Utility of Gait Biofeedback Training to Improve Walking Biomechanics in Patients with Chronic Ankle Instability: A Critically Appraised Topic

Abstract

Clinical Scenario: Chronic ankle instability (CAI) is a condition that involves feelings of the ankle 'giving way,' pain, and decreased self-reported function. Individuals with CAI often demonstrate persistent biomechanical impairments during gait that are associated with repetitive lateral ankle sprains (LAS) and the development of early onset ankle posttraumatic osteoarthritis (OA). Traditional rehabilitation strategies have not successfully improved these reported aberrant gait biomechanics; thus, traditional rehabilitation may not effectively reduce the risk of recurrent LAS and ankle OA among individuals with CAI. Conversely, targeted gait training with biofeedback may be effective at decreasing the risk of recurring LAS and ankle OA if these rehabilitation strategies can promote individuals with CAI to develop a gait strategy that protects against subsequent LAS and ankle OA. ***Clinical Question:*** Can targeted gait biofeedback interventions cause individuals with CAI to implement a walking gait pattern that is not associated with recurrent LAS and ankle OA? ***Summary of Findings:*** Five studies assessed gait biofeedback interventions targeting plantar pressure and/or ankle kinematics involving visual biofeedback (n=3), auditory biofeedback (n=1), and haptic biofeedback (n=1). Plantar pressure was medially shifted during a single session while receiving biofeedback (n=2), immediately after biofeedback (n=1), and 5-minutes after receiving biofeedback (n=1) in three studies. One study demonstrated reduced ankle inversion after 8-sessions of biofeedback training. One study did not substantially improve plantar pressure while receiving visual feedback. ***Clinical Bottom Line:*** Targeted gait training strategies appear effective in acutely altering gait biomechanics in

individuals with CAI while receiving and immediately after biofeedback has been removed. Long term outcomes are not currently established for gait training strategies in those with CAI.

Strength of Recommendation: Limited evidence (grade B) suggests that targeted gait biofeedback strategies can alter specific CAI gait biomechanics to a strategy not associated with recurrent LAS and ankle OA immediately and after multiple sessions of gait training.

Clinical Scenario

Lateral ankle sprains continue to be the most common musculoskeletal injury in the United States.[1] A prospective study demonstrated that 40% of lateral ankle sprains will lead to chronic symptoms of 'giving way,' persistent pain, and continual re-sprains which is characterized as chronic ankle instability (CAI).[2] Individuals with CAI can present with isolated or a combination of sensory-perceptual, pathomechanical, or motor-behavioral impairments.[3] Aberrant biomechanical patterns during gait are a common motor-behavioral impairment associated with CAI.[4] Specifically, individuals with CAI often demonstrate an increased ankle inversion angle,[5–7] greater lateral deviation of the center of pressure (COP) and increased lateral plantar pressures during gait.[8] This common biomechanical profile among individuals with CAI is associated with an increased risk of recurrent lateral ankle sprain (LAS) and the development of posttraumatic osteoarthritis (PTOA) at the ankle.[9–11] This lateral-centric pattern consistently places the individual's COP closer to the boundary of the foot, which not only positions the ankle closer to the mechanism of injury of a LAS (recurrent sprains result), but also causes abnormal stresses across the talar cartilage (ankle PTOA develops).[12,13]

Despite the success of impairment-based interventions improving measures of postural control, muscle strength, and arthrokinematic restrictions, evidence does not support the utility of these interventions to improve abnormal gait patterns in CAI.[14,15] This observation is further supported by the results of two critically appraised topics evaluating the efficacy of bracing, taping, and neuromuscular training on improving gait biomechanics in patients with CAI.[16,17] Unfortunately, neither of the examined strategies were able to produce beneficial changes in walking gait biomechanics that may protect patients with CAI from experiencing recurrent LAS and developing ankle OA.

The International Ankle Consortium (IAC) advises clinicians to assess for gait abnormalities and implement gait training to treat patients with CAI;[18] however the IAC currently does not provide recommendations to which gait training intervention(s) should be incorporated in a rehabilitation plan when treating patients with CAI. Common methods for gait training that have improved biomechanical risk factors for other chronic lower extremity pathologies, such as patellofemoral pain, include visual biofeedback via videos and mirrors where clinicians verbally instruct patients on how to correct unwanted movement patterns.[19] Although effective for pathologies of the knee, this strategy may be difficult to execute when targeting ankle motion considering the smaller range of motion and less obvious abnormal patterns. Identifying effective interventions capable of targeting aberrant gait patterns associated with CAI is warranted.

Focused Clinical Question

Can targeted gait biofeedback interventions cause individuals with CAI to implement a walking gait pattern that is not associated with recurrent LAS and ankle PTOA?

Search Strategy and Criteria

Several databases (PubMed, MEDLINE, CINAHL, and SPORTDiscus) were searched from inception to September 2, 2021. The following search terms were used to identify studies that would address the clinical question:

- **P**atient/Client Population: Chronic ankle instability
- **I**ntervention/exposure: biofeedback OR feedback
- **C**omparison: pre- and post-biofeedback
- **O**utcomes: walking gait biomechanics

The search specifically listed articles for (chronic ankle instability) AND (biofeedback OR feedback) AND (walk OR gait).

The reference lists of the articles identified were also manually searched to ensure a comprehensive search. Studies were assessed via abstract screening to identify those to be excluded as per the inclusion/exclusion criteria below.

Inclusion criteria:

- Individuals with CAI, including all ages
- Studies that assessed lower limb biomechanics before and during or after a targeted gait biofeedback intervention in patients with CAI.
- Studies available in the English Language
- Level 3 evidence or higher

Exclusion criteria:

- Did not use participants with CAI
- Studies using interventions other than gait training with biofeedback
- Studies that did not assess lower limb biomechanics during gait or following a targeted gait biofeedback intervention
- Studies without available full text in English language

Evidence of Quality Assessment

The studies included were assessed for methodological quality using the Physiotherapy Evidence Database (PEDro) scale.[20] The PEDro scale can score a maximum of 10 points, reflecting internal validity and statistical reporting to better direct clinical decision-making. Each included article was independently reviewed by two authors (L.D and L.F). If a score was not agreed upon, a third reviewer made the final decision (R.K).

Summary of Search and Key Findings

- A literature search was performed to identify studies of level 3 evidence or higher that assessed the effect of targeted gait training on gait biomechanics in individuals with CAI.
- Forty studies were identified in our initial search and 5 studies met the inclusion criteria. Details for the included studies can be found in Table 1.
- All included studies assessed unimodal biofeedback strategies used to target altered gait patterns in adults with CAI. Three studies investigated visual biofeedback[21–23] (real-time visual biofeedback[21,23] and shoe mounted laser[22]) during treadmill walking, one study investigated auditory biofeedback during treadmill walking,[24] and one study investigated haptic (vibration) biofeedback during both treadmill and overground walking.[25]
- Of the five studies, three interventions targeted plantar pressure using pressure insoles,[22–24] one targeted center of pressure using vertical ground reaction forces using an embedded force plate,[25] and one targeted ankle kinematics using 3D motion capture.[21]
- Measures of plantar pressure were reduced in the lateral column of the foot and COP shifted medially while using visual,[22] auditory,[24] and haptic[25] biofeedback strategies.
- The ankle inversion angle was decreased at initial contact and throughout the stride cycle using visual biofeedback.[21]

Results of Quality Assessment from Best Available Evidence

From the five studies assessed, three scored 4/10,[22–24] one scored 5/10,[25] and one scored 8/10[21](Table 1). None of the included articles[21–25] had a protocol in place to blind subjects or therapists administering the test. All studies[21–25]reported key outcomes from more than 85% of the subjects initially allocated to treatment or control group, statistical comparisons were conducted, and variability reported. Koldenhoven et al.[21] was the only article to conceal allocation to groups and detail groups to be similar at baseline.

Summary of Best Evidence

Clinical Bottom Line

Limited quality evidence exists demonstrating that targeted gait biofeedback strategies improve measures of gait biomechanics in individuals with CAI. Collectively, the body of evidence included to answer the clinical question aligns with the strength of recommendation of grade B.

Implications for Practice, Education, and Future Research

The majority of the studies included in our critically appraised topic support the use of various targeted gait biofeedback strategies to train individuals with CAI to modify biomechanical gait patterns (eg. plantar pressure, and lower limb kinematics and muscle activity) that have been associated with recurrent LAS or ankle PTOA.[21,22,24,25] Only one form of visual biofeedback (real-time video) was unable to produce a clinically meaningful (i.e. small effect sizes) reduction in lateral plantar pressure for individuals with CAI; yet, as noted by the study's authors, this form of biofeedback and particularly the chosen feedback cue, did cause the majority of participants to alter their gait, but not in a patterned effect as observed in the other included studies.[23] Forty studies were initially identified by the search and 5 studies were included based on our inclusion criteria (Table 1). All studies acutely assessed a biofeedback training session or program involving visual, auditory, or haptic feedback techniques.

Three of the 5 studies investigated various methods of visual biofeedback and their effects on gait biomechanics.[21–23] Two of these studies assessed plantar pressure outcome measures before and while receiving the visual biofeedback[22,23] while the third study assessed lower extremity kinematics before and after 8-sessions of visual biofeedback training.[21] A study by Torp et al.[22] utilized a shoe-mounted laser to provide visual biofeedback throughout the stride cycle with the goal of reducing plantar pressure under the lateral column of the foot while receiving biofeedback. Participants were instructed to keep the crossline of the laser projection in a vertical position while walking.[22] The participants were able to decrease plantar pressure in the lateral column of the foot and shift the location of COP medially during the first 80% of the stance phase.[22] A decrease in pressure under the lateral column of the foot and medial shift in the COP is a desired change in the gait pattern as it reduces the threat of the COP exceeding the lateral boundary of the foot which could result in a LAS. This method of visual biofeedback is accessible for clinicians and may be useful for reducing lateral pressures while receiving feedback, however, the long-term effects remain unknown.

A study by Ifarraguerri et al.[23] also measured plantar pressure while individuals received biofeedback during treadmill walking. A commercially-available high-definition camera was placed behind participants as they walked on a treadmill and projected the video to a television screen in front of the participant.[23] Participants were instructed to "walk in a manner where you can no longer view the outside or inside of your foot on the television screen while you walk" to promote a neutral foot position during walking.[23] Plantar pressure was significantly reduced for peak pressure and the pressure-time integral in the medial forefoot and midfoot, however, these reductions were not clinically meaningful when considering their small percent changes and effect sizes.[23] There were no differences between the baseline measures and while receiving the video biofeedback for measures of lateral plantar pressure.[23] Therefore, the technique of Ifarraguerri et al. [15] is not recommended at this time for improving gait biomechanics for individuals with CAI. Further refinement for cues or feedback techniques may be needed to decrease lateral plantar pressure measures.[23]

The study performed by Koldenhoven et al.[21] involved providing visual biofeedback generated by a computer that was based on the frontal plane kinematic position of the ankle at initial contact, and was updated for each initial contact.[21] This study aimed to reduce ankle inversion angle at initial contact over the course of 8 training sessions.[21] The intervention group received gait biofeedback and the control group walked on the treadmill for the same amount of time with no biofeedback. Both groups also received 8-sessions of impairment-based rehabilitation. Compared to the baseline assessment, the gait biofeedback group decreased ankle inversion angle by 7.3° at initial contact and 5.9° throughout the stride cycle, while there were no changes in ankle inversion angle for the non-biofeedback group.[21] This finding further demonstrates that to acutely alter gait mechanics, a targeted training program must be completed. Unfortunately, this gait biofeedback technique is heavily lab based and not currently available to clinicians. It is uncertain how this biofeedback technique would impact gait mechanics over an extended period of time after the training sessions have ended.

One study assessed the use of auditory biofeedback to reduce plantar pressure under the lateral aspect of the foot.[24] Donovan et al.[24] placed a force sensitive sensor inside the shoe under the lateral column of the foot that made an audible noise when the pressure placed on the sensor exceeded the threshold. Participants were instructed to "walk in a manner that is similar to your normal walking pattern, but try to make it so the device no longer makes a noise."[24] Plantar pressure measurements were taken before and during biofeedback administration.[24] Peak pressure and pressure time integral in the lateral midfoot and forefoot were significantly reduced while receiving the auditory feedback during walking.[24] This indicated that the auditory biofeedback was capable of reducing lateral plantar pressure during walking in individuals with CAI. Long term outcomes and outcomes for after the auditory biofeedback is removed are not currently established.

Migel and Wikstrom[25] assessed the use of haptic (vibration) biofeedback to reduce lateral plantar pressure in laboratory and real-world environments. Similar to Donovan et al.,[24] a pressure sensor was placed under the lateral aspect of the foot and provided a vibration stimulus to the lower leg when pressure exceeded the threshold.[25] Participants were instructed to "walk so you do not get the vibration."[25] Individuals participated in 2 separate sessions in which they either: 1) walked on a treadmill for 10 minutes (laboratory training), or 2) walked on a one mile loop of brick sidewalk (real-world training) while receiving the biofeedback. Plantar pressure measures were collected in each session at baseline, immediately after, and 5-minutes after biofeedback was removed.[25] Immediately after the lab based training, the center of pressure was located more medially during the first 90% of stance and 5-minutes after lab training, the center of pressure remained more medial from 20-90% of stance. Results were similar for real-world training in that the center of pressure was more medial during the first 70% of stance immediately after training and the first 60% of stance 5-minutes after feedback was removed. Thus, haptic biofeedback was capable of shifting lateral plantar pressures more medially immediately and 5-minutes after biofeedback in individuals with CAI. Longer term outcomes are not yet available for haptic biofeedback training.

Researchers and clinicians should consider the attention of focus of participants when creating or refining biofeedback techniques. An internal focus of attention draws the individual's attention to their bodily movements. Alternatively, an external focus directs the individual's attention to an external factor during the movement.[26] Previous research has stated that an external focus of attention is favorable for enhancing performance and learning.[27–29] From the 5 studies included, the instructions from Ifarraguerri et al.[23] used an internal focus of attention technique were the participant's foot placement was visually represented as a video of themselves walking. This contrasted the remaining 4 studies[21,22,24,25] that focused attention externally on a sound, vibration, or visually using a laser or spot. Given Ifarraguerri et al.[23] was the only study to not report consistent improvements, it may suggest that internal focus of attention techniques are not sufficient for improving foot placement in individuals with CAI. This is speculative; however, it may provide direction for further refinement for cues and feedback techniques in the future.

Gait training that utilizes targeted biofeedback appears to be effective in improving the respective specified gait biomechanical outcome measures (plantar pressure, kinematics) in individuals with CAI during, immediately after, and shortly after the biofeedback has been removed. It is not yet understood if medial shifts in plantar pressure are related to a decrease in ankle inversion angles or vice versa as this relationship was not measured in the included studies. No long-term outcome studies for gait training were identified in individuals with CAI, and from the included studies the longest follow up was 24-72 hours.[21] Therefore it is unclear how effective these treatments would be in the subsequent months or years after training has ended.

Future research should continue to build-upon these findings that suggest targeted biofeedback, via externally focused attentional strategies (visual, auditory, and haptic), can generate acute changes in gait that may mitigate long-term consequences associated with CAI, while acknowledging the limitations of these preliminary reports (i.e. short follow-up, different lengths and modes of intervention, and solely a young adult population). Promoting proper gait biomechanics may reduce the risk of subsequent ankle sprains for individuals with CAI and thus improving their overall quality of life.

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Table 1. Summary of Best Evidence

	Donovan et al.[16]	**Ifarraguerri et al.[15]**	**Koldenhoven et al.[13]**	**Migel & Wikstrom[12]**	**Torp et al.[14]**
Study Design	Descriptive laboratory	Descriptive laboratory	Randomized controlled trial	Randomized crossover trial	Descriptive laboratory
Participants	10 CAI Sex: 3 Male; 7 Female Age: 21.5±3.1	26 CAI Sex: 11 Male; 15 Female Age: 20.9±2.4	27 CAI (13 BF, 14 nBF) Sex: 8 Male; 19 Female Age: 21.8±3.4	19 CAI Sex: 10 Male; 9 Female Age: 22.6±4.2	26 CAI Sex: 11 Male; 15 Female Age: 20.9±2.4
Inclusion/exclusion Criteria	***Inclusion Criteria:*** CAI criteria established by International Ankle Consortium ***Exclusion Criteria:*** Other known lower extremity injuries or pathologies Ankle sprain in last 6 weeks	***Inclusion Criteria:*** CAI criteria established by International Ankle Consortium ***Exclusion Criteria:*** Lower extremity surgery Fracture in ankle or foot region Ankle sprain in last 6 weeks Current symptoms from another known lower extremity injury or pathology	***Inclusion Criteria:*** CAI criteria established by International Ankle Consortium ***Exclusion Criteria:*** Lower extremity surgery Fracture in ankle or foot region Ankle sprain in last 6 weeks Conditions known to affect gait Pregnancy Participating in rehabilitation	***Inclusion Criteria:*** CAI criteria established by International Ankle Consortium Age: 18-45 ***Exclusion Criteria:*** Lower extremity surgery Fracture in ankle or foot region	***Inclusion Criteria:*** CAI criteria established by International Ankle Consortium Age: 18-40 ***Exclusion Criteria:*** Lower extremity surgery Fracture in ankle or foot region
Intervention Investigated	Auditory BF provided if vertical force exceeded the set threshold under the 5th metatarsal head using a force sensitive resistor on affected limb while walking.	Video BF provided on a television screen to promote neutral foot position on affected limb while walking.	Eight sessions (2x week) of video BF to reduce affected limb ankle inversion at IC during walking was used. nBF walked on treadmill for 8 sessions without feedback.	Vibration BF was provided to lateral malleolus during laboratory treadmill walking for 10 min and outdoor walking for 1 mile using a force sensitive resistor on placed under the 5th metatarsal head of affected limb.	Visual BF provided by a laser attached to dorsal foot of the affected limb and athletic tape attached vertically to a wall. Participants had to match the laser to the vertical orientation of the tape while walking.

Outcome Measures	Plantar pressure measures of peak pressure, pressure time integral, time to peak pressure, contact area and contact time from 9 regions of the foot. sEMG amplitude from the TA, PL, MG, and GM 200 ms pre-contact and 200 ms post-contact.	Plantar pressure measures of peak pressure, pressure time integral, contact area and contact time from 9 regions of the foot.	Stride normalized 3D ankle, knee and hip joint kinematics and kinetics collected PRE and POST. Stride normalized sEMG amplitude from TA, FL, MG, and GM collected PRE and POST.	COP position relative to the 5th metatarsal head during the stance phase collected PRE, POST, and RET.	Plantar pressure measures of contact area, contact time, peak pressure, pressure time integral, and COP position relative to the medial border of the foot during the stance phase.
Results	***Plantar pressure:*** BF reduced peak plantar pressure 39.6% (ES=2.19) in lateral midfoot, 36.4% (ES=1.97) in lateral forefoot, and 16.9% (ES=1.34) in central forefoot. BF reduced pressure time integral 42.5% (ES=3.04) in lateral midfoot and 40.9% (ES=2.20 in lateral forefoot. BF reduced time to peak pressure 28.9% (ES=0.98) and total contact area 18.0% (ES=2.47) in the lateral midfoot. Toes 2-5 had a 13% (ES=0.99) decrease in contact area with BF. ***sEMG amplitude:*** PL amplitude increased 59.9% (ES=1.09) with BF post-contact; MG amplitude	BF reduced peak pressure 8.4% (ES=0.31) and pressure time integral 9.1% (ES=0.38) in medial forefoot.	BF group reduced ankle inversion angle 173.8% (ES=1.60) PRE to POST intervention at IC. Ankle inversion angle reduced 88.1% (ES=1.20) throughout the entire stride cycle for the BF group PRE to POST. No changes in ankle inversion angle at IC or during stride cycle for nBF group. BF group had a 160.0% (ES=0.71) change from knee IR during PRE (-2.0±4.3°) to knee ER (1.2±4.2°) at POST during terminal swing. No change in nBF group at terminal swing. No differences in ankle, knee or hip joint kinetics and sEMG measures.	***Laboratory Walking:*** COP position was more medial 20-90% of stance for both POST (ES=0.81-1.07) and RET (ES=0.62-0.91) compared to PRE. ***Outdoor Walking:*** COP position was more medial 10-60% of stance for both POST (ES=0.83-1.15) and RET (ES=0.51-1.15) compared to PRE.	BF decreased peak pressure 9.2% (ES=0.58) in lateral midfoot, 9.9% (ES=0.46) in central forefoot, and 11.8% (ES=0.61) in lateral forefoot. BF decreased pressure time integral 13.4% (ES=0.57) lateral heel and 11.1% (ES=0.50) in lateral midfoot. Lateral COP progression was reduced from 60-80% of the stance phase (ES=0.56-0.62) during BF.

	increased 82.2% (ES=1.05) with BF post-contact.				
Level of Evidence	3	3	2	2	3
Quality Assessment Score	PEDro 4/10	PEDro 4/10	PEDro 8/10	PEDro 5/10	PEDro 4/10
Contribution to CAT Question	5 – conclusive contribution	3 – inconclusive contribution	5 – conclusive contribution	5 – conclusive contribution	5 – conclusive contribution

List of Abbreviations:

BF – biofeedback; CAI – chronic ankle instability; COP – center of pressure; ES = effect size; ER – external rotation; GM – gluteus medius; IC – initial contact; IR – Internal Rotation; MG – medial gastrocnemius; nBF – no biofeedback; PL – peroneus longus sEMG – surface electromyography; RET – retention; TA – tibialis anterior