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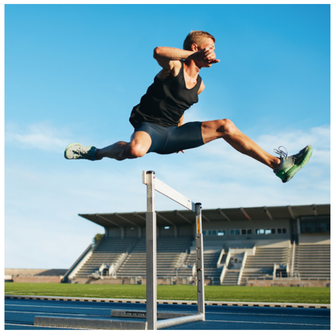

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ORIGINAL ARTICLE

EXERCISE PHYSIOLOGY AND BIOMECHANICS

Improvement of athletic performance with haptics: results of the POWER-UP Trial

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ABSTRACT

BACKGROUND: Adult athletic performance in most sports relies on adequate muscle tone, strength, flexibility, and movement coordination. Neuromuscular training to improve athletic performance has been embraced in athletic programs aimed at aiding college athletes seeking a future professional sports career or high achievement in national/international athletic competitions. Since strength, power, and endurance are essential attributes for athletes playing sports, the aim of this study was to assess whether the use of haptic patch technology could improve muscular strength, power, and endurance.

METHODS: Healthy college athletes aged 18-30 (N.=70; 30 males and 40 females) were randomized and enrolled as research participants in this blinded treatment *versus* placebo study. While 34 subjects initially received the active patch (VICTORY patch), 36 initially received a non-active patch that appeared identical to the active patch. After each group completed their study ARM, they crossed over to the other group, and received either an active or non-active placebo patch. Standard neuromuscular performance evaluative methods were used to acquire the data. This included obtaining measurements for neuromuscular changes in specified muscle groups through strength testing, and measurements pertaining to complex neuromuscular pattern performance. Neuromuscular data and comparative results for such aspects as peak power, concentric peak force, jump height, and knee extension/flexion was collected at a baseline; then retested after 1-24 hrs of patch use; then at 7-10 days a new baseline without a patch testing was completed with a repeat after 1-24 hrs of patch use. Descriptive statistical methods included the Shapiro-Wilk test, Wilcoxon signed-rank tests, Mann-Whitney U Tests, and Spearman's rank correlation were used for data analysis. Data analysis was also performed to compare results between the active patch group and placebo patch group.

RESULTS: Results showed that participants receiving the active patch demonstrated greatest improvement at 70-80 min of patch use, and the active patch group showed statistically significant improvements in the evaluated neuromuscular attributes in knee extension and knee flexion than the placebo patch group.

CONCLUSIONS: Incorporating haptic patch use in college athlete and other young adult athlete training programs aimed at improved neuromuscular functioning may be beneficial to improved athletic performance. Haptic patch use within an athletic training program may be an especially useful strategy in athletes who sustained minor injuries preventing participation in their usual daily training regimen to recover lost strength, power, or endurance, as well as college athletes who are attempting to achieve improved performance toward a goal of future professional or nationally-competitive sport play.

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KEY WORDS: Haptic technology; Athletic performance; Athletes; Muscle tonus; Knee.

Strength, power, and endurance are essential attributes for playing professional football, baseball, tennis, and other sports. Adult athletic performance in most sports relies on adequate muscle tone, strength, flexibility, and movement coordination, inclusive of solo athletics such as swimming or track. Sensorimotor control is the integration of sensory information that allows the Central Nervous System to execute movements efficiently and accurately. For this reason, sensorimotor control (with its various subsystems) has a major impact on athletic performance. The function of the proprioceptive subsystem is to transmit information from the joints and muscles that allow the development of kinesthetic awareness.[1] Optimizing sensorimotor control inclusive of the proprioceptive subsystem is a key aim of neuromuscular training (NMT) training regimens in athletes.[2-4]

NMT regimens to improve athletic performance have been increasingly embraced in athletic programs aimed at aiding college football or soccer players seeking a future professional sports career or high achievement in national/international athletic competitions. One strategy utilized in NMT regimens are the inclusion of exercises that generate a neuromuscular potentiation effect (also called post-activation potential, PAP). Through the performance of an intense exercise to temporarily increase the excitability of the somatic nervous system (within the peripheral nervous system, PNS), an enhancement of the force and power of a subsequent movement can be achieved. While the percentage of all college athletes who participate in NMT exercising remains unknown, prior studies have suggested that most do not perform NMT as a regular component of their athletic training regimens.[4, 5] However, fewer athletic injuries have been found among athletes who participated in sports training regimens that regularly included NMT as an aspect of the training regimen.[6, 7]

Haptic technology generates a feedback response to tactile sensations through bi-directional communication. This bi-directional communication is a central aspect of haptic-controlled systems and devices.[8] Diverse pathways of neural networks in the central nervous system (CNS) and PNS respond to tactile sensations as well as all other kinds of sensory information.[9]

In healthcare, haptic technology has been associated with robotic surgical/rehab devices and prosthetics.[10] Haptics have also been categorized into brain-computer interface (BCI) and neurofeedback (NF) systems/devices. While BCI predominates in the medical (and entire) haptic realm, NF has been studied to evaluate its impact on human internal control.[11, 12] One example is haptic technology implanted in the footwear of TBI rehab patients, providing NF to these patients to improve balance when standing.[13] Another example is a haptic-controlled pressure sleeve that produces different tactile sensations in order to trigger improved EEG-evidenced sensation perception.[14]

Haptic vibrotactile trigger technology (VTT) has been studied more recently as an adjunct or alternative therapy for the treatment of insomnia, psychiatric disorders, balance issues, and pain.[15-18]

Haptic technology has been utilized in athletic training to improve performance, in rehabilitation post-injury, and in learning (*e.g.*, muscle memory).[19] Haptic technology includes haptic devices that stimulate the skin's sensory nerves through such mechanisms as the transmission of electrical pulses or mechanical vibrations; thereby, communication with sensory nerves and the brain can be achieved that can result in lessened perceptions of pain, and increased sensory brain signaling activity such as required for balance and muscle group coordination. Incorporating haptic devices (*e.g.*, haptic patches) in NMT regimens can act as an augment to an athlete's physical training program.

Peak performance is identified by measuring neuromuscular changes in specified muscle groups, as well as in complex neuromuscular pattern performance. By evaluating change in isolated muscle function of athletes during selected training regimens – both with and without the use of wearable haptic device utilization – training regimens may be better able to maximize neuromuscular proprioceptive responses in the training of an athlete. Standard protocols for testing peak performance include both aerobic and non-aerobic tests; these include maximal oxygen uptake testing, anaerobic power and capacity (*e.g.*, Wingate Anaerobic Test [WAnT]), vertical jump testing, strength testing, agility testing, and many other quantifiable assessments.

The purpose of this IRB-approved, double-blind, randomized POWER-UP (Performance Output With Haptics--Evaluating Athlete Response and Unrealized Potential) Trial was to evaluate whether the use of a wearable haptic patch (SuperPatch Company's VICTORY patch; Toronto, Canada) in college Division 1 athletes can increase athletic strength, power, and endurance. In particular, this study's aim was to evaluate the effectiveness of the VICTORY patch in increasing muscular strength, power, and endurance, and through the utilization of standard protocol testing in athletes of peak performance capability. An experimental medical research study design was selected, so that outcomes could be compared between research participants wearing the VICTORY patch with participants wearing an identical patch that was a placebo.

Materials and methods

The study design was an IRB-approved, randomized, double blinded "treatment *versus* placebo" crossover study. The treatment was a wearable haptic patch (VICTORY patch; SuperPatch Company, Toronto, Canada), and an identical-appearing wearable placebo patch.

Description of the topical intervention

The active patches have an adhesive backing on one side and contain no drug or energy source. The non-invasive, 2 x 2-inch non-pharmacological patches are embedded with proprietary sensory pattern imprints making up/compiling the haptic VTT (Figure 1).[20] The non-active patch looked similar to the active patches but did not incorporate the VTT.

Research participants were college students recruited voluntarily for participation from University of Arizona varsity athletic teams (N.=70; 30 males and 40 females). The total number of participants by sport was as follows: 15 participants (swim-distance); 7 (track & field – cross-country); 6 (gymnastics); 6 (track & field – sprinter); 4 (baseball); 4 (beach volleyball); 4 (swim – short sprint); 4 (track & field – hurdler); 4 (track & field – thrower); 4 (soccer); 3 (softball); 2 (diving); 2 (tennis); 2 (golf); 1 (track & field – high jump); 1 (track & field – pole vault); and 1 (volleyball).

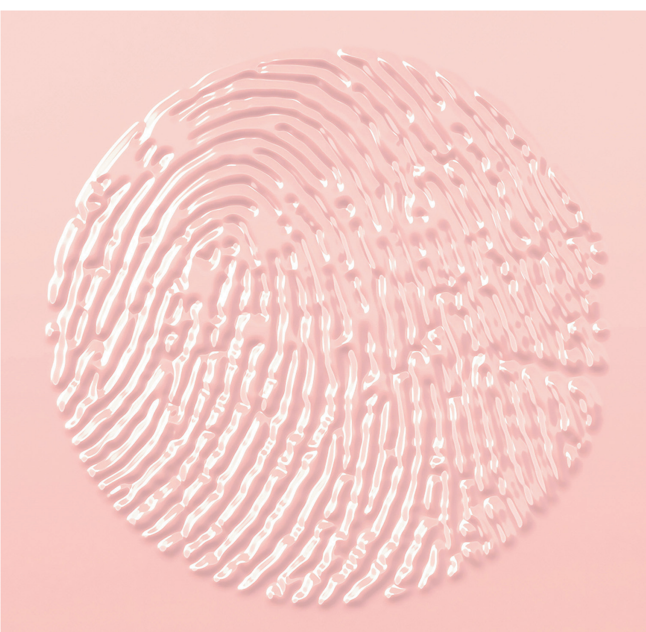

Figure 1.—Non-invasive, 2x2-inch non-pharmacological patches embedded with proprietary sensory pattern imprints making up/compiling the haptic VTT.

Each of the 70 participants were randomized to initially receive either the VICTORY patch (experimental patch) or the placebo patch (control patch). Simple randomization was selected for this study and interventions were sequentially numbered. Administering personnel did not have access to the randomization numbering or allocation sequence. Ninety-three percent (93%) of the athletes indicated that their right side was their dominant side, while the remaining 7% indicated their left side was dominant. For both groups, participants provided a baseline measurement of the testing platforms evaluated (Day 0). Whichever patch the athlete was randomized to was applied by the research team at least 1 to 24hours prior to retesting on the mid-anterior thigh of the dominant leg (Day 1). After a minimum of 7 days' wait, a baseline measurement was then repeated (Day 8 to 11) followed by the athlete receiving the alternative patch retested 1 to 24 hours later in the same manner as the initial comparison sessions. Both the active and placebo groups wore their patch approximately the same duration (~227.2 minutes for Active and ~222.4 minutes for control) over the study period.

During each session, participants underwent three movements to assess performance and strength. These were knee flexion, knee extension, and a countermovement jump. The VALD Forceframe and ForcePlate testing and training platform (VALD, Brisbane, Australia) was utilized to provide the measurements used to generate knee flexion and extension data. Forceframe testing was used to measure the force generated in isolation of each of those movements. Jumping exercises on the VALD force plate were performed to measure maximum power during three repetitions.

The Inclusion criteria for this study were healthy adults aged 18-30 on a University of Arizona varsity athletic team who were able to provide written informed consent, and provided agreement to have their physical activity objectively measured for physical activity, as well as attendance and participation in intervention.

Exclusion criteria for this study included a history of the use of drugs of abuse (illicit or prescription); having any type of implanted device or adherence/wearing of any electrical device other than a hearing aid; any current medical or musculoskeletal injury that would prohibit athletic participation; allergies to topical adhesives; any significant injuries in the last month prior to the intervention that could potentially impact tested performance measures; and new injuries occurring during the course of the study that could potentially impact the performance measures utilized in the study.

Procedures

Data was collected just prior to first patch use (Day 0) for both the active patch group and control group. Then, data was obtained at three different time points, which were 1 to 24 hrs after baseline, Day 8-11, and 1 to 24 hrs after retest. After completing the study period, subjects crossed over and were re-evaluated using either the 'active' or 'non-active' patch, depending on which group they were initially assigned. Physical fitness assessments providing quantitative data were administered, that enabled identification of isolated neuromuscular changes in specified muscle groups as well as complex neuromuscular pattern performance. These assessments enabled measurements of individual muscle strength (VALD Forceframe) and Force plate measurements of compound movements of the investigational muscle groups and measurements of joint movement capacity (*e.g.*, flexion/extension) and jump capacity/speed. At each follow-up assessment, subjects were asked if they experienced any side effects during the study period.

This study was approved by the Institutional Review Board (IRB) of the University of Arizona. In addition, it was performed in accordance with all Declaration of Helsinki principles, and written Informed Consent was obtained from all research participants prior to enrollment in this study.

Statistical analysis

Normality of data distributions was assessed for all performance outcomes (knee flexion, knee extension, and countermovement jump metrics) using the Shapiro-Wilk Test, stratified by group (active *vs.* placebo) and time (before *vs.* with patch application). A substantial proportion of outcomes violated normality assumptions (mean 74.8% of tests with $P<0.05$; observed P value rang 0.0000-1.0000). Accordingly, all performance analyses were conducted using nonparametric methods: Wilcoxon signed-rank tests for within-group comparisons, Mann-Whitney U Tests for between-group comparisons, and Spearman's rank correlation for associations between continuous variables. All tests were two-tailed with $\alpha=0.05$.

Statistical tests to analyze the collected data included Wilcoxon Signed Ranks Test and Mann-Whitney U Test. Data collected on all 70 participants was analyzed just prior to first patch use (Day 0) to determine mean, median, and mode on each variable, as well as bell curve. Spearman's correlation was generated for all data to distinguish effect size, including comparison of athlete performance and total time with a patch worn.

Results

The overall results showed that the haptic patch was effective in increasing neuromuscular potentiation effect within the context of specific movements such as knee flexion/extension and showed an increase in knee flexion and knee extension results as compared to placebo. Within the Active Patch Group, statistically significant results were shown in knee extension for L Max Force (mean absolute increase of 11.6), R Max Force (mean absolute increase of 10.3), L Avg Force (mean absolute increase of 11.3), R Avg Force (mean absolute increase of 10.2). Comparative results within the Placebo Patch Group were not statistically significant. For Knee Flexion, the Active Patch Group showed statistically significant increases in L Max

TABLE I.—*Power-up outcome comparison between active and control patches for knee extension, knee flexion, and countermovement jump.*

Knee extension	VTT patch	Analysis	Knee Extension	Placebo	Analysis
Left max force	11.6N (+6%)	P=0.007, r=0.32	Left max force	7.3N (+3%)	P=0.867, r=0.02
Right max force	10.3N (+5%)	P=0.037, r=0.25	Right max force	6.6N (+3%)	P=0.247, r=0.14
Left average force	11.3N (+5%)	P=0.002, r=0.38	Left average force	7.0N (+3%)	P=0.317, r=0.12
Right average force	10.2N (+6%)	P=0.001, r=0.42	Right average	8.0N (+4%)	P=0.076, r=0.21
Knee flexion	VTT patch	Analysis	Knee Flexion	Placebo	Analysis
Left max force	19.8N (+7%)	P<0.001, r=0.58	Left Max Force	5.8N (+2%)	P=0.130, r=0.18
Right max force	17.9N (+7%)	P<0.001, r=0.61	Right Max Force	12.8N (+5%)	P=0.002, r=0.38
Left average force	17.5N (+7%)	P<0.001, r=0.57	Left Average Force	6.7N (+3%)	P=0.165, r=0.17
Right average force	19.9N (+8%)	P<0.001, r=0.61	Right Average	15.1N (+6%)	P<0.001, r=0.44
CMJ	VTT patch	Analysis	CMJ	Placebo	Analysis
Jump height [in]	-0.2in (-1.5%)	P=0.086, r=0.21	Jump Height [in]	0.0in (0%)	P=0.737, r=0.04
Concentric peak force Asymmetry [%]	-0.6%	P=0.026, r=0.27	Concentric Peak Force Asymmetry [%]	0.6%	P=0.175, r=0.16
Eccentric peak force [N]	44.8N (+3%)	P=0.005, r=0.34	Eccentric Peak Force [N]	31.7N (+2%)	P=0.017, r=0.28

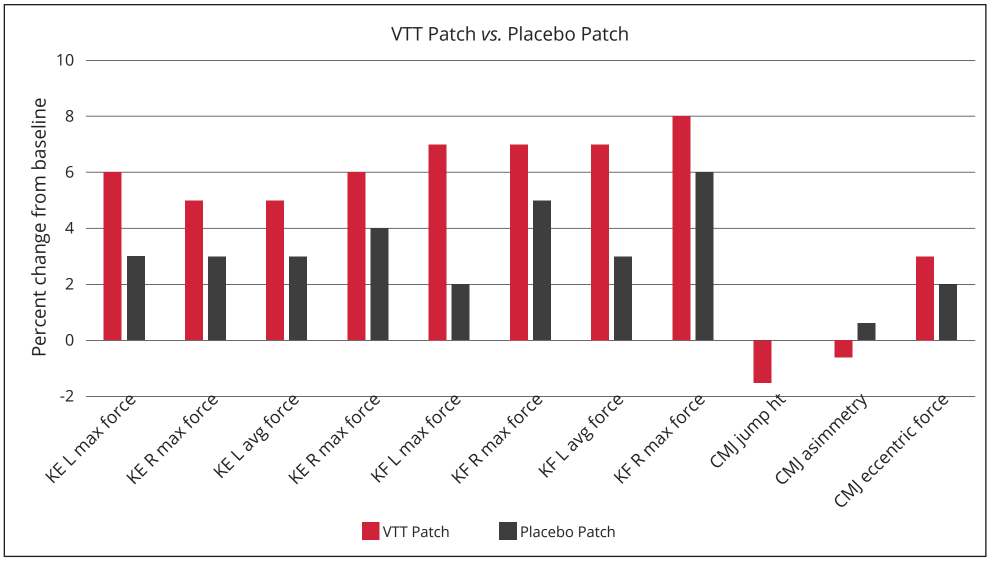

Figure 2.—Percent change from baseline between active and control patch for knee extension (KE), knee flexion (KF), and countermovement jump (CMJ).

Force (mean absolute increase of 19.8, R Max Force (mean absolute increase of 17.9), L Avg Force (mean absolute increase of 17.5), and R Avg Force (mean absolute increase of 19.9). With the exception of R Avg and R Max Force, comparative results for the Placebo Patch Group were not statistically significant (Table I).

Both knee extension and flexion findings on initial post baseline assessment (first follow-up) showed a statistically significant 5-8% increase in max and average forces generated in flexion and extension of either leg, with +2.8% difference between the active-patch group and the placebo group which was not statistically significant (Figure 2). The active patch group showed a statistically significant improvement in isolated knee strength and decrease in CMJ asymmetry, including Eccentric Peak Force and Concentric Peak Force (Asym). Comparative results for the Placebo Patch Group were not statistically significant (Table I).

A small, post-analysis rank correlation (Spearman's $\rho<0.30$) was observed among several outcome measures relating to how long each subject wore their patch prior to measurement. Results indicated that athletes who wore the patch longer prior to evaluation tended to demonstrate slightly greater improvements. The upward trend became the most apparent among those who had worn the patch for roughly 70-80 minutes or more before testing. No side effects were reported amongst the study participants.

Discussion

Athletic teams, including their administrative and coaching staffs, medical teams, and trainers, have many training and treatment options available for use with their athletes in order to prevent, recover, or to improve and maximize performance. These methods may include incorporating strength training, endurance workouts, agility drills, ensuring proper nutrition, as well as mental preparation. Adequate sleep and stress management are also crucial for recovery and overall well-being. When considering what methods to incorporate into their training and treatment regimens, including supplements, coaching staff and clinicians have to be aware of existing anti-doping, alcohol, and drug-screening guidelines and regulations.

An increased understanding of the role and how neural networks in the CNS and PNS respond to tactile sensations may provide the means to improve athletic performance and recovery. Recent research has indicated that haptic technology may be able to influence the neural pathways and enhance peak performance and assist in recovery by resetting the neurofeedback messaging loop that is responsible for balanced messaging pathways.

The promising findings of improved performance across knee flexion and knee extension, especially in the non-dominant leg, may be due to the neurofeedback balancing effects of the haptic patch. The improvement of performance and reduction of asymmetric measurements between dominant and non-dominant legs after placement of the active patch as compared to placebo, have the potential to be the result of the body balancing the targeted muscle groups to be in sync with each other. While more research is necessary to confirm these trends and better define these clinical effects, the results of this study suggest that haptic VTT patches may offer significant benefits to athletes in terms of improved performance, injury prevention or lessened asymmetries between muscle groups.

Limitations of the study

Since study subjects were randomized, blinded, and then were crossed over to receive either "active" or "non-active" patches, data was collected on each subject for both patches, allowing a matched data set amongst all subjects for active and placebo patches. The resulting and compelling outcomes after analysis were very promising. However, the relatively small sample size (70 subjects) may limit the generalizability of our findings. While we observed trends and significant performance improvement favoring the haptic patches in several outcomes, a larger sample could provide more robust statistical power to better elucidate differences between haptic patches, control, and other non-invasive, non-drug, athletic training methods. One study subject inadvertantly received the active patch both times and was excluded from analysis.

Despite its limitations, this study's findings strongly suggest that further research on haptic viobrotactile trigger technolgy is warranted. The promising results of this POWER-UP study indicate that further evaluation of this product across other athletic disciplines would be welcomed.

Conclusions

Incorporating haptic patch use in college athlete and other young adult athlete training programs aimed at improved neuromuscular functioning may be beneficial to improved athletic performance. Haptic patch use within an athletic training program may be an especially useful strategy in athletes who sustained minor injuries preventing participation in their usual daily training regimen to recover lost strength, power, or endurance, as well as college athletes who are attempting to achieve improved performance toward a goal of future professional or nationally-competitive sport play.

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Conflicts of interest
The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.
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Authors' contributions
All authors read and approved the final version of the manuscript.
Congresses
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