undesired pathologic movement, while still maintaining full, functional active range of motion. By providing this correction, less stress is applied on tissues, which can lead to a decrease in overuse injury. The recommendation given by Kase et al[2] involves using Kinesio® Tape to correct movement and compression at the medial longitudinal arch.

3.5. Procedures

Once participants arrived to the research laboratory, they completed the IRB-approved informed consent, Health History Questionnaire, Physical Activity Readiness Questionnaire (PAR-Q), and demographic questionnaire. The demographic questionnaire gave additional information about age, gender, years of running experience, miles ran per week, average running distance, and any previous injuries. Subjects were asked to report to the research laboratory once, as they completed two, half-mile runs; one with tension and one without tension applied to the Kinesio® Tape. Participants were randomly assigned to run with the designated tension prior to arrival. A random number generator picked either the number one or two. The number one indicated the first half-mile is to be the experimental trial and the number two indicated the first half-mile is to be the control trial.

Next the NDT was completed on each participant's feet three times: while barefoot, while barefoot with Kinesio® Tape applied before the half-mil run, and barefoot with Kinesio® Tape applied after the half-mile run. The NDT is a reliable and valuable measurement to determine the degree of pronation and change in the medial longitudinal arch height from a non-weight-bearing position to a weight bearing position. A difference of more than 10 mm is considered as over pronation. To begin, the participants sat in a relaxed position with the hip and knees flexed to 90°. A designated examiner marked the navicular tuberosity with a pen. The examiner then placed the participant's foot in a subtalar neutral position, meaning the talar depressions felt on both sides of the talus are equal. While in this position, the examiner measured the height from the ground to the navicular tuberosity by placing an index card on the side of the foot and marking the distance. The participant then stood with equal weight on both feet. The height from the ground to the navicular tuberosity was again marked on the index card. The difference between to two marks on the index card were measured to determine if there is excessive pronation.[44]

Following NDT measurements, a clinician who is a Certified Kinesio® Tape Practitioner (CKTP) applied the Kinesio® Tape. Participants were blinded to the taping technique they receive. First the skin was cleaned with an alcohol prep pad and any excess hair was trimmed. Once the skin had been cleaned, Kinesio® Tape was applied with the designated tension based on the number participants were randomly assigned. In the experimental trial, a Mechanical Correction was applied on the arch of the foot. The participants lay in a supine position. A single strip of Kinesio® Tape was cut measuring the distance from the distal portion of the lateral malleolus to the proximal portion of the medial malleolus. The base was applied from the distal portion of the lateral malleolus to the lateral 1/3 of the foot's plantar surface with no tension. The participant will then supinate their foot while the tape is applied from the middle of the foot's plantar surface to the navicular with 75% tension. Lastly the tail was applied from the navicular to the proximal portion of the medial malleolus with no tension. Once applied, the tape was rubbed to activate the adhesive. In the control trial, the same taping technique was applied but without tension and Mechanical Correction.

Following NDT and Kinesio® Tape procedures, anthropometric data was collected. Height, weight, anatomical leg length (at the levels of the condyles), and ankle width (at the levels of the malleoli) were measured. The areas where markers were placed were cleaned with an alcohol prep pad. Thirty-six, 14 mm reflective markers were placed on the participant. These markers were placed on each anterior superior iliac spine, posterior superior iliac spine, iliac crest, superior anterolateral thigh as a reference, inferior anterolateral thigh as a reference, mid posterolateral lateral thigh, medial femoral condyle, lateral femoral condyle, superior anterolateral calf as a reference, inferior anterolateral calf as a reference, mid posterolateral calf as a reference, lateral malleolus, medial malleolus, first metatarsal head, second metatarsal head, second metatarsal base, fifth metatarsal head, and back of the heel. Markers on the knee, ankle, and shoe were secured with KT tape, while the rest were secured with surgical tape. The medial femoral condyle, medial malleolus, and second metatarsal head markers were taken off after a still image was captured before running trials. The cameras use the markers to etect joint angles and position in reference to the still images captured before each trial. These cameras were calibrated for 30 minutes before each use, which was completed once the participant arrives.

Before participants began their running trial, they were given a one-minute warm-up at a self-selected speed. After the warm-up, they were given a one-minute rest period to stretch before the running trial begun. Participants then began a half-mile run at a self-determined tempo pace with a zero percent incline.

Eight Vicon (Centennial, Colorado, USA) three-dimensional motion capture cameras collecting data at 240 Hz were used to capture marker trajectory data for 10 seconds after each tenth of a mile for 0.5 miles. Vicon Nexus 2.8.0 was used to capture, process, and filter marker trajectory data using a Woltring filter.[48] Marker trajectory data was then exported to python (Anaconda Suite, Version 2.7) where kinematics were modeled using a custom written script.[47] Initial contact and toe-off were then defined in Nexus with the assistance of synchronized digital video to define each gait cycle for the entirety of the capture. Kinematics for each gait cycle in the capture were then averaged into one representative time series and interpolated into 101 data points representing 0 to 100% of the gait cycle using Vicon Polygon 4.3.1. The loading response corresponded to the first instance in the interpolated gait cycle in which the sagittal plane orientation of the foot segment relative to the ground was neutral or zero degrees. Mid-stance corresponded to the instance in the stance phase of the interpolated gait cycle in which the sagittal plane knee flexion angle was the greatest. Kinematics for each joint were identified at these time points and the change in angle, or excursion, during the weight acceptance phase was then calculated by subtracting the angle at mid-stance from the angle at the loading response.

After the run was over, participants were given a 30-minute rest after the first running trial in order to allow the effects of the Kinesio® Tape to wear off. After the 30-minutes, the opposite intervention was applied, and markers were adjusted. The medial femoral condyle, medial malleolus, and second metatarsal head markers were reapplied and then taken off after another still image was taken. Running procedures then began. During the running sessions, joint angles from the Vicon software were collected for ten seconds every tenth of a mile. During these ten seconds, the maximum, minimum, and average joint angles were calculated.

3.6. Analysis

This within-subjects study applied a pretest/posttest design with subjects randomly divided into experimental and control groups. Statistical analysis for the approved research was computed using SPSS software (Version 23.0). To observe changes in NDT scores a two-way, within-subjects ANOVA model was estimated. In order to analyze difference in gait kinematics, an additional two-way, within-subjects ANOVA model was utilized for 18 angle measurements for each leg, thereby totaling 36 models.

3.7. Conclusion

The purpose of this study was to examine the effect Kinesio® Tape has on pronated feet in recreational runners, as well as subsequent changes in lower extremity kinematics due to the application of Kinesio® Tape. Three-dimensional (3D) motion analysis was used to record joint angles. The NDT was also used to record changes in the medial longitudinal arch height. With lower extremity injuries being so common in recreational runners, the results of this study may allow clinicians to incorporate Kinesio® Tape into their practice to help avoid or treat musculoskeletal injuries. Kinesio® Tape may be able to be used as an alternative modality to orthotics or personalized shoes to correct over pronation. Overall, this study will be used to determine the effect Kinesio® Tape has on an over pronated foot in order to add another treatment option and improve patient outcomes.

CHAPTER 4. MANUSCRIPT

4.1. Abstract

[Study Design] Randomized Controlled Trial

[Background] Excessive pronation of the foot is a common pathomechanic that often leads to lower extremity injuries. Kinesio® Tape is proposed as a viable treatment intervention to reduce excessive pronation, but the procedure has never been substantiated through research. The navicular drop test (NDT) is a reliable method in measuring the amount of pronation, while three-dimensional (3D) motion analysis is the gold standard in capturing gait kinematics. There is a need for outcome measures to determine if there is a positive effect in response to Kinesio® Tape on a pronated foot.

[Objectives] To determine the effect Kinesio® Tape has on navicular drop test (NDT) scores and joint kinematics through the use of 3D motion analysis in recreational runners.

[Methods] This study consisted of twenty volunteers (M=24.4, SD=7.358) who had an NDT score greater than 10 mm. Participants ran two separated half-miles, one with a mechanical Kinesio® Tape technique (75% tension from lateral side of the plantar surface to navicular tuberosity) and the other with a sham Kinesio® Tape technique (0% tension from anchor to tail). NDT measurements were taken on both of the participant's bare feet immediately on arrival, immediately after Kinesio® Tape application, and immediately after the half-mile with Kinesio® Tape still applied. 3D motion analysis measured gait kinematics during the half-miles of the hip, knee, ankle, and foot.

[Results] NDT scores for the tension trials were statistically significant when compared before tape application, immediately after tape application, and after the half-mile run. When using an ANOVA to evaluate the change of angles throughout the half-mile interval, 3D motion

analysis was able to capture six cases of statistical significance. When calculating Kinesio® Tape's effects alone through 3D motion analysis, there was no statistical significance.

[Conclusions] A mechanical Kinesio® Tape application on excessively pronated feet improved the amount of pronation after application and after a half-mile run as reported by NDT scores, and could potentially be an intervention to alter gait kinematics according to 3D motion analysis.

[Level of Evidence] Therapy, level 2b

[Key Words] Pronation, 3D motion analysis, NDT

4.2. Introduction

Excessive pronation of the foot is a common pathomechanic that often leads to lower extremity injuries, such as medial tibial stress syndrome and patellafemoral pain syndrome.[17] Populations prone to these types of injuries are recreational runners, as 79-90% of all running-related injuries effect the lower extremities.[45] Often presenting with an overly pronated foot type, excessive stress and force are placed on a recreational runner's foot, tibia, femur, and pelvis, thereby creating biomechanical errors.[1] Pronation of the foot is a key component of the gait cycle during initial foot contact. However, excessive pronation should be minimized by clinicians to decrease running-related injuries.[17] To help correct an overly pronated foot position, clinicians have used various interventions such as athletic tape and orthotics.[30] One proposed intervention is Kinesio® Tape to support the medial longitudinal arch of the foot thereby alleviating the excessive pronated position.

Kinesio® Tape is an elastic tape that can support or reposition joints, facilitate and inhibit muscle activity, prevent injury, and improve proprioception.[21,22] When applying Kinesio® Tape with 50-75% tension, Kinesio® Tape is theorized to provide a biomechanical correction to a joint by stimulating joint receptors and mechanoreceptors and in sense, limit the amount of mobility.[2] Studies conducted to investigate the effects of Kinesio® Tape are widely inconsistent due to the tension and type of tape applied.[2,30,34] For example, a study conducted by Luque-Suarez et al applied Kinesio® Tape with 100% tension in an effort to correct excessive pronation. Proper taping techniques following the guidelines of Dr. Kase, the creator of Kinesio® Tape, should be incorporated when using the intervention. Failure to abide by the published methodology can lead to incorrect results and findings by researchers or practitioners.

To date, there are two studies that have examined Kinesio® Tape's effects on pronation. It should be noted the research is limited due to the correct application of the tape. Another reason research is limited is due to the use of insufficient outcome measurements to detect positive effects from Kinesio® Tape. In one study, researchers applied Kinesio® Tape with 100% tension from the lateral malleolus to middle third of the tibia while using the Foot Posture Index (FPI) to detect a change in pronation. Researchers found there were no significant differences in FPI scores in participants with 100% tension compared to a control group with no tension.[30] Although the Kinesio® Tape did not produce significant changes in pronation, it should be noted there are more reliable outcome measures, such as the NDT and plantar pressure platforms, to measure pronation.[31,32,46] In the second study, the Kinesio® Tape was applied with 75% from the medial aspect of the tibia to the medial longitudinal arch. A plantar pressure was used to calculate a significant increase in time-to-peak force (TTPF) immediately after application ($p = 0.022$), as well as 24 hours after application ($p = 0.043$), implying Kinesio® Tape can correct excessive pronation immediately and over time. However, the participants in this study were only asked to walk across the platform and did not perform vigorous activities.[34] Without proper tape application, outcome measures, and testing procedures, the use of Kinesio®

Tape for correcting pronation cannot be ruled out. Therefore, research that explores the integrity of Kinesio® Tape is required.

Three-dimensional (3D) motion analysis is a reliable and valid intervention to analyze joint kinematics during a runner's gait cycle.[3,4] By analyzing specific body parts during dynamic movements, cameras are used to help identify gait defects through the use of a marker system placed on the body.[3,4] Often considered the gold standard, reliable and accurate data can be collected to measure joint kinematics during functional tasks in multiple planes.[3,4] When it comes to outcome measures, 3D motion analysis has the reliability and validity to measure a change in kinematics. A study conducted by Chenug et al[43] used 3D motion analysis to capture how a change in pronation can affect runner's rearfoot kinematics before and after fatigue. In order to test a difference in degrees of pronation, motion control shoes versus neutral shoes were compared and contrasted. The 3D motion analysis displayed no significant difference in pronation with the motion control shoes, but the neutral shoes showed a significant increase in pronation after fatigue.[43] This study validates the ability of 3D motion analysis to evaluate foot kinematics and detect if an intervention creates a positive effect on pronation.

Due to the lack of literature on this topic, it is important to investigate whether Kinesio® Tape has an effect on the foot posture of recreational runners. With excessive pronation being a common etiology for running-related injuries, Kinesio® Tape could be an intervention to not only correct this biomechanical error, but also improve overall gait. Gait has been analyzed by 3D motion analysis and justified it to be a reliable measuring device. Multiple studies have demonstrated the validity of 3D motion analysis; although there is limited published research that has used it to measure pronation in runners. Dynamically evaluating the change Kinesio® Tape could have on pronation and gait needs to be researched to investigate the product as a possible alternative to orthotics or athletic tape. 3D motion analysis alongside an applicable outcome measure, such as navicular drop test, is an efficient method for detecting changes in foot posture and kinetic chain angles. Since there is evidence that Kinesio® Tape can correct joint positioning, correction of pronation and its effect on the superior kinetic chain would assist recreational runners who struggle with chronic lower extremity injuries.

4.3. Methods

4.3.1. Subjects

Twenty adults (m=10, f=10) ranging from 18 to 44 (M=24.4, SD=7.358) volunteered for this study through email listserv and word-of-mouth in the Fargo-Moorhead area. Before participants arrived, a random number generator picked either the number one or two. The number one indicated the first half-mile would be the experimental trial and the number two indicated the first half-mile would be the control trial. Inclusion criteria was participants had to have been running an average distance of 10 miles per week in the last three months[5] and a Navicular Drop Test (NDT) height greater than 10 mm.[44] The NDT is inexpensive and less time-consuming than other foot measuring parameters, such as the FPI or pressure platforms. Participants were excluded if they had a current lower extremity injury that inhibited them from running one mile, lower extremity surgery within the past three months prior to data collection, orthopedic pain with running on a treadmill, uncontrolled asthma, or a cardiovascular condition that would have prevented them from safely participating in exertional exercise. They were also excluded if there were any contraindications to Kinesio® Tape, including allergy to adhesive, malignancy site, cellulitis, skin infection, open wounds, diabetes, or fragile skin. To screen for inclusion and exclusion criteria, participants completed and Health History Questionnaire and Physical Activity Readiness Questionnaire (PAR-Q). This study was approved by the

University's Institutional Review Board. Prior to the study, all participants read and signed a written informed consent defining the procedures and risks involved.

4.3.2. Navicular Drop Test

A clinician trained in measuring NDT scores first measured the amount of pronation in bilateral feet of each participant to determine inclusion criteria. Measurements were taken on both of the participant's bare feet immediately on arrival, immediately after Kinesio® Tape application, and immediately after the half-mile with Kinesio® Tape still applied. The participant started by sitting in a relaxed position with their hips and knees flexed to 90°. The clinician marked the navicular tuberosity with a pen and placed the participants foot in a subtalar neutral position. From there, the clinician marked the height from the ground to the navicular tuberosity on an index card. The participant then stood with equal weight on both feet to measure the height from the ground to the navicular tuberosity again on the index card. A ruler was used to measure if a difference of more than 10 mm occurred, which is considered over pronation.[44]

4.3.3. Kinesio® Tape Application

Once initial NDT scores were obtained, a Certified Kinesio® Tape Practitioner (CKTP) applied Kinesio® Tape to the arches of both feet with the participant lying supine on a taping table. The experimental trial was conducted with 75% tension, while the control trial was conducted with 0% tension. Two Y-strips were cut measuring the distance from the distal portion of the lateral malleolus to the proximal portion of the medial malleolus. In the experimental trial, the base was applied with 0% tension from the distal portion of the lateral malleolus to the lateral 1/3 of the foot's plantar surface. The taped was then stretched to 75% while being applied from the middle of the foot's plantar surface to the navicular tuberosity. Lastly, the tail was applied from the navicular tuberosity to the proximal portion of the medial malleolus with 0% tension.

Following taping procedures, the NDT was conducted a second time. The NDT was conducted one final time after the running trial was completed.

4.3.4. 3D Motion Analysis Protocol

Following NDT and Kinesio® Tape procedures, anthropometric data was collected. Height, weight, anatomical leg length, knee width (at the levels of the condyles), and ankle width (at the levels of the malleoli) were measured. Thirty-six, 14 mm reflective markers (High Precision 14.0 mm Pearl Markers) were placed on the participant in accordance with conventional gait model 2.4.[47] These markers were placed on each anterior superior iliac spine, posterior superior iliac spine, iliac crest, superior anterolateral thigh as a reference, inferior anterolateral thigh as a reference, mid-posterolateral lateral thigh as a reference, medial femoral condyle, lateral femoral condyle, superior anterolateral calf as a reference, inferior anterolateral calf as a reference, mid-posterolateral calf as a reference, lateral malleolus, medial malleolus, first metatarsal head, second metatarsal head, second metatarsal base, fifth metatarsal head, and back of the heel at the level of the calcaneus. Markers on the knee, ankle, and shoe were secured with KT tape, while the rest were secured with surgical tape. The medial femoral condyle, medial malleolus, and second metatarsal head markers were used only for calibration and removed following the collection of a calibration trial

Before participants began their running trial, they were given a one-minute warm-up at a self-selected speed. After the warm-up, they were given a one-minute rest period to stretch before the running trial began. Participants then began a half-mile run at a self-determined speed with a zero percent incline. This speed remained constant throughout both running trials.

Eight Vicon (Centennial, Colorado, USA) 3D motion capture cameras collecting data at 240 Hz were used to capture marker trajectory data for 10 seconds after each tenth of a mile for

0.5 miles. Vicon Nexus 2.8.0 was used to capture, process, and filter marker trajectory data using a Woltring filter.[48] Marker trajectory data was then exported to python (Anaconda Suite, Version 2.7) where kinematics were modeled using a custom written script.[47] Initial contact and toe-off were then defined in Nexus with the assistance of synchronized digital video to define each gait cycle for the entirety of the capture. Kinematics for each gait cycle in the capture were then averaged into one representative time series and interpolated into 101 data points representing 0 to 100% of the gait cycle using Vicon Polygon 4.3.1. The loading response corresponded to the first instance in the interpolated gait cycle in which the sagittal plane orientation of the foot segment relative to the ground was neutral or zero degrees. Mid-stance corresponded to the instance in the stance phase of the interpolated gait cycle in which the sagittal plane knee flexion angle was the greatest. Kinematics for each joint were identified at these time points and the change in angle, or excursion, during the weight acceptance phase was then calculated by subtracting the angle at mid-stance from the angle at the loading response.

After the run was over, the NDT was completed one last time for the trial. Participants were given a 30-minute rest after the first running trial to allow the to allow for the possible effects of Kinesio® Tape to subside. After the 30-minutes, NDT procedures were repeated, the opposite intervention was applied, and markers were adjusted if needed. The medial femoral condyle, medial malleolus, and second metatarsal head markers were reapplied and then removed after another still image was obtained. Participants were given another one-minute warm-up if needed before the second running trial began. During the running sessions, joint angles from the Vicon software were collected for ten seconds every tenth of a mile. During these ten seconds, the maximum, minimum, and average joint angles were calculated.

4.3.5. Statistical Analysis

This within-subjects study applied a pretest/posttest design with subjects randomly divided into experimental and control groups. Statistical analysis for the approved research was computed using SPSS software (Version 23.0). To observe changes in NDT scores a two-way, within-subjects ANOVA model was estimated. To analyze difference in gait kinematics, an additional two-way, within-subjects ANOVA model was utilized for 18 angle measurements for each leg, thereby totaling 36 models.

4.4. Results

The NDT measurements were collected prior to taping, just after taping, and immediately following the one-mile run. Data were collected independently for the right (Table 11) and left legs (Table 12). The decrease in the NDT measurement after taping and post run for the treatment group is immediately discernible from the descriptive statistics.

Table 11. Right Leg NDT Results

Measurement	Group	Mean	SD
Sham	Bare	13.30	4.00
	Taped	12.05	4.82
	Post run	12.75	4.13
Treatment	Bare	13.60	3.95
	Taped	8.05	3.55
	Post run	9.10	3.39

Table 12. Left Leg NDT Results

Measurement	Group	Mean	SD
Sham	Bare	13.65	4.42
	Taped	12.35	4.78
	Post run	12.85	4.30
Treatment	Bare	14.35	4.20
	Taped	8.45	4.07
	Post run	9.10	3.85

To test the observed changes, a two-way within-subjects ANOVA model was estimated. For the model with the right leg measurement as the dependent variable, Mauchly's test rejected the assumption of sphericity for the interaction term (W=0.651, p=.021), so the Greenhouse-Geisser correction was used to adjust the degrees of freedom. Residual analysis indicated adequate normality to meet test assumptions. The omnibus test found a statistically significant effect due to the interaction of the taping condition and the repeated measure (F[1.6, 30.6]=24.92, p<.001, η^2=.059).

Simple effects were analyzed with one-way repeated measures ANOVA models. For the sham taping condition, the time variable was statistically significant (F[2, 38]=3.88, p=.029, η^2=.169). For the tape with tension, the time variable was again statistically significant, but with a much larger effect size (F[2, 38]=49.19, p<.001, η^2=.721). The descriptive statistics and plot (Figure 1) clarify the meaning of these results. In the sham condition, the score decreases upon tape application, and the measurement post run lies about midway between those two measurements. In the tension condition, the score drops substantially upon tape application. Following the run, the decrease from baseline is not as extreme but remains significantly below the pre-tape measurement.

Simple effects comparing the two conditions are statistically significant for the taped (F[1, 19]=27.14, p<.001, η^2=.588) and post-run measurements (F[1, 19]=29.68, p<.001, η^2=.610) but not for the pre-tape measurement (F[1, 19]=0.461, p=.505, η^2=.023). These results reinforce that the two samples were statistically indistinguishable before the application of tape but differed substantially based on whether or not the tape was applied with tension.

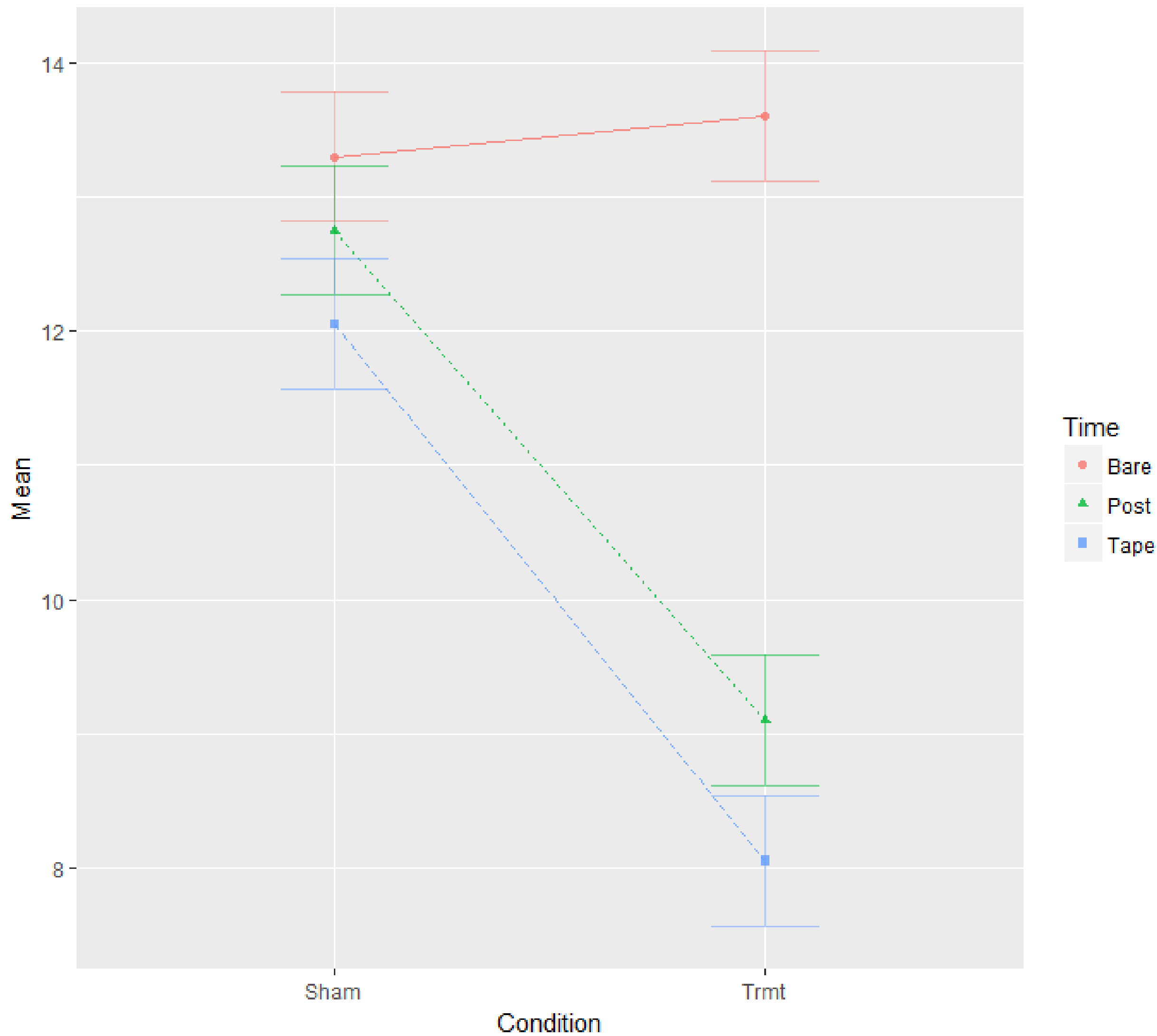

Figure 1. Interaction Plots for Right Leg Measurement

Results for the left leg measurements were qualitatively similar. Mauchly's test rejected the assumption of sphericity for the interaction term (W=0.503, p=.002), so the Greenhouse-Geisser correction was used to adjust the degrees of freedom. Residual analysis indicated adequate normality to meet test assumptions. The omnibus test found a statistically significant effect due to the interaction of the taping condition and the repeated measure (F[1.5, 28.5]=20.98, p<.001, η^2=.061).

Once again, simple effects were analyzed with one-way repeated measures ANOVA models. One difference is that for the sham taping condition, the time variable was not statistically significant at the 5% level ($F[2, 38]=2.967$, $p=.064$, $\eta^2=.135$). For the tape with tension, the time variable was statistically significant, again with a much larger effect size ($F[2, 38]=75.49$, $p<.001$, $\eta^2=.799$). The descriptive statistics (Table 2) and plot (Figure 2) show a pattern that is similar to the results found for the right leg.

Simple effects comparing the two conditions are statistically significant for the taped ($F[1, 19]=32.88$, $p<.001$, $\eta^2=.634$) and post-run measurements ($F[1, 19]=37.70$, $p<.001$, $\eta^2=.974$) but not for the pre-tape measurement ($F[1, 19]=0.78$, $p=.39$, $\eta^2=.039$). These results reinforce that the two samples were statistically indistinguishable before the application of tape but differed substantially based on whether or not the tape was applied with tension.

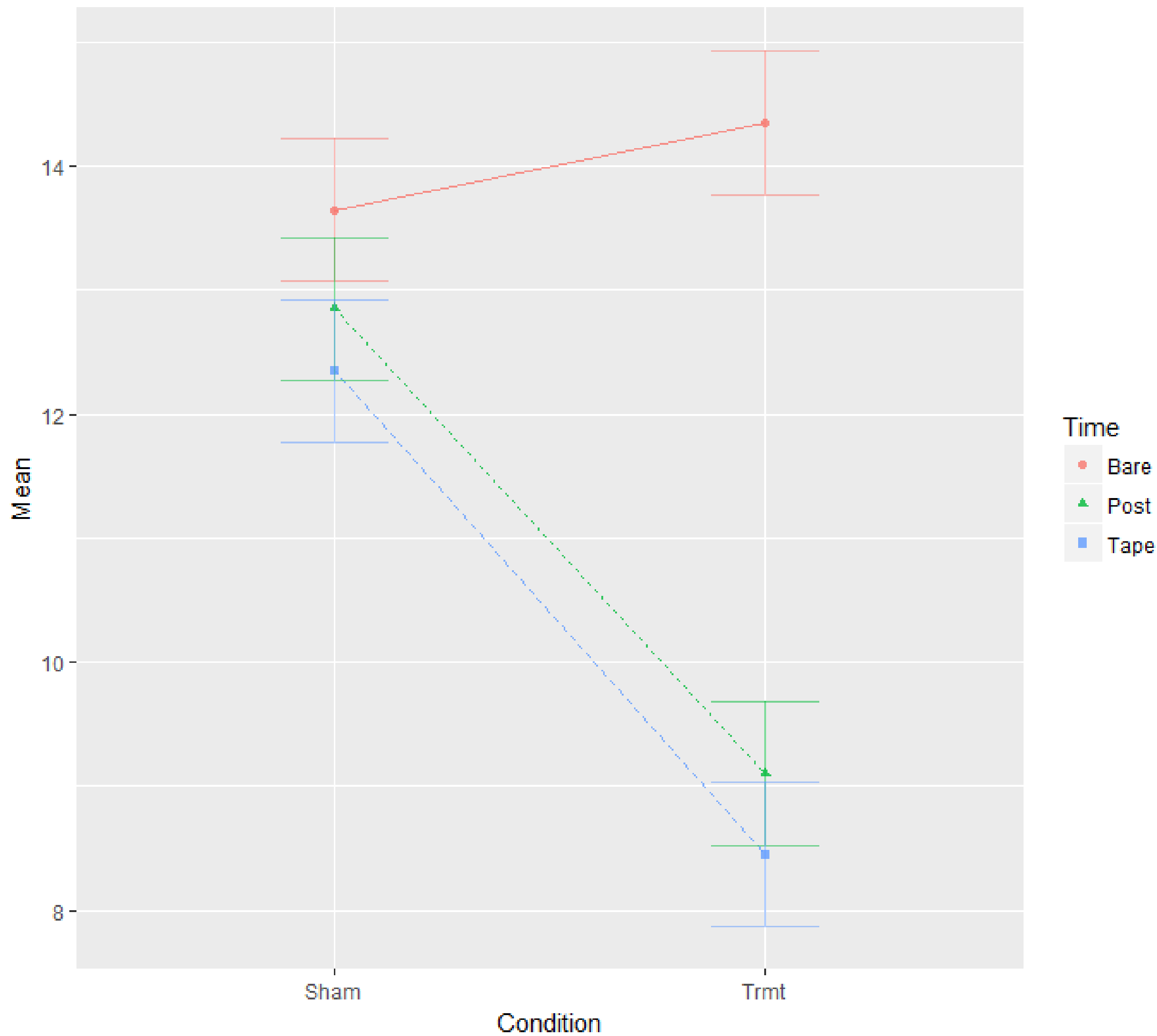

Figure 2. Interaction Plot for Left Leg Measurements

In addition to direct measures of pronation, measurements were collected on various angles during the run. Complete data were available for only 16 participants at the first three time points due to concern with the markers falling off mid-way through the run. All participants were observed in both sham and treatment conditions. Descriptive statistics are provided for each angle, by condition, and observation time.

A two-way, within-subjects ANOVA model was estimated for each of the 18 angle measurements for each leg, a total of 36 models. Degrees of freedom were corrected using the

Greenhouse-Geisser estimate whenever Mauchly's test of sphericity was statistically significant at the 5% level. Full results of the 36 models are available in Table 13 and Table 15 for the right leg and Table 14 and Table 16 for the left leg. In no case, did the tape condition lead to a statistically significant difference in any of the angles. For the repeated measure, there were six cases in which statistically significant differences were observed over time. However, these should not be over-interpreted because effect sizes are all small and the multiplicity of tests raises the chance of Type I error

Table 13. Repeated Measures for Right Kinematics

Right	Rpt Meas					
Dependent variable	Mauchly's W	p	df	F	p	eta-sq
Hip Sagittal	**0.587**	**0.024**	**1.17, 17.61**	**4.34**	**0.034**	**0.016**
Hip Frontal	0.84	0.294	2, 30	0.835	0.444	<.001
Hip Transverse	0.825	0.261	2, 30	0.197	0.822	0.002
Knee Sagittal	0.672	0.062	2, 30	1.671	0.205	0.019
Knee Frontal	0.934	0.62	2, 30	1.376	0.268	0.001
Knee Transverse	0.588	0.024	1.176, 17.64	1.943	0.161	0.018
Ankle Sagittal	**0.479**	**0.006**	**.96, 14.37**	**7.424**	**0.002**	**0.063**
Ankle Frontal	0.514	0.01	1.03, 15.42	0.919	0.41	<.001
Ankle Transverse	0.934	0.622	2, 30	0.345	0.711	0.001
Foot Prog Sagittal	0.875	0.392	2, 30	2.508	0.098	0.019
Foot Prog Frontal	0.931	0.607	2, 30	1.139	0.333	0.001
Foot Prog Transverse	0.613	0.032	1.93, 29.01	3.137	0.058	0.027
Forefoot Sagittal	0.918	0.548	2, 30	1.052	0.362	0.007
Forefoot Frontal	0.725	0.105	2, 30	0.206	0.814	0.001
Forefoot Transverse	0.718	0.099	2, 30	2.281	0.12	0.022
Pelvis Sagittal	0.889	0.438	2, 30	1.776	0.187	0.006
Pelvis Frontal	0.608	0.031	1.22, 18.24	2.872	0.072	0.012
Pelvis Transverse	0.842	0.299	2, 30	2.908	0.07	0.007

Table 14. Repeated Measures for Left Kinematics

Left	Rpt Meas					
Dependent variable	Mauchly's W	p	df	F	p	eta-sq
Hip Sagittal	0.782	0.179	2, 30	2.129	0.136	0.007
Hip Frontal	0.744	0.126	2, 30	2.512	0.098	0.004
Hip Transverse	0.927	0.589	2, 30	1.052	0.362	0.007
Knee Sagittal	0.449	0.004	.90, 13.47	1.002	0.351	0.016
Knee Frontal	0.973	0.826	2, 30	1.224	0.308	0.002
Knee Transverse	**0.717**	**0.097**	**2, 30**	**6.1**	**0.006**	**0.036**
Ankle Sagittal	**0.539**	**0.013**	**1.08, 16.17**	**7.514**	**0.002**	**0.026**
Ankle Frontal	0.581	0.022	1.16, 17.43	0.691	0.509	0.001
Ankle Transverse	0.697	0.08	2, 30	2.081	0.142	0.013
Foot Prog Sagittal	**0.873**	**0.386**	**2, 30**	**4.724**	**0.016**	**0.018**
Foot Prog Frontal	0.931	0.608	2, 30	0.264	0.77	<.001
Foot Prog Transverse	0.926	0.582	2, 30	0.355	0.704	0.002
Forefoot Sagittal	0.829	0.27	2, 30	2.375	0.11	0.009
Forefoot Frontal	0.776	0.17	2, 30	0.46	0.636	0.003
Forefoot Transverse	0.969	0.807	2, 30	2.228	0.125	0.021
Pelvis Sagittal	0.715	0.096	2, 30	1.464	0.247	0.008
Pelvis Frontal	**0.729**	**0.109**	**2, 30**	**3.381**	**0.047**	**0.009**
Pelvis Transverse	0.814	0.237	2, 30	0.22	0.804	<.001

Table 15. Tape Interaction for Right Kinematics

Right	Tape			
Dependent variable	df	F	p	eta-sq
Hip Sagittal	1, 15	2.09	0.169	0.004
Hip Frontal	1, 15	0.012	0.913	<.001
Hip Transverse	1, 15	1.633	0.221	0.015
Knee Sagittal	1, 15	0.033	0.857	<.001
Knee Frontal	1, 15	0.258	0.619	0.005
Knee Transverse	1, 15	0.168	0.688	0.001
Ankle Sagittal	1, 15	0.388	0.543	0.004
Ankle Frontal	1, 15	0.012	0.914	<.001
Ankle Transverse	1, 15	1.904	0.188	0.028
Foot Prog Sagittal	1, 15	0.009	0.925	<.001
Foot Prog Frontal	1, 15	1.344	0.264	0.009
Foot Prog Transverse	1, 15	1.075	0.316	0.016
Forefoot Sagittal	1, 15	0.478	0.499	0.002
Forefoot Frontal	1, 15	0.335	0.571	0.001
Forefoot Transverse	1, 15	0.09	0.768	0.001
Pelvis Sagittal	1, 15	0.1	0.756	<.001
Pelvis Frontal	1, 15	3.845	0.069	0.007
Pelvis Transverse	1, 15	0.034	0.856	<.001

Table 16. Tape Interaction for Left Kinematics

Left	Tape			
Dependent variable	df	F	p	eta-sq
Hip Sagittal	1, 15	0.069	0.797	<.001
Hip Frontal	1, 15	0.638	0.437	0.001
Hip Transverse	1, 15	3.636	0.076	0.012
Knee Sagittal	1, 15	0.153	0.702	0.001
Knee Frontal	1, 15	0.959	0.343	0.005
Knee Transverse	1, 15	0.339	0.569	0.002
Ankle Sagittal	1, 15	0.041	0.841	<.001
Ankle Frontal	1, 15	0.424	0.525	0.004
Ankle Transverse	1, 15	0.011	0.918	<.001
Foot Prog Sagittal	1, 15	0.064	0.804	<.001
Foot Prog Frontal	1, 15	0.05	0.826	<.001
Foot Prog Transverse	1, 15	0.166	0.69	0.001
Forefoot Sagittal	1, 15	0.007	0.935	<.001
Forefoot Frontal	1, 15	0.173	0.683	0.001
Forefoot Transverse	1, 15	0.522	0.481	0.002
Pelvis Sagittal	1, 15	1.942	0.184	0.004
Pelvis Frontal	1, 15	0.27	0.611	<.001
Pelvis Transverse	1, 15	0.001	0.974	<.001

4.5. Discussion

With excessive pronation being the common cause of lower extremity injuries in recreational runners, clinicians have investigated other treatment options to fix this biomechanical error.[1,17,30] The purpose of this study was to measure a change in pronation and gait kinematics through NDT scores and 3D motion analysis while running with Kinesio® Tape as the intervention. The clinical impact of the results will give clinicians another tool to aid the large population of recreational runners for correcting excessively pronated feet in hopes of avoiding running-related injuries.

All subjects in the study were diagnosed to have an over-pronated foot through the use of the NDT. When Kinesio® Tape was applied with proper tension, a considerable drop in scores was observed. After the tape was applied, an average decrease of 5.55 mm occurred in right foot, while an average decrease of 5.90 mm occurred in the left foot. After the half-mile run, scores increased slightly, suggesting the effects of the tape lessened, but still remained significant, as the right foot increased by an average of 1.05 mm and the left foot increased by an average of 0.65 mm. These results suggest that Kinesio® Tape is an effective modality by decreasing the amount of pronation when measured by the NDT. Kinesio Tape® produced a decrease in pronation in a study conducted by Griebert et al[34] when participants with medial tibial stress syndrome (MTSS) walked across a plantar pressure platform to test the rate of loading. A significant increase in time-to-peak force in MTSS patients occurred at the medial midfoot ($p = 0.05$). This increase was observed before application to immediately after application ($p = 0.022$), as well as 24 hours after application ($p = 0.043$). The implications of this study suggest Kinesio® Tape can correct excessive pronation by slowing the rate of loading on the medial arch. Although positive effects were produced, participants were only required to walk across the pressure platform, instead of performing more vigorous activities, such as running or jumping.[34] In contrast, a study conducted my Luque-Suarez et al[39] was unable produce significant results when the Foot Posture Index (FPI) was used to detect a change in pronation. Once Kinesio® Tape was applied, FPI scores were obtained after the tape was applied and then after 1 minute, 10 minutes, 60 minutes, and 24 hours later. No statistical differences in FPI scores were calculated between an experimental and control technique, implying Kinesio® Tape has no effect on reducing pronation. Although the researchers reported no change in pronation, researchers cannot rule out the possibility of using Kinesio® Tape to reduce pronation due to there being more reliable outcome measures compared to the FPI.[39] Thus, it is difficult to compare our data to previously published research due to the different objective measures that were used. However, our study used a proven reliable tool in the NDT with participants performing a vigorous activity.

To the author's knowledge, this is the first study to investigate the effect of Kinesio® Tape on pronation using the NDT. Sufficient outcome measures, such as the NDT, plantar pressure platform, and high-speed film, have been used to detect a change in pronation when traditional taping was used.[31,32,33,39] A study conducted by Zuil-Escobar et al[46] evaluated the correlations of the NDT, FPI, and several footprint parameters in patients with a low medial longitudinal arch. The NDT showed significant correlations to the footprint parameters compared to the FPI only having a good correlation. The NDT has fewer disadvantages compared to footprint parameters and the FPI as it is inexpensive, does not include body composition, is influenced by navicular height, is less time consuming, and less chance for error. With a high intra-rater and inter-rater reliability, clinicians should choose the NDT as the first outcome measure to examine individual's foot posture. That being said, experience of the examiner plays a factor in the tests reliability, as the examiner must be able to properly locate the navicular tuberosity and place the subtalar joint in a neutral position. If performed correctly, the NDT is highly correlated with more advanced software, such as digital footprint parameters[46] The authors of the current study can make the argument that a reliable outcome measure was used in detecting Kinesio® Tape's effect on pronation.

While the NDT was able to produce significant results from the Kinesio® Tape, the 3D motion analysis produced statistical significance in only six cases where gait kinematics where altered. When using an ANOVA to evaluate the change of angles throughout the half-mile interval, the angles that showed significant change were right hip sagittal ($p=0.034$), right ankle sagittal ($p=0.002$), left knee transverse ($p=0.006$), left ankle sagittal ($p=0.002$), left foot progression sagittal ($p=0.016$), and pelvis frontal movements ($p=0.047$). An excessively pronated foot occurs from adduction and plantarflexion of the talus and eversion of the calcaneus.

Interestingly, both the left and right ankle sagittal movements were statistically significant implying the amount of plantarflexion was reduced. Although this does not indicate Kinesio® Tape was the reason for the change in ankle sagittal movement, a methodology that investigated a broader change over time should be conducted to see if Kinesio® Tape could make a difference.

Of the six statistically significant angles, four significant movements occurred in the sagittal plane. In a study conducted by Kadaba et al[37], with-day and between-day gait analysis reliability of motions in the sagittal, frontal, and transverse planes were compared. Better reliability was demonstrated for same-test day angles compared to between-day for motions in the frontal and transverse planes, but excellent reliability was observed in both for motions in the sagittal plane. This study justifies consistent sagittal plane joint angles can be repeated by 3D motion analysis, especially studies conducted on the same day.[37] Our study followed similar protocols, with comparison of experimental versus sham tape occurring on the same-test day. In detecting statistically significant changes in right ankle and left ankle sagittal movements, and alteration in the amount of plantarflexion and dorsiflexion occurred, indicating 3D motion analysis is able to analyze an aspect of pronation.

However, the results of the six significant cases cannot be over-interpreted. Albeit statistical significance was obtained, the effect sizes were small and Type I error is likely due to the number of analyses conducted. With the amount of analyses, there was an increased chance of over-inflated results. Based on the statistical analyses, there is a clinical trend that Kinesio® Tape can change pronation to a statistically significant degree and that the effect lasts quite well over a one-mile run. However, there is almost no difference in observed angles due to that change in pronation. A study conducted by Tateuchi et al[1] was able to detect a change in kinetic chain kinematics when the amount of pronation was changed by increasing calcaneal eversion. To analyze a difference in pronation, participants stood directly on the floor, a wooden wedge creating 5° of calcaneal eversion, and a wooden wedge creating 10° of calcaneal eversion. A significant difference in calcaneal eversion, otherwise known as pronation, was produced by the three conditions ($p < 0.016$). Compared to standing on a flat surface, the two eversion conditions produced a statistically significant increase in hip flexion, adduction, and internal rotation. Anterior pelvic tilt also increased during the two eversion conditions compared to the no eversion condition. This study demonstrates that by changing the amount of pronation at the foot, increases in hip, pelvis, and thorax angles occur.[1] In relation to our study, six cases of statistical significance occurred in gait kinematics, implying some joint angles changed over the half-mile trials.

Although 3D motion analysis was able to produce six cases of statistical significance, we cannot be certain Kinesio® Tape altered gait kinematics. When calculating Kinesio® Tape's effects alone through 3D motion analysis, there was no statistical significance. With there being no difference in the sham versus tension technique, we can say a Kinesio® Tape Mechanical Correction for an excessively pronated foot does not alter gait kinematics. Fatigue or a change in running mechanics could have been the reason for statistical significance in the repeated measures. A longitudinal study should be conducted to analyze if a change in gait kinematics occurs. In conclusion, there was no immediate effect on the biomechanics for any of the participants when using a Kinesio® Tape Mechanical Correction for an excessively pronated foot.

The findings from the NDT scores support the use of Kinesio® Tape reducing the amount of pronation. In addition, there is some evidence that Kinesio® Tape can affect particular joint angles superior to the foot. However, this study contains several limitations. First, markers for the 3D motion analysis had difficulty remaining in position. Of the twenty participants, markers were able to stick to sixteen participants for at least three-tenths of a mile in both running trials. Therefore, we were unable to capture data for joints throughout the entire half-mile intervals. Future updates to the computer software will allow us to use all intervals, throughout both half-miles. An additional limitation to the markers was that they were placed on the shoe. This did not allow for accurate placement on the anatomical mark and could have altered kinematic data. Another limitation to our study was that participants had to run in their own shoes. The difference in brand and model could have altered foot and ankle kinematic results. Had subjects all ran in the same neutral shoes, an effect in gait kinematics could have been produced. Sample size was also a limiting factor, as a greater change in gait kinematics could have been seen with more subjects. Our study consisted of participants running on a treadmill and this is not the same as more dynamic, sport movements. More vigorous activity could have changed the overall effect Kinesio® Tape had. Finally, a longer distance may be warranted to produce greater effects over time.

Future research should be conducted to identify if a Kinesio® Tape Mechanical Correction on the arch of the foot can alter gait kinematics. By being able to keep the markers attached to the shoes throughout the whole trial, significant results may be produced by the 3D motion analysis. Initial results were promising, but having a larger sample size could produce more powerful statistical significance. Additionally, since NDT scores were statistically significant and only observed at an immediate time period, future research should consider a longer running distance to explore if the technique can still produce a significant effect on pronation over longer periods of time. Lastly, researchers should test this methodology on individuals with a confirmed pathology diagnosis (e.g. MTSS, PFPS, etc.) to determine if there is a positive effect on NDT scores, as well as reduced symptoms in pain as recorded through patient-outcome metrics.

4.6 Conclusion

The results from the NDT scores support the use of Kinesio® Tape in decreasing the amount of pronation during a half-mile run. NDT scores were lower in the trials where tension was applied compared to the control trials. Gait kinematics from the 3D motion analysis were promising, but only produced six cases of statistical significance out of thirty-six. With a small effect size, we are unable to suggest definitively that Kinesio® Tape had an effect on joint angles. Although continued research is needed to determine if a Kinesio® Tape Mechanical Correction for pronation can improve gait kinematics, clinicians can be confident in using this taping technique on patients to improve their excessive pronation in hopes of ultimately decreasing the chance of a running-related injury.

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