Investigating the therapeutic effects of Neubie Direct Current Neuromuscular Electrical Stimulation treatment on pain, range of motion, and biometrics measured by the Biostrap wrist-worn photoplethysmography (PPG) device.

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Abstract

Background: According to Centers for Disease Control and Prevention (CDC), approximately 20.4% of adults in the US suffer from chronic pain[1], with 7.4% reporting high impact chronic pain which is associated with decreased quality of life, opioid dependence, and poor mental health[2-4]. Neuromuscular electrical stimulation (NMES) is a safe and minimally invasive therapy which has been shown to aid in the management or relief of chronic pain, including reducing pain from orthopedic conditions or procedures and improving the associated range of motion[5-7].

Objective: This study aimed to evaluate the therapeutic effects of Neubie Direct Current NMES on self-reported pain and range of motion and biometrics including resting heart rate, heart rate variability, and sleep quality in patients with orthopedic pain.

Methods: Participants were recruited from multiple sites with access to the Neubie device. Measurements were collected on 17 participants with current orthopedic pain, ages 22-61, using the Biostrap wrist-worn photoplethysmography (PPG) device with in-application prompts for daily survey responses for seven weeks. Following a two-week baseline, participants underwent a total of eight (8) Neubie sessions over approximately four (4) weeks under the care of a certified Neubie specialist. Participants were followed for one additional week of discontinued therapy to measure the lasting benefits of Neubie Direct Current NMES.

Results: A total of 833 days of biometric data were analyzed throughout the 7-week study duration. Analysis of data throughout study phases showed improvements in self-reported pain and range of motion, in addition to decreased resting heart rate (RHR), increased heart rate variability (HRV), and sleep efficiency.

Conclusions: Consistent application of Neubie Direct CurrentNMESn under the care of a certified specialist may provide quantitative improvements in pain, range of motion, and physiological biometrics in a population of

orthopedic pain without neurological disease. Further research is required to establish the statistical significance of these outcomes.

Background

According to Centers for Disease Control and Prevention (CDC), approximately 20.4% of adults in the US suffer from chronic pain[1], with 7.4% reporting high impact chronic pain which is associated with decreased quality of life, opioid dependence, and poor mental health[2-4]. Neuromuscular electrical stimulation (NMES) is a safe and minimally invasive therapy which has been shown to aid in the management or relief of chronic pain and increase range of motion.

NMES is the application of an electrical current on the skin above a muscle tissue for the purpose of activating muscle fibers and initiating a muscular contraction. This is

In January 2021, Neufit and Biostrap Labs launched a multi-site study to investigate the therapeutic effects of Neubie Direct Current NMES treatment on self-reported pain, range of motion and biometrics measured by the Biostrap wrist-worn photoplethysmography (PPG) device. Participants with orthopedic-related pain, ages 22-61, were recruited from two sites in the United States with access to the Neubie device and certified health professionals to conduct a total of eight (8) treatments over a 4-week period. Participants established a 2-week baseline prior to Neubie intervention and were also followed for an additional week to assess the potential lasting or compounding physiological effects of the therapeutic intervention. Treatment protocols were individualized with a perceived intensity of stimulation ranging between 4-8 out of 10 in terms of participant-reported discomfort.

Methods

Treatment protocols included one initial evaluation session followed by 7 interventional sessions, with 2-3 sessions per week. Treatment session duration was roughly 1 hour per session for all 8 sessions. The initial evaluation included a scan of the body using the NEUBIE and carbon fiber pads to identify areas with greatest sensitivity/discomfort to stimulation. These locations were then used as the targeted areas for the duration of treatments. During treatment sessions, electrode pads attached to the NEUBIE were placed on targeted areas and intensity of electrical current was increased to a perceived intensity of a 4-8 out of 10 by the participant (this level of intensity is ideal for maximum stimulation while still allowing for full movement through prescribed exercises in session). Participants underwent a series of physical therapy exercises as directed by their certified practitioner. The specific exercises used depended on the targeted area, designed to activate the muscles, increase blood flow, stimulate the nerves, and increase movement in the areas experiencing limited range of motion or pain. The prescribed exercises were performed in sets, with the electrical current from the NEUBIE on during active periods of movement, and off while in resting periods. Stimulation frequencies used for training varied by exercise type, ranging from 40-55 pulses per second (PPS) for exercises designed to cause greater contraction or motor recruitment in the muscles to 500 PPS for exercises designed to reduce tone or aid in the elongation of muscles.

Throughout the baseline, intervention, and wash-out phases, participants wore a Biostrap EVO wrist-band PPG device. Biometrics and sleep staging were derived from each sleep session as daily outcomes, as this is when many biometrics are closest to basal values. Upon waking each morning, a survey with likert-scale questions around pain, perceived sleep, and perceived wellness were administered through the Biostrap mobile application for iOS and Android devices.

Baseline	**Intervention**	**Wash-Out**
Weeks: 1-2	Weeks: 3-6	Week 7
No Intervention	8 Neubie Sessions	Discontinued Use
Nightly biometrics	Nightly biometrics	Nightly biometrics
Morning Survey	Morning Survey	Morning Survey

Participants with specified contraindications including pregnancy, use of a pacemaker, active or recent cancer, active or recent blood clots, or history of epilepsy were excluded from this study. Additionally, participants who had recently utilized any form of electrical stimulation therapy or with a history of neurological disease were also excluded.

Devices

Neufit NEUBIE

The NEUBIE (NEUro-BIo-Electric) Direct Current Neuromuscular Electrical Stimulation (NMES) Device (Neufit; Austin, TX, USA) is a device that uses electrical frequencies to stimulate muscle activation, blood flow, and various aspects of the nervous system. NMES is a safe and noninvasive therapy that has been utilized in physical therapy and pain management, and has been shown to affect reflex patterns[11-14], brain activity[15-18], muscle output[19-20], and pain[21-23]. NMES is administered via devices which send electrical impulses through the skin to nerves in tissue to elicit muscle contractions and sensory impulses[24-25]. These impulses mimic action potentials from both the peripheral and central nervous systems[26]. The impulses are interpreted by sensory and motor neurons to activate contractile and sensory muscle fibers and 1a/1b afferents, resulting in the stimulation of muscle, tissue, and nerve activation, as well as increasing blood flow[25-30]. The NEUBIE device uses a direct current (DC) frequency via conductive pads placed at the targeted area, and an additional waveform to dissipate heat caused by the DC stimulation. DC fields have been shown to accelerate the body's own physiological processes of healing, repair, and regeneration[31-36], and to have unique effects on the nervous/neuromuscular system[36-38]. Treatments with the NEUBIE are active rather than passive; traditional NMES treatments have patients lying down, passively accepting current. In contrast, the DC signal of the NEUBIE permits movement, even at therapeutic levels of stimulation. This allows for optimal, eccentric contractions, which has been noted to play a role in effective rehabilitation[39-42].

The physiological and neurological responses to NMES provide evidence-based therapeutic effects. Specifically, Incorporating NMES into physical training and therapeutic rehabilitation programs have been shown to enhance long-term outcomes by supporting adaptation of cells in muscles, blood vessels, and

nerves[43]. E-stim is considered safe with minimal side effects or contraindications when used properly. The NEUBIE device is FDA cleared for the following indications:

- Maintaining or increasing range of motion
- Increasing local blood circulation
- Neuromuscular re-education
- Preventing atrophy
- Reducing spasms
- Preventing venous thrombosis after surgery
- Management or relief of chronic pain
- Management of post-surgical and post-traumatic acute pain

Biostrap EVO

The Biostrap EVO (Biostrap; Bradbury, CA, USA) is a clinical-grade, wrist-worn biometric sensor which captures high-fidelity raw photoplethysmography (PPG waveform), accelerometer, and gyroscope data. Each waveform is analyzed via advanced cloud processing techniques to ensure data integrity to derive biometric outputs including heart rate, heart rate variability, respiratory rate, oxygen saturation, arterial compliance, physical activity, and sleep parameters. Biostrap has integrated survey tools to collect participant self-reported data.

Results & Discussion

Resting Heart Rate

Chronic pain can place additional strain on many physiological systems, including the heart and circulatory systems, while additionally limiting the ability to engage in regular physical activity. While an acute increase in resting heart rate (RHR) was recognized in the early stages of the intervention phase, the majority (63%) of participants completed the washout phase with a RHR value below baseline without increasing levels of physical activity.

The American Heart Association recommends lowering RHR as much as possible[5]. Typically accomplished through exercise training[6], dietary changes, meditation, or interventions aimed at reducing physiological stress, a decrease in RHR reflects increased cardiovascular efficiency and decreased systemic stress.

Heart Rate Variability

Patients with chronic pain tend to exhibit lower heart rate variability (HRV), which has been associated with poor adaptability, psychological flexibility, and stress[7]. In a systematic review of 2283 studies, researchers concluded that indices of HRV can be used to index the activity of the neurophysiological pathway responsible for adaptively regulating inflammatory processes in humans[8] and may therefore represent a valuable metric to track in populations with chronic pain.

Throughout all phases of this study, the participant's nocturnal HRV was collected. Preliminary analysis revealed day-to-day improvement trends in HRV during the intervention phase, with the majority (63%)

of the participants completing the study with a higher HRV value than baseline. Additionally, these improvements were maintained throughout the washout phase after therapy was discontinued.

Sleep

Significant clinical evidence suggests that sleep and pain are related. However, many questions remain about the direction of causality and mechanisms that may account for their association. In a critical review of recent prospective and experimental literature (2005-present), researchers found that micro-longitudinal studies employing deep subjective and objective assessments of pain and sleep support the notion that sleep impairments are a stronger, more reliable predictor of pain than pain is of sleep impairments[9]. Patients with chronic pain may often experience frequent micro-arousals or awakenings per evening, thereby decreasing their amount of restorative deep sleep.

Throughout each of the study phases, the majority of participants (56%) experienced improved sleep efficiency marked by less awakenings per evening, and less amount of time awake in bed, resulting in an average improvement of 7% in overall recovery throughout the intervention phase. The improvements in decreased awakenings were maintained throughout the washout period.

Pain & Range of Motion

Limited range of motion (ROM) has been associated with various conditions including orthopedic-related pain[10] and can have an impact on a patient's daily functioning and overall quality of life. Throughout this study, participants self-reported their perceived pain and ROM each morning immediately upon awakening. On average, participants' pain decreased by 21% and ROM increased by 27% throughout this investigational study. Surprisingly, the greatest improvement in pain and ROM were experienced during the washout period. This improvement during the washout phase post-intervention may be a result of extended recovery time after 4 weeks of continuous intervention.

Conclusion

Neubie Direct Current NMES therapy, when performed by a certified practitioner, may provide quantitative therapeutic benefits including improvements in self-reported pain, range of motion, sleep efficiency and physiological biometrics in a population with orthopedic pain but without neurological disease.

Further research with larger and more diverse populations with chronic pain is required to establish the statistical significance of these outcomes.

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