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Todd E. Davenport
University of the Pacific, tdavenport@pacific.edu

Stephen F. Reischl
University of Southern California

Somporn Sungkarat
Chiang Mai University

Jason Cozby
University of Southern Claifornia

Lisa Meyer
University of Southern California

See next page for additional authors

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Alteration in Corticospinal Excitability, Talocrural Joint Range of Motion, and Lower Extremity Function Following Manipulation in Non-disabled Individuals

Todd E. Davenport, PT, DPT, OCS[1]
Stephen F. Reischl, PT, DPT, OCS[2]
Somporn Sungkarat, PT, PhD[3]
Jason Cozby, PT, DPT, OCS[2]
Lisa Meyer, PT, DPT, OCS[4]
Beth E. Fisher, PT, PhD[5]

[1]*Assistant Professor, Thomas J. Long School of Pharmacy and Health Sciences, University of the Pacific, Stockton, CA*
[2]*Adjunct Associate Professor of Clinical Physical Therapy, Division of Biokinesiology and Physical Therapy at the Herman Ostrow School of Dentistry, University of Southern California, Los Angeles, CA*
[3]*Assistant Professor and Associate Dean for Research and International Affairs, Faculty of Associated Medical Sciences, Chiang Mai University, Chiang Mai, Thailand*
[4]*Adjunct Instructor of Clinical Physical Therapy, Division of Biokinesiology and Physical Therapy at the Herman Ostrow School of Dentistry, University of Southern California, Los Angeles, CA*
[5]*Associate Professor of Clinical Physical Therapy and Director of the Neuroplasticity and Imaging Laboratory, Division of Biokinesiology and Physical Therapy at the Herman Ostrow School of Dentistry, University of Southern California, Los Angeles, CA*

ABSTRACT

Background: Clinical outcomes of manual therapy procedures, including manipulation, have been studied. However, mechanisms underlying observed improvements remain unclear. **Objective:** To determine the effect of ankle joint manipulation on corticospinal excitability, ankle dorsiflexion range of motion (DF ROM), and lower extremity functional behavior in nondisabled individuals. **Method:** Six nondisabled individuals (age range: 31-50 years) received the main outcomes measurements of this study, before and after long axis distraction manipulation of the talocrural joint. Main outcomes measures were motor evoked potential (MEP) amplitude of gastrocnemius (GN) and tibialis anterior (TA) using transcranial magnetic stimulation, ankle DF ROM with the knee flexed and extended using standard goniometric techniques, and unilateral anterior squat reach (ASR) distance. All subjects received the main outcomes measures. **Results:** Significant increase in GN MEP amplitude ($P < .05$), but not TA MEP amplitude, were documented following intervention. Significant improvements also were noted in ankle DF ROM with knee extended and flexed ($P < .001$) and ASR distance ($P < .05$) Significant correlations were found between standardized change in GN MEP amplitude and ankle dorsiflexion with knee flexed ($\rho = .582$, $\rho^2 = .339$, $P < .01$), and standardized changes in GN MEP amplitude and ASR distance ($\rho = .601$, $\rho^2 = .361$, $P < .01$). **Conclusions:** Increased corticospinal excitability appears to mediate improvements in ankle DF ROM and lower extremity function following long axis distraction manipulation to the talocrural joint in nondisabled individuals. These results establish comparative values with which to compare the corticospinal responses to manual therapy intervention in individuals with pathology.

Key Words: ankle, manipulation, transcranial magnetic stimulation, functional testing

INTRODUCTION

Ankle sprains are the most common injury to the ankle joint, affecting up to 2 million people and approximately 53 per 10,000 individuals per year.[1,2] Ankle sprains are common in younger and active individuals.[3-8] Certain sports and work activities may result in an even higher incidence and risk for injury.[9-15] Ankle sprains are a clinically important problem because they result in a substantial number of missed work days[8] and participation in sports activity,[3,5] as well as lead to potential early arthritic changes in the talocrural joint.[16] The prognosis for functional recovery following ankle sprain typically includes a rapid clinical improvement within the first two weeks after injury.[17] However, a series of recent studies indicate a subgroup of individuals appears predisposed to continued pain, functional deficits, and prolonged risk for additional reinjury between 6 weeks and 3 years postinjury.[17-25] The prolonged disability associated with ankle sprains represents the possibility of increased direct and indirect health care costs associated with ankle sprains, and may be reduced through identification of optimal approaches to clinical management.

One reason for continued pain and elevated risk for reinjury may be limited ankle joint mobility, which may occur as either a cause or consequence of ankle sprain. Limited ankle dorsiflexion has been documented as a major short-term sequel to ankle sprain.[26,27] In addition, several studies have identified limited talocrural joint dorsiflexion range of motion (DF ROM) as an important predisposing factor to ankle sprains.[28-30] Limited ankle DF ROM will position the talocrural joint in plantar flexion during weight bearing activities. This position is notable because the most common mechanism of injury for ankle sprains involves plantar flexion and inversion of the ankle and foot. The injury mechanism places excessive load on the anterior talofibular ligament (ATFL). With failure of ATFL, secondary restraint to inversion occurs by way of the calcaneofibular and posterior talofibular ligaments, placing them at similar risk for injury. Thus, limited ankle DF ROM may result in injury and consequent structural and functional compromise of the ankle lateral collateral ligaments.

Physical therapists use mobilization and manipulation to improve ankle DF ROM following ankle sprains. Despite the intuitive appeal of applying these procedures to promote parallel improvements in talocrural DF ROM and functioning in individuals following ankle sprains, this notion has been the focus of relatively few prospective studies.[31] Pellow and Brantingham[32] were among the first to report reduced pain and improved function in individuals with ankle sprains receiving an ankle mortise distraction technique. Whitman and colleagues[33] reported rapid functional improvement after talocrural manipulation in a competitive volleyball player with a mild unilateral

ankle sprain. More recently, Whitman and coworkers[34] documented favorable clinical outcomes in approximately 75% of their sample with post-acute ankle sprains following two sessions of mobilization and manipulation directed at joints distal to the knee. Although initial results are promising, mechanisms underlying the clinical effects of manual therapy in individuals with ankle sprains remain unclear.

Through further study of the potential role for neuroplasticity to mediate the relationship between brain activity and behavior in people with ankle sprains, it may be possible to better understand those mechanisms that result in a symptomatic and behavioral benefit. Various central and spinal sensorimotor mechanisms of manual therapy procedures recently have been investigated. Inhibition of the Hoffman reflex following spinal manipulation and increased lower extremity muscle strength have been observed following manual therapy directed to the lumbopelvic.[35-39] Manual therapy procedures may facilitate descending inhibitory inputs to local spinal circuits that cause the observed H-reflex depression, suggesting a broader effect on the central nervous system (CNS).[40] Dishman and colleagues[41] identified a short-term increase in motor evoked potential (MEP) amplitude for the lumbar paraspinals in healthy volunteers following manipulation of the lumbar spine, using single-pulse transcranial magnetic stimulation (TMS) directed to contralateral motor cortex. Haavik-Taylor and Murphy[42] also documented a significant muscle-specific pattern of effects following cervical spine manipulation on short interval intracortical facilitation, short interval intracortical inhibition, and cortical silent period of abductor pollicis brevis and extensor indicis without significant change in F wave in asymptomatic individuals with a history of recurrent neck pain. These results suggest a potentially broad effect of manual therapy on the neuromotor processing of functional behavior by the CNS.

Our collective understanding of the role for neuroplasticity to explain short-term symptomatic and behavioral changes in response to ankle manipulation is hampered by shortcomings in the current literature. For example, the study of manual therapy directed to the spine potentially jeopardizes the specificity of conclusions that can be drawn, since spinal manipulation is poorly localized even in skilled and experienced practitioners.[43] In addition, no correlation has been made between neuromotor changes and potential alteration in functional behavior using valid and reliable measurements. The purpose of this pilot study was to determine the effect of talocrural manipulation on gastrocnemius and tibialis anterior MEP, ankle DF ROM, and unilateral anterior squat reach (ASR) distance in nondisabled individuals.

METHOD

Subjects

Participants

Six nondisabled individuals (2 females, 4 males) ranging in age from 30-51 years participated in this study. Subjects were excluded if they experienced a lower extremity injury in the past 12 months, a history of lower extremity or low back surgery, lower extremity neuropathy, vestibular dysfunction, diabetes or active arthritis, or if there were any contraindications to undergoing talocrural joint manipulation (ie, gross mechanical instability, history of connective tissue disease). Based on the TMS safety guidelines,[44] other exclusion criteria include neurological disorders; psychological problems; history of significant head trauma; any electrical, magnetic, or metal device implanted in the body (ie, cardiac pacemakers or intracerebral vascular clip); pregnancy; history of seizures or unexplained loss of consciousness; immediate family member with epilepsy; use of seizure threshold lowering medication; current use of alcohol or drugs; history of schizophrenia; or history of hallucinations.

Procedure

The Institutional Review Board of the University of Southern California Health Sciences Campus approved the study protocol. The protocol is described in detail elsewhere.[45] The following paragraphs include a brief description of the protocol. After an intake screening interview and informed consent was obtained, all subjects then received preintervention measurements, intervention, and postintervention measurements. Pre- and postintervention measurements included corticospinal excitability, ankle DF ROM, and anterior reaching distance achieved during a single leg squat (ASR distance). The right lower extremity was tested in all subjects. After postintervention testing, all subjects were discharged from the study. Completion of all study took up to two hours per subject during one day.

Transcranial magnetic stimulation measurement

All the TMS assessments were carried out with a single-pulse magnetic stimulator (Magstim 200^2). A Double Cone 110 mm coil was used to generate the TMS pulse. This pulse provides stimuli of sufficient depth of penetration to activate the cortical representational areas of lower extremity muscles. The skin over the designated muscles of the right lower extremity was prepared with cleansing gel and alcohol to decrease impedance for applying surface electromyography (EMG) electrodes. Surface EMG electrodes (Ag-AgCl, 12 mm diameter, interelectrode distance: 17 mm) were attached over the muscle belly of TA and GN, and the ground electrodes were placed over the medial and lateral femoral epicondyle, respectively for each muscle. The electrodes remained in place between the two TMS test sessions. The EMG signals were filtered with 1-1000 Hz bandwidth filter, amplified, and digitized at 2000 Hz. The data were displayed and stored with customized MATLAB module (dwaq; dataWizard acquisition, ADW) in 600-ms samples beginning 100 ms before TMS stimulus.

To determine the optimal TMS stimulus point ("hotspot"), the participants were required to wear a swim cap with 1 cm × 1 cm grid. The coil was initially placed on a potential spot for the target muscle, and then systematically moved in 1 cm increments in each direction to find the point that induced the most consistent and prominent motor evoked potentials (MEPs) with the shortest latency.[46] To control TMS coil positioning variability, a stereotactic image guidance system (Brainsight™ Frameless) was used. The hotspot of each muscle was marked on a 3D reconstruction of a standard magnetic resonance image of the brain in the first test session, and the same point of stimulation was used for the postintervention test session. For TMS data collection, pulses were delivered as participants actively contracted TA and GN by performing ankle dorsiflexion and plantar flexion, respectively, through a small, consistent amount of range. Ten TMS pulses at 100% of MT were delivered with an inter-stimulus interval of approximately 5 to 10 seconds, also during closed chain active ankle plantar flexion (ie, "seated heel raise") to mid-range.

Ankle dorsiflexion range of motion measurement

Following the TMS hotspot location and MT measurement, all subjects received

ankle DF ROM measurements. In the first measurement, subjects laid prone on a padded table. A single blinded and standardized examiner measured ankle DF ROM with the knee fully extended using a 15.24 cm goniometer in a standard manner.[47] The measurement was repeated with the knee fully flexed. This measurement of ankle DF ROM demonstrates strong test-retest reliability with knee both flexed (ICC = .97) and extended (ICC = .98).[47]

Anterior squat reach test

Following the ankle DF ROM measurement, all subjects completed the ASR measurement. This test is a component of the star balance excursion test, which has been described as a clinical test of dynamic balance.[48] Subjects assumed unilateral stance on the right lower extremity in the center of a grid marked circumferentially in 45° increments. Subjects then assumed a single leg squat and reached with the left lower extremity, tapping the heel on the ground anterior to the stance limb as far as possible. After a brief learning period consisting of 6 trials,[49] subjects completed 3 repetitions of ASR standing on the right lower extremity. Repetitions were excluded if the subject (1) was unable to maintain weight bearing during the trial, (2) lifted the stance foot, (3) lost balance, or (4) did not maintain the hold or start positions for one second. The mean of the 3 trials was taken as the ASR measurement. This test demonstrates good test-retest reliability (ICC = .67-.97).[48,50]

Intervention

With the subject in a seated position on a treatment table and the lower extremity of interest stabilized to the table with a belt, a standardized licensed physical therapist grasped the foot of interest with the thenar eminences on the plantar surface of the subject's foot. A thrust was delivered parallel to the long axis of the subject's lower leg after the treating therapist induced passive ankle dorsiflexion to end range (Figure).[45,51]

Data Analysis

Transcranial magnetic stimulation data were analyzed off-line with a customized MATLAB (Mathworks, Natick, MA) software, dataWizard (version 08.11, A.D.W., USC) by the same rater.[52] The average of 10 trials for each stimulus intensity was calculated and used for data analysis. Percent change in GN MEP, TA MEP, ankle DF ROM, and ASR test performance were calculated according to the formula: *(postintervention value – preintervention value)/ preintervention value x 100.* These calculations were completed in order to standardize the data to the starting value for each subject.

Distribution of the data was then summarized by visual inspection of histograms and the Shapiro Wilk test of data normality. Nonparametric statistical tests were used for analysis, because the data was non-normally distributed. For analysis of unstandardized measurements, the Wilcoxon signed-rank test was used to assess the significance of pairwise between-group median differences, and the Kruskal-Wallis test was used for comparison of group medians among multiple independent variables. Spearman's rho (ρ) and explained variance (ρ^2) were calculated for bivariate correlations among standardized changes in MEP amplitude, ankle DF ROM, and ASR performance. Strength of the association among the variables was interpreted using Munro's[53] criteria: very low = .15-.24, low = .25-.49, moderate = .50-.69, high = .70-.89, and very high = .90-1.00.

RESULTS

No significant differences were observed in median MEP amplitude for GN or TA across the 4 TMS intensities, so MEP data was pooled for analysis. Following intervention, median GN MEP increased 23.8% from .504μV (interquartile range [IQR]: .488) to .624μV (IQR: .375; Table). Median ankle DF ROM with knee extended increased 130.8% from -6.5° (IQR: 7.0) to 2.0° (IQR: 4.5) and median ankle DF ROM with knee flexed increased from 5.0° (IQR: 9.0) to 14.0° (IQR: 6.3) following intervention. Median ASR distance also increased 7.2% from 32.1 cm (IQR: 7.4) to 34.4 cm (IQR: 4.8). No significant change in TA MEP was noted after intervention. Percent change in GN MEP amplitude demonstrated significant moderate correlations with percent change in ankle DF ROM with knee flexed (ρ = .582, ρ^2 = .339, P < .01) and ASR distance (ρ = .601, ρ^2 = .361, P < .01), and percent change in ankle DF ROM with knee flexed showed significant high correlation with percent change in ASR distance (ρ = .700, ρ^2 = .490, P = .001).

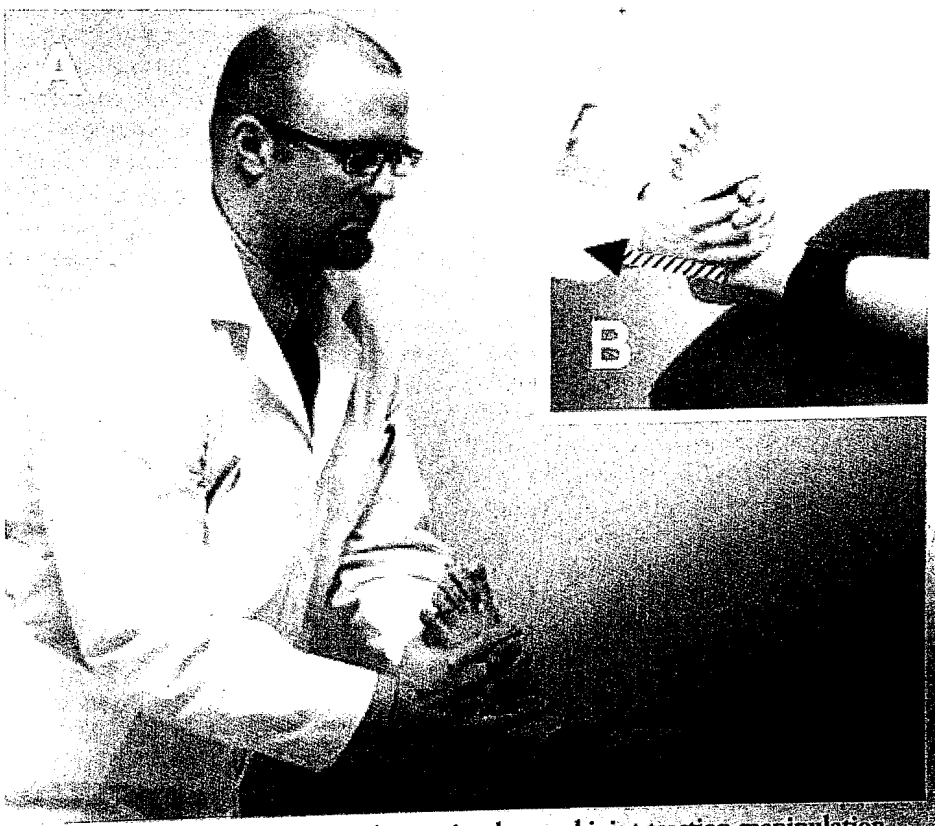

Figure. Intervention under study: long axis talocrural joint traction manipulation. (A) With the subject in a seated position on a treatment table and the lower extremity stabilized to the table with a belt, the treating investigator grasped the foot of interest with the thenar eminences on the foot's plantar surface. (B) After inducing passive ankle dorsiflexion (open arrow), a thrust was then delivered parallel to the long axis of the subject's lower leg (hatched arrow).

Table. Effect of Talocrural Joint Manipulation on MEP Amplitude, Ankle DF ROM, and ASR Measurements

	Preintervention measurement*	Postintervention measurement	Percent change change	*P*-value
GN MEP (μV)	.504 (.488)	.624 (.375)	23.8%	.037†
TA MEP (μV)	.771 (1.05)	.767 (1.04)	-0.5%	.695
Ankle DF ROM, knee extended (°)	-6.5 (7.0)	2.0 (4.5)	130.8%	<.001§
Ankle DF ROM, knee flexed (°)	5.0 (9.0)	14.0 (6.3)	180.0%	<.001§
ASR distance (cm)	32.1 (24.7 – 39.5)	34.4 (29.6 – 39.2)	7.2%	.047†

* - Values expressed as median (interquartile range)
† - Statistically significant, $P < .05$
§ - Statistically significant, $P < .001$

Abbreviations: GN, gastrocnemius; TA, tibialis anterior; MEP, motor evoked potential; DF ROM, dorsiflexion range of motion; ASR, anterior squat reach

DISCUSSION

The talocrural joint long-axis traction manipulation has been described as a procedure to improve ankle DF ROM following ankle sprain.[32,33,45,51] This study documented the effect of talocrural joint long-axis traction manipulation on corticospinal excitability and lower extremity functional behavior in nondisabled individuals. To date, the literature regarding neuromotor effects of manual therapy has involved procedures directed to the spine.[41,42] However, spinal manipulation is poorly localized even in the hands of skilled and experienced practitioners.[43] Thus, the emphasis on spinal manual therapy procedures in research designs of studies to date potentially inhibits the specificity of conclusions that can be drawn from these studies about the effect of manual treatment procedures.

This study provides support for using the talocrural joint to study the neuromotor effects of manipulation in individuals with lower extremity pathology. The talocrural joint is a promising body region to elucidate the potential neuromotor effects of manual therapy for a number of reasons.[45] The talocrural joint is relatively large, so intervention may be more specifically localized to the talocrural joint than smaller joints of the spine. Muscle groups crossing the talocrural joint are relatively large, which provide for reliable placement of EMG electrodes with minimal cross-talk. Valid and reliable behavioral measurements for talocrural joint range of motion and lower extremity functional behavior already exist, making possible empirical examination of the relationship between short-term CNS neuroplasticity and the changes in functional behavior that have been elucidated by clinical studies.

In this study, GN MEP amplitude was observed to increase significantly following talocrural long-axis traction manipulation, which indicates increased corticospinal tract excitability involving this muscle group. Treatment effects seem unique to GN, because significant increases in TA MEP amplitude were not observed. Studies to date using TMS methodology to determine the effect of manual therapy procedures on corticospinal excitability have not measured the effect of intervention on opposing muscle groups. Thus, the discrepant effect of manipulation on antagonist muscle groups observed in this study represents a new finding in the literature that requires additional replication in studies of the spine and upper extremity. This finding also indicates the need to assess the potential for differential effects of treatment on antagonist muscle groups in the ankles of individuals with symptoms.

In addition to significant increase of GN MEP amplitude, parallel significant improvements in ankle DF ROM and ASR distance were observed following long-axis traction talocrural joint manipulation. These findings confirm observations from prior studies and clinical experience with manual therapy of relatively rapid improvement in symptoms and ankle DF ROM following manipulation. Collins and colleagues[54] found an increase in ankle DF ROM in response to manual therapy without corresponding change in pressure or thermal pain thresholds. A follow-up study by this group found a significant association between improvement in a clinical measure of talocrural posterior glide and improvement in talocrural DF ROM.[55] Overall these findings suggest a primarily mechanical effect of treatment. However, the magnitude, time, and speed of loading that characterize manipulation seem inadequate to reverse maladaptive fibrosis that has been hypothesized to result in arthrokinematic and osteokinematic ankle mobility limitations following sprains.[49,56] Significant moderate to high correlations between changes in GN MEP amplitude, ankle DF ROM, and ASR distance that were identified in this study suggest the potential mechanistic importance of short-term neuromotor adaptation to promote improvements in ankle DF ROM and lower extremity functional behavior. Additional work is necessary to elucidate the nature and time course of these neuromotor changes in individuals with lower extremity disablement.

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