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original research

Gait Kinematics After Taping in Participants With Chronic Ankle Instability

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Context: Chronic ankle instability is characterized by repetitive lateral ankle sprains. Prophylactic ankle taping is a common intervention used to reduce the risk of ankle sprains. However, little research has been conducted to evaluate the effect ankle taping has on gait kinematics.

Objective: To investigate the effect of taping on ankle and knee kinematics during walking and jogging in participants with chronic ankle instability.

Design: Controlled laboratory study.

Setting: Motion analysis laboratory.

Patients or Participants: A total of 15 individuals (8 men, 7 women; age = 26.9 ± 6.8 years, height = 171.7 ± 6.3 cm, mass = 73.5 ± 10.7 kg) with self-reported chronic ankle instability volunteered. They had an average of 5.3 ± 3.1 incidences of ankle sprain.

Intervention(s): Participants walked and jogged in shoes on a treadmill while untaped and taped. The tape technique was a traditional preventive taping procedure. Conditions were randomized.

Main Outcome Measure(s): Frontal-plane and sagittal-plane ankle and sagittal-plane knee kinematics were recorded throughout the entire gait cycle. Group means and 90% confidence intervals were calculated, plotted, and inspected for percentages of the gait cycle in which the confidence intervals did not overlap.

Results: During walking, participants were less plantar flexed from 64% to 69% of the gait cycle (mean difference = 5.73° ± 0.54°) and less inverted from 51% to 61% (mean difference = 4.34° ± 0.65°) and 76% to 81% (mean difference = 5.55° ± 0.54°) of the gait cycle when taped. During jogging, participants were less dorsiflexed from 12% to 21% (mean difference = 4.91° ± 0.18°) and less inverted from 47% to 58% (mean difference = 6.52° ± 0.12°) of the gait cycle when taped. No sagittal-plane knee kinematic differences were found.

Conclusions: In those with chronic ankle instability, taping resulted in a more neutral ankle position during walking and jogging in shoes on a treadmill. This change in foot positioning and the mechanical properties of the tape may explain the protective aspect of taping in preventing lateral ankle sprains.

Key Words: external ankle supports, ankle prophylactic measures, recurrent ankle sprains

Key Points

- Taping the ankles of participants with chronic ankle instability resulted in more neutral positioning when they walked or jogged in shoes on a treadmill.
- Taping may protect the ankle by way of its mechanical properties and its neuromuscular effect on ankle position.

Lateral ankle sprains are very common injuries,[1] comprising an estimated 85% of all ankle injuries.[2,3] A history of ankle sprain has been found to be the leading risk factor in predicting future sprains.[4–6] Up to an estimated 70% of individuals who incur an initial ankle sprain and who are exposed to sports with a high risk of ankle-joint injuries will develop chronic ankle instability (CAI),[7,8] which is characterized by residual symptoms for at least 1 year after the initial ankle sprain.[8–10] Although the high prevalence of CAI is known, very little is actually understood regarding the mechanism or prevention of lateral ankle sprains.

Gait kinematic alterations in those with a history of lateral ankle sprain have been hypothesized to contribute to CAI.[11–13] In a cadaver study[14] of foot–floor clearance, inverting the foot 10°, regardless of plantar flexion, caused a collision between the lateral aspect of the foot and the floor, resulting in an ankle sprain. Individuals with CAI underestimate the combined motions of plantar flexion and inversion during passive joint position sense testing.[15] These alterations in joint position sense may lead to alterations in kinematics during gait, which may contribute to ankle sprains and instability; an increased plantar-flexion touch-down position upon initial contact is known to increase the risk of ankle-joint injury.[14,16] Recently, researchers have compared the ankle kinematics of CAI participants with healthy controls while walking and jogging on a treadmill barefoot[17,18] and shod[19] and walking on a walkway while shod.[20] Compared with healthy controls, frontal-plane and sagittal-plane kinematics were altered during various aspects of the gait cycle, and these changes are believed to contribute to repetitive incidences of ankle sprains.

Prophylactic ankle taping is a common means of reducing the risk of injury to the lateral ankle ligaments, including recurrent ankle sprains.[21,22] The purpose of ankle taping is to restrict ankle inversion and plantar-flexion motion.[22,23] In healthy people, taping reduces sagittal-plane range of motion compared with the untaped condition while running, cutting, and landing from a drop.[24–26] Sagittal-plane kinematics during walking have been reported to be altered at foot contact and toe-off in individuals with CAI wearing an ankle brace.[27] During a functional drop landing, those with CAI demonstrated a decreased plantar-flexion angle immediately (50 milliseconds) before and at initial contact while wearing prophylactic ankle-joint taping compared with the untaped condition.[28] Previous researchers, however, have focused on discrete time points[27] or a specific window[28] during the gait cycle. We know of no literature evaluating frontal-plane and sagittal-plane kinematics during the entire walking and jogging gait cycle when CAI participants were taped.

Therefore, the purpose of our study was to compare frontal-plane and sagittal-plane ankle kinematics in shod CAI participants while walking and jogging on a treadmill with or without traditional ankle taping. The secondary purpose was to evaluate sagittal-plane knee kinematics to determine if changes occurred with ankle taping. We evaluated kinematics at the knee to determine if kinematic alterations at the ankle affected movement up the kinetic chain.

METHODS

We used a pretest-posttest crossover design. The independent variable was condition (untaped, taped), and the dependent variables were the frontal-plane and sagittal-plane motions at the ankle and knee (in degrees). All participants walked and jogged in shoes on a treadmill in both conditions while kinematic data were captured.

Participants

A total of 15 volunteers (8 men, 7 women; age = 26.9 ± 6.8 years; height = 171.7 ± 6.3 cm; mass = 73.5 ± 10.7 kg) with self-reported CAI were recruited from a large public university and the surrounding community. The study methods were approved by the university's institutional review board, and all recruits provided written informed consent before data collection. All participants had a history of at least 1 ankle sprain (mean = 5.3 ± 3.1 sprains), with the first sprain occurring more than 12 months earlier, and reported multiple recurrent episodes of their ankle giving way during functional activities. A score below 87% on the Foot and Ankle Ability Measure–Sport was the threshold for CAI (mean score = 75.8% ± 13.3%).[29,30] In those who reported bilateral CAI, the self-perceived worse ankle was the test ankle. All participants were involved in moderate or vigorous physical activity at least 3 times per week as determined by the Godin Leisure Time Exercise Questionnaire. Exclusion criteria were a history of ankle fracture, vestibular or neurologic disorders, or any lower extremity or lumbosacral injuries within the previous 3 months that could adversely affect neuromuscular function.

Instruments

Gait kinematics were computed from captured reflective marker locations sampled at 250 Hz using a 12-camera analysis system (model MX t20; Vicon Motion Systems, Inc, Lake Forest, CA). Synchronized ground reaction force data were collected by a multi-axis strain gauge force plate embedded under a custom-built treadmill (model OR 6–7; Advanced Mechanical Technology, Inc, Watertown, MA). Vertical ground reaction forces were sampled at 1000 Hz with a threshold of 60 N to determine initial contact and toe-off during walking and running. Additionally, three-dimensional joint kinematics were collected using a Vicon Plug-in Gait model (Oxford Metrics Group, Oxford, UK).

Participant Preparation

To capture lower extremity kinematics, we placed markers directly on the skin at previously described locations using double-sided tape.[31] Markers were positioned bilaterally on the lateral midthigh, lateral tibiofemoral joint line, femoral head, tibial tuberosity, lateral midshank, and lateral malleolus. A custom foot marker set was placed on the posterior calcaneus, second metatarsal head, medial side of the first metatarsophalangeal joint, and lateral side of the fifth metatarsophalangeal joint. Virtual markers were established bilaterally for the anterior and posterior iliac spines and the medial and lateral calcanei. All participants wore running shoes (model Defyance; Brooks Sports, Inc, Bothell, WA). After consultation with the shoe manufacturer, we removed the heel counter and regions directly over the first and fifth metatarsal heads to allow accurate marker placement directly onto the skin (Figure 1). According to the manufacturer, removing these regions did not affect the integrity of the shoe.

Data Collection

After collecting anthropometric data, we randomly assigned participants to condition order. All data were collected during 1 visit, with approximately 15 minutes between conditions for setup. For the untaped condition, we applied markers and conducted static calibration trials in accordance with standard Vicon methods.[32,33] For data collection, participants walked and then jogged on the treadmill at speeds of 1.34 m/s and 2.68 m/s, respectively. They were given at least 3 minutes at each speed to warm up and adjust to the pace of the treadmill before data were collected. Walking always preceded jogging, and they were given the option of a 5-minute rest before jogging. Data were collected continuously at each pace until three 15-second trials were conducted.[18,33]

For the taped condition, the same clinician with more than 9 years of experience as a certified athletic trainer (L.C.) performed a traditional ankle-taping procedure[34] bilaterally on all participants. She used nonadhesive foam prewrap (Mueller Sports Medicine, Inc, Prairie du Sac, WI) and 1.5-in (3.81-cm) self-adhesive athletic tape (Johnson & Johnson Products, Inc, New Brunswick, NJ) to apply a common preventive taping method. After the prewrap, she applied base strips, 3 stirrups, 2 heel locks, and 2 figure-of-eights. After the ankle was taped, she set up the markers and collected data as in the untaped condition. All data were collected by the same investiga-

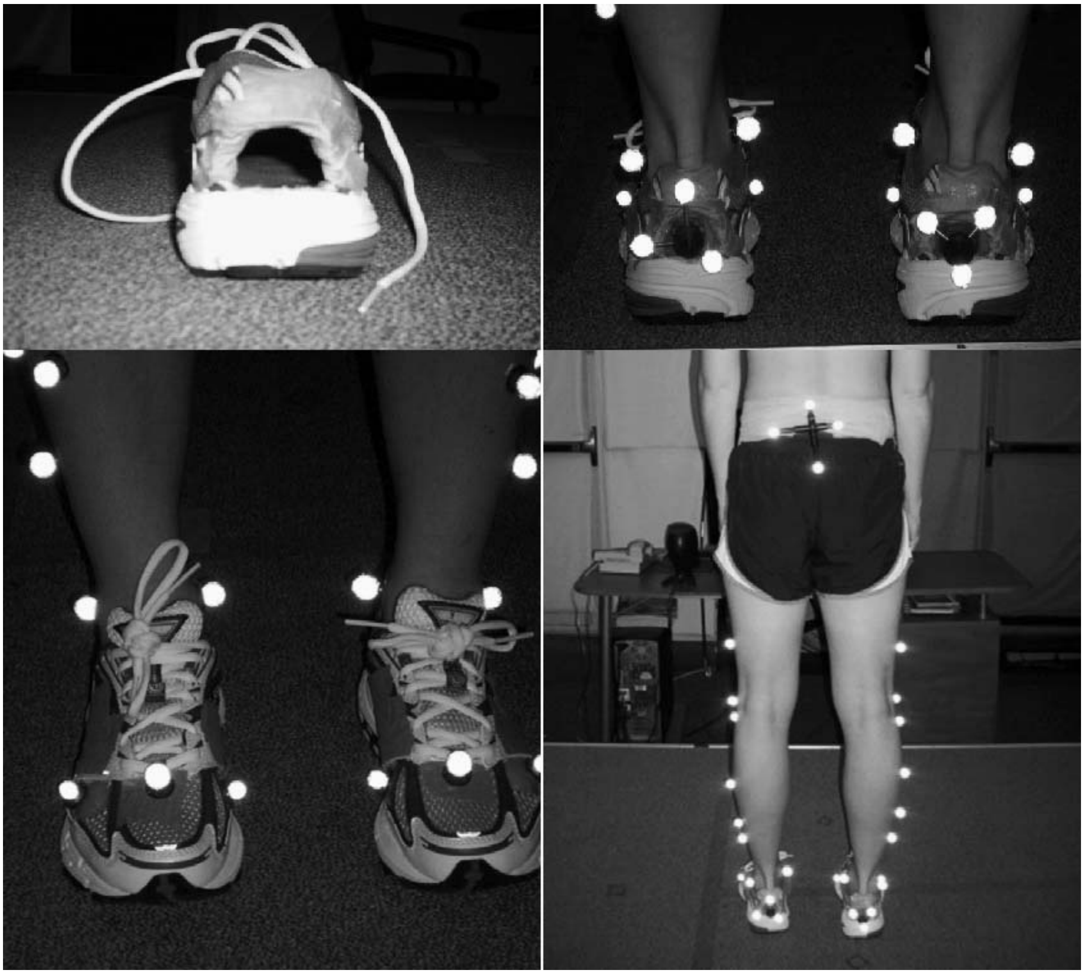


Figure 1. Patient setup.

tor, who was blinded to the involved limb but not to condition.

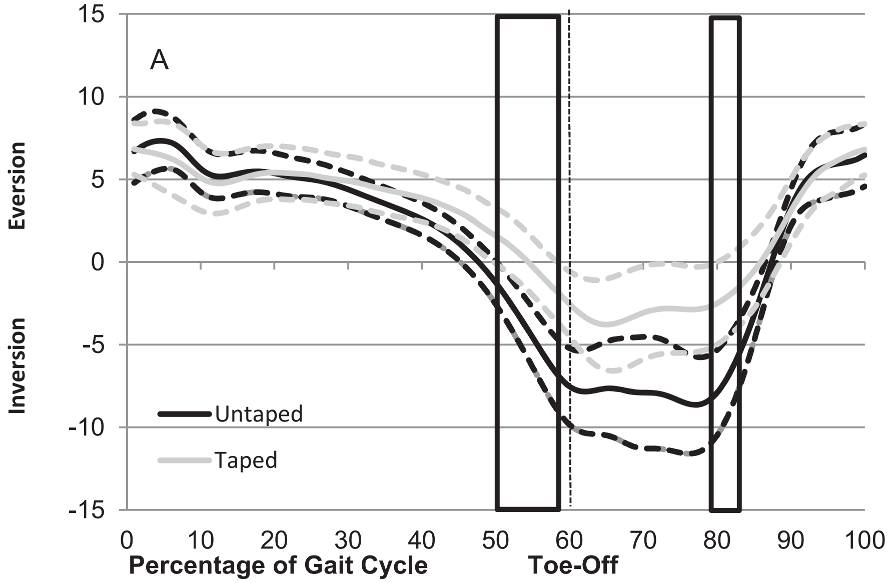
Data Processing

Three trials, consisting of 15 seconds of gait cycles, were collected for each participant. We inspected each trial to find 1 complete trial per participant with adequate data for processing. Kinetic and kinematic data for each limb were resampled through a custom program in MATLAB (version 7.04; The MathWorks, Inc, Natick, MA). The data were organized to 100 frames so that each frame represented 1% of the entire gait cycle (heel strike to heel strike). This was done individually for each person based on the average stride-cycle time for the involved limb.

We visually inspected kinematic data ensembles to determine outliers[19] by graphing ensemble averages for each trial and then visually evaluating them for kinematic averages that were outside physiologic norms or consisted of unusual kinematic patterns. If a participant's ensemble graph was identified as being a potential outlier, the graphs of each stride contributing to the ensemble were then similarly evaluated. To be identified as an outlier, all of the person's strides in the specific condition had to be grossly abnormal. Additionally, all the authors agreed upon the classification of each outlier before removing it from the dataset. One participant was removed from all trials due to problems with data collection, reducing our dataset to 14. In the taped condition, 2 outliers were identified and removed from further statistical analysis for ankle kinematics. We speculated that outliers might have occurred in the taped condition because the markers might not have stuck to the tape as well as to the skin, causing the markers to loosen. No other participant was removed from the knee analysis. Thus, 14 people were included for the knee and the untaped condition at the ankle and 12 for the taped condition at the ankle.

Statistical Analysis

For all analyses, we analyzed the walking and jogging data separately. Similarly, data in the frontal and sagittal planes and from the ankle and knee joints were evaluated independently. For each plane of motion, we calculated group means and associated 90% confidence intervals throughout the gait cycle[19,35] using Excel (version 2010; Microsoft Corporation, Redmond, WA). A curve analysis was performed to identify time increments in which the confidence intervals did not overlap for more than 3 consecutive percentages of the gait cycle.[19] For the increments in which the confidence intervals did not overlap, we calculated group mean differences and associated standard deviations.



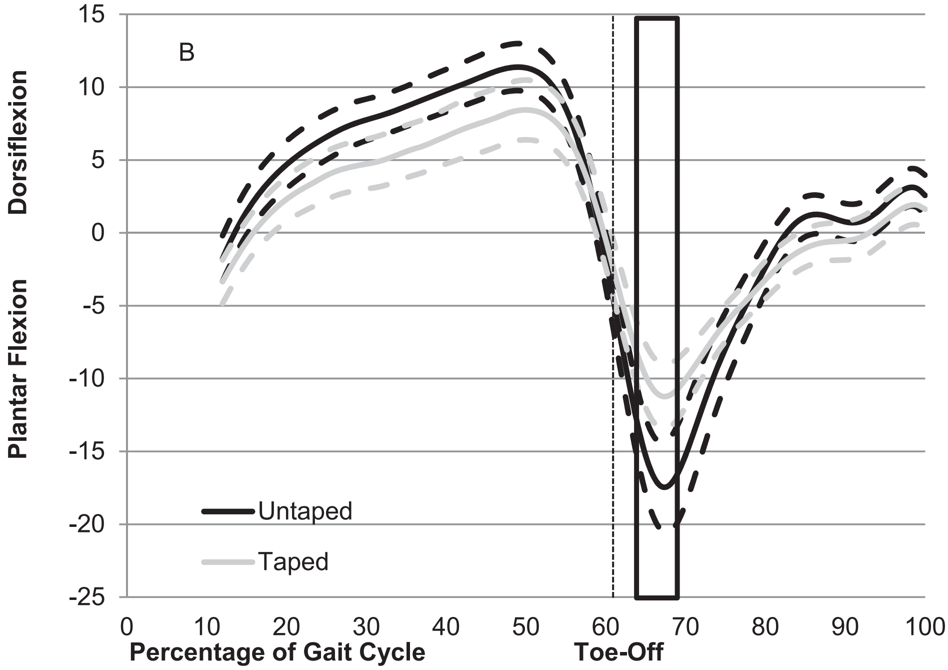


Figure 2. Ankle kinematics while walking: 0% represents initial contact, 62% is toe-off, and 100% is terminal swing. Solid lines represent the group means, and dashed lines represent the 90% confidence intervals. A, Frontal-plane kinematics: in the taped condition, participants were less inverted from 51% to 61% (mean difference = 4.34° ± 0.65°) and from 76% to 81% (mean difference = 5.55° ± 0.28°). B, Sagittal-plane kinematics: in the taped condition, participants were less plantar flexed from 64% to 69% (mean difference = 5.73° ± 0.54°). Dotted lines represent 90% confidence intervals.

RESULTS

Ankle Kinematics

The ankle kinematics between the untaped and taped conditions while walking are shown in Figure 2. The stance phase while walking occurred from 0% to 62% of the gait cycle. In the sagittal plane, taped participants were less plantar flexed during the swing phase, from 64% to 69% of the gait cycle (mean difference = 5.73° ± 0.54°). The effect size for the difference between conditions was 0.84, indicating a large effect. In the frontal plane, taped participants were less inverted from 51% to 61% (mean difference = 4.34° ± 0.65°) and 76% to 81% (mean difference = 5.55° ± 0.28°) of the gait cycle. Effect sizes for these windows were 1.01 and 0.89, respectively, again indicating a large clinical effect due to the tape application. Ankle kinematics while jogging demonstrated that average toe-off occurred at 35% of the gait cycle (Figure 3). From 12% to 21% of the gait cycle, participants were less dorsiflexed (mean difference = 4.91° ± 0.18°) while taped. Tape also reduced the amount of inversion from 47% to 58% of the gait cycle (mean difference = 6.52° ± 0.12°). Effect sizes for the 2 significant sections during jogging were 1.34 and 0.98, respectively, representing large effects.

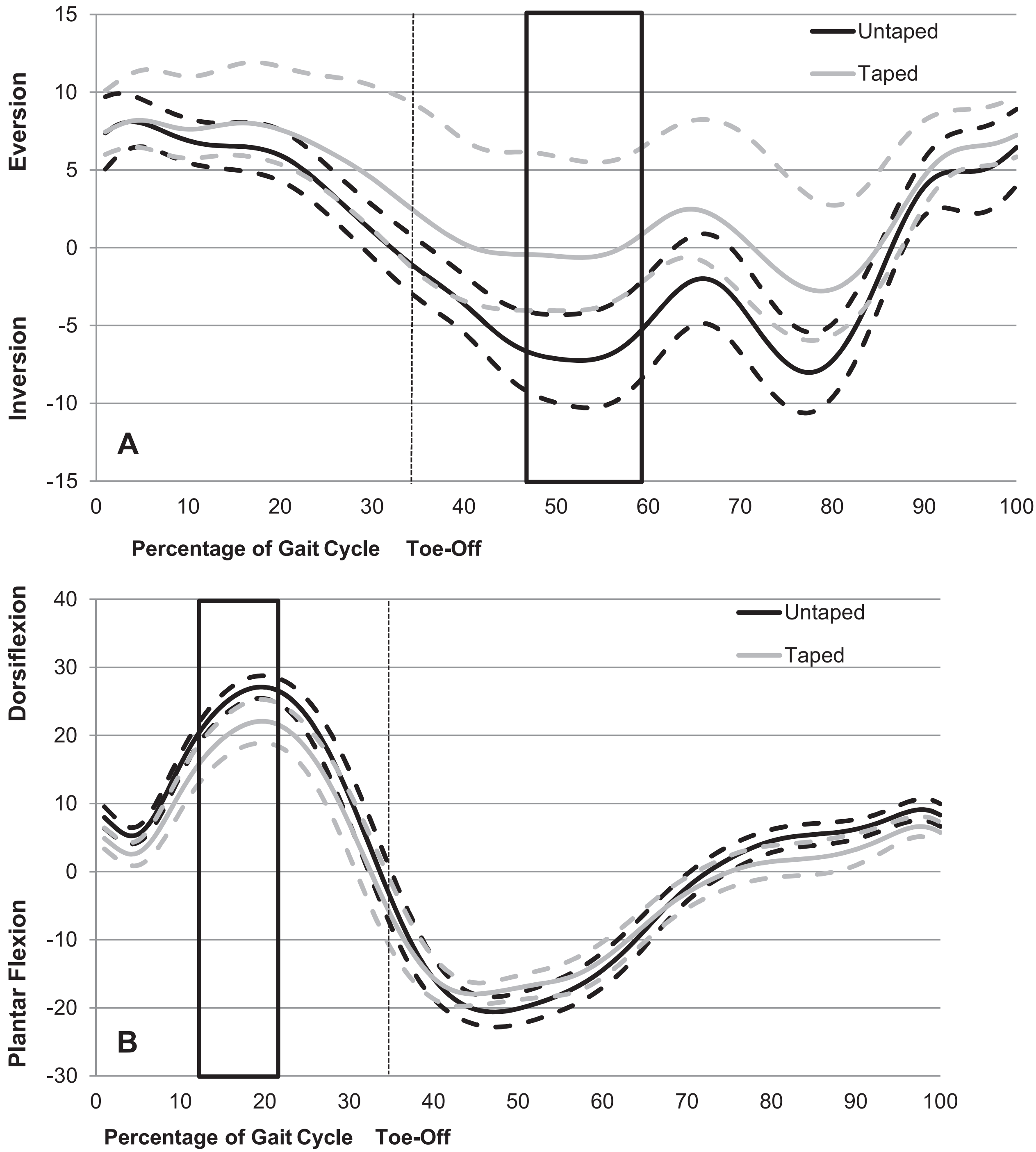


Figure 3. Ankle kinematics while jogging: 0% represents initial contact, 35% is toe-off, and 100% is terminal swing. Solid lines represent the group means, and dashed lines represent the 90% confidence intervals. A, Frontal-plane kinematics: in the taped condition, participants were less inverted from 47% to 58% (mean difference = 6.52° ± 0.12°). B, Sagittal-plane kinematics: in the taped condition, participants were less plantar flexed from 12% to 21% (mean difference = 4.91° ± 0.18°).

Knee Kinematics

At the knee, we observed no differences in sagittal-plane kinematics between the taped and untaped conditions at either speed (Figure 4).

DISCUSSION

At the ankle, tape caused kinematic changes in participants with CAI in both the frontal and sagittal planes. In general, taped CAI participants tended to be in a more neutral position at different increments in the gait cycle. All of our findings had large effect sizes, indicating that the tape application resulted in clinically meaningful alterations in kinematics. Interestingly, the increments during which these changes were observed varied between walking and jogging speeds. We did not detect any kinematic changes just before or immediately after heel strike at either speed. Nor did we observe any sagittal-plane kinematic changes at the knee between conditions.

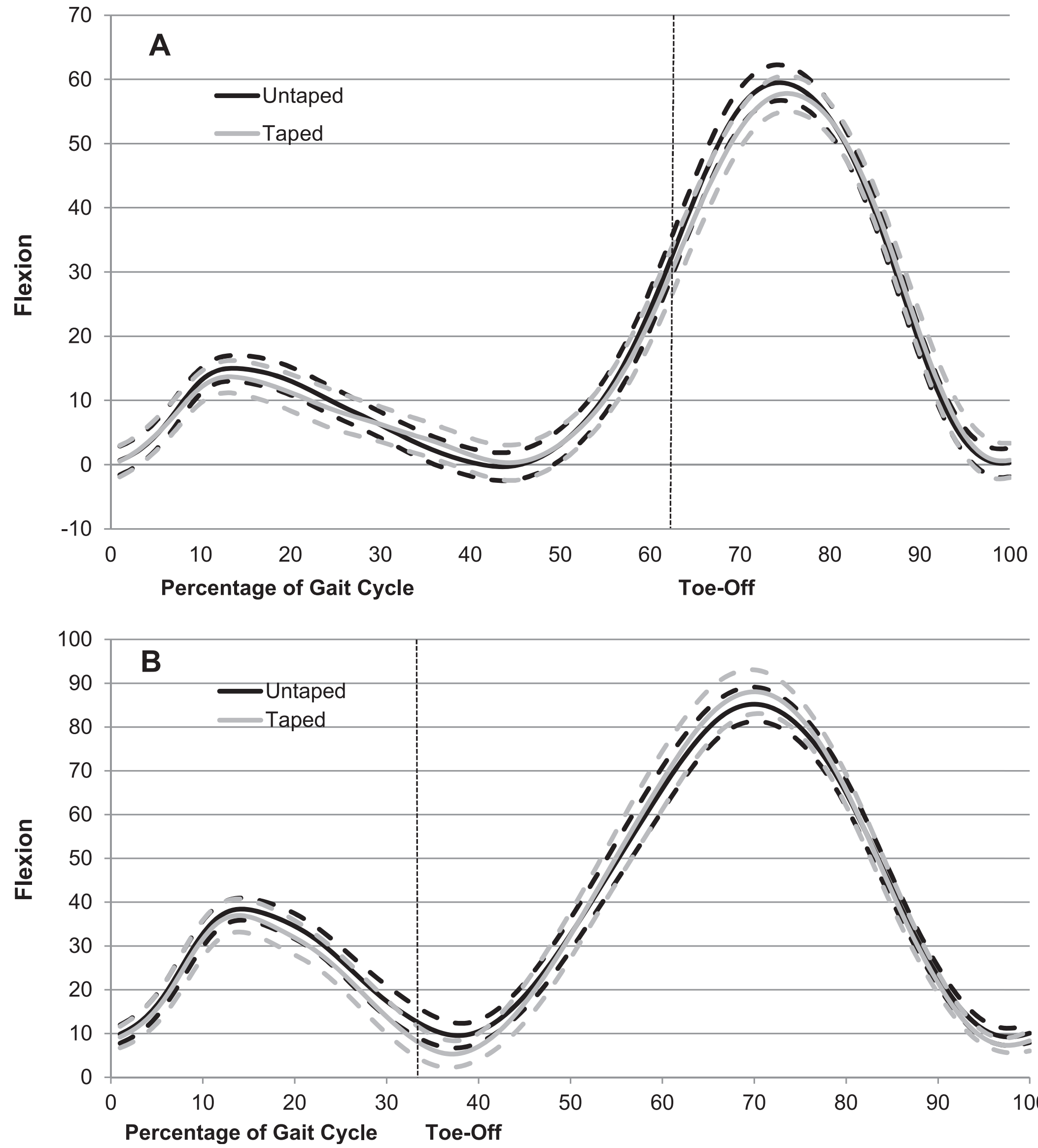


Figure 4. Knee sagittal-plane kinematics while walking and jogging: 0% represents initial contact, and 100% represents terminal swing. Solid lines represent the group means, and dashed lines represent the 90% confidence intervals. A, Walking: toe-off is 62% of gait cycle. B, Jogging: toe-off is 35% of gait cycle. Dotted lines represent 90% confidence intervals.

Although the use of tape and other external supports at the ankle has been documented to reduce the risk of lateral ankle sprains,[21,36–39] the mechanism of protection is still debated. Tape application restricts open chain range of motion and laxity,[23,40–42] indicating the mechanical benefits of support. However, the mechanical restraint of tape associated with reducing ankle sprains may only occur at the extreme ranges of motion and has been reported to have no effect on stabilizing the joint within the midrange of motion.[43] Taping has also been suggested to provide neuromuscular benefits[44–46] via cutaneous proprioceptive input, which increases motoneuron pool excitability.[47] The increase in motoneuron pool excitability may aid in changing joint position sense,[48] postural control,[44] and lower leg muscular activity.[41,49] The increased firing of afferent signals at the ankle has been hypothesized to better position the lower extremity during function.[42,48,49] Our kinematic findings occurred during various aspects of both walking and jogging, which may support both theories. While walking, an individual does not use as large of an arc of motion, and thus, kinematic changes at this speed may be due to neuromuscular benefits. Changes during jogging may be due to the mechanical benefits of tape, given the increased range of motion used at this speed.

After the tape application, CAI participants were less inverted from 51% to 61% of the gait cycle while walking, representing the time from heel-off to toe-off during stance.[50] It has been suggested that ankle sprains occur during initial loading or unloading.[51] However, in a recent case report[52] that captured video-analysis data during an accidental lateral ankle sprain after a lateral cut, the injury occurred during unloading, with the forefoot in contact with the ground while the rear foot drifted laterally and inverted. Similarly, in a prospective study,[53] individuals who sustained inversion ankle sprains presented with greater lateral plantar pressure and a more lateral center of pressure at forefoot push-off than those who did not sprain their ankles. These authors also reported that maximum inversion velocity occurred later in the inversion-sprain group than in the uninjured group. During the latter aspect of weight bearing, an inverted ankle may be unable to make the necessary postural adjustments to counter the inversion torque and subtalar shearing placed on it, resulting in an inversion sprain.[54] Our study showed that, at this critical aspect of the gait cycle, tape positions an unstable ankle in a more neutral, less precarious position, potentially reducing the risk of a lateral ankle sprain.

After toe-off while walking, taped participants went from being less plantar flexed almost immediately to being less inverted than in the untaped condition. The increment of these changes lasted from 64% to 81% of the gait cycle, representing initial swing and midswing, including foot–floor clearance.[50] Individuals with CAI have less foot–floor clearance during gait compared with those who have stable ankles.[17,55] Konradsen and Voigt[14] suggested that joint position sense error during foot–floor clearance may lead to unintentional contact of the lateral aspect of the foot with the floor, resulting in ankle sprain. Because our findings occurred within the midrange of motion, we hypothesize that the tape application might stimulate the plantar surface of the foot to better position itself to clear the floor and avoid midswing contact. Researchers should evaluate muscle stimulation in taped participants with CAI.

During jogging, the total amount of ankle sagittal-plane motion was greater than during walking (Figure 3), and taped participants with CAI were less dorsiflexed leading up to peak dorsiflexion during the stance phase. During this time in the gait cycle when dorsiflexion motion is greatest, the lack of dorsiflexion may be due to the mechanical properties of tape. However, because this restricted range of motion occurs during full weight bearing, we do not believe this finding positively or negatively affects ankle sprain risk. During midstance, the likelihood of ankle sprain is minimal due to the stability of the joint.[51,56] Future investigators should determine the potential consequences of reduced dorsiflexion during midstance.

Although the finding was not statistically different from the untaped condition, our participants were more everted during foot–floor clearance while jogging in the taped condition, most likely to ensure adequate clearance. Successful advancement of the foot from behind the body to the front during the swing phase is essential during gait. Tape may have resulted in better positioning of the foot to avoid contact with the ground. Previous researchers[42,49] have reported increased muscular activation in taped participants during simulated inversion. For example, peroneus muscle reaction time to a simulated ankle sprain was improved with the application of tape in participants with ankle instability.[42] Future investigators should evaluate muscular activity during functional activities such as walking and jogging.

Earlier authors[17,18,20] have found that, compared with healthy controls, individuals with CAI are more inverted from 200 milliseconds before to 200 milliseconds after heel strike, which may be a factor in ankle sprains and instability. Interestingly, we did not find that tape altered ankle kinematics during this window. However, we did find that prophylactic taping altered kinematics earlier in swing, from 76% to 81% of the gait cycle while walking: the average stride time for our participants was 1200 milliseconds, indicating that each percentage point represented about 12 milliseconds. The period of 76% to 81% of the gait cycle while walking represents 912 to 972 milliseconds of a 1200-millisecond stride, which occurs before the previously established terminal swing window. In the current study, we evaluated only the effect of tape on those with CAI. Future researchers should study healthy participants to determine if tape alters their kinematics.

Existing literature[27,28,57,58] on the effect of ankle prophylactics on the gait of CAI participants is limited. Spaulding et al[27] compared ankle sagittal-plane kinematics in those with CAI who wore a flexible brace or a semirigid brace or were unbraced; no sagittal-plane differences were found between conditions when participants walked on a level surface at foot contact or toe-off. Our results are similar in the sagittal plane at those points in the gait cycle; however, an advantage of our study was our ability to evaluate 2 planes of motion throughout the entire gait cycle and not just at 2 discrete time points.

Altering and restricting range of motion at the ankle is detrimental to proximal joints such as the knee.[25,26,59,60] At initial contact from a jump, ankle bracing increased knee flexion.[26] However, the increased knee flexion was not associated with an increase in knee-injury risk.[26] We did not find sagittal-plane kinematic differences at the knee. Although these results do not agree with those of previous researchers, the differences in tasks may be the reason. Jumping and landing require the lower extremity to absorb a significantly larger amount of force than walking or jogging.

In athletes, ankle sprains are believed to occur while landing awkwardly from a sporting task; however, patients with CAI report feeling unstable while walking and jogging on a level surface.[29] Interestingly, many previous investigations[24–26,61,62] into ankle prophylactics have focused on healthy participants and kinematic differences during a jumping task. To our knowledge, the single reported study[27] evaluating the kinematics of CAI patients, ankle braces, and walking on a level surface was limited because only 2 discrete points in the gait cycle were assessed. We found similar results immediately after toe-off but no sagittal-plane differences between groups at initial contact.

As with all research, there were limitations to this study. First, all participants wore the same style of laboratory shoes, regardless of foot type. Given the nature of the data collection, we had to provide the shoes with cutouts for marker placement on the skin. A second limitation is that all participants ran at predetermined paces. Using unfamiliar shoes and preset speeds may have caused them to adjust their gaits to accommodate the pace. We tried to minimize any unnatural gait by providing adequate time for them to adjust to the shoes and the treadmill speed. Third, data were collected immediately after tape was applied. Future investigators should evaluate if the kinematic changes of tape we found persist after prolonged application and activity. We also evaluated only an active intervention and an untaped control condition. Research should be conducted to determine if similar results are seen under a placebo condition. Finally, future authors should evaluate if the application of tape affects kinematics while athletes perform other sport maneuvers, such as sprinting, jumping, and cutting.

CONCLUSIONS

Overall, we found that, in those with CAI, ankle tape altered frontal-plane and sagittal-plane kinematics at the ankle while walking and jogging in shoes on a treadmill. In each case, the ankle was positioned more neutrally with tape. The changes seen in the taped condition may contribute to a reduced risk of ankle sprains due to better positioning of the ankle throughout the gait cycle. Tape may protect the ankle via its mechanical properties as well as its neuromuscular effect on ankle position just before critical aspects of gait, such as toe-off and foot–floor clearance.

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