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Limbic Entrainment for Normalizing Gait in Individuals with a Recent History of Ankle Injury

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Abstract

This case series examined the effectiveness of limbic entrainment for normalizing gait in individuals with recent ankle sprains. The limbic system consists mainly of the amygdala and the hypothalamus, and is connected to the motor areas of the brain via the ventral striatum. Auditory stimuli have been shown to have the greatest effect on motor responses, since the auditory areas of the brain are connected most directly to the motor and limbic areas. Two subjects were tested in this case series by walking at a self-selected pace before and after limbic entrainment. Entrainment was achieved through 15 minutes of relaxation while listening to antecedent sonic driving through a shamantic drumming track. Significant differences were observed in cadence, step length, force distribution, and single support line. Future research is suggested, including more subjects, as well as subjects with varying length of time between the injury and testing.

Introduction

Ankle sprains are common injury, especially among athletes, and can have many effects on daily activities. [19-21] Typical treatments for ankle injuries include exercises to restore strength, range of motion, neuromuscular coordination, and gait mechanics. [19] Gait is an especially important aspect of rehabilitation, as abnormal gait can have effects on other parts of the body further up the kinetic chain. [19] Many of these treatments take time to see results, and are therefore not ideal for a person wanted to immediately return to their activity. [19] Limbic entrainment is a proposed method for normalizing gait in individuals with a range of pathologies. [15] The effectiveness of limbic entrainment for individuals with gait dysfunction due to strokes and Parkinson's disease has been studied and shown to be useful, however the far less is known about the effectiveness of limbic entrainment for individuals with ankles sprains.[15,25-28] Limbic entrainment is an relatively easy intervention, and if effective, could be valuable for athletes wanting immediate results in the normalization of gait to return to their activities. [15,19]

Limbic entrainment consists of using an auditory stimulus to entrain the limbic and nervous systems to a specific beat frequency in hopes of having an effect on the motor coordination of tasks such as walking or running.[11,15] The nervous system can be effected by external stimuli, such as metronome beats. [1-5,29,30] The link between the nervous system, auditory sensory system, limbic system, and motor system is complex, and not fully understood. [11-18] Studies have been conducted to determine if auditory or visual stimuli have a greater effect on motor function, and it is easier for the human body to synchronize with auditory stimuli. [3,4] This is due to the structure of the brain, and the close link of the motor areas with the auditory and limbic areas. There is not a universal agreement on all of the structures that make up the limbic system, however two of the primary structures that are directly used in entrainment are the amygdala and the hypothalamus.[6,23] In relation to limbic entrainment, the amygdala is involved with integrating information from temporal areas and the hypothalamus, and the hypothalamus is involved with many functions and is where many neural pathways converge.[23] The amygdala and the motor related areas, including the lateral and medial precentral, postcentral guyrus, motorcingulate, primary motor corticies, are connected through the ventral striatum[8, 9,15,16]. The amygdala, along with auditory centers of the brain, influences complex motor behavior.[8,15] The basal ganglia are involved in both limbic and motor function, and basal ganglia are active in the neural processing of the timing of auditory stimulus to motor behavior.[9,16] Further, the inferior colliculus is a main auditory center, is involved with timing exercises, and is readily entrained by auditory stimuli.[15, 18] The inferior colliculus has connections to the cerebellum, which is involved in sensorimotor tasks and other muscular coordination tasks.[15,16,18] The connection between the inferior colliculus and the cerebellum is important to the connection between auditory entrainment and motor actions during limbic entrainment.[15,18]

Since gait is a complex motor function, it is possible that the limbic system could be entrained using an auditory stimulus to affect gait patterns.[2,3] Studies have shown that gait can be altered by exposing a patient to different stimuli.[3,11,15] Entrainment happens more readily in patients with any gait dysfunction, but especially in extreme cases such as in stroke and Parkinson's disease patients.[11] The specific gait parameters that showed the most improvement in entrainment studies included step length, velocity, cadence, and symmetry of gait.[11] Significant differences have also been found in motor recruitment patterns and gait kinematics when a subject is exposed to auditory entrainment, and although this was not examined in this case series, it would be an area for future research.[11]

Auditory stimuli may reorganize the neuromotor coordination pattern via the limbic system, and enable the gait pattern to be maintained even after the stimulus is gone.[3] Gait dysfunction can be partially attributed to poor timing in movement.[11,12] The rate that auditory neurons fire affect the firing repetitions of motor neurons, and therefore listening to music has an effect on movement pattern.[11] Listening to a beat activates basal ganglia and supplementary motor areas, which are involved in the motor response to an auditory beat.[2,16] These areas are also involved in timing of current and future movements, and can be referred to as an entrainment timer.[2] The entrainment timer, or the timing of movement through auditory entrainment, is a crucial part of why auditory entrainment works.[2,11] The planning of motor movements is the aspect of motor coordination that is most effected by entrainment.[11] Rhythm provides the brain with an anticipatory timing period which can provide the basis for period of gait.[11] The brain has a time period that has been entrained in the motor pathways before the stride even happens, so planning for movement becomes more regular and efficient.[11] This can be thought of as an external time keeping system for gait, and by having a subject listen to a beat pattern for an extended period of time, the auditory and motor systems are entrained to a certain beat frequency.[11] This system could be involved with beat-based entrainment that lasts beyond when the stimuli is removed.[2] Research has also suggested that entrainment could have long term gait effects if training occurred regularly for three weeks.[11]

There are many components to gait, and as outlined earlier, the specific gait parameters that showed the most improvement in many entrainment studies included step length, velocity, cadence, and symmetry. [11] Typical values for velocity in healthy adult gait are 80 meters per minute, and cadence is about 105-120 steps per minute.[24] Step length focuses on the step length difference between the right and left sides, and symmetry includes various different aspects of gait including percent of gait spent in each phase, single support line, and vertical ground reaction forces measured for each leg during gait.

Gait can be broken down into the following phases: initial contact, loading response, mid-stance, terminal stance, pre-swing, initial swing, mid swing, and terminal swing (Figure 1). Initial contact through pre-swing are considered to be part of the stance phase, and the initial swing through terminal swing phase are considered to be part of the swing period of gait (Figure 1). The typical values for each of the relevant phases are summarized in Table 1.

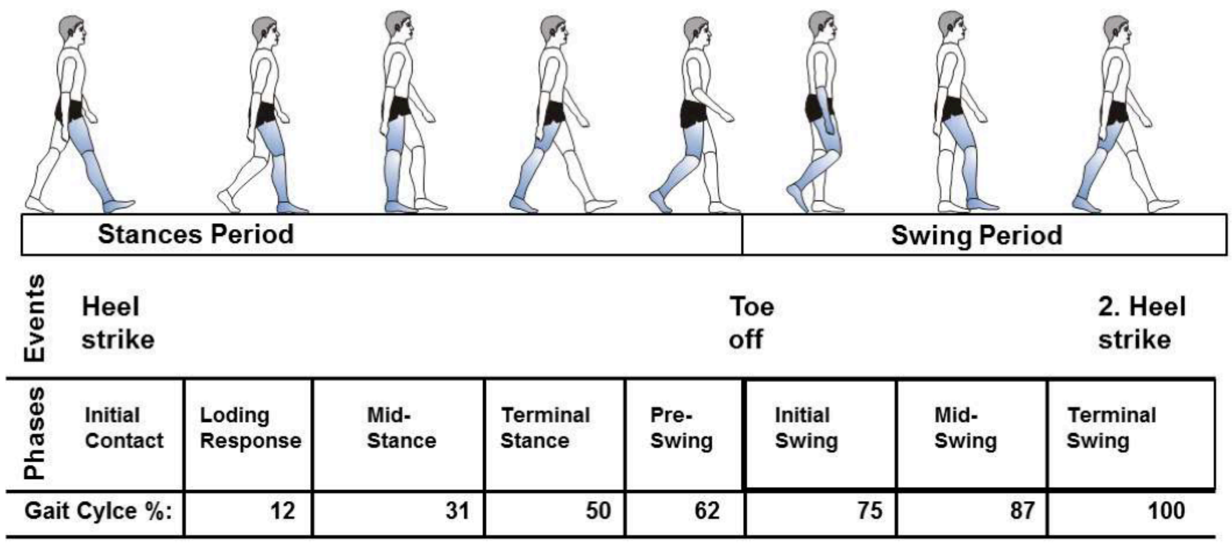


Figure 1. The phases of normal gait. Taken from the Noraxon Myopressure Bilateral Gait Report.

Phase of Gait	Percent of Time in Phase
Stance Phase,%	60
Loading Response,%	10
Mid Stance,%	20
Swing Phase,%	40
Pre-Swing,%	10

Table 1. Normative values of times spent in each phase of gait.[22]

The purpose of this case series is to determine if limbic entrainment is a valid method of normalizing gait, specifically in regards to step length, velocity, cadence, and symmetry of gait. This case series is intended to act as a pilot for other research on limbic entrainment and gait dysfunction due to ankle sprain. The hypothesis is that limbic entrainment through sonic driving will normalize gait, specifically velocity, step length, cadence, and symmetry in individuals with a recent history of ankle sprain.

Methods

This study analyzed data from two subjects. Prior to testing, age, height, sex, weight, and physical activity level were measured for each participant. Subjects were recruited via flyers in the student recreation center at Western Washington University, and referrals were given to students who fit the criteria by the facility's athletic trainer. Both subjects were given an informed consent waiver detailing the study and risks involved, as well as an ankle injury questionnaire. The ankle injury questionnaire asked the following questions:

General
1. Which ankle is injured? RIGHT LEFT
2. What is your current ankle injury and when did it occur?
3. How did your current ankle injury occur?
4. Is this your first injury to your ankle, or have you had chronic injuries to this ankle?
5. If chronic, how long have you been experiencing pain in this ankle and how did you sustain your initial injury?
6. Have you received treatment for your ankle injury? YES NO
7. If yes, what treatment?

Severity
<u>Current pain</u> (circle one)
None Mild Moderate Severe Unbearable
<u>Impact on daily activity</u> (circle one)
No impact
Mild limitation
Moderate limitation
Severe limitation

<u>Testing:</u>
After measurements were taken and the participants completed the questionnaire, the subjects were shown the Noraxon Myopressure treadmill. The subjects were instructed to self-select a comfortable walking pace on the treadmill, and then walk for about a minute until instructed to stop.[17] The subjects kept their shoes on in an attempt to simulate a more normal gait for overground walking. Measurements were recorded for the last 30 seconds of walking, but participants were not told when measurements were beginning or ending to ensure that they were not changing their gate for the data collection period. After the walking, the subjects were walked immediately to a treatment table, where they were instructed to lie down, close their eyes, and relax while listening to a repetitive drumming track. This shamantic drumming video was started 30 seconds into the following track obtained from YouTube https://www.youtube.com/watch?v=w-3c34zmllw. The subjects were then left to listen to the track for 15 minutes. After listening to the drumming for 15, the subjects were immediately taken back to the treadmill to repeat the walking trial. The subjects were instructed to walk at the same pace as they walking pre-testing, and gait

measurements were taken for the last 30 seconds of the minute of walking without the subject's knowledge. It is important that the subjects began their walking trial right after listening to the drumming, since some studies have shown that any changes from entrainment via an auditory stimulus since gait patterns were retained for only 3-15 minutes.[3] After the subjects completed the post-treatment testing, they were asked about any perceptions they had while listening to the drumming track or during the walking trials.

Data Analysis:

All analyses were done using excel. The Noraxon Myopressure treadmill automatically calculated standard error and percent differences between the right and left sides for each subject. Data was compared between the left and right sides for each subject before the entrainment and after, and some comparisons were made between subjects. The specific parameters analyzed included force data, step length, cadence, velocity, single support line, and the time spent in each phase of gait.

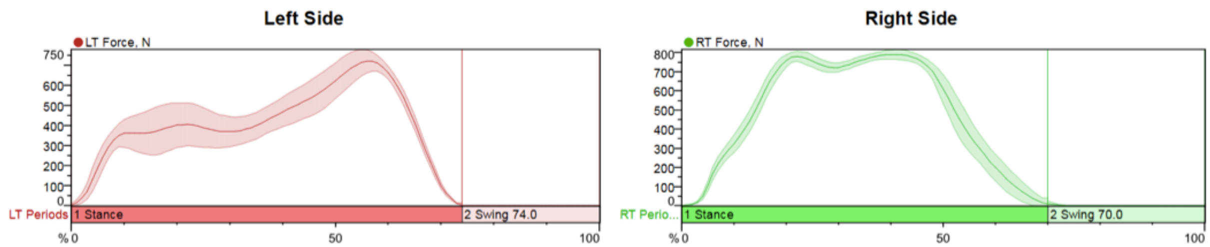
Results

Subject 1 was a 22-year-old male, and reported a right ankle injury six days prior to testing. He sprained his ankle playing rugby, and this was the first injury to his ankle. He had not received any treatment for his ankle, and reported moderate pain and mild limitation to daily activity. Subject 1 reported being active 6-7 days a week, including playing rugby and strength training. Post treatment, Subject 1 reported that he felt similarly pre- and post-treatment. He reported feeling very relaxed during the treatment, and zoning out but not falling asleep.

Subject 2 was a 21-year-old female, and reported a left ankle sprain that occurred a month and eight days prior to the testing. She sprained her ankle hiking, and reported spraining the same ankle five years prior to her current injury. Subject 2 reported undergoing physical therapy for her injury prior to testing. She reported mild pain, and no impact on daily activity. Subject 2 reported being active about two times a week playing volleyball for her physical activity level. She reported feeling relaxed during the entrainment, and not having much perception of time. She also reported that walking seemed faster post-treatment.

Force Data:

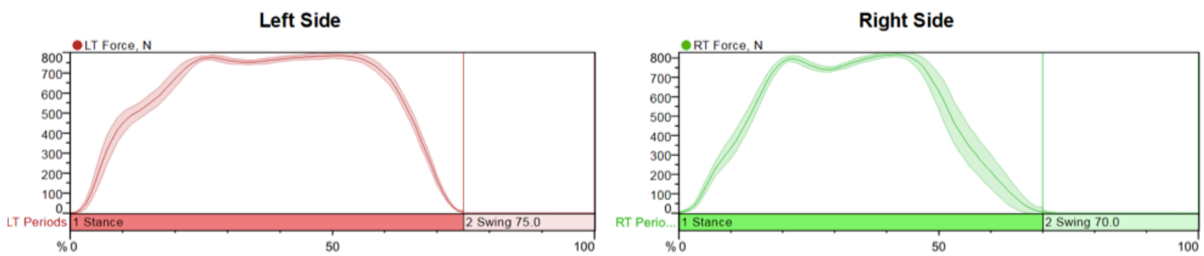
Differences were observed in the maximum ground reaction forces achieved during toe-off as seen on the force distribution graphs. For Subject 1 pre-treatment, there was a 9.86% difference between the right and left foot (Figure 2,3). Post-treatment there was only a 3.79% difference in the force of toe-off between the right and left feet. (Figure2,3) For Subject 2, there was a minimal difference in force of toe-off both pre- and post-treatment, with a 3.31% difference between feet pre-test and 4.38% difference post-test (Figure 3,4). For Subject 1, a more normal force curve for both feet was measured post-test, with a greater heel strike force measured on the uninjured side post-test (Figure 2,3).



Ampltitude Parameters

Channel	Minimum, N			Maximum, N			Range, N		
	Stance	Swing	Total	Stance	Swing	Total	Stance	Swing	Total
LT Force, N	3.42	0	0	713	13.1	713	710	13.1	713
RT Force	0.955	0	0	791	9.12	791	790	9.12	791

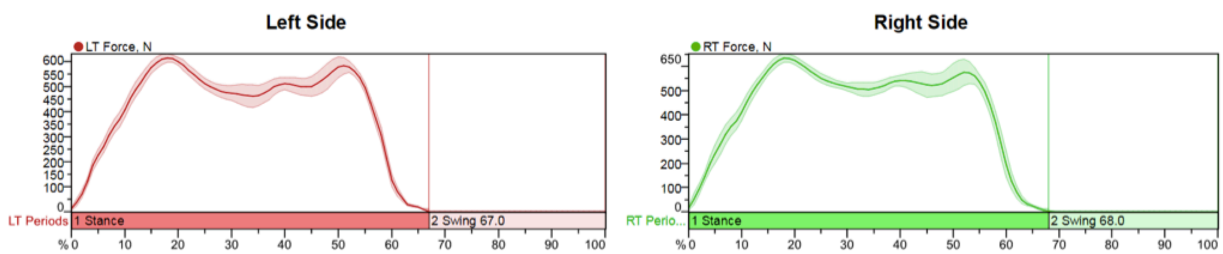
Figure 2. Vertical ground reaction force data for Subject 1 pre-treatment, injured right ankle.



Ampltitude Parameters

Channel	Minimum, N			Maximum, N			Range, N		
	Stance	Swing	Total	Stance	Swing	Total	Stance	Swing	Total
LT Force, N	1.35	0	0	786	13.5	786	784	13.5	786
RT Force	4.06	0	0	817	6.15	817	813	6.15	817

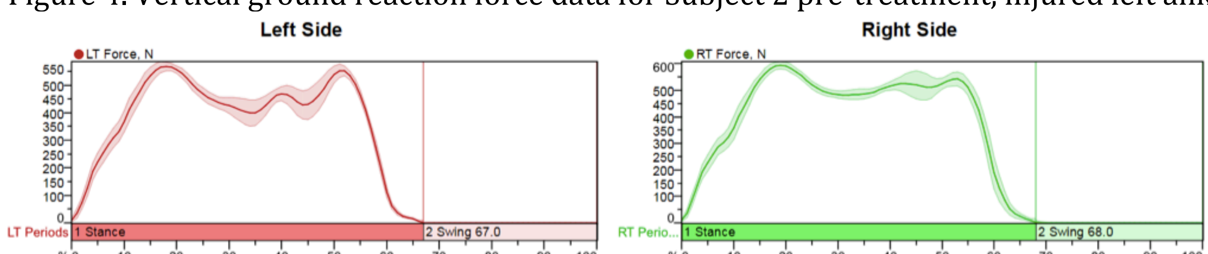
Figure 3. Vertical ground reaction force data for Subject 1 post-treatment, injured right ankle.



Ampltitude Parameters

Channel	Minimum, N			Maximum, N			Range, N		
	Stance	Swing	Total	Stance	Swing	Total	Stance	Swing	Total
LT Force, N	10.4	0	0	614	2.12	614	604	2.12	614
RT Force	8.05	0	0	635	2.62	635	627	2.62	635

Figure 4. Vertical ground reaction force data for Subject 2 pre-treatment, injured left ankle.



Ampltitude Parameters

Channel	Minimum, N			Maximum, N			Range, N		
	Stance	Swing	Total	Stance	Swing	Total	Stance	Swing	Total
LT Force, N	8.9	0	0	568	2.92	568	559	2.92	568
RT Force	8.35	0	0	594	2.93	594	586	2.93	594

Figure 5. Vertical ground reaction force data for Subject 2 post-treatment, injured left ankle.

Step Length:

	Left	Right	Diff, %
Subject 1 Pre-Treatment (cm)	32±2	46±2	43.2
Subject 1 Post-Treatment (cm)	31±2	40±2	29.3
Subject 2 Pre-Treatment (cm)	55±1	55±1	0.8
Subject 2 Post-Treatment (cm)	55±1	56±1	1.4

Table 2. Step length values for Subjects 1 and 2 in centimeters for the right and left legs, as well as the percent differences between right and left step length pre- and post- treatment.

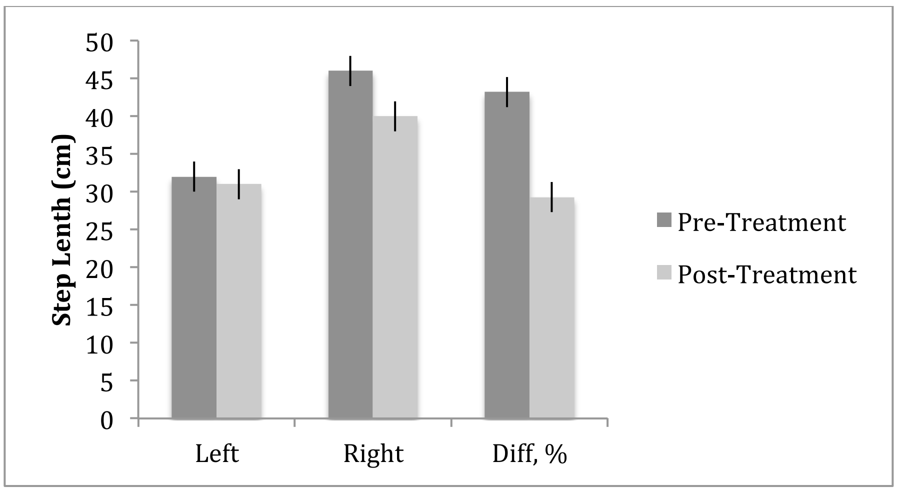


Figure 6. Subject 1 step length pre- and post-treatment in centimeters with standard error, as well as the percent difference between each side.

Subject 1 had a significant decrease in the percent difference between right and left leg stride lengths post-treatment. Subject 2 did not demonstrate a significant change in step length pre-post treatment.

Cadence:

	Pre-Treatment (steps/min)	Post-Treatment (steps/min)
Subject 1	77±3	83±3
Subject 2	94±1	93±1

Table 3. Cadence in steps per minute for Subjects 1 and 2, pre- and post-treatment with standard error.

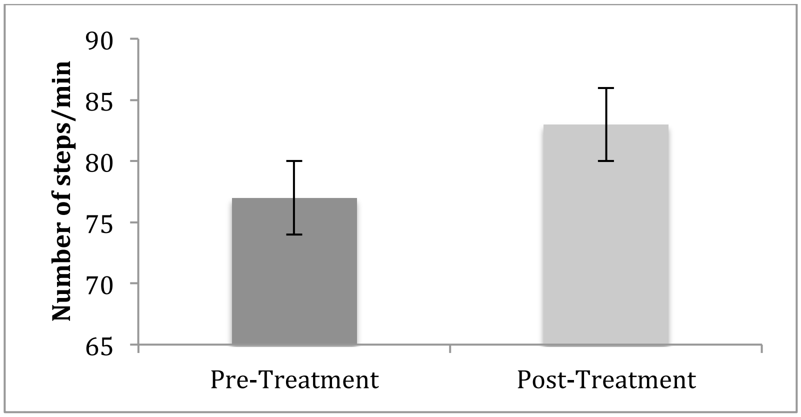


Figure 7. Subject 1 cadence in steps per minute pre- and post-treatment. Standard error shown as measured by the Noraxon Myopressure treadmill.

Subject 1 demonstrated an increase in cadence in steps per minute pre- to post-treatment (Figure 7;Table3). Subject 2 did not demonstrate an increase in cadence pre- to post-treatment (Table 3).

Velocity:

	Pre-Treatment (meters/min)	Post-Treatment (meters/min)
Subject 1	30	30
Subject 2	51	51

Table 4. Velocity measurement in meters per minute for Subjects 1 and 2, before and after limbic entrainment.

Velocity did not change for either subject between the two trials (Table 4). Subject 2 had a velocity that was closer to the normal value than Subject 1.

Single Support Line:

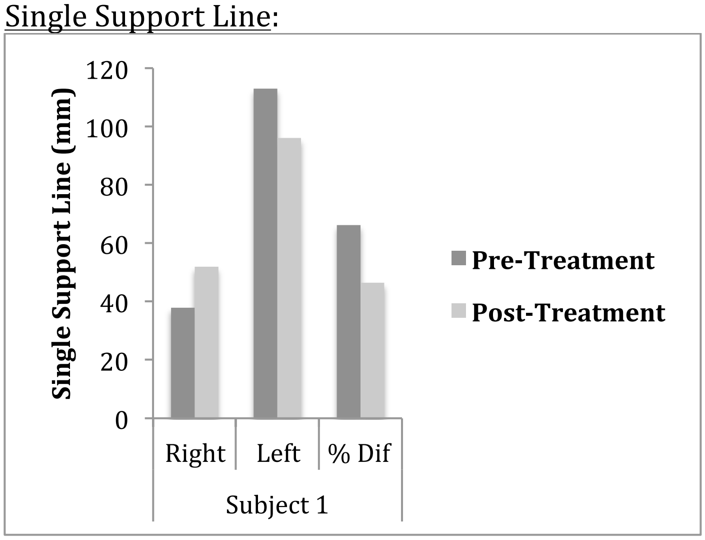


Figure 8. Subject 1's single support line in millimeters for each foot, pre- and post-treatment. Error shown in Table 5.

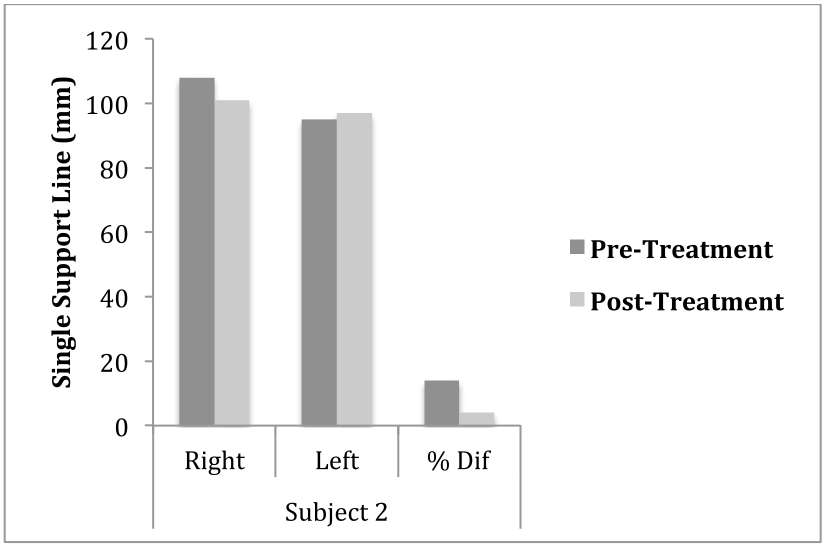


Figure 9. Subject 2's single support line for each foot in milimeters, pre- and post-treatment. Error shown in Table 5.

		Pre-Treatment (mm)	Post-Treatment (mm)
Subject 1	Right	38±9	52±10
	Left	113±10	96±17
	% Dif	**66.3**	**46.5**
Subject 2	Right	108±7	101±6
	Left	95±7	97±6
	% Dif	**14**	**4.1**

Table 5. Single support line data in mm for both subjects with standard error. Percent differences between the right and left feet were calculated by the Noraxon Myopressure treadmill.

The percent difference between the right and left foot single support lines decreased for both subjects rom the pre-treatment test to the post-treatment test (Figure 8,9;Table 5). This decrease in percent difference indicates greater symmetry in gait from the pre-test to the post-test.

Phases of Gait:

		Subject 1		Subject 2	
Phase of Gait		Pre-Treatment	Post-Treatment	Pre-Treatment	Post-Treatment
Stance Phase,%	Left	74.2±1.5	75.2±1.6	67.1±0.6	67.2±0.8
	Right	70.2±1.9	69.5±2.0	68.4±0.8	68.5±1
	% Dif	-5.5	-7.6	2	1.8
Loading Response,%	Left	23.9±1.7	24.9±1.4	17.9±0.9	17.9±1
	Right	20.6±1.2	19.9±1.1	17.5±0.8	17.8±0.5
	% Dif	-14.1	-20.3	-2.7	-0.8
Mid Stance,%	Left	29.8±1.8	30.5±2.1	31.7±1	31.6±1.2
	Right	25.6±1.6	24.8±1.6	33.0±0.7	32.8±0.9
	% Dif	-14.1	-18.7	4	3.9
Swing Phase,%	Left	25.8±1.5	24.8±1.6	32.9±0.6	32.8±0.8
	Right	29.8±1.9	30.5±2.0	31.6±0.8	31.5±1
	% Dif	15.8	23.1	-4	-3.7
Pre-Swing,%	Left	20.5±1.3	19.8±0.9	17.7±0.8	17.8±0.6
	Right	23.9±1.7	25.0±1.6	18.0±1.0	17.91.1
	% Dif	16.9	26.1	3	0.7

Table 6. Percent of gait spent in each phase. Data for subjects 1 and 2 shown pre- and post-treatment. Percent differences between the right and left feet calculated by the Noraxon Myopressure treadmill.

Discussion

Entrainment is more effective in subjects with severe gait dysfunction, especially in patients with stroke and Parkinson's disease. [11,29,30] Since subject 1 had a more recent injury than Subject 2, and reported more pain and limitation than Subject 2, his gait potentially was more responsive to the limbic entrainment treatment. Subject 1 overall showed more improvements in the examined parameters than Subject 2, as his gate seemed to become more symmetrical after the treatment. In addition to the second subject's ankle injury happening over a month prior to the testing, she had been receiving physical therapy after her injury. She reported no limitation of daily activity due to her ankle sprain, where the first subject reported a mild limitation to his daily activity due to his injury.

Force Data:

For Subject 1, a more normal vertical ground reaction force graph for both feet was measured post-test, with a greater heel strike force measured on the uninjured side post-test (Figure 2,3). This could be a marker of less compensation, as the healthy heel strike, unloading, and toe off portions of the force graph change with injury. Also, there was only a 3.79% difference after the treatment in the force of toe-off between the right and left feet, which is indicative of a more symmetrical gate (Figure2,3). Subject 2 had more similar vertical ground reaction force graphs pre- and post-treatment (Figures 3,4). This indicates that gait was more normal for Subject 2 than Subject 1, which is expected since Subject 2 reported less pain and limitation to daily activities.

Step Length:
Subject 1 had a substantial decrease in the percent difference between right and left leg stride lengths post-treatment (Figure 6). Step length is the distance measured between the toe of one foot and the toe of the other on each step. A smaller percentage of difference between the injured and uninjured side indicates a more symmetrical gate, which one of the desired outcomes of limbic entrainment. Subject 2 did not demonstrate a significant change in step length pre-post treatment. Subject 2 had a very small percentage difference between step length compared to Subject 1, as Subject 2's percent difference pre-test was 0.8% and Subject 1's was 43.2% (Table 2).

Cadence:
Normal values for cadence for a healthy adult are about 105-120 steps per minute.[24] The subjects self-selected their pace on the treadmill pre-test, and used the same speed for the pre- and post-test measurements. Cadence increased for Subject 1 from pre-treatment to post-treatment (Figure 7). Although Subject 1 had a lower than normal cadence post-treatment, the increase in cadence was substantial from the pre-test to the post-test. Subject 2 had an overall cadence that was closer to normal, since her pre-test cadence was 94±1 steps/min pre test, and 93±1 steps per minute post test. This is a healthier cadence overall than Subject 1's. Since Subject 2 had an injury that was less severe, she may not have benefited as much from the treatment since limbic entrainment is more effective in patients with more serious gait dysfunctions.[11]

Velocity:
Velocity did not change for either subject between the pre- and post-treatment measurements, but this is most likely due to the fact that the subjects were required to walk at the same speed on the treadmill during the post-treatment that they selected for their trial before the entrainment. The normal value for velocity for a healthy adult is 80 meters/minute, and Subject 2 had a velocity that was closer to this normal value than subject 1 (Table 4).

Single Support Line:
The single support line is how much weight is being put on each foot during walking. Both subjects showed a decrease in the percent difference in single support line between the injured and the uninjured side after the treatment (Figures 8,9, Table5). The percent difference in the single support line decreased from 66.3% to 46.5% after limbic entrainment for Subject 1, and decreased from 14% to 4.1% for Subject 2.
This is another parameter that is indicative of limbic entrainment normalizing gait by making gait more symmetrical in regards to weight bearing during ambulation. Since both subjects initially demonstrated favoring of their injured sides, the decrease in percent difference in single support line supports the hypothesis that gait symmetry is improved with limbic entrainment.

<u>Phase of Gait</u>:
Subject 2 had percentage values that are closer to the healthy values for the stance phase, loading response phase, swing phase, and pre-swing phase (Tables 1,6).[22] The percent difference between the right and left sides decreased slightly for Subject 2, while they slightly increased for each phase for Subject 1. As discussed previously, Subject 1 had a more recent ankle injury and seems to show more deviation from a healthy gait. It does not seem as though limbic entrainment had a substantial positive impact on percentage of time spent in each phase of gait for either subject. Phase of gait is not one of the main parameters that have shown improvement in other research.[11]

There are several limitations to this study. Subjects wore their shoes during the testing in an effect to mimic functional gait, however wearing shoes could have affected the Noraxon Myopressure treadmill's ability to measure certain parameters accurately. Treadmill walking has been shown to automatically improve gait, so the subjects could have performed better during the trials than they would have walking overground.[12, 13, 14] Another limitation is that only two subjects were measured in this study. One subject was male and one was female, and different ankles were injured between each subject. There was also a large discrepancy in the time since their injuries occurred, making it difficult to compare the two cases. Overall, this study is meant to pilot research into whether limbic entrainment could be a useful intervention for normalizing gait in individuals with ankle sprains, and identifies several gait parameters that could be affected through entrainment. Though there is a great discrepancy between Subject 1 and Subject 2's results, each subject was at a different place in the healing process. Future research could examine the different effects of entrainment directly following an injury, a few days after an injury, and several weeks after an injury. This study suggests there may be a difference in effects of limbic entrainment with varying time between injury and treatment.

Future research should also include long-term effects of limbic entrainment on normalizing gait. Other research has suggested that training over several weeks can be effective for normalizing gait in a clinical setting.[24] Also, looking further into muscle recruitment and gait kinematics could provide insight into the most effective parameters for limbic entrainment, as significant differences have been reported in motor recruitment patterns with entrainment.[11]

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