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Effects of Bimodal Transcranial Direct Current Stimulation on Modulation of Spinal Circuitry in People with Chronic Post-Stroke Hemiparesis

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EFFECTS OF BIMODAL TRANSCRANIAL DIRECT CURRENT STIMULATION ON MODULATION OF SPINAL CIRCUITRY IN PEOPLE WITH CHRONIC POST-STROKE HEMIPARESIS

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is approved in partial fulfillment of the requirements for the degree of

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Abstract

Background: Stroke can lead to gait abnormalities such as foot drop. Foot drop can result from decreased corticospinal tract input to the ankle dorsiflexors and/or from exaggerated stretch reflexes on the soleus due to reduced reciprocal inhibition from spinal reflex pathways. Transcranial direct current stimulation (tDCS) attempts to modulate corticospinal tract input and spinal reflex pathways by delivering electrical signals to parts of the brain. The degree of neuromodulation from tDCS can be measured through the Hoffman Reflex (H-reflex)—a tool used to estimate alpha motor neuron excitability which is increased in individuals post-stroke.

Purpose: The primary purpose of this study was to examine the acute effects of a session of bimodal tDCS combined with upslope treadmill walking on the H-reflex amplitude on people with chronic post-stroke hemiparesis. The secondary purpose of this study was to determine if reduced H-reflex excitability contributes to improved gait and balance function.

Methods: Six individuals with chronic post-stroke hemiparesis received two randomly assigned treatment sessions. Each session included upslope treadmill walking paired with either bimodal or sham tDCS. Soleus H-reflex amplitude (H-max/M-max ratio), gait metrics, the Berg Balance Scale (BBS), and the Timed Up and Go (TUG) Test were collected pre- and post-treatment sessions. A 2 x 2 repeated measures ANOVA was used to analyze data.

Results: No statistically significant differences in H-reflex amplitude were observed between bimodal tDCS and sham groups. A statistically significant increase in paretic limb stride length was observed following stimulation. In addition, participants in the bimodal tDCS group had a higher BBS score after stimulation compared to the sham group. There were no differences between groups for the other dependent variables.

Discussion: Further research on a larger sample size of this patient population is warranted on bimodal tDCS' ability to regulate H-reflex excitability and improve function.

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Introduction

Stroke is one of the leading causes of acquired disability among adults in the western world (Gomez Palacio Schjetnan, Faraji, Metz, Tatsuno, & Luczak, 2013). Individuals post-stroke may develop significant motor impairments involving neuromuscular control, movement, and mobility (Langhorne, Coupar, & Pollock, 2009). These impairments may be associated with gait deficits in patients with post-stroke hemiparesis (Hsu, Tang, & Jan, 2003).

One of the biggest risks in patients with chronic stroke symptoms is the risk of falling due to poor locomotor control (Weerdesteyn, de Niet,van Duijnhoven, & Geurts, 2008). This risk is evident in post-stroke stages due to chronic gait deficits that include poor ability to maintain momentum and inappropriate foot force control, particularly with the paretic foot (Chen et al., 2003). Individuals may demonstrate decreased hip flexion, knee extension, and ankle plantar flexion angles during the push-off phase (late stance) as well as reduced electromyography (EMG) activity in the gastrocnemius and soleus which collectively contribute to the lack of propulsive forces needed for gait progression (Weerdesteyn et al., 2008). Additionally, the paretic limb exhibits decreased ankle dorsiflexion and knee flexion angles during swing phase (Weerdesteyn et al., 2008). Dorsiflexion angles are decreased due to the premature activation of the gastrocnemius and soleus and subsequent inability to selectively activate the tibialis anterior (Weerdesteyn et al., 2008). As such, patients with stroke can manifest slower walking speeds with insufficient foot clearance, placing them at a high risk for trip related falls (Weerdesteyn et al., 2008).

Stroke lesions in one cerebral hemisphere can result in an imbalance in cortical excitability (Makela et al., 2015). Functional magnetic resonance imaging (fMRI) studies have shown that there are decreases in ipsilesional primary motor cortex (M1) and corticospinal tract (CST) activity along with increases in contralesional M1 and CST activity following a stroke

(Lefaucheur et al., 2017). There is an initial decrease in ipsilesional CST excitability post-stroke, which results in increased excitability of the contralesional CST due to a decrease in interhemispheric inhibition traveling from the ipsilesional M1 to the contralesional M1 (Lefaucheur et al., 2017). Further decrease of ipsilesional CST activity is then driven by an increase in interhemispheric inhibition traveling from the contralesional M1 to the ipsilesional M1 (Lefaucheur et al., 2017). Deficits in CST activity have been associated with numerous muscles involved in gait abnormalities in patients post-stroke. Foot drop results from decreased CST input to the ankle dorsiflexors, leading to hyperactivity in the plantar flexor muscles (Thompson, Estabrooks, Chong, & Stein, 2009). Foot drop can also result from exaggerated stretch reflexes that develop following central nervous system (CNS) lesions (Thompson et al., 2009). Spinal reflex pathways ensure that antagonist muscles remain inhibited when agonist muscles are active (Nielsen, Crone, & Hultborn, 2007). Those with CNS lesions, however, have reduced reciprocal inhibition, leading to hyperreflexia, spasticity, and clonus (Nielsen et al., 2007).

The Hoffman Reflex (H-Reflex) is valuable for assessing the response of the nervous system to various neurologic conditions such as stroke (Palmieri, Ingersoll, & Hoffman, 2004). This reflex estimates the excitability of an alpha motor neuron by measuring the effectiveness of synaptic transmission as electrical stimulation travels through a Ia sensory fiber to its respective efferent motor fibers. This electrically induced H-reflex is comparable to the mechanically induced spinal stretch reflex. A twitch response from the efferent portion of the H-reflex pathway is measured through electromyography (EMG). Electrically stimulating a peripheral nerve to measure the H-reflex also causes activation of efferent fibers which results in an EMG recorded muscle response known as the M-wave (Palmieri et al., 2004). The maximum H-reflex amplitude is termed Hmax and is a measure of maximal reflex activation; the maximum M-wave amplitude is termed Mmax and is a measure of maximal muscle activation (Palmieri et al., 2004). Hmax is usually increased in a spastic lower limb while Mmax is unaffected (Matthews, 1966). Evidence shows that patients with CNS lesions display significantly higher Hmax/Mmax ratios in the soleus (Thompson et al., 2009). There is little or no modulation of the soleus H-reflex due to reduced presynaptic inhibition in patients with spasticity, thus causing hyperactivity in the plantar reflex (Thompson et al., 2009). Foot drop is the result of these mechanisms. Furthermore, while non-impaired individuals show attenuation of reflex amplitude following cycling and walking, indicative of activity-dependent spinal cord plasticity, it appears to be impaired in people post-stroke (Sabatier et al., 2015).

In healthy individuals, the soleus H-reflex amplitude is lower during gait than during standing. Additionally, the H-reflex is modulated throughout each step cycle during gait, progressively increasing throughout the stance phase and being inhibited during the swing phase (Lamontagne et al., 2017). This modulation is impaired in patients with stroke. Phase dependent modulation may be masked by the inability to down-regulate reflexes during locomotor tasks (Fund & Barbeau, 1994). Moreover, active pedaling in patients with stroke leads to decreases in spinal excitability, as measured with the Hmax/Mmax ratio, for more than 30 minutes after exercise (Tanuma et al., 2017). This is thought to be the result of the repetitive stretch and shortening of the soleus muscle during pedaling, which causes repetitive activation of muscle spindles. Cyclical and repetitive training can increase presynaptic inhibition of soleus Ia afferents (Tanuma et al., 2017).

A study comparing H-reflex pathway adaptations following walking on different slopes between non-impaired and stroke-impaired individuals demonstrated that soleus H-reflex amplitudes are decreased following 20 minutes of level, downslope, and upslope walking in non-impaired individuals with H-reflex amplitudes increasing in individuals with chronic post-stroke hemiparesis (Liang et al., 2019). This finding is consistent with previous research showcasing that there is increased presynaptic inhibition of soleus Ia afferents through decreased H-reflex amplitude after level and downslope walking in non-impaired individuals (Sabatier et al., 2015). While higher mean Hmax/Mmax ratios were observed in the paretic legs compared to the non-impaired after walking under different conditions, the difference was not statistically significant (Liang et al., 2019). This increased ratio and increased excitability of the Ia afferent was attributed to decreased propulsion forces in paretic limbs related to decreased walking speeds as well as general variability in the type and site of cortical lesions (Liang et al., 2019).

Non-conventional strategies, such as Transcranial Direct Current Stimulation (tDCS), attempt to facilitate motor recovery through neuroplastic changes in the brain caused by cortical stimulation (Lefaucheur et al., 2017). tDCS can be performed with the anode placed over the lesioned hemisphere to promote excitation, or with the cathode placed over the non-lesioned hemisphere to promote inhibition. Bimodal tDCS involves simultaneous excitation of the ipsilesional hemisphere and inhibition of the contralesional hemisphere. There is promising evidence that bimodal tDCS can lead to improvement in upper extremity motor function when combined with physical and occupational therapy (Lindenberg, 2010; Lindenberg, 2012) or constraint-induced movement therapy (Bolognini et al., 2011) in chronic stroke populations. Current research on bimodal tDCS on the lower extremity is more limited. However, a recent study has shown that bimodal tDCS can improve function in the lower extremity when compared to anodal or cathodal tDCS alone (Andrade et al., 2017). Additionally, evidence suggests bimodal tDCS can improve lower extremity function when measuring gait and standing balance (Awosika & Cohen, 2019). Evidence also suggests that using the EEG 10/20 system to guide electrode placement over the cortex has been a successful method of targeting cortical excitation to the lower extremities (Kaski, Quadir, Patel, Yousif, & Bronstein, 2012).

The primary purpose of this study was to examine the acute effects of single session bimodal tDCS combined with upslope treadmill walking on excitability of the IA afferent-motor neuron pathway, assessed using the H-reflex amplitude. We hypothesized that following bimodal tDCS with upslope walking, we would see reduced H-reflex excitability, indicative of neuroadaptation but not following sham stimulation. We also hypothesized that bimodal tDCS with upslope walking would improve gait and balance characteristics as measured by changes in gait metrics and Berg Balance Scale scores, respectively.

Methods

Participants

Six participants with chronic post-stroke hemiparesis were recruited with the following inclusion and exclusion criteria: no family history of epilepsy, no history of seizures, no metal implants or pacemakers, at least 6 months post-stroke, cortical or subcortical stroke lesion not involving the cerebellum, no previous injury to the central nervous system other than the stroke, and no peripheral nerve injury in the lower extremities, and ability to ambulate without an assistive device. Each participant received written and verbal information about the experimental procedures and was given the opportunity to sign a written, informed consent provided by a member of the research group.

Procedures

The participants received two randomly assigned treatment sessions at least seven days apart (Thair, Holloway, Newport, & Smith, 2017). The first session included a Fugl-Meyer assessment in order to determine disease severity and functional level (Fugl-Meyer et al., 1975). Each session included 20 minutes of treadmill walking at a self-selected speed at a 5% incline paired with either bimodal or sham tDCS. H-reflex excitability as measured by the Hmax/Mmax ratio, gait metrics assessed on the Zenomat, Timed Up and Go Test (TUG), and the Berg Balance Scale (BBS) were measured at each session.

Bimodal and sham tDCS

A random assignment generation tool was used to determine whether the participant received bimodal tDCS or sham tDCS for the first session, which led to the participant receiving the opposite treatment intervention for the subsequent session. For example, a participant having bimodal tDCS for the first session was then automatically assigned to have sham tDCS for the second session. Application of bimodal tDCS involves anodal stimulation of the ipsilesional hemisphere and cathodal stimulation of the contralesional hemisphere. Saline-soaked electrodes (5 x 5cm) were placed bilaterally over the motor areas representing the lower extremity. The EEG 10/20 system was used for guiding electrode placement over the cortex.

Application of bimodal tDCS followed precedent from bimodal tDCS studies: A neuroConn DC-STIMULATOR PLUS constant current electrical stimulator was used to deliver a direct current through saline soaked surface sponge electrodes. Stimulation intensity was set to 2 mA for 20 minutes with a 10s fade-in and 10s fade-out phases for patient comfort. An additional 5-minute application of bimodal tDCS before treadmill training was utilized to account for any troubleshooting issues involving the device, thus resulting in a total of 25 minutes of bimodal tDCS stimulation. For sham tDCS we followed a similar application of electrodes and stimulation; however, the current was only applied for 30s with a 10s fade-in and fade-out phase to emulate the tingling sensation felt in bimodal tDCS (Di Lazzaro et al., 2014).

SOL H-Reflex Elicitation and Electromyography (EMG) Recordings

Spinal cord circuitry changes were measured by differences in the activity of the H-reflex amplitude on the paretic soleus before and after 20 minutes of upslope treadmill walking in both control and treatment sessions. The method used in this study emulated the protocol used in previous studies by involving gradual electrical stimulation of the tibial nerve (Akazawa, Aldridge, Steeves, & Stein, 1982). Electromyography was used to detect changes in soleus activity after tibial nerve stimulation (Akazawa et al., 1982). To elicit soleus H-reflexes and M-waves, bipolar self-adhesive electrodes (2.2 x 2.2 cm for the cathode and 2.2 x 3.5 cm for the anode, VerMed, INC.,Bellows Falls, VT, United States) were placed over the popliteal fossa to stimulate the tibial nerve using a constant current stimulator and isolation unit (DS7A, Digitimer Ltd., Welwyn Garden City, United Kingdom), with a square pulse stimuli of 1 ms duration, a current range of 50 milliamps~200 mA, and total output capability of 400V (Liang et al., 2019). Stimulating electrodes were placed in a location where the H-reflex threshold is minimized and stimulation of other nerves avoided (Liang et al., 2019). To avoid variability in electrode placement between sessions, the electrode positions were outlined using temporary tattoo ink and a picture was taken to document electrode positions in relation to bony landmarks, moles, or scars on the skin. The same researcher placed the electrodes on each participant for each session. H-reflexes and M-waves were recorded while the participant maintained neutral weight-bearing while standing within the range of soleus EMG background activity. A recruitment curve was generated by gradually increasing the stimulation intensity until maximal soleus H-reflex and maximal M-waves were obtained.

Gait Metrics and Timed Up and Go test

The Timed Up and Go (TUG) test is a measure of mobility and was also used to assess gait speed both pre and post tDCS stimulation. The participants begin the test seated in a standard chair and stand upon the researcher's command; the patient will walk 3 meters, turn around, and sit back into the chair. The researcher began timing using a stopwatch when the patient initiated movement and stopped timing when the participant sat back into the chair. This test was performed on a Zeno Platinum Walkway (Zenomat), which gathers data on the gait parameters of the participant. This data was processed by PKMas version508c2 and the following metrics were processed: step length, absolute step length, stride length, step time, stride time, swing time, stride velocity, cadence, direction of progression, and TUG time.

Berg Balance Scale

The Berg Balance Scale (BBS) is a 14-item test performed in clinical settings to assess functional balance. The participants were asked to perform 14 functional tasks such as static standing balance, sit-to-stands, and functional reach both pre and post tDCS stimulation. Each task is graded on a 5-point ordinal scale from “0-4” with “0” indicating the lowest level of function and “4” as the highest level of function. The highest score possible is 56 with a difference of 8 points between administrations signifying a significant improvement in function (Steffen, Hacker, & Mollinger, 2002). Tools required for administration of this measure include a yardstick, 2 chairs (1 with an armrest and 1 without), footstool, a stopwatch, and a 15-m walkway.

Outcome Measures

The dependent variables in this study include H-reflex excitability as measured by the Hmax/Mmax ratio, gait metrics assessed on the Zenomat, Timed Up and Go Test (TUG), and the Berg Balance Scale (BBS). The following gait metrics obtained from the Zenomat include: paretic (P) and non-paretic (NP) step length, stride length, stride width, step time, stride time, and stride velocity. In addition, overall velocity, ambulation time, and cadence were measured.

Statistical Analysis

To determine if bimodal tDCS paired with upslope walking would reduce H-reflex excitability and improve gait and balance function in patients with post-stroke hemiparesis, a 2 (stimulation: bimodal, sham) x 2 (time: pre, post) repeated measures ANOVA was performed for each gait variable including paretic (P) vs non-paretic (NP) step length, stride length, stride width, step time, stride time, stride velocity, velocity, ambulation time, and cadence. The same 2x2 repeated measures ANOVA was performed for TUG scores and Hmax/Mmax ratio.

Results

Subject Participation

All participants (n=6) were included for gait variables. For the H-reflex data (n=3). 3 participants were excluded from the analysis; 1 did not have a valid recruitment curve and should have been excluded from this study during screening and 2 other participants had inconsistent recordings, and thus were not comparable.

Characteristics of Participants

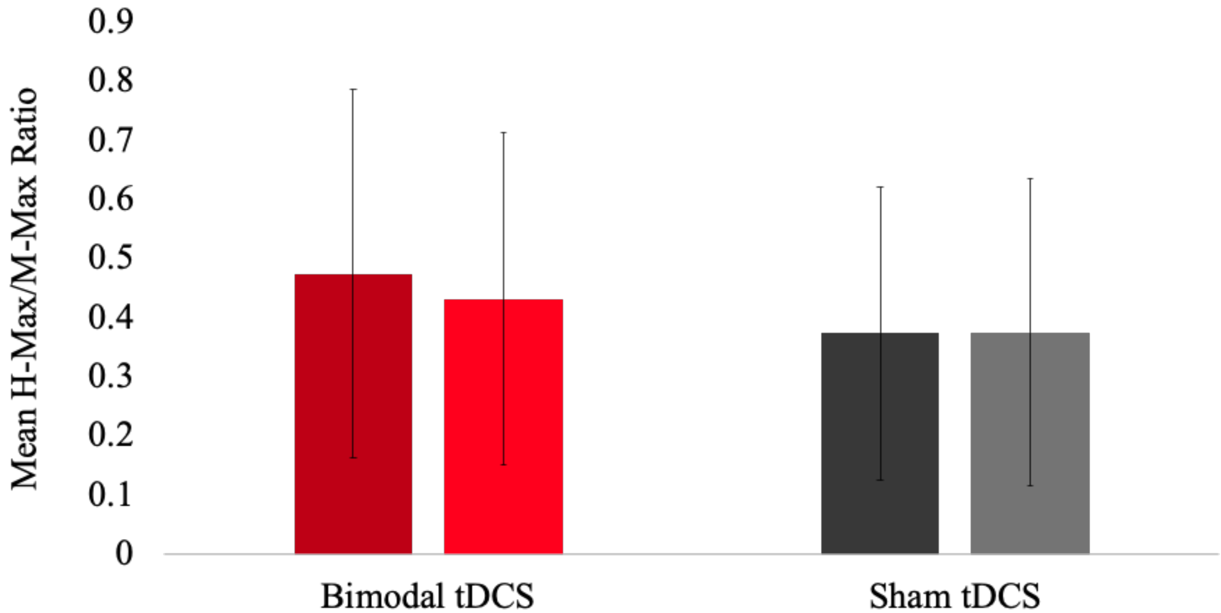
Table 1. Characteristics of Participants

Participant	Age (years)	Sex	Time since stroke (years)	Paretic side	LE Fugl-Meyer score (/34)	Overground Walking Speed (m/s)
1	55.11	F	6.07	R	34	0.44
2	49.12	M	4.54	R	26	0.89
3	69.10	M	9.55	R	17	0.18
4	67.81	M	8.06	R	21	0.76
5	70.10	M	3.00	R	21	0.89
6	57.10	M	6.67	L	29	0.49

Legend
Abbreviations: M = Male, F = Female, R = Right, L = Left
(Mean ± SD)
Age= 61.38 ±8.76 years
Time since stroke= 6.32±2.36 years
Fugl-Meyer score= 24.67±6.22
Walking Speed=0.61±0.31 m/s

For the H-max/M-max ratios, the two-way ANOVA revealed no significant interaction between stimulation and time ($F(1, 2)=2.374$, $p=0.263$). Furthermore, no significant differences were found for the main effects of stimulation ($F(1,2)=5.851$, $p=0.137$) and time ($F(1,2)=6.910$, p=0.119) (**Figure 1**). Participants 3, 4, and 6 were not included due to invalid recordings as a result of procedural error.

Figure 1. Comparison of H-Max/M-Max
n = 3



Gait Metrics

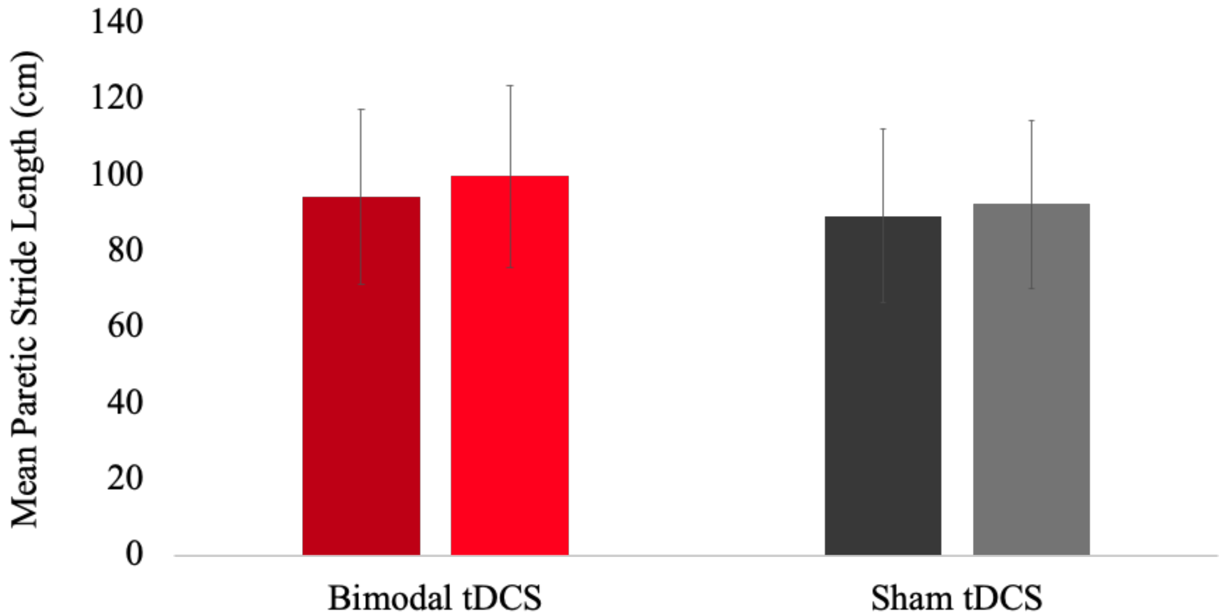
For each of the following variables of gait metrics: P and NP step length, NP stride length, P and NP stride width, P and NP step time, P and NP stride time, P and NP stride velocity, velocity, ambulation time, and cadence, no significant interaction between stimulation and time was observed. No significant differences were found for the main effects of stimulation and main effects of time **(Table 2)**.

Table 2. Mean Values and Standard Deviations of Gait *Denotes Significant Value		
Gait Metric and Stimulation Type	Mean Value (pre, post)	Standard Deviation (pre, post)
P step length - Bimodal	47.217, 49.755	14.280, 16.228
P step length - Sham	47.547, 47.537	15.137, 15.610
NP step length - Bimodal	48.266, 48.839	6.54, 8.194
NP step length - Sham	48.687, 47.819	6.948, 5.434
P stride length - Bimodal	* 94.399, 99.711	23.054, 23.908
P stride length - Sham	*89.295, 92.299	22.882, 22.155
NP stride length - Bimodal	98.261, 100.831	20.667, 19.596
NP stride length - Sham	94.562, 95.467	14.245, 14.333
P stride width - Bimodal	15.236, 13.142	11.291, 13.191
P stride width - Sham	15.334, 13.417	10.454, 11.364
NP stride width - Bimodal	19.718, 19.440	7.872, 8.156
NP stride width - Sham	19.459, 18.494	4.370, 4.121
P step time - Bimodal	0.651, 0.635	0.114, 0.091
P step time - Sham	0.696, 0.680	0.148, 0.085

NP step time - Bimodal	0.541, 0.552	0.057, 0.074
NP step time - Sham	0.605, 0.571	0.113, 0.053
P stride time - Bimodal	1.167, 1.111	0.074, 0.059
P stride time - Sham	1.165, 1.156	0.129, 0.089
NP stride time - Bimodal	1.168, 1.186	0.121, 0.130
NP stride time - Sham	1.306, 1.256	0.286, 0.053
P stride velocity - Bimodal	82.108, 89.530	21.197, 20.640
P stride velocity - Sham	91.754, 82.463	18.690, 11.028
NP stride velocity - Bimodal	90.105, 87.271	11.744, 22.171
NP stride velocity - Sham	77.846, 80.005	19.788, 4.914
Velocity - Bimodal	82.210, 87.520	21.607, 22.447
Velocity - Sham	76.478. 76.757	19.607, 14.033
Ambulation Time - Bimodal	9.160, 8.846	4.361, 4.616
Ambulation Time - Sham	9.960, 9.333	5.182, 3.008
Cadence - Bimodal	102.981, 104.344	8.449, 7.339
Cadence - Sham	99.807, 97.566	16.056, 6.127

For paretic stride length, there was a statistically significant main effect of time ($F(1,5)=21.542$, $p=0.006$), where an increase in stride length on the paretic limb was observed following the application of bimodal tDCS (Pre=94.399±23.053, Post=99.711±23.908), regardless of stimulation type. There was no significant main effect of stimulation ($F(1,5)=0.533$, $p=0.498$). This is seen in **Figure 2.**

Figure 2. Paretic Stride Length
n = 6

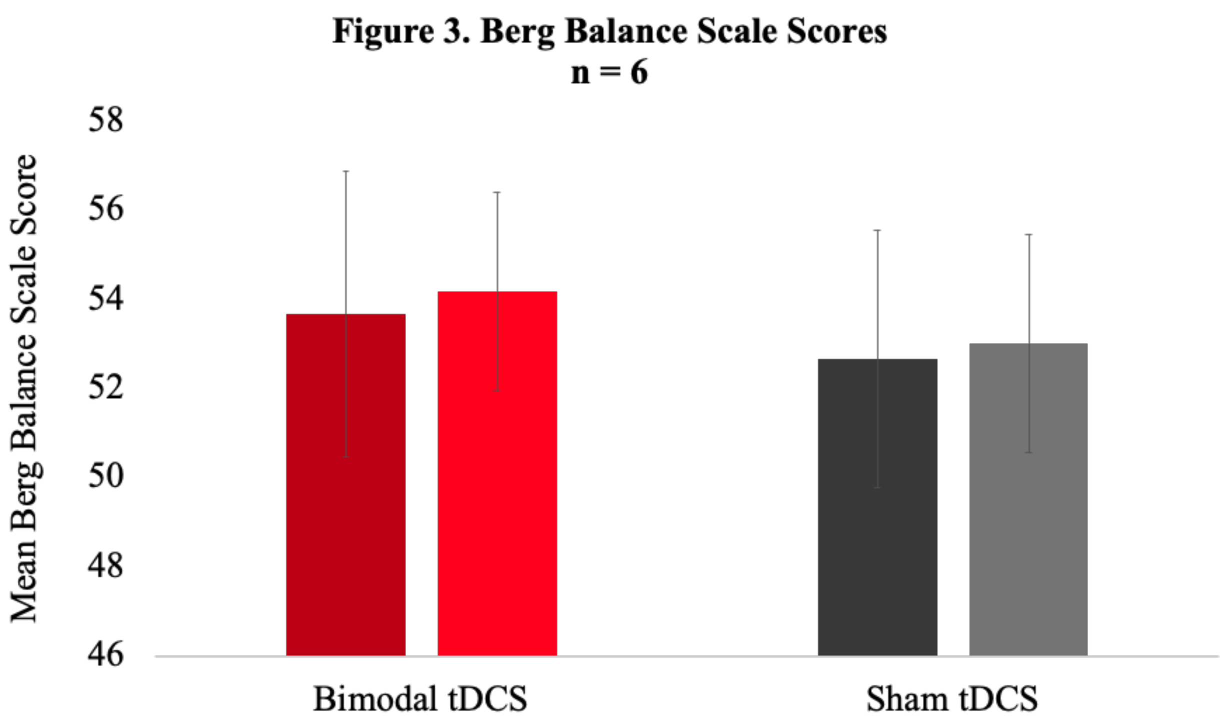


Timed Up and Go (TUG)

For the TUG, the two-way ANOVA revealed no significant interaction between stimulation and time ($F(1,5)=0.021$, $p=0.891$). No significant differences were found for the main effects of stimulation ($F(1,5)=2.984$, $p=0.145$) and time ($F(1,5)=5.874$), $p=0.060$).

Berg Balance Scale (BBS)

For the BBS, there was no statistically significant interaction between stimulation and time (F(1,5)=0.065, p=0.809). The main effect of stimulation (F(1, 5)=2.358, p=0.185), was also not significant. However, we observed a statistically significant main effect of time (F(1,5)=10.974, p=0.021) (**Figure 3**.), where higher BBS scores were observed after stimulation, regardless of stimulation type.



Discussion

The aim of this study was to determine whether application of bimodal tDCS paired with uphill treadmill walking would have transient effects in the excitability of the Ia afferent pathway assessed by the H-reflex, BBS performance, gait metrics, and TUG score in individuals with chronic post-stroke hemiparesis. Based on previous studies, our hypothesis was that bimodal tDCS would significantly reduce H-reflex amplitudes in the paretic lower extremity, improve performance on the BBS, improve symmetry in gait metrics, and improve TUG performance compared to sham tDCS.

Our main finding was that there was no significant difference in H-reflex excitability with bimodal or sham tDCS between pre- and post-measurements. This suggests that the type of stimulation, sham or bimodal tDCS, did not cause a change in H-max/M-max ratio after intervention and over time. However, an observable decrease in the amplitude of the H-max/M-max ratio was noted between pre and post application of bimodal tDCS (Pre=0.475±0.312, Post=0.432±0.281) but not sham stimulation (Pre=0.374±0.248, Post=0.376±0.259). The observable decrease shows potential for significance as previous research has shown that the H-max/M-max ratio increased following ambulation on a sloped surface in participants with chronic stroke (Liang et al., 2019). This may indicate that bimodal tDCS can potentially assist in preventing exaggeration of the H-reflex following slope walking, and possibly restore normal adaptations of reflex suppressions following locomotor tasks.

A higher BBS score was observed following stimulation, regardless of stimulation type. A previous study showed that real tDCS, regardless of anodal, cathodal, or bimodal setup, is associated with increases in BBS scores compared to sham stimulation in persons with acute stroke impairments (Andrade et al., 2017). This study concludes that real tDCS can improve BBS scores, translating to improved lower extremity function and a reduction in falls in persons with acute stroke impairments. It is important to note that tDCS in the aforementioned study was delivered for five consecutive days per week for two weeks straight, a higher intensity compared to our study, and did not include persons with chronic stroke impairments. Comparatively, a previous study investigating lower limb motor function following anodal tDCS stimulation vs sham stimulation combined with conventional physical therapy during a subacute infarction period found no significant changes in BBS scores with tDCS (Chang, Kim, & Park, 2015). The contrast in findings places into question the reliability and validity of utilizing the BBS as an outcome measure tool in the stroke population. According to a systematic review from 2019, the BBS has excellent test-retest, intra- and inter-rater reliability, and internal consistency but has low ability to predict falls due to the lack of dynamic balance and ambulation components in the tool (Kudlac et al., 2019). The BBS also only assesses components of the activity domain of the ICF model. Additionally, the increase in BBS scores observed in our study regardless of stimulation type could be attributed to practice effect since the tests were administered a total of four times for each participant, twice within each session.

We observed an increase in stride length of the paretic limb post stimulation regardless of stimulation type. It has been documented that people after stroke tend to have poor gait adaptation to variations in task demands and effectuate variations in walking speed mainly through modulations of stride length (Roerdink, Lamoth, Kwakkel, Wieringen, & Beek, 2007). Regulating and increasing stride length can play a large role in improving gait coordination and locomotor performance. Yet, our results do not support that bimodal tDCS yields significant increases in stride length compared to sham stimulation. Stride length improved regardless of stimulation type suggesting that these improvements were likely due to practice effect.

We found no significant difference between real and sham bimodal tDCS for paretic and non-paretic step length, stride width, step time, stride time, or stride velocity, as well non-paretic stride length. As previously mentioned, others have shown that bimodal tDCS yielded qualitative improvements in LE function of individuals with chronic stroke impairments. Our results indicate that although these qualitative improvements occur, quantitative effects on gait might not occur. Additionally, no significant difference between real and sham bimodal tDCS for TUG performance was found. We observed non-significant post-intervention TUG times that were faster than pre-intervention TUG times. This could indicate that a "warm up" effect exists that improves the confidence or speed of participants or that a learning effect could exist for the TUG test. Furthermore, our small sample size might have resulted in a type-II error and a larger sample size might have revealed a difference.

Our study contained multiple limitations. A major limitation of this study is the small sample size of 6 participants. Data collection was scheduled to be conducted from October 2019 through May 2020. All 6 participants' data was collected prior to the closure of the University of Nevada Las Vegas' on-campus activities beginning March 13th 2020, including access to research laboratories, due to the worldwide coronavirus pandemic. Consequently, data collection had to be halted following this date. Moreover, data from 3 of the 6 participants' (subjects 3, 4, and 6) Hmax/Mmax ratio was excluded due to invalid recording techniques from recording procedural errors. Another limitation of the study is the potential of a learning effect to occur with the TUG. As there was a main effect on time nearing significance for TUG, scores may be improving between pre- and post- intervention of bimodal tDCS stimulation. However, this may be due to a learning effect with repeated administration within and in between sessions. The learning effect is a phenomenon observable in other physical therapy functional outcome measurements, such as the 6-minute walk test where walking distance tends to increase with test familiarization and repeated administration (Wu, Sanderson, & Bittner, 2003). Therefore, the potential for the learning effect to occur with the TUG cannot be overlooked.

Bimodal tDCS has been shown to be effective in improving both upper extremity and lower extremity function in individuals post stroke (Lindenberg, 2010; Lindenberg, 2012), (Awosika & Cohen, 2019). However, parameters such as optimal dosage and electrode placement regarding tDCS application are not well defined at this time making it difficult to justify the clinical application and effectiveness of tDCS (Brunoni et al., 2012). Additionally, physical therapists looking to incorporate tDCS into a patient's plan of care would have to be thorough with ensuring that the intervention is safe and appropriate for a particular patient so that a serious adverse event does not occur. Serious adverse events are defined as: irreversible damage of brain tissue, persistent disability, unexpected inpatient hospitalizations, death or is life-threatening, or medical or surgical intervention is necessary to preclude permanent imminent impairments of a body structure or function due to tDCS (Godinho et al., 2017).

Although our study's target population was individuals with chronic post-stroke hemiparesis, it cannot be ignored that the rehabilitation field has a widely accepted notion of a proportional recovery rule with a critical window for recovery within the first 3-6 months poststroke (Ballester et al., 2019). A systematic review including 14 studies suggested that recovery reaches a plateau at 15 weeks post stroke for patients with severe hemiparesis and 6.5 weeks for patients with mild hemiparesis (Hendricks, Van Limbeek, Geurts, & Zwarts, 2002). Furthermore, evidence regarding non-invasive brain stimulation in acute periods following stroke remains inconclusive (Coleman et al., 2017). Future research should employ the application of bimodal tDCS and its effectiveness on modulating spinal cord circuitry to improve functional outcomes on acute and subacute post-stroke individuals. Future research should also attempt the same methods on a larger and more variable sample size, including participants with different types of strokes, given that this study demonstrated potential for bimodal tDCS to improve paretic limb stride length and balance. Future studies can also explore bimodal tDCS applications combined with a dual task condition. A decrease in the amplitude of the H-reflex has been found when a static postural task was combined with a dual-task condition compared to combining it with a single-task condition, which further adds to the existing literature associating a decrease in H-reflex amplitude during challenging postural tasks in order to maintain postural stability (Weaver, Janzen, Adkin, & Tokuno, 2012). Lastly, future research could utilize a different balance outcome measurement, such as the Mini-BESTest, due to the ceiling effect of the BBS. The ceiling effect of the BBS was found to be higher when compared to the Mini-BESTest (73.1% vs 3.8%, respectively) in a study that utilized these assessments in balanced trained community-dwelling older adults (Ban, Sevšek, & Rugelj, 2017). Utilizing the Mini-BESTest for our study, we may have been able to detect differences regarding the balance of the participants following real tDCS stimulation. Additionally, future research can examine balance via postural sway. Postural sway can be evaluated with force plates during static balance tasks and are correlative of postural stability and balance with quantitative measurements (Lee & Sun, 2018).

Conclusion

Bimodal tDCS paired with upslope walking did not significantly reduce H-reflex excitability; however, there was an observable decrease in H-max/M-max ratio following bimodal tDCS compared to sham stimulation. Regardless of stimulation type, participants demonstrated statistically significant increases in paretic limb stride length and BBS scores following stimulation. No other outcomes were significantly different when comparing between interventions or time. Based on these findings, bimodal tDCS may be a useful tool when paired with a cyclical task to improve stride length and functional balance in patients who experienced a stroke and shows potential to modulate H-reflex excitability in participants with chronic post-stroke hemiparesis. Further research on a larger sample size of this patient population is warranted to assess the efficacy of bimodal tDCS on its ability to regulate H-reflex excitability and improve function. Furthermore, future research should focus on optimal dosage of bimodal tDCS and utilizing quantitative balance measures with lower ceiling effects.

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Curriculum Vitae

Rafael Lorenzo Cabrera
Email: rcabrera1722@gmail.com

Education

DPT	University of Nevada, Las Vegas – Las Vegas Physical Therapy	2018–2021
BS	University of Nevada, Las Vegas – Las Vegas Kinesiological Sciences	2013–2017

Clinical Experience

2021	Student Physical Therapist, MountainView Hospital
(Spring)	Las Vegas, NV
2020	Student Physical Therapist, Southern Hills Hospital and Medical
Center	
(Fall)	Las Vegas, NV
2020	Student Physical Therapist, Fyzical Therapy & Balance Centers
(Summer)	Las Vegas, NV
2019	Student Physical Therapist, Outpatient Therapy Center at Centennial
Hills	
(Summer)	Las Vegas, NV

Work Experience

2017–2018 Rehabilitation Technician – ATI Physical Therapy

Research Activity

Liang J, **Cabrera RL**, Gan J, Laudermilch L, Wolkenhauer B. Effects of Bimodal Transcranial Direct Current Stimulation on Modulation of Spinal Circuitry in People with Chronic Post-Stroke Hemiparesis.

Certifications

American Heart Association, BLS for Healthcare Providers (April 2021-April 2023)
HIPAA Training Certified (February 2019)
Blood-borne Pathogens Training Certified (February 2019)

Skills

Computer skills: Word Processing: Microsoft Word
Data Presentation: Microsoft PowerPoint
Data Entry and Analysis: Microsoft Excel

Neurosoftware: tDCS: Neurocomm

Honors and Awards

2019 UNLVPT Student Opportunity Research Grant, $4,651
2017 Magna Cum Laude – University of Nevada, Las Vegas
2013–2016 Dean's Honor List – University of Nevada, Las Vegas

Service / Volunteer Activity

October 2019 High Rollers Wheelchair Rugby
September 2019 Parkinson's Moving Day
January 2019 UNLVPT Interview Day
November 2018 Parkinson and Movement Disorder Alliance Renew!

Professional Growth and Continuing Education

- 2020 UNLVPT Distinguished Lecture Series presented by Dr. Catherine Lang, PT, PhD, FAPTA – November 5th, 2020
    - November 5th, 2020
        - "Wearable sensors are changing how we think about movement and rehabilitation"
- "How An Organization's End-Of-Life Initiatives Can Help Patients and Providers Alike: A Cleveland Clinic Story" – November 8, 2019
- 2019 UNLV PT Brown Bag Lecture Series
    - September 19, 2019
        - "45th Mary McMillan Lecture: If Greatness is a Goal..." presented by James Gordon, PT, EdD
    - October 2, 2019
        - "Ride on: Adventures in Traumatic Brain Injury" presented by Greg Nordfelt
    - November 6, 2019
        - "Gait Outcomes for Stroke Rehabilitation" presented by Corey Sommerville, PT, MPT, NDT
- 2019 UNLVPT Distinguished Lecture Series presented by Anthony Delitto PT, PhD, FAPTA – September 12-13, 2019
    - September 12, 2019
        - "Finishing the Job of Evidence Based Practice"
    - September 13, 2019
        - "The Time for Implementation is NOW"
- American Physical Therapy Association Combined Sections Meeting and Exposition - Washington, DC - January 23-26, 2019
    - January 24, 2019
        - How to Avoid a Fall: Protective Limb Responses in Aging and Stroke
        - Rehabilitation in the Digital Age: Virtual Reality, Games for Health, and TeleRehab

        - Science Meets Practice: Neuroplasticity Following ACL Injury and Reconstruction
    - January 25, 2019
        - Sleep: The Impact of Sleep on Pain, Healing, and Wellness
        - Evidence-Based Exercise Interventions for People with Parkinson Disease
        - Many Faces of Sports of Physical Therapy
    - January 26, 2019
        - Creating a Boutique Experience in Your Clinic: A Win for Patients and Therapists
        - Dealing with the Dark Side of Plasticity: Pain in Neurorehabilitation
        - Measuring Pediatric Disorders Through the Lifespan: A Clinician's Perspective
- 2018 UNLVPT Distinguished Lecture Series presented by Irene Davis PhD, PT, FACSM, FAPTA, FASB – November 15-16, 2018
    - November 15, 2018
        - "Footwear Matters: Let's Think Differently about the Foot"
    - November 16, 2018
        - "Solving Running Injuries: Well Aligned, Soft Landings"
- 2018 UNLVPT Brown Bag Lecture Series
    - October 4, 2018
        - Development of a Strength Training Program in Duchenne Muscular Dystrophy presented by Donovan Lott, PT, PhD
    - November 8, 2018
        - "Can an Acute Exercise Bout Influence the Sensorimotor Locomotor Memories?" presented by Charalambos Charlambous, PhD

Membership in Professional Organizations

2018–Present Member American Physical Therapy Association
2018–Present Member Nevada Physical Therapy Association

John Patrick Gan
Email: JohnPGan@gmail.com

Education

DPT	University of Nevada, Las Vegas	2018 - current	Doctor of Physical Therapy Class of 2021
BS	University of Nevada, Las Vegas	2014-2017	Bachelor of Science Kinesiology

Licensure

Nevada State Physical Therapy License May 2021

Certifications

American Heart Association, BLS for Healthcare Providers (April 2021 – April 2023)
Otago Exercise Program Certified (April 2020)
STEADI Older Adult Fall Prevention Training Certified (April 2020)
CITI Biomedical IRB Course Completion (March 2019)
HIPPA Training Certified (March 2019)
Blood-Borne Pathogens Training Certified (March 2019)

Clinical Experience and Employment

Summerlin Hospital Medical Center Las Vegas, NV	Inpatient Rehab	(Jan 2021 – April 2021)
Cleveland Clinic - Lou Ruvo Center for Brain Health Las Vegas, NV	Outpatient Neurorehabilitation/ underserved	(Sep 2020 – Dec 2020)
Renown Regional Medical Center Reno, NV	Acute (Neuro ICU, NICU, PICU)	(Jul 2020 – Sep 2020)
VA Southern Nevada Healthcare System North Las Vegas, NV	Outpatient orthopedics/underserved	(Jul 2019 – Aug 2019)
Edwin Suarez Physical Therapy Las Vegas, NV	Physical Therapy Technician	(Jul 2015 – Aug 2018)

Membership in Professional Organizations

American Physical Therapy Association (2018 - present) –member ID: 835501

Honors and Awards

2019 UNLVPT Student Opportunity Research Grant - $4651.00
2015-2017 University of Nevada, Las Vegas Dean's Honor List

Leadership and Service

Parkinson's Moving Day (September 2019)
UNLVPT Student Interviews Volunteer (January 2019)
Renew! Retreat for people impacted by Parkinson's (November 2018)

Continuing Education

- 2021 APTA Combined Sections Meeting (CSM) – Virtual Poster Presentation
    - "Effects of Bimodal Transcranial Direct Current Stimulation on Modulation of Spinal Circuitry in People with Chronic Post-Stroke Hemiparesis"
- 2020 APTA Combined Sections Meeting (CSM) – Denver, CO
- 2019 APTA Combined Sections Meeting (CSM) – Washington D.C.
- UNLVPT Distinguished Lectures
    - Anthony Delitto PT, PhD, FAPTA
- September 12, 2019: "Finishing the Job of Evidence Based Practice"
- September 13, 2019: "The Time for Implementation is NOW"
    - Adrian Louw, PT, PhD, CSMT
- April 22, 2019: "Teaching Patients About Pain"
- April 23, 2019: "Teaching Patients About Pain
    - Irene Davis, PhD, PT, FACSM, FAPTA, FASB
    - November 15, 2018: "Footwear Matters: Let's Think Differently about the Foot"
    - November 16, 2018: "Well Aligned, Soft Landings: A Cure for Running Injuries?"
- UNLVPT Brown Bag Lecture Series
    - November 20, 2019: "Physical Therapy Service in Haiti" by Brooke Conway, PT, DPT
    - October 2, 2019: "My TBI and me" by Greg Nordfelt
    - September 19, 2019: "45th Mary McMillan Lecture: If Greatness Is a Goal…." by James Gordon, PT, EdD, FAPTA
    - November 8, 2018: "Can an acute exercise bout influence the sensorimotor locomotor memories?" by Charalambos Charlambous, PhD
    - September 6th, 2018: "Why your DPT is worthless and what you can do to change it!" by Beren Shah, PT, DPT and Rob Robb, PT, DPT

Lana Laudermilch
lana.lorain@gmail.com

Education

University of Nevada, Las Vegas 2018-2021
Doctorate of Physical Therapy (DPT)

University of Nevada, Las Vegas 2013-2017
Bachelors of Science (BS) in Kinesiological Sciences, Magna Cum Laude

Licensure

Doctorate of Physical Therapy License (In Progress) Estimated May 2021

Work Experience

Graduate Assistant | ***University of Nevada Las Vegas - Physical Therapy Department***
Jun 2019- Jun 2020
- Utilize time management, leadership, and communication skills to work with faculty
- Collect and analyze data on neuromodulation and assessment of cortical and spinal circuitry
- Assist first year students with neuroanatomy class
- Attend monthly stroke support groups in the community

Front Office Assistant | ***Summerlin Hospital Outpatient Therapy***
Mar 2015 - Dec 2020
- Engage in and develop patient interaction skills and inter-professional communication skills
- Answer patient questions, schedule therapy appointments, verify insurance
- Perform other front desk responsibilities by utilizing strong multi-tasking and organizational skills

Clinical Experience

Student Physical Therapist | ***Valley Hospital, NV*** Jan 2021-Apr 2021
- Develop plans of care and discharge recommendations for patients with a variety of musculoskeletal, neurological, integumentary, and cardiopulmonary conditions in the acute care setting, including the intensive care unit

Student Physical Therapist | ***Boulder City Hospital, NV*** Sep 2020-Dec 2020
- Engage in and develop plans of care for patients in skilled nursing facility, long term care, medical/surgical unit, and geriatric psychiatric unit
- Participate in weekly interdisciplinary team conferences to discuss patient management and discharge

Student Physical Therapist | ***Synergy Physical Therapy Anthem, NV*** Jul 2020-Sep 2020
- Engage in and develop plans of care for a variety of orthopedic and neurological conditions

Student Physical Therapist | ***Full Range Physical Therapy, NV*** Jul 2019-Aug 2019
- Engage in and develop plans of care for a variety of orthopedic and neurological conditions
- Participate in community events, including Elko Nevada's Senior Olympic Games

Research Activity

Graduate Research | ***University of Nevada Las Vegas- Physical Therapy Department***
Aug 2019 - Jun 2020

- Research focuses on the characterization of the spinal reflex circuit function and Achilles' tendon micromorphology in individuals with chronic post-stroke hemiparesis

Graduate Research | ***University of Nevada Las Vegas- Physical Therapy Department***
Feb 2019 - Present

- Research and exploration focuses on modulation of the spinal circuit using transcranial direct current stimulation in individuals post-stroke

Membership in Professional Organizations

Member | ***Diversity, Equity, & Inclusion Club, UNLV Physical Therapy Dept.***
Aug 2020 - Present

- Promote volunteerism and community involvement in issues surrounding diversity and marginalized populations
- Provide a platform for students to express concerns or ideas regarding diversity and inclusion efforts within the program

Member | ***American Physical Therapy Association***
Nov 2018 - Present

- Advocate with other physical therapists and student physical therapists for the elevation of the profession
- Attend annual national conferences for exposure to new evidence-based practice, technology, and products in the physical therapy field

Member | ***Kinesiology Club, UNLV***
Fall 2016 - Dec 2017

- Attend monthly meetings to meet UNLV Physical Therapy faculty and practicing physical therapists in the community
- Take part in community service and fundraising

Volunteer Activity

Active Volunteer | ***Rock Steady Boxing Club***	Sep 2018 - Present
Event Volunteer | ***Fall Prevention Screening, Heritage Park Senior Center, Henderson***	Mar 2020
Event Volunteer | ***Amtryke Bike Build***	Feb 2020
Event Volunteer | ***Parkinson's Moving Day***	Sep 2019, May 2021
Volunteer | ***Physical Therapy Service Day at Three Square, Las Vegas***	Oct 2018
Coach & Volunteer | ***Downtown Las Vegas Soccer Club***	Aug 2013 - May 2014

Academic Service

Research Participant | ***University of Nevada, Las Vegas*** Fall 2018 - Present

- *Physical Therapy Dept. Cervical Manipulation Study (Sep 2018)*
- *School of Nursing Cognitive and Sensorimotor Function Study (Mar 2020)*

Honors and Awards

Summerlin Hospital Volunteer Scholarship Fall 2018 - Spring 2019
UNLV Dean's List Fall 2014 - Fall 2017

Continuing Education Attended (Last 3 Years)

"How Two UNLVPT Alums Paid Off $300,000 in Student Loans" by Danielle Garcia PT, DPT and Ron Garcia PT, DPT, ATC ***Feb 2021***

"Wearable sensors are changing how we think about movement and rehabilitation" by Catherine Lang, PT, PhD, FAPTA ***Nov 2020***

"Now that I'm a licensed therapist, how do I start my own private practice?" by Ashley Reagor, PT, MSPT, ATC ***Sep 2020***

"Gait Outcomes for Stroke Rehabilitation" by Corey Somerville, PT, MPT, NDT ***Nov 2019***

"Implementation: Finishing Job of Evidence Based Practice"by Anthony Deloitte, PT, PhD, FAPTA ***Sep 2019***

"The Critical Benefits and Roles of Rehabilitation in Cancer Care"by Leslie J. Waltke, PT, DPT ***Apr 2019***

"Teaching Patients about Pain: Pain Neuroscience Education"by Adrian Louw, PT, PhD ***Apr 2019***

American Physical Therapy Association Combined Sections Meeting in Washington D.C. ***Jan 2019***

"Can an acute exercise bout influence the sensorimotor locomotor memories"by Charlambous, PhD ***Nov 2018***

"Footwear Matters: Let's Think Differently about the Foot"by Irene Davis, PhD, PT ***Sep 2018***

"Why your DPT is worthless and what you can do to change it!"by Beren Shaw, DPT and Rob Robb, DPT ***Sep 2018***

Certifications

Basic Life Support CPR & AED Apr 2021 - Present
STEADI Older Adult Fall Prevention Apr 2020 - Present
OTAGO Exercise Program Apr 2020 - Present

Benjamin Wolkenhauer
Wolkenhauer.b@gmail.com

Experience

January 2021-April 2021

Student Physical Therapist: *Synergy Physical Therapy, Henderson: NV*
Fourth and final clinical rotation in outpatient setting. I managed 100% caseload by the end of the rotation, performing evaluation, examination, interventions, and managing plan of care for orthopedic, neurological, geriatric, and pediatric patient populations.

September 2020-December 2020

Student Physical Therapist: *Sunrise hospital and medical Center, Las Vegas: NV*
Third clinical rotation in inpatient rehab facility setting. I conducted skilled evaluation, examination, and interventions with emphasis on safe procedures and resolving activity limitations and improving patient participation for safe home discharge. I managed 80-90% caseload by the end of the rotation.

July 2020-September 2020

Student Physical Therapist: *St. Mary's Regional Medical Center, Reno: NV*
Second clinical rotation in acute, inpatient setting. Conducted skilled evaluation and interventions while demonstrating medical competence and safe procedures. Specialized inpatient practice settings included wound care, ICU, and aquatic therapy.

July 2019-August 2019

Student Physical Therapist: *Select Physical Therapy: Puyallup, WA*
First clinical rotation in an outpatient orthopedic setting. Provided skilled evaluation, examination, interventions, education, and medical screening at a 50% caseload. Patient populations included 50% orthopedic, 30% oncology, 10% vestibular, 10% pediatric.

May 2019-May 2021

Neuromodulation researcher: *University of Nevada, Las Vegas: Las Vegas, NV*
The IRB approved research involves monitoring neuromodulation of the stroke population and potential benefits to gait and balance. Responsibilities include applying the neuromodulation safely to our patients, gathering several outcome measures before and after application, statistical analysis of data, data interpretation, and presentation of projects in multiple formats including powerpoint presentation, academic writing, and poster presentation.

Education

Fall 2013-Spring 2018

Eastern Washington University: *Cheney, WA*
- Bachelor of Science, Biology; Graduated Cum Laude
- Student research in comparative physiology and wetland ecology

University of Nevada, Las Vegas: *Las Vegas, NV*
- Doctor of Physical Therapy, May 2021

June 2018-

present • Student membership in the American Physical Therapy Association 2018-2021

Honors and Awards

-UNLV PT student opportunity research grant (2019): $4,651

Continuing Education

-Attendance at the APTA's combined sections meeting; 2021
-Attendance at the APTA's combined sections meeting; Denver, 2020
-Attendance at the APTA's combined sections meeting; Washington DC, 2019
-Attendance and co-authorship of *What is Lymphadema?* 2019 Pierce County Cancer Survivorship Conference
-Attendance at multiple CEU approved lecture series:

Implementation: Finishing the Job of Evidence Based Practice, by Dr. Anthony Delitto, PT, PhD, FAPTA

"Footwear Matters: Lets Think Differently about the Foot" Irene Davis, PhD, PT, FACSM, FAPTA, FASB

"Well Aligned, Soft Landings: A Cure for Running Injuries?" Irene Davis, PhD, PT, FACSM, FAPTA, FASB