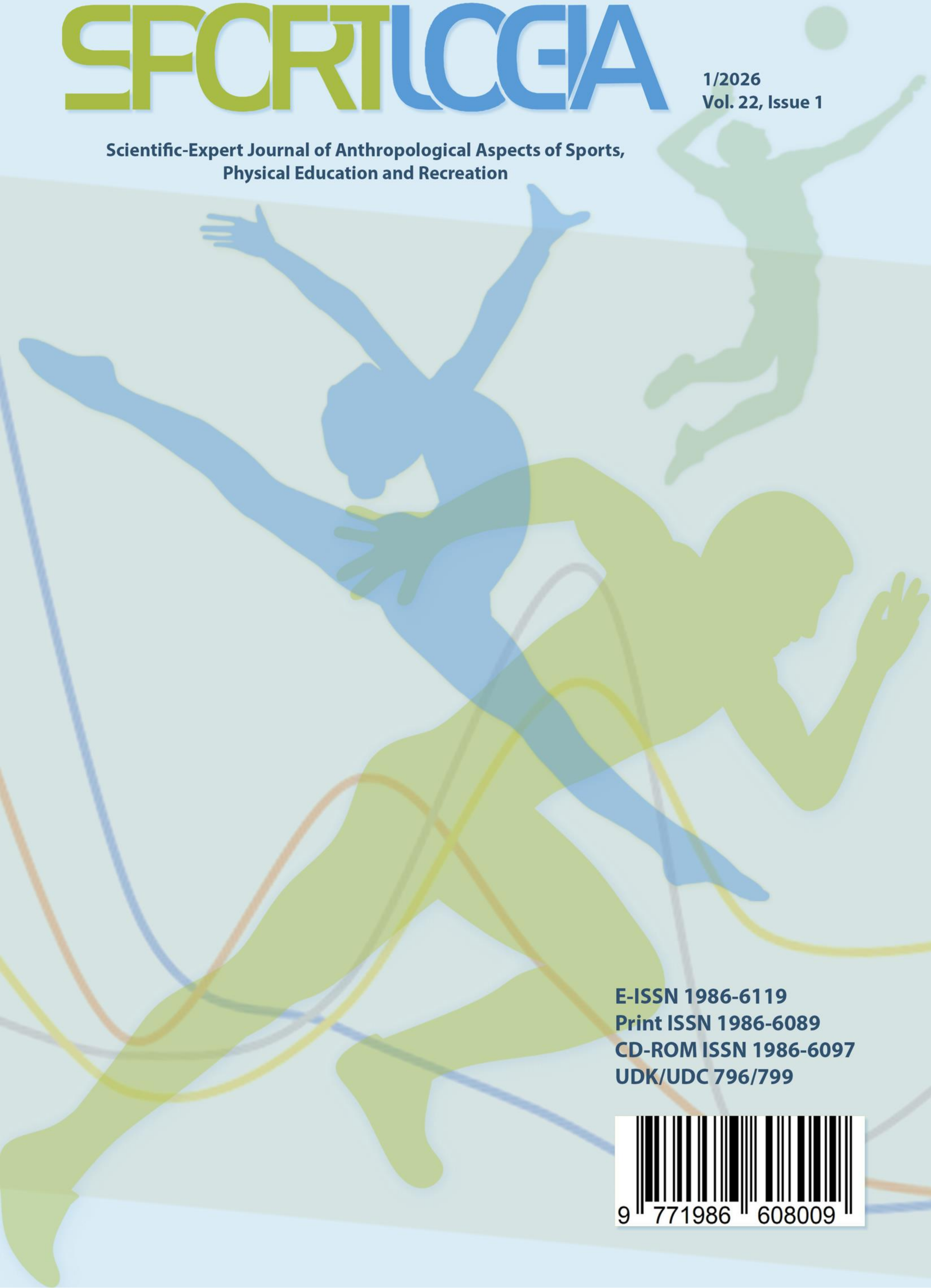
SPORTLOGIA

1/2026
Vol. 22, Issue 1

Scientific-Expert Journal of Anthropological Aspects of Sports, Physical Education and Recreation



E-ISSN 1986-6119
Print ISSN 1986-6089
CD-ROM ISSN 1986-6097
UDK/UDC 796/799

PUBLISHER / IZDAVAČ
University of Banja Luka, Faculty of Physical Education and Sport, Banja Luka, Bosnia and Herzegovina
Univerzitet u Banjoj Luci, Fakultet fizičkog vaspitanja i sporta, Banja Luka, Bosna i Hertegovina

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Web site: https://sportlogia.ffvs.unibl.org/ (full text available free of any charge)

ABSTRACT OR INDEXED-IN:
Cross Ref, Academic Search Premier, CAB Abstracts, EBSCO SPORTDiskus with Fulltext, EBSCOhost Research Databases, Fulltext Sources Online, Cab Global Health, Google Scholar, INASP - International Network for the Availability of Scientific Publication, Open Access Map, Science Gate, WorldCat.

Sportlogia journal (print ISSN 1986-6089, e-ISSN 1986-6119, CD-ROM ISSN 1986-6097) is published two times in one volumen per year till 2014 (every June and December), in one issue per year from 2015 until 2024, and since 2024 again in two issues per year by Faculty of Physical Education end Sports, University of Banja Luka, Bulevar Vojvode Petra Bojovića 1A, 78000 Banja Luka, Bosnia and Herzegovina.

SPORTLOGIA
Scientific-Expert Journal of Anthropological Aspects of Sports, Physical Education and Recreation

Submitted: 03/05/2025
Accepted: 25/12/2025
Online first: 29/12/2026
UDK: 615.84:[537.8:616.314

Original article

The Effects of Pulsed Electromagnetic Field (PEMF) Therapy on Recovery from Strenuous Exercise

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Abstract

This study investigated whether pulsed electromagnetic field (PEMF) therapy enhanced recovery after fatiguing exercise. Thirty recreationally-trained participants were randomly allocated to PEMF (22:32 min:s of PEMF therapy), PLAC (placebo; held device that was not on), or CONT (control) groups. Fatigue was induced by a Yo-Yo running protocol. Recovery interventions were provided after the fatigue protocol (0 hours), and at 24, 48, and 72 hours. Recovery was measured quantitatively by a cycle ergometer peak power (PP) and cadence test, vertical jump, and leg/back dynamometer. These were measured at baseline, and after the interventions from 0-72 hours. Qualitative recovery was measured by visual analogue and Likert scales pre and post intervention. A 3 (group) x 5 (time) repeated measures ANCOVA, with sex as a covariate, derived between-group differences. Change scores relative to baseline were calculated, and analyzed by a 3x4 (0-baseline, 24-baseline, 48-baseline, 72-baseline) repeated measures ANCOVA. Paired samples t-tests compared the qualitative measures pre and post recovery intervention. A 3x8 and 3x4 repeated measures ANCOVA calculated differences in perceived recovery and change scores. There were no significant time by group ANCOVAs for any variable. The PEMF group did have 11-385% greater PP change scores at each time point. There was a significant decrease (p=0.015; d=0.949) in the PEMF group Likert scale score at 72 hours with the qualitative data indicating recovery for this group. Large standard deviations suggested variation in individual responses. Although significant differences were lacking, PEMF therapy may be beneficial for recovery from fatiguing exercise among some individuals.

Keywords: electromagnetic fields, fatigue, Likert scale, muscle soreness, peak power

Citation: Lockie, R.G. et al. (2026). The Effects of Pulsed Electromagnetic Field (PEMF) Therapy on Recovery from Strenuous Exercise. *SportLogia. 22(*1), 1-18. https://doi.org/10.63356/spl.2026.001

Introduction

Athletes use many different approaches to optimize their performance. Strength and conditioning programs, sport-specific skills training, and nutrition are all typically part of an athlete's preparation for competition. Athletes may also adopt other, more novel modalities that could contribute to their physical preparation and recovery to provide an additional advantage. Indeed, recovery from intensive exercise and competition is an essential part of an athlete's preparation. Recovery can be defined as the return to homeostasis of various physiological systems following the metabolic, thermoregulatory, and inflammatory challenges incurred by exercise (Hausswirth & Le Meur, 2011). Optimal recovery is intended to negate the fatigue or damage incurred during intensive exercise, such that the individual may meet or exceed performance in a particular activity (Bishop et al., 2008). Athletes are typically encouraged to utilize strategies that will optimize recovery, as this could assist with physiological adaptations from training, while also allowing the athlete to be more physically prepared for their subsequent training sessions or competition.

Numerous approaches have been advocated to expedite the recovery process, such as stretching, massage, compression, hot and cold water immersion, and electromyostimulation (Barnett, 2006). One example of a more novel approach to enhancing athletic performance is pulsed electromagnetic field (PEMF) therapy. In recent years, several different companies have promoted the use of PEMF therapy (Longoria & Gielen, 2021; Pawluk, 2007). Lockie (2020) provided a review of PEMF therapy specific to strength and conditioning. Pulsed electromagnetic field therapy involves using a device that emits slow frequency electromagnetic currents with an extended range of frequencies that may increase cell membrane permeability and stimulation of many intracellular functions (Abdelhalim et al., 2019). One of the perceived benefits of PEMF therapy is that it is non-invasive and requires no electrode placement, or placement of any other type of invasive device (Hug & Röösli, 2012; Longoria & Gielen, 2021). PEMF therapy has been acknowledged as a safe process (Lisi et al., 2019; Wu et al., 2018), and most PEMF devices will emit a frequency much lower than many other everyday electronic devices. As an example, one commercial PEMF therapy device has a frequency range of 3-11875 hertz (Hz) (HAELO, 2021). This frequency is much lower than that for a television broadcast (54-700 megahertz), cellphone (1.9-2.2 gigahertz), or diagnostic radiation such as magnetic resonance imaging (5-50 exahertz) (National Cancer Institute, 2019). The frequency range for PEMF therapy devices would position them in the non-ionizing radiation part of the electromagnetic spectrum, and frequencies in in this range are not known to directly damage deoxyribonucleic acid (DNA) or cells (National Cancer Institute, 2019). Furthermore, a systematic review of the literature indicated that there were no adverse treatment affects reported across 11 studies that analyzed different PEMF treatments via different clinical applications (e.g., osteoarthritis, fibromyalgia, pain perception, heart rate variability) (Hug & Röösli, 2012). Accordingly, PEMF therapy should provide no more than minimal risk to the user.

Most research utilizing PEMF therapy has focused on clinical applications (Hug & Röösli, 2012). As an example, PEMF therapy has been used to stimulate bone healing as it can stimulate the bone in a similar manner to mechanical loading (Hannouche et al., 2001). As detailed by Hannouche et al. (2001), when a bone is subjected to mechanical stress, strain gradients are created, resulting in pressure gradients in the interstitial fluid. This drives fluid through the canaliculae in the bone from regions of high to low pressure, exposing the osteocyte membranes to flow-related shear stress and streaming electrical potentials (Duncan & Turner, 1995; Hannouche et al., 2001). These streaming potentials could contribute to mechanotransduction, which is the conversion of a biophysical force into a cellular response (Duncan & Turner, 1995). In order to replicate these effects, an exogenous electrical field can be administered at the fracture site (Hannouche et al., 2001). Angiogenesis (creation of new blood vessels controlled by signals from chemicals in the body) and vasodilation (phenomenon in which the blood vessels widen, thus increasing blood flow) can also occur with the use of PEMF therapy (Strauch et al., 2009). Strauch et al. (2009) also suggested that PEMF therapy facilitated the treatment and management of post-surgical wounds, edema, and pain. Research investigating PEMF therapy for athletic populations is lacking, which highlights why work in this area is needed.

Relative to athletic performance, one of the strategies that manufacturers have advocated for PEMF therapy has been to facilitate recovery from intensive exercise (Longoria & Gielen, 2021). The anecdotal recommendations for PEMF therapy in the optimization of recovery from intensive activity have been linked to factors such as improved blood circulation, muscle oxygen uptake, and removal of waste products resulting from exercise (Pawluk, 2007). Other modalities used to enhance recovery also could affect blood circulation. For example, sports massage during the recovery process may stimulate blood circulation that assists with ameliorating the inflammatory response after exercise (Zainuddin et al., 2005). Intermittent pneumatic compression devices are said to assist with blood circulation, which should encourage reabsorption of interstitial tissue swelling to promote healing to injured tissue (Chleboun et al., 1995; Hanson et al., 2013). To provide an example, Hanson et al. (2013) found that 20 minutes of intermittent pneumatic compression in collegiate female athletes led to lower blood lactate levels following a Wingate test (30-second [s] maximal cycling test against a set load) compared to passive or active recoveries. Thus, if PEMF therapy could influence blood circulation, it could be surmised that it may encourage similar positive effects on recovery from exercise as those seen for massage therapy (Zainuddin et al., 2005) and intermittent pneumatic compression (Hanson et al., 2013). A starting point for investigating PEMF therapy would be to ascertain whether performance in high-intensity activities (e.g., actions requiring maximal strength and power) are recovered quicker following bouts with this modality.

There is a lack of research regarding PEMF therapy and recovery from exercise (Tamulevicius et al., 2021). If PEMF therapy is effective in recovering physical performance from high-intensity exercise, there are advantages to this modality. As noted, PEMF therapy has been designed to be non-invasive to the individual (Hug & Röösli, 2012; Longoria & Gielen, 2021), which could be especially useful for athletes. Given the product design (i.e., cords, coils, and mats that can be used when the athlete is sitting or lying down in a training facility or residence) (Longoria & Gielen, 2021), it could be easily utilized by the athlete if evidence suggests it was effective. Nonetheless, Hannouche et al. (2001) has noted that the underlying effects of treatments such as PEMF therapy are not well understood. Therefore, this study investigated whether PEMF therapy could enhance recovery from fatiguing exercise. Recreationally trained college-aged men and women were recruited for this cross-sectional analysis. A specific PEMF therapy device was used in this study (Longoria & Gielen, 2021), and compared to a placebo and a control condition. The recovery interventions were implemented immediately after the fatigue protocol, and 24 hours, 48 hours, and 72 hours post-fatigue protocol (Magrini et al., 2018). It was hypothesized that PEMF therapy would enhance recovery (i.e., a faster return to baseline) from fatiguing exercise as demonstrated by qualitative measures of muscle soreness, and quantitative measures of maximal strength and power.

Methods

Design

A cross-sectional study was used, which has been adopted in other research investigating recovery protocols (Ascensão et al., 2011; Hanson et al., 2013). Participants were randomly allocated to one of three recovery conditions: PEMF therapy (participants sat and received 22:32 minutes:s [min:s] of PEMF therapy while holding a specific device); placebo (participants sat for 22:32 min:s with a device that that was not on, but they were unaware that this was the case); and control (participants were seated for 22:32 min:s with no external device). Due to the variety of variables analyzed in this study, the researchers could not control all variables to ensure all groups were balanced. Rather, block randomization was used (i.e., each group was required to have 10 participants) (Suresh, 2011), and participants were randomly allocated to each group until the capacity of 10 was reached. Fatigue was induced by a 3-stage Yo-Yo fatiguing protocol (Gathercole et al., 2015). Quantitative measures of recovery were provided by a 6-s peak power test on a cycle ergometer;

vertical jump (VJ) performance as a measure lower-body power; and isometric strength as measured by a leg/back dynamometer. Recovery was monitored qualitatively by a visual analogue scale (VAS) and Likert scale to rate muscle soreness. The recovery interventions were provided immediately after the fatigue protocol (0 hours), and 24 hours, 48 hours, and 72 hours post-fatigue protocol. The quantitative measures were taken at baseline (prior to the fatigue protocol), immediately after the 0-hour recovery intervention, and after the recovery interventions at 24 hours, 48 hours, and 72 hours. The qualitative measures were taken prior to and after the recovery intervention on each testing occasion.

Participants

Thirty recreationally-active, college-aged participants (age: 23.70 ± 3.66 years; height: 1.68 ± 0.09 m; body mass: 73.16 ± 14.18 kg), which included 19 men (age: 23.79 ± 3.49 years; height: 1.71 ± 0.09 m; body mass: 79.36 ± 12.68 kg) and 14 women (age: 23.57 ± 4.01 years; height: 1.65 ± 0.10 m; body mass: 64.75 ± 11.83 kg), completed this study. Participants were recruited from the student population at the university via information sessions and word-of-mouth on campus. Inclusion criteria for participants included whether they were recreationally active, having trained in either aerobic or resistance exercise for a minimum of 1 hour at moderate-vigorous intensity 3 times a week for the past year. Participants also were required to free of lower-extremity injury within the past 6 months and not have any other disabilities that influenced study participation. The sample and resulting group sizes were similar to previous research investigating exercise recovery protocols (Ascensão et al., 2011). Participants received and signed a written informed consent detailing the risks and benefits of participation, as well as an overview of the study. They then read and completed a physical activity readiness questionnaire (PAR-Q) prior to their study participation. The institutional review board approved the study (HSR-18-19-586).

Measurements and Procedures

Prior to study participation, participants were instructed not to exercise heavily in the 24 hours before attending the laboratory for all visits. On arrival at the laboratory for the first visit, participants completed the required paperwork (informed consent, PAR-Q). Following this, height was measured barefoot using a portable stadiometer (Detecto, Webb City, MO, USA). Body mass was recorded by electronic digital scales (Ohaus, Parsippany, NJ, USA). The structure of the testing protocol is shown in Figure 1. As stated, participants were randomly allocated into one of three groups via block randomization (Suresh, 2011); PEMF therapy recovery intervention (PEMF); placebo recovery intervention (PLAC); and the control condition (CONT).

Participants completed the same dynamic warm-up prior to each testing session. This warm-up was comprised of cycling for 5 minutes at a power of 100-120 Watts on a cycle ergometer (Wattbike Pro, Nottingham, UK), followed by three bouts of maximal standing-start accelerations for approximately 2 s. Participants then completed approximately 10 minutes of full-body dynamic stretching. The dynamic stretches involved walking lunges, straight leg kicks, hip openers, side lunge with groin stretch, quadruped calf stretch, and leg swings. Performance pre-testing was conducted prior to the fatigue protocol, following procedures adapted from Magrini et al. (2018). Post-testing of these performance measures occurred at 0 hours (immediately after the recovery protocol), 24 hours, 48 hours, and 72 hours post-fatiguing exercise and the recovery protocol. The testing battery was completed in the order presented, with approximately 2 minutes recovery between each test. The qualitative muscle soreness measures were recorded prior to and after the specific recovery protocol completed by each participant. Participants were instructed to not make significant changes in their diet during the four days they were required to be in the laboratory, refrain from intensive lower-body exercise during their study participation, nor take any type of supplementation (e.g., whey protein) or complete any type of other intervention (e.g., massage) that could facilitate their recovery from the fatiguing exercise (Chleboun et al., 1995). Session 1 had a duration of approximately 90-120 minutes. Sessions 2-4 each lasted approximately 40-50 minutes.

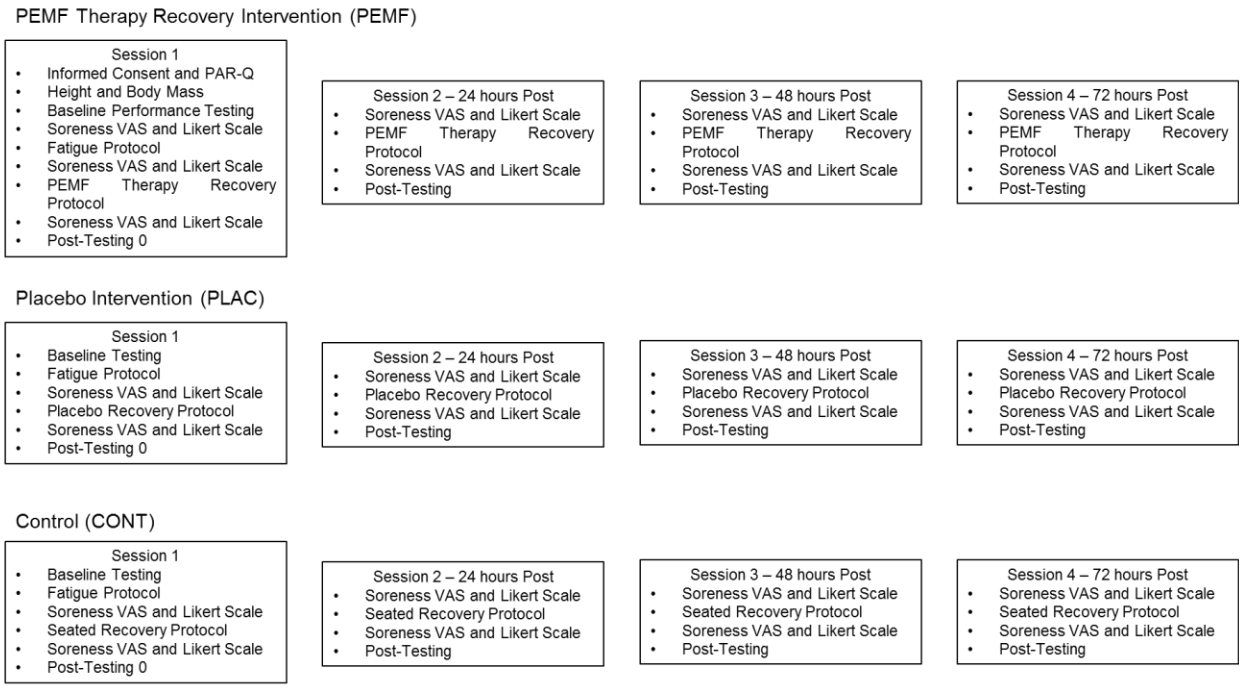

Figure 1. Structure for the study testing protocols for each of the recovery intervention groups (PEMF, PLAC, and CONT).

6-second (s) Peak Power Test

After the dynamic warm-up, the first performance test was the 6-s peak power sprint test performed on a factory-calibrated cycle ergometer (Wattbike Pro, Nottingham, UK). The cycle ergometer used in this study operated with air-braked and magnetically braked systems. A lever regulated the air flow through the flywheel to control air-braked resistance (Levels 1-10), and a turn dial adjusted the magnetically-braked resistance (Levels 1-7). Saddle height was determined relative to each participant such that their knee reached almost full extension (approximately 170°) when the foot was in the bottom position. The fore and aft position of the saddle were aligned so the tip of the knee dropped over the center of the pedal when feet were horizontal. Handlebar height was adjusted to level with the saddle height and handlebar fore and aft position was adjusted so there was an approximate 90° angle between the arms and torso. The feet were secured to the pedals via foot straps. The set-up for each participant was noted such that the same set-up was used for each 6-s sprint test on each testing occasion, with 2 trials performed. The resistance for the 6-s sprint for each participant was based on manufacturer guidelines.

The sprint was initiated from a stationary, seated position, and participants were required to remain seated throughout the test. The test was initiated following a 5 s countdown followed by a firm verbal command, and participants received strong verbal encouragement throughout the 6 s. Test completion was also indicated with a firm verbal command. Participants were instructed to attempt to reach their peak power as quickly as possible. After the first trial, a 60-s active recovery "easy spin" at a self-selected cadence was performed with air-braked and magnetically-braked resistance returned to Level 1 as needed. Following the active recovery, an additional 6-s maximal sprint was performed using the same start position and resistance setting. Peak power (PP) and peak cadence (PC) were recorded for both sprints, with the best sprint used for analysis.

Vertical Jump (VJ)

The VJ was also used to track recovery from fatigue, as eccentric capacity and the stretch-shortening cycle are essential components to jump performance (Magrini et al., 2018). A jump mat (Probotics Inc, Alabama, USA) was utilized to measure jump height and followed established protocols (Magrini et al., 2018). To measure VJ height, the participant initially started on the jump mat. Five successive VJs with countermovement were performed, with 10 s rest allowed between efforts. No restrictions were placed on the depth of the countermovement, but participants were instructed to jump as high and as explosively as possible. VJ height was calculated via the software for the jump mat. VJ height was converted from inches to centimeters then averaged across the five trials.

Isometric Leg/back Dynamometer Strength Test

Following completion of the jumps, participants completed the isometric strength test using a leg/back dynamometer (Fabrication Enterprises, Inc., New York, USA) (Magrini et al., 2018). The dynamometer measurement provided a metric of leg/back isometric maximal strength (LBD). Participants were positioned so that their arms were extended and both hands were on the handle positioned at the mid-thigh (knee flexion angle of approximately 110°). From here, and while maintaining proper spinal alignment and their feet flat on the base, recruits pulled the handle upward as hard as possible by attempting to extend the hips and knees. Participants completed three trials with 60-s rest between attempts. Measurements were taken to the nearest kilogram, with the best trial at each time point used for analysis.

Isometric Leg/back Dynamometer Strength Test

Qualitative measures of muscle soreness were taken at several time points (Figure 1):

- Immediately after the fatigue protocol and before the recovery protocol;
- Immediately after the recovery protocol (0 hours);
- Prior to and after the recovery protocol at 24 hours;
- Prior to and after the recovery protocol at 48 hours; and,
- Prior to and after the recovery protocol at 72 hours.

Two different scales were used. Firstly, a visual analogue scale (VAS) was used, in which a 100-mm (10-cm) line which was anchored at the extremes by "No Soreness" and "Extremely Sore" (Figure 2) (Delextrat et al., 2013). Participants marked the location on the line that best corresponded to their perceived level of soreness, and the distance from the left access was measured to the nearest 1 mm (Delextrat et al., 2013). The second pain/soreness measure was a Likert scale shown in Table 1 (Gibson et al., 2006). Participants checked the corresponding box to their soreness at the time of the respective test.

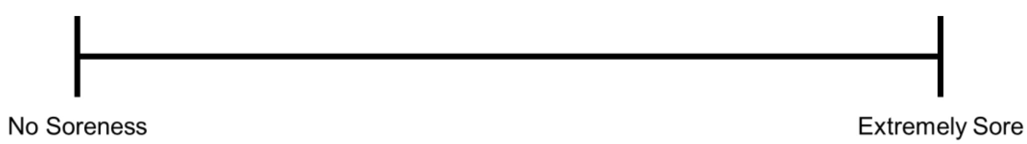

Figure 2. Visual analogue scale for muscle soreness (not to scale) (Delextrat et al., 2013).

Table 1. Modified Likert scale used in muscle soreness assessment (Gibson et al., 2006).

Please check the sentence below that best describes your level of muscle soreness.	
( ) 0	A complete absence of soreness
( ) 1	A light soreness in the muscle/s felt only when touched/a vague ache
( ) 2	A moderate soreness felt inly when touched/a slight persistent pain
( ) 3	A light muscle soreness when walking up and down stairs
( ) 4	A light muscle soreness when walking on a flat surface
( ) 5	A moderate muscle soreness, stiffness, or weakness when walking
( ) 6	A severe muscle soreness, stiffness, or weakness that limits my ability to move

Fatigue Protocol

Following the warm-up and baseline assessment in testing session 1, participants completed the fatigue protocol, which was adapted from Gathercole et al. (2015). A 3-stage Yo-Yo fatiguing protocol (Figure 3) was completed indoors on a basketball court to elicit neuromuscular fatigue. Firstly, Yo-Yo Intermittent Recovery Test 1 (YYIRT1) was performed twice consecutively. Briefly, the YYIRT1 involved repeated 2 x 20 m runs at a progressively increased speed, which was controlled by audio beeps from an iPad handheld device (Apple Inc., Cupertino, California) connected via Bluetooth to a portable speaker (JBL FLIP 5, Los Angeles, CA) located immediately adjacent to the running lane indicated by markers. Between each running bout, the participant had a 10-s rest period in which they were required to move to a cone 5 m away before returning to the start line. The YYIRT1 has four running bouts at 10-13 kilometers per hour ($km \cdot hr^{-1}$), and another seven runs at 13.5-14 $km \cdot hr^{-1}$. Following this, the YYIRT1 continues with stepwise 0.5 $km \cdot hr^{-1}$ speed increments after every eight running bouts until exhaustion. After completing the YYIRT1 twice, participants then completed the Yo-Yo Intermittent Endurance Test Level 1 (YYIET1). This test also featured 2 x 20 m runs at a progressively increased speed but had shorter recovery times of 5 s between shuttles. During this recovery time, participants had to move to a cone 2.5 m away before returning to the start line. The same iPad (Apple Inc., Cupertino, California) and Bluetooth portable speaker (JBL FLIP 5, Los Angeles, CA) were used for the YYIET1. The YYIET1 started at a speed of 8 $km \cdot hr^{-1}$, which then increased by 1 $km \cdot hr^{-1}$ after the first stage, and 1 $km \cdot hr^{-1}$ after the second stage. The test continued with stepwise 0.5 $km \cdot hr^{-1}$ speed increments after every stage until failure.

This study used the Level 1 versions of the YYIRT and YYIET test, which differed from Gathercole et al. (2015) who used the Level 2 versions for each test. However, similar to Gathercole et al. (2015), the purpose of the 3-stage Yo-Yo fatiguing protocol was to elicit fatigue and not measure physiological capacity. In the final stages, participants were encouraged to continue performing each Yo-Yo test regardless of whether shuttle runs were made within the time. Thus, participants volitionally terminated the exercise only once they self-determined they could not continue. In between each of the Yo-Yo tests and after the last one, participants completed 5 minutes of active recovery (i.e., walking without sitting down), and consumed water as required (Gathercole et al., 2015). Following the fatigue protocol, participants completed their recovery intervention and post-testing.

Recovery Procedures

After completion of the fatigue protocol and active cooldown, participants were seated and completed their respective recovery protocol. The timing of when the participants initiated their recovery protocol was adapted from other literature that utilized recovery interventions (Hanson et al., 2013; Robertson et al., 2004), and also followed manufacturer recommendations. For the PEMF group, they utilized a PEMF device (HAELO, Encino, CA, USA) that consisted of a Symphony One unit and magnetic coil (Longoria & Gielen, 2021). The size of the unit was 0.26 m x 0.20 m x 0.08 m, with a mass of approximately 2.5 kg (HAELO, 2021). The device had a frequency range of 3-11875 Hz and a coil rating of 1.01 Ohm (HAELO, 2021). The researcher used an app (HAELO, Encino, CA, USA) to drive the device from their phone, which paired via Bluetooth to the device. A frequency set called ‘Recover’ was utilized, which was recommended by the manufacturer. The exact electromagnetic frequency emitted by the coil during this set was not provided to the researchers for proprietary reasons. Nonetheless, this frequency set was described by the manufacturer thusly: “Deep recovery of muscles, bones, ligaments, and fascia after strenuous workout or competition that typically produces soreness, stiffness, and pain. Supports a quick recovery for regular and consistent routines” (Longoria & Gielen, 2021). Participants held the PEMF device to their chest (as per manufacturer guidelines) while they were seated, and the frequency set had a duration of 22:32 min:s. Following a meta-analysis of the PEMF literature, Wu et al. (2018) recommended exposure durations of ≤30 min for better efficacy in pain relief and recovery of function. Although this meta-analysis by Wu et al. (2018) focused on osteoarthritis, this recommended time frame has application for the current study (especially relative to recovery of pain and muscle soreness).

For the PLAC group, participants held the device to their chest for 22:32 min:s in their recovery protocol, but the device was not turned on and participants were not informed that the device was not on. For the control condition, participants were seated in a chair with no external device for 22:32 min:s, which was the duration of the PEMF therapy protocol. The recovery protocols were also applied at 24 hours, 48 hours, and 72 hours after the fatiguing exercise. This was adapted from previous research that applied intermittent pneumatic compression for several days after a fatiguing exercise intervention (Chleboun et al., 1995). Manufacturer guidelines also encouraged multiple applications of the 'Recover' frequency set, so this was incorporated into the study.

Statistical Analyses

Statistical analyses were processed using the Statistics Package for Social Sciences (SPSS) Version 29.0 (IBM Corporation, New York, USA). Normality of the data was evaluated by the Shapiro-Wilk test and visual analysis of stem-and-leaf plots. If a variable was not normally distributed, extreme outliers (variables identified as being 3 box lengths outside of the box in the plot) were treated via a Winsorization process (Lien & Balakrishnan, 2005). Descriptive statistics (mean ± standard deviation [SD]) were calculated for each variable. A one-way analysis of variance was used to compare age, height, and body mass of the groups. For the analyses of the recovery protocols, Sex was used as a covariate for all repeated measures analysis of covariance (ANCOVA) calculations, with significance set *a priori* at $p < 0.05$. If a significant interaction between the groups was found for any part of the statistical analysis, a Bonferroni adjustment was applied for post hoc comparisons. For the quantitative measures (PP, PC, VJ, and LBD), a 3 (PEMF, PLAC, CONT) x 5 (baseline, 0 hours, 24 hours, 48 hours, 72 hours) repeated measures ANCOVA derived any differences between the recovery interventions. Change scores were also calculated as the difference between the post-test at the different time points relative to baseline data. The change scores were analyzed by a 3 (PEMF, PLAC, CONT) x 4 (0-baseline, 24-baseline, 48-baseline, 72-baseline) repeated measures ANCOVA.

For the qualitative measures (VAS and Likert scale), normality of the data was also evaluated by the Shapiro-Wilk test and visual analysis of stem-and-leaf plots. As will be detailed, the majority of the qualitative data was not normally distributed. There can be a tendency for scale data, such as for the VAS and Likert scales, to not have normal distribution (Jamieson, 2004). However, Norman (2010) has argued that parametric statistics can be used on ordinal data derived from Likert scales. Furthermore, ANCOVAs can be robust to data normality violations (Olejnik & Algina, 1984). Thus, parametric statistics were still used in the qualitative data analysis. Paired samples t-tests were firstly used to ascertain whether there were significant changes in perceived recovery prior to and after each session's intervention. Effect sizes (d) were calculated for the pre- and post-recovery intervention values within each session, where the difference between the means was divided by the pooled SD. A d less than 0.2 considered a trivial effect; 0.2 to 0.6 a small effect; 0.6 to 1.2 a moderate effect; 1.2 to 2.0 a large effect; 2.0 to 4.0 a very large effect; and 4.0 and greater an extremely large effect (Hopkins, 2004).

Following this, a 3 (PEMF, PLAC, and CONT) x 8 (baseline, 0 hours, 24 hours pre, 24 hours post, 48 hours pre, 48 hours post, 72 hours pre, 72 hours post) repeated measures ANCOVA was used to calculate changes in perceived recovery across the interventions. Lastly, change scores were calculated within each session for the qualitative measures to ascertain whether a greater magnitude of change for perceived recovery was present for any intervention. A 3 (PEMF, PLAC, and CONT) x 4 (0 hours-baseline, 24 hours post-pre, 48 hours post-pre, 72 hours post-pre) repeated measures ANCOVA was adopted for this part of the analysis.

Results

All PP, PC, VJ, and LBD data were normally distributed (p = 0.117-0.779). The change scores at 24 hours relative to baseline, PC48-baseline, LBD48-baseline, and PC72-baseline were not normally distributed ($p \leq$ 0.011). Once the extreme outliers were treated, all change score variables were normally distributed (p = 0.052-0.846). There were no significant differences in age, height, and body mass between the groups (Table 2), despite the CONT group having more women than the other two groups due to random allocation. Descriptive data for the quantitative measures are displayed in Table 3, while the change scores for PP, PC, VJ, and LBD are shown in Figure 3.

Table 2. Descriptive (mean ± SD) data for age, height, and body mass for college aged men and women allocated to the pulsed electromagnetic therapy (PEMF), placebo (PLAC), or control (CONT) recovery conditions groups.

	PEMF (7 men, 3 women)	**PLAC (7 men, 3 women)**	**CONT (4 men, 6 women)**
Age (years)	23.10 ± 3.54	25.20 ± 4.54	22.70 ± 3.34
Height (m)	1.65 ± 0.10	1.70 ± 0.05	1.71 ± 0.12
Body Mass (kg)	70.70 ± 12.34	77.29 ± 13.44	74.93 ± 17.62

Table 3. Descriptive (mean ± SD) data for peak power (PP), peak cadence (PC), vertical jump (VJ), and leg/back dynamometer (LBD) strength recorded at baseline, and immediately after (0 hours), 24 hours, 48 hours, and 72 hours post-fatiguing protocol for college aged men and women who received pulsed electromagnetic therapy (PEMF), a placebo (PLAC), or control (CONT) recovery conditions.

	PEMF (*n* = 10)	**PLAC (*n* = 10)**	**CONT (*n* = 10)**	**All (*N* = 30)**
PP Baseline (watts)	927.25 ± 296.28	910.70 ± 244.00	887.75 ± 345.80	908.57 ± 288.28*
PP0 (watts)	884.85 ± 285.55	871.40 ± 213.37	831.05 ± 301.12	862.43 ± 260.99
PP24 (watts)	1005.45 ± 311.03	959.90 ± 248.97	899.05 ± 310.21	954.80 ± 284.76*
PP48 (watts)	996.10 ± 304.28	943.60 ± 217.64	947.00 ± 331.86	962.23 ± 279.66*§
PP72 (watts)	997.25 ± 309.12	964.10 ± 204.66	911.90 ± 277.73	957.75 ± 260.52*§
PC Baseline (revolutions)	148.10 ± 16.86	141.00 ± 15.79	136.80 ± 12.68	141.97 ± 15.43
PC0 (revolutions)	148.55 ± 17.06	139.10 ± 14.88	135.15 ± 10.56	140.93 ± 15.04
PC24 (revolutions)	152.85 ± 19.93	145.15 ± 17.65	139.40 ± 11.02	145.80 ± 17.00*
PC48 (revolutions)	152.25 ± 16.83	147.75 ± 17.96	141.55 ± 10.58	147.18 ± 15.58*§
PC 72 (revolutions)	151.45 ± 16.33	142.14 ± 20.49	140.15 ± 9.85	144.58 ± 16.38
VJ Baseline (cm)	47.22 ± 12.40	38.16 ± 7.73	38.84 ± 9.78	40.74 ± 10.86
VJ0 (cm)	45.42 ± 11.91	37.34 ± 7.28	36.04 ± 9.37	39.60 ± 10.27
VJ24 (cm)	50.25 ± 12.10	39.54 ± 6.51	35.81 ± 9.93	41.87 ± 11.31
VJ48 (cm)	46.20 ± 11.19	40.48 ± 7.45	37.70 ± 10.50	41.46 ± 10.16
VJ72 (cm)	46.74 ± 12.33	40.94 ± 7.66	37.29 ± 8.96	41.66 ± 10.29
LBD Baseline (kg)	125.07 ± 30.96	136.99 ± 38.45	120.52 ± 30.67	127.53 ± 33.14
LBD0 (kg)	122.48 ± 36.76	137.98 ± 38.99	123.69 ± 28.38	128.05 ± 34.53
LBD24 (kg)	144.07 ± 57.88	145.58 ± 36.79	130.13 ± 34.81	139.93 ± 43.42
LBD48 (kg)	137.63 ± 50.30	138.96 ± 34.81	133.31 ± 37.94	136.63 ± 40.17
LBD72 (kg)	135.24 ± 39.60	150.79 ± 43.62	134.69 ± 36.43	140.24 ± 39.33

* Significantly different from 0 hours.
§ Significantly different from baseline.

For PP, the main effect of time was significant ($F_{(4,23)}$ = 7.169, p < 0.001, ηp^2 = 0.555). The time by group ANCOVA ($F_{(8,48)}$ = 1.007, p = 0.443, ηp^2 = 0.144) and main effect between groups ($F_{(2,26)}$ = 0.699, p = 0.506, ηp^2 = 0.051) were not significant. Across all groups, PP0 was significantly lower than PP at all other times ($p \leq$ 0.003). Baseline PP was significantly lower than PP48 (p = 0.007) and PP72 (p = 0.010). For the PP change scores, the main effect of time was significant ($F_{(3,24)}$ = 7.374, p < 0.001, ηp^2 = 0.512). Across the groups, PP0-baseline difference was significantly (p < 0.001) lower than PP differences compared to baseline at 24, 48, and 72 hours. The time by group ANCOVA ($F_{(6,50)}$ = 0.909, p = 0.496, ηp^2 = 0.098) and main effect between groups ($F_{(2,26)}$ = 1.407, p = 0.263, ηp^2 = 0.098) were not significant. Although it was not significant, the PEMF group had a magnitude of change that was 11-385% greater at 24 hours, 16-109% greater at 48 hours, and 31-190% greater at 72 hours.

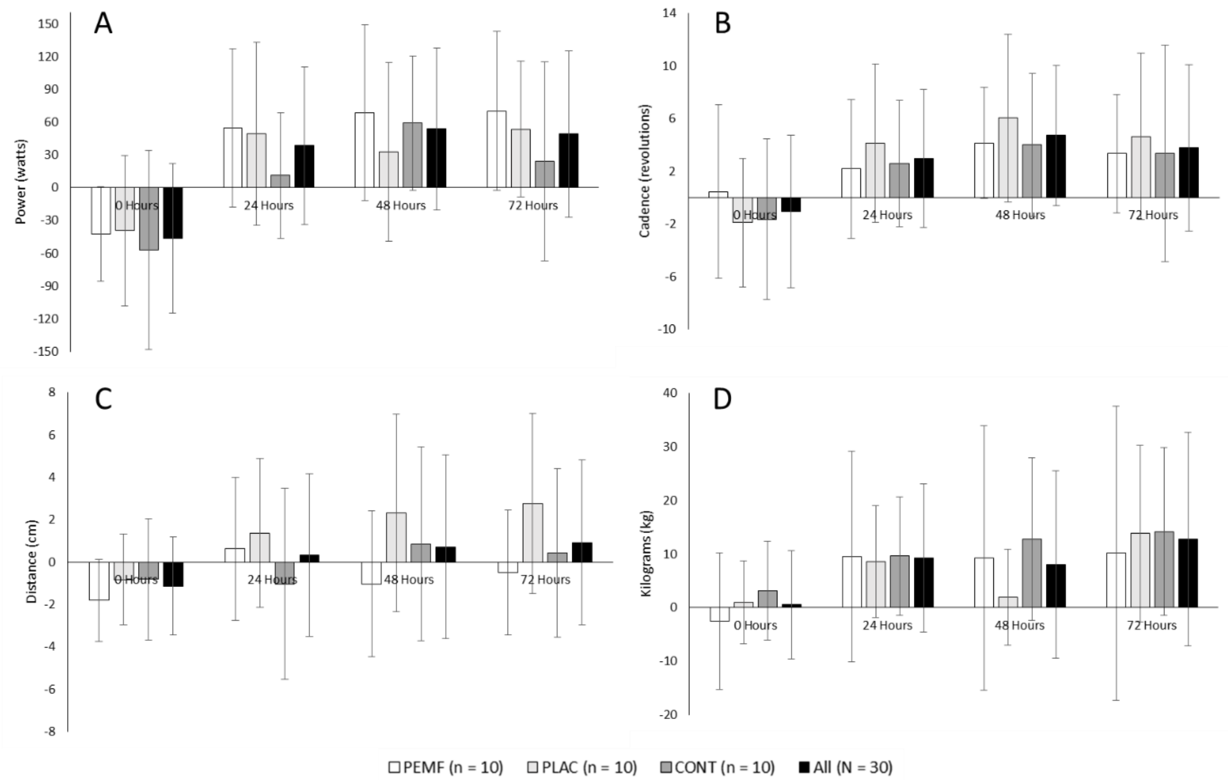

Figure 3. Descriptive (mean ± SD) data for change scores relative to baseline for peak power (A), peak cadence (B), vertical jump (C), and leg/back dynamometer strength (D) recorded at 0 hours, 24 hours, 48 hours, and 72 hours post-fatiguing protocol for college aged men and women who received pulsed electromagnetic therapy (PEMF), a placebo (PLAC), or control (CONT) recovery conditions.

For PC, the main effect of time was significant ($F_{(4,23)}$ = 4.355, p = 0.009, ηp^2 = 0.431). The time by group ANCOVA ($F_{(8,48)}$ = 0.569 p = 0.798, ηp^2 = 0.087) and main effect between groups ($F_{(2,26)}$ = 1.189, p = 0.321, ηp^2 = 0.084) were not significant. Across the groups, PC0 was significantly lower than PC24 (p = 0.002) and PC48 (p < 0.001). Baseline PC was significantly lower than PP48 (p = 0.002). With regards to the change scores, there was a significant main effect for time ($F_{(3,24)}$ 5.356, p = 0.006, ηp^2 = 0.401). The difference compared to baseline at 0 hours was significantly (p < 0.001) lower than at 24, 48, and 72 hours across all groups The time by group ANOVA ($F_{(6,50)}$ = 0.932, p = 0.481, ηp^2 = 0.101) and main effect between groups ($F_{(2,26)}$ = 0.376, p = 0.690, ηp^2 = 0.028) were not significant.

For the VJ, the main effect of time ($F_{(4,23)}$ = 0.854, p = 0.506, ηp^2 = 0.129), time by group ANCOVA ($F_{(8,48)}$ = 1.218, p = 0.309, ηp^2 = 0.169), and main effect between groups ($F_{(2,26)}$ = 3.381, p = 0.050, ηp^2 = 0.206) were not significant. Regarding the change scores, the main effect of time ($F_{(3,24)}$ = 1.144, p = 0.352, ηp^2 = 0.125), time by group ANCOVA ($F_{(6,50)}$ = 1.797, p = 0.119, ηp^2 = 0.177), and main effect between groups ($F_{(2,26)}$ = 1.075, p = 0.356, ηp^2 = 0.076) were not significant.

Regarding the LBD, the main effect of time ($F_{(4,23)}$ = 1.085, p = 0.387, ηp^2 = 0.159), time by group ANCOVA ($F_{(8,48)}$ = 0.939, p = 0.494, ηp^2 = 0.135), and main effect between groups ($F_{(2,26)}$ = 0.622, p = 0.545, ηp^2 = 0.046) were not significant. That same was true for the LBD change scores. The main effect of time ($F_{(3,24)}$ = 1.332, p

= 0.287, $\eta p^2 = 0.143$), time by group ANCOVA ($F_{(6,50)} = 1.119$, $p = 0.365$, $\eta p^2 = 0.118$), and main effect between groups ($F_{(2,26)} = 0.400$, $p = 0.674$, $\eta p^2 = 0.030$) were not significant. Although not significant, it was notable that the PEMF group did have the highest magnitude for their change scores at 24 hours post-fatiguing activity, with a difference of 21-54% compared to the PLAC and CONT groups.

Only two of 12 VAS variables were normally distributed (0-baseline $p = 0.108$; VAS Pre at 48 Hours $p = 0.624$); all other variables were not normally distributed ($p \leq 0.037$). All Likert scale variables were not normally distributed ($p \leq 0.043$). However, as previously stated parametric statistics were still used for qualitative data analysis (Norman, 2010; Olejnik & Algina, 1984), and data was presented as mean ± SD. The pre- and post-recovery session comparisons for the VAS and Likert scales is shown in Table 4. There were few significant results for any of the groups when comparing pre and post recovery intervention data. There was a significant decrease, with a moderate effect, in the Likert scale score for the PEMF group 72 hours after the fatiguing protocol, which suggested a positive effect of the intervention on recovery. There was also a significant decrease in the Likert scale score 24 hours after the fatiguing protocol for the CONT group, which had a moderate effect. What is worth noting is that for the PEMF groups, even though the effects were typically small, post VAS or Likert scale score was always lower than the pre value for the 24, 48, and 72 hour measures. This cannot be said for the PLAC and CONT groups.

Table 4. Descriptive (mean ± SD) data for pre- and post-recovery intervention for the visual analogue scale (VAS) and Likert scale immediately after (0 hours), 24 hours, 48 hours, and 72 hours post-fatiguing protocol for college-aged men and women who received pulsed electromagnetic therapy (PEMF), a placebo (PLAC), or control (CONT) recovery conditions.

	PEMF (*n* = 10)				PLAC (*n* = 10)				CONT (*n* = 10)			
	Pre	Post	*p*	*d*	Pre	Post	*p*	*d*	Pre	Post	*p*	*d*
VAS												
Baseline-0	2.65 ± 1.44	3.28 ± 2.00	0.366	0.301	1.80 ± 1.97	1.78 ± 1.63	0.930	0.029	2.78 ± 1.99	2.85 ± 1.67	0.873	0.052
24 Hours	2.93 ± 1.66	2.90 ± 1.40	0.954	0.019	2.23 ± 1.81	1.88 ± 1.40	0.343	0.316	1.44 ± 0.52	1.43 ± 0.61	0.969	0.013
48 Hours	2.23 ± 1.60	1.88 ± 1.22	0.105	0.569	1.95 ± 1.30	1.75 ± 1.16	0.280	0.363	1.65 ± 1.29	1.35 ± 1.29	0.394	0.283
72 Hours	2.73 ± 2.41	2.46 ± 2.50	0.128	0.531	1.10 ± 1.37	1.00 ± 0.85	0.779	0.091	2.05 ± 0.60	1.95 ± 0.64	0.555	0.194
Likert												
Baseline-0	2.50 ± 1.65	2.40 ± 1.84	0.832	0.069	1.70 ± 1.77	2.00 ± 1.15	0.496	0.224	1.30 ± 1.16	1.49 ± 1.63	0.604	0.170
24 Hours	2.30 ± 1.06	1.90 ± 0.88	0.223	0.414	2.30 ± 1.70	1.90 ± 1.37	0.343	0.316	2.00 ± 1.25	1.30 ± 0.68*	0.025	0.850
48 Hours	1.90 ± 1.20	1.79 ± 1.34	0.343	0.316	1.90 ± 1.37	2.00 ± 1.25	0.832	0.069	1.60 ± 1.35	1.60 ± 0.97	1.000	0.000
72 Hours	2.00 ± 1.63	1.50 ± 1.65*	0.015	0.949	1.40 ± 1.17	1.40 ± 1.17	1.000	0.000	1.20 ± 0.42	1.60 ± 0.84	0.223	0.414

* Significantly ($p < 0.05$) different from the session pre-recovery protocol value.

When comparing the qualitative measures across the groups for all the time points, there was a general trend for the qualitative measures to all decrease over time. Nonetheless, the main effect of time ($F_{(7,20)} = 0.667$, $p = 0.697$, $\eta p^2 = 0.189$), time by group ANCOVA ($F_{(14,42)} = 0.983$, $p = 0.486$, $\eta p^2 = 0.247$), and main effect between groups ($F_{(2,26)} = 2.271$, $p = 0.123$, $\eta p^2 = 0.149$) were not significant for the VAS (Figure 4A). This was also the case for the Likert scale data (Figure 4B). The main effect of time ($F_{(7,20)} = 1.704$, $p = 0.165$, $\eta p^2 = 0.374$), time by group ANCOVA ($F_{(14,42)} = 0.939$, $p = 0.528$, $\eta p^2 = 0.238$), and main effect between groups ($F_{(2,26)} = 1.052$, $p = 0.364$, $\eta p^2 = 0.075$) were not significant.

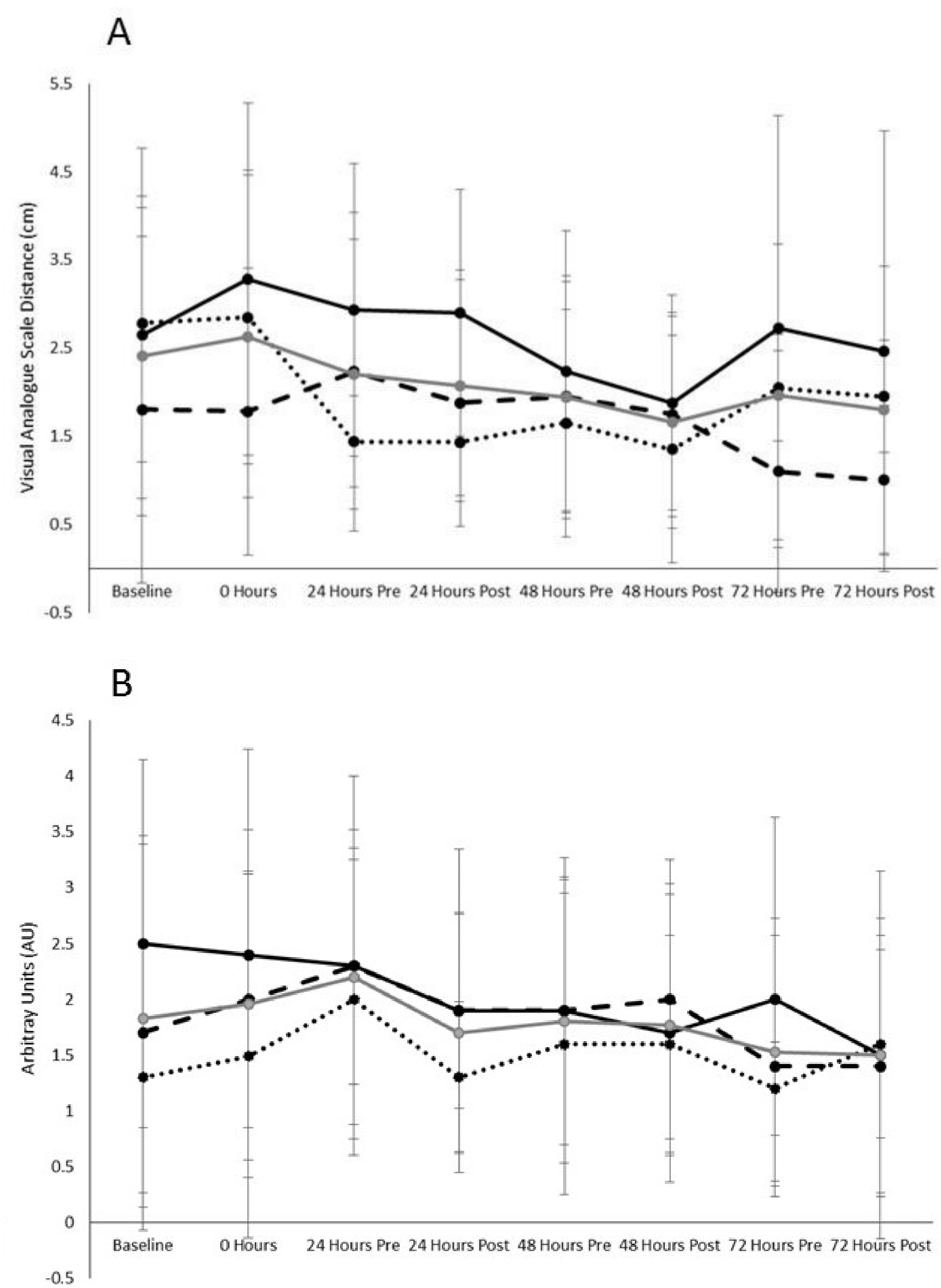

Figure 4. Descriptive (mean ± SD) data for visual analogue scale (VAS; A) and Likert scale (B) values recorded at baseline, immediately after the first recovery protocol (0 hours), and pre- and post-recovery protocol 24 hours, 48 hours, and 72 hours post-fatiguing protocol for college aged men and women who received pulsed electromagnetic therapy (PEMF), a placebo (PLAC), or control (CONT) recovery conditions.

Change score data relative to the baseline for the VAS and Likert scale is shown in Figure 5. A negative value indicates less fatigue and soreness and better recovery. For the VAS change scores in each testing day (Figure 5A), the main effect of time ($F_{(3,24)}$ = 0.121, p = 0.947, ηp^2 = 0.015), time by group ANCOVA ($F_{(6,50)}$ = 0.373, p = 0.893, ηp^2 = 0.034), and main effect between groups ($F_{(2,26)}$ = 0.167, p = 0.847, ηp^2 = 0.013) were not significant. This was also the case for the Likert scale (Figure 5B); the main effect of time ($F_{(3,24)}$ = 2.810, p = 0.061, ηp^2 = 0.260), time by group ANCOVA ($F_{(6,50)}$ = 1.273, p = 0.286, ηp^2 = 0.133), and main effect between groups ($F_{(2,26)}$ = 1.209, p = 0.315, ηp^2 = 0.085) were not significant. Although not significant, what was notable was that the PEMF had VAS and Likert scale scores that indicated recovery at 24, 48, and 72 hours, with 165-225% differences for both scales at 72 hours post-fatiguing protocol.

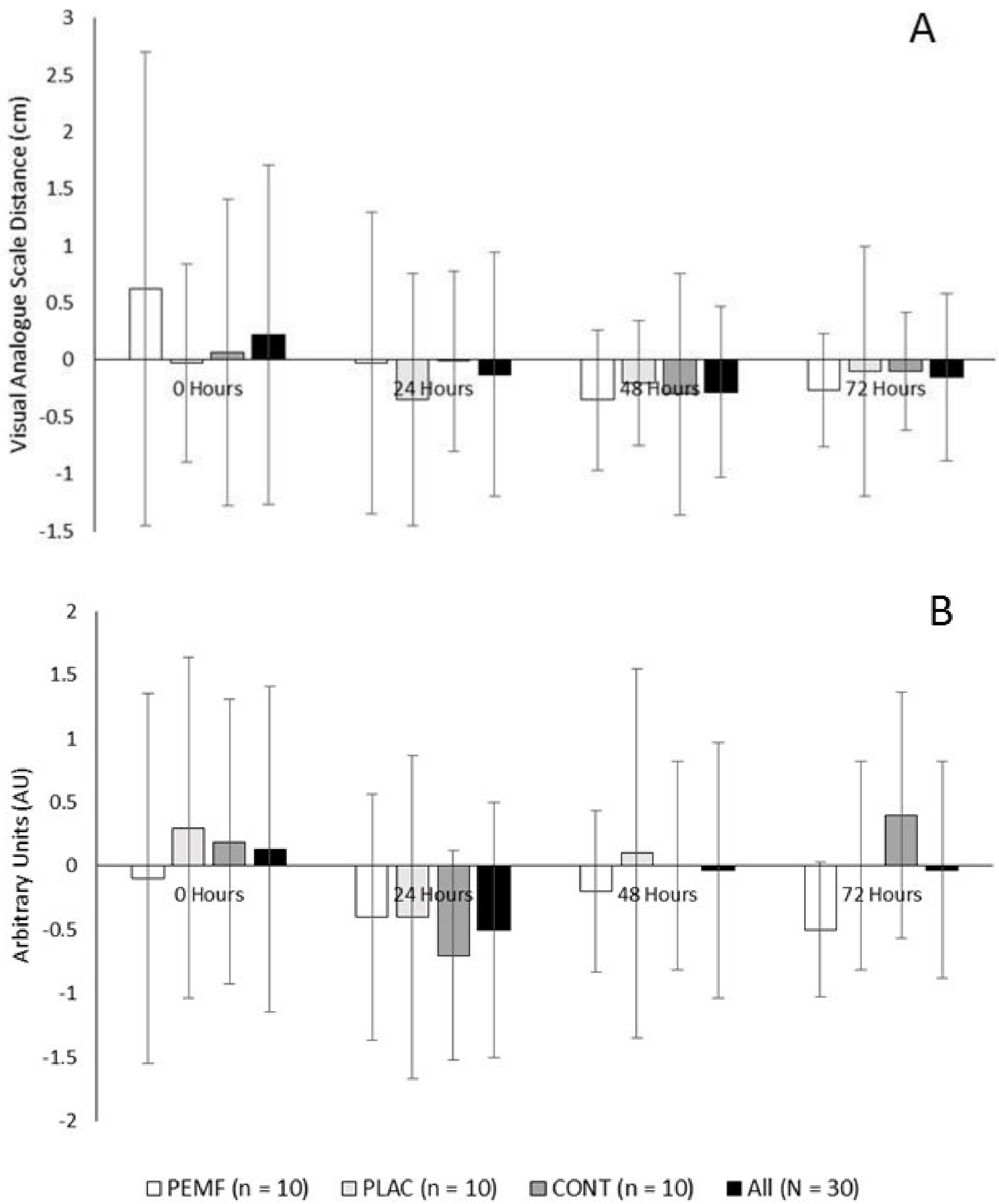

Figure 5. Descriptive (mean ± SD) data for change scores within each session for visual analogue scale (VAS; A) and Likert scale (B) values recorded at 0 hours, 24 hours, 48 hours, and 72 hours post-fatiguing protocol for college aged men and women who received pulsed electromagnetic therapy (PEMF), a placebo (PLAC), or control (CONT) recovery conditions.

Discussion

The purpose of this investigation was to determine if using PEMF therapy following a fatiguing exercise protocol led to enhanced improved recovery when compared to a placebo and control group. It was hypothesized that PEMF therapy would enhance recovery from fatiguing exercise as demonstrated by quantitative measures of maximal strength and power (6-s cycling test PP and PC, VJ height, and LBD) and qualitative measures of muscle soreness (VAS and Likert scale scores). These hypotheses were generally not supported, as significant differences were not discovered between the treatments. However, larger, non-significant improvements in PP from a 6-s cycling sprint test were found for the PEMF group at 24, 48, and 72 hours. Additionally, although not significant, the qualitative measures (VAS and Likert scale) indicated recovery post-intervention at each time point, with a significant decrease in Likert scale score from pre- to post-intervention at 72 hours. While the current results were not statistically significant, these small changes in performance and perceived recovery may mean the difference in more effective training, in addition to success in competition and should not be quickly dismissed. This is especially true considering the small margins that could dictate athletic success at different levels of competition (Hall et al., 2012).

As stated, the results from this study indicated no significant differences between the recovery protocols in this study. Previous research has shown non-significant effects of recovery from different interventions, including massage (Robertson et al., 2004), stretching (Torres et al., 2013), and pneumatic compression (Overmayer & Driller, 2018), and there has been some skepticism in the literature as to the benefits of PEMF therapy in clinical environments (Wade, 2013). However, for PP measured during the 6-s cycling sprint test, the PEMF group exhibited greater change scores compared to the PLAC and CONT groups; 11-385% greater at 24 hours, 16-109% greater at 48 hours, and 31-190% greater at 72 hours. As recovery is the return to homeostasis of various physiological systems following the challenges incurred by exercise (Hausswirth & Le Meur, 2011), the data could indicate the PEMF group was experiencing a greater positive change in PP relative to baseline following the intervention. While not measured in this study, there are physiological mechanisms associated with PEMF therapy which could benefit recovery. Angiogenesis (creation of new blood vessels) and vasodilation (widening of blood vessels) occur with the use of PEMF therapy (Strauch et al., 2009). The use of PEMF therapy can cause a rise the structural integrity of the extracellular matrix of bone and cartilage, thus enhancing repair and alteration of the homeostatic balance (Peng et al., 2021). Previous research has suggested that PEMF therapy could positively influence ventilatory threshold in endurance runners across six running sessions (Tamulevicius et al., 2021). The results from this study suggest PP could be positively influenced by PEMF therapy during the 72 hours post-fatiguing exercise.

Although not significant, the relatively large percentage differences in change scores should not be quickly dismissed. Peak power in this study is derived from the formula: *force x (distance/time)*. Force and movement speed are clearly important for athletes across a range of sports. Any intervention that could encourage the faster restoration of these variables, especially within the context of time between training sessions and competition, would be invaluable for athletes. For example, the marginal gains theory postulated by Sir Dave Brailsford stated that making small improvements in a number of areas for an athlete can cumulatively lead to greater success (Hall et al., 2012). Small improvements in performance because of expedited recovery could be essential for an athlete whose margins for victory can be in the hundredths of seconds. Indeed, adequate recovery can result in the restoration of physiological and psychological processes so the athlete can meet or exceed performance in a particular activity (Bishop et al., 2008). It is plausible that PEMF therapy could be incorporated into an athlete's recovery regime and may be able to contribute to the improvements in performance following training or competition that are necessary for success.

Nonetheless, there were no discernible differences between the groups for PC from the cycling test, the VJ, and LBD, at any of the time points or for the change scores. What could have impacted the VJ and PBD, especially in light of the PP results and non-significant time course changes from baseline to 72 hours, was that rate of force development was not considered in these measures. For example, an individual may modify their VJ technique when fatigued to attain the same jump height (i.e., spending more time in the eccentric phase to generate force, resulting in a slower rate of force development but same resulting jump height)

(McMahon et al., 2018). The same could be also true for the LBD, where the time to achieve the maximal force output does not incorporate a time measurement (Magrini et al., 2018). It is a limitation of the current study where a force plate was not available to measure the VJ and LBD. Accordingly, future PEMF therapy research should incorporate force plates when measuring the VJ and a maximal isometric pull following a fatiguing protocol. Even though the absolute measure of jump height and maximal strength may not have a different recovery path compared to a placebo or control conditions, variables such as contraction time during a VJ (McMahon et al., 2018), and the rate of force development during a maximal pull (Haff et al., 2015), could exhibit different results.

As for the quantitative measures, there were no significant between-group differences for the VAS and Likert scale scores. There was a significant decrease in Likert scale score from pre to post intervention for the CONT group at 24 hours and for the PEMF group at 72 hours. Notably, and although not significant, the PEMF group was the only group to have decreases in their VAS or Likert scale scores from pre- to post-recovery intervention at all time points. These data would suggest that there was some perceived reduction in muscle soreness following the intervention. Delayed onset muscle soreness (DOMS) is the sensation of muscle pain or tenderness that generally develops 24 hours after exercise (Zainuddin et al., 2005). While DOMS is a complex phenomenon (Connolly et al., 2003), from an athlete's perspective it will negatively impact their ability to train. Following a review of literature, Connolly et al. (2003) noted that strength loss usually peaks immediately after exercise or within the first 48 hours, while pain and tenderness peaks 24-72 hours after exercise. While time and rest should influence the DOMS experienced by an individual (in part shown by the CONT group's significant result), PEMF therapy could help expedite this process for some individuals. To provide support to this theory, PEMF therapy has been used in the treatment of low back pain (Elshiwi et al., 2019; Lisi et al., 2019). A PEMF therapy treatment protocol that involved twice daily, 30-minute sessions for six weeks, followed by 30-minute sessions completed 2-3 times per week for the next six weeks, led to a decrease in pain measured by a VAS, and an improvement in low back function measured by the Oswestry Disability Index (Lisi et al., 2019). Elshiwi et al. (2019) found that 12 PEMF therapy sessions over four weeks led to a significant decrease in pain intensity measured by a VAS and improved low back function and range of motion in participants diagnosed clinically with chronic non-specific low back pain. The afore-mentioned studies did not measure any mechanisms for how pain could have been reduced, but there were suggestions that analgesia and other neurological adaptations, reduced inflammatory response, and anabolic effects on osteoblasts and chondrocytes could have contributed to reduced perception of low back pain (Elshiwi et al., 2019; Lisi et al., 2019). Although low back pain and muscle soreness are different, these studies do provide a foundation for why the PEMF group in the current study may have indicated lower VAS and Likert scale scores following their recovery treatment. Even with the non-significant results, the data does suggest potential value for using PEMF therapy in the reduction of perceived muscle soreness.

There were large standard deviations for many of the quantitative and qualitative measures across the three groups, indicating variation in individual responses to the recovery interventions. Following a review of PEMF therapy literature, Lockie (2020) also noted that this was the case in the clinical application of this technique, such as with the treatment of bone fractures. This would suggest that some individuals may be high or low responders to the PEMF device, in addition to the placebo and control conditions. Recognizing how the individual responds to a particular intervention is an important part of a strength and conditioning coaches' skillset. Anecdotally, some adverse reactions to PEMF therapy have been said to include fatigue, sleep pattern changes, pain, loss of energy, prickly sensations in the skin, dizziness, and heart palpitations (Pawluk, 2007). None of the participants in the PEMF group from this study reported any adverse reactions. Even though the frequencies associated with PEMF therapy should have no negative effects on human health (Wade, 2013), Lockie (2020) recommended that any negative experiences for athletes should be detailed, so coaches should do so with their athletes if they use this protocol. Positive experiences for athletes with PEMF therapy should also be documented by coaches. The results from this study suggest that some individuals will respond well to EPMF therapy in the 72 hours post-fatiguing exercise. For these individuals, PEMF therapy could be included as part of their recovery protocols.

There are limitations for this research that should be discussed. The potential mechanisms for how PEMF therapy could be effective were not investigated in this study. Given the paucity of research analyzing PEMF therapy and athletic performance (Tamulevicius et al., 2021), the starting point for research in this area is to ascertain whether there is an absolute effect on variables such as force and power. However, future studies could investigate neuromuscular function or inflammatory markers and how they respond to PEMF therapy. This study attempted to isolate one recovery device (i.e., PEMF therapy). In practice, athletes will likely use multiple devices (e.g., nutrition and hydration, massage, compression) to assist with their recovery from training and competition (Barnett, 2006). Nonetheless, future studies could assess whether PEMF therapy used in conjunction with other modalities can expedite an athlete's recovery. Only one PEMF therapy application, which had a duration of 22:32 min:s, was analyzed in this study over the course of three days. There may be a dose:response relationship between PEMF therapy and recovery, which requires further investigation. The intensity of the PEMF device in this study may also not have been intense enough to induce more substantial recovery from the intensive exercise. This study only utilized a running assessment to induce fatigue (Gathercole et al., 2015); other protocols (e.g., cycling, resistance exercise) could lead to different results than what was shown in this research. As previously stated, the VJ and LBD measurements did not incorporate any time or rate of force development metrics (Haff et al., 2015; McMahon et al., 2018), which could have elucidated different results to those found in this study. To assist with sample size, the sexes were combined within each group. Moreover, due to the random allocation of participants into each group, there were unequal numbers of men and women in each group. Future research should investigate whether there are sex differences in recovery from fatiguing exercise with the use of PEMF therapy. The training history of participants in each group could have varied, which may have some influence on the observed results. The participants in this study were also recreationally-active men and women. Professional or elite athletes may respond differently to PEMF therapy than the participants in the current study.

Conclusion

Athletes seek any advantage that could assist with their performance and recovery. PEMF therapy may be beneficial to help with recovery from strenuous exercise among some individuals. While not conclusive, the results from this study suggest that PEMF therapy could be added to an athlete's recovery regime with some potential positive impacts (i.e., faster recovery of PP, improved perception of recovery after 24-72 hours). As previously stated, PEMF devices are designed to be non-invasive, so could be used in conjunction with other activities (e.g., users can sit with their device while doing other things such as working on a computer or watching film, while receiving a massage, during a meal, etc.). Although more research is needed to ascertain mechanisms for how PEMF therapy could affect recovery following strenuous exercise, the current results show potential for using PEMF devices as part of a recovery protocol for athletes, especially in the first 72 hours post-strenuous exercise.

Acknowledgements: Equipment for this research was provided by HAELO (Encino, CA, USA). The authors would like to thank Mara Ballard and Jeff Monroe for supporting this research, and the participants for their efforts.

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SPORTLOGIA
Scientific-Expert Journal of Anthropological Aspects of Sports, Physical Education and Recreation

Submitted: 13/10/2025
Accepted: 15/12/2025
Online first: 27/01/2026
UDK: 796.093:[005.334:351.74/.75

Original article

Relationships between an occupationally relevant specialist police physical assessment and unloaded and loaded longer duration events

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Abstract

Specialist law enforcement personnel, including Police Tactical Group (PTG) operators, are required to perform a diverse range of physically demanding tasks under high-stress conditions. These tasks typically include short duration, explosive, high-intensity activities, such as casualty drags and obstacle negotiation, as well as extended-duration load carriage events, such as rural area searches. These tasks are performed while wearing and carrying personal protective equipment and a combat rifle. To assess occupational readiness, physical fitness assessments are routinely conducted within these units. The aim of this study was to determine relationships between an occupationally relevant urban-based fitness assessment (RUSH) and other, longer duration assessments, be they loaded or unloaded. Retrospective data from 145 male PTG operators (mean body weight = 91.07±10.45kg, mean age = 36.0±6.5yrs) from nine different PTG units were analyzed. Timed performance data were provided for the RUSH, a 2.4km and a 5km unloaded run and a 2km (17.5kg) and a 10km (25kg) loaded march. Correlations were determined via a Spearman's Rho with alpha levels set at 0.05. The unloaded 2.4km run was the only assessment to show a statistically significant (p=0.041), albeit weak (r=0.217), correlation with RUSH performance. These findings suggest that the RUSH assessment captures distinct physical fitness attributes not currently assessed in endurance-based events, be they unloaded or loaded. The RUSH assessment, designed to simulate intense, short duration, urban tasks, may offer valuable insights into operational readiness and could serve as a valuable component to the PTG fitness assessment battery.

Keywords: tactical, law enforcement, load carriage, physical employment standards, fitness testing

Citation: Irving, S., Schram, B., Pope, R., Robinson, J., & Orr, R. (2026). Relationships between an occupationally relevant specialist police physical assessment and unloaded and loaded longer duration events. *Sportlogia. 22(*1), 19-29. https://doi.org/10.63356/spl.2026.002

Introduction

Tactical special operations law enforcement units are comprised of personnel specially trained to a higher level than general duties officers (Irving et al., 2019; Thomas et al., 2017). These elite units are internationally recognized under various designations, including Special Operations Units, Tactical Response Groups, and in the United States, Special Weapons and Tactics (SWAT) teams (Davis et al., 2016; Sarao, 2014). In Australia and New Zealand, comparable units are known as Police Tactical Groups (PTG), with individual members referred to as tactical group members or operators (Irving et al., 2019; Thomas et al., 2019). These PTG units are routinely engaged in high-risk, short-notice operations that demand rapid and complex decision-making, often performed under considerable psychological and physiological stress (Irving et al., 2019; Maupin et al., 2018; Robinson et al., 2018). Tasks typically involve the execution of high-risk warrants, emergent entries, apprehension of armed offenders, counter-terrorism responses, hostage rescue scenarios, and, in some jurisdictions, long range reconnaissance and covert surveillance missions (Irving et al., 2019; Marins et al., 2020). These duties are performed while carrying substantial occupational loads, often up to 28kg, which imposes significant strain on both the metabolic and musculoskeletal systems. (Irving et al., 2019; Orr et al., 2022; Thomas et al., 2017). During operations, tactical operators may also be required to execute fire and movement tactics, negotiate physical barriers, and extract injured civilians or fellow officers to safety (Irving et al., 2019). Such demands highlight the critical importance of physical capability within this specialist policing domain.

In their investigation of the occupational role and scope of PTG operators, Irving et al., (2019) identified a high risk warrant execution and long range rural search operations as being the two most common tasks performed. These tasks represent distinct physiological profiles. Where warrant executions can be typified as short-duration, high-intensity, activities, long range rural searches are generally more prolonged, even multi-day, activities (Irving et al., 2019; Orr et al., 2019). Importantly, both of these tasks, while taxing different energy systems, include elements of load carriage which is known to impact on tactical task performance (e.g., mobility and attention to task (Carlton et al., 2014)) in these high-risk environments (Orr et al., 2019; Robinson et al., 2018).

In law enforcement short duration tasks are often assessed through obstacle courses, designed to replicate explosive work in urban environments. Obstacles may include scaling walls and fences, sprinting, crawling, and dragging injured colleagues or members of the public to safety (Dawes et al., 2022; Lockie, Pope, et al., 2020). Such events require anaerobic power, absolute strength, and the ability to express power through explosive movements (Dawes et al., 2022; Lockie, Pope, et al., 2020; Moreno et al., 2019; Sax van der Weyden et al., 2021). For example, casualty drags, which often feature in obstacle course evaluations, are short-duration (i.e., <20m), high-intensity events that rely heavily on absolute muscular strength, particularly in the upper body, posterior chain, and hand grip (Lockie, Moreno, et al., 2022; Lockie, Moreno, et al., 2020; Moreno et al., 2019). In contrast, for longer duration load carriage tasks, which are conducted over greater distances and durations, relative strength, muscular endurance, and aerobic fitness are required (Cooper, 2014; Knapik et al., 2012; Mala et al., 2015; Orr et al., 2019; Robinson et al., 2018). While both task types (being short explosive obstacle courses and long duration load carriage activities) are vital to PTG occupational readiness, they rely on distinct physical modalities and energy systems (Lockie, Balfany, et al., 2019; Orr, 2012; Robinson et al., 2018). Nonetheless, there are some commonalities. Both typically involve operators to wear occupational loads, and both are influenced by critical velocity (i.e. the maximum speed or power output that can be maintained for a prolonged duration). Critical velocity has demonstrated a significant relationship with sprinting (Dawes et al., 2015; Dawes et al., 2017; Winters et al., 2021), performance in tactical load carriage tasks (Dicks, 2019), and has the added benefit of increasing survivability in combat environments (Dicks et al., 2021; Dicks & Pettitt, 2021; Lockie, Dawes, et al., 2019).

Given the distinct physical demands of short duration versus extended duration tasks, there is a need for an assessment tool which accurately reflects the operational realities of PTG operators. The urban rush (RUSH) is a new high-intensity, task-specific physical assessment designed to simulate tactical movements in urban environments. Unlike conventional obstacle courses which are typically completed by general duties police officers who do not wear tactical loads (Dawes et al., 2022; Janković et al., 2015; Lockie, Beitzel, et al., 2022; Lockie et al., 2018; Lockie, Moreno, Rodas, et al., 2021; Lockie et al., 2024; Lockie, Pope, et al., 2020; Stanish et al., 1999), the RUSH involves short, explosive efforts that closely replicate operational tasks such as crawling, sprinting, engaging targets, and dragging a casualty, all performed while wearing operational Personal Protective Equipment (PPE), and carrying a primary weapon system (i.e. a combat rifle) (Thomas et al., 2019). While the RUSH assessment has demonstrated relevance to occupational movements and tactical skills, it represents only a portion of the physical profile required for real-world operational roles (Strader et al., 2020; Thomas et al., 2019). Specifically, it may not adequately assess fitness components associated with longer duration tasks, such as sustained load carriage and extended patrol operations (Maupin et al., 2018; Thomas et al., 2019).

Currently, PTG units perform a variety of assessments to evaluate fitness attributes associated with occupational performance. While the 10km pack march wearing 25kg is widely adopted, other tests, including a 2km loaded move wearing 18 kg, and unloaded runs over 2.4km and 5km are used by some units (Thomas et al., 2019). Notably these physical assessments are predominantly aerobic in nature and therefore may not fully reflect the demands of key occupational tasks from which the RUSH test is derived. Given the limited time available in operational settings to conduct comprehensive physical evaluations, it is important to consider whether the RUSH test, despite its occupational relevance, captures distinct fitness components not already measured by existing protocols. Therefore, the aim of this study was to determine relationships between RUSH performance and other longer duration assessments currently used by PTG units, be they unloaded or loaded. It was hypothesized that the RUSH would not be significantly correlated to longer duration assessments currently used by units.

Methods

Experimental approach to the problem

This study was conducted as a retrospective cohort study with data provided by each of the Australia and New Zealand PTG units (n=9). The testing protocols were provided to the PTG trainers and the physical assessment data collected as part of each agency's normal physical training practices undertaken in the workplace. These assessments were supervised by either a qualified physical training instructor, senior PTG instructor, or strength and conditioning specialist depending on the unit's staffing.

Participants

Data were collected from 145 male specialist PTG officers (mean age = 36.2 ± 6.5 years: mean height = 182.3 ± 6.6 cm: mean weight = 91.1 ± 10.5 kg) who were representative of all nine PTG units. The inclusion criteria for this study were: operators had to be a fully qualified and current specialist operations law enforcement officer serving in their respective PTG; and of an operational deployable status (i.e., fully operational). The exclusion criterion was that an officer was on restricted duties due to medical or injury reasons which would prevent them from undertaking the physical protocols of the study. The PTG operators voluntarily completed the physical assessment as part of their general operational and physical training time in their respective specialist workplaces. Ethics approvals for this study were provided by Bond University Human Research Ethics (#15412) The research also adhered to the recommendations of the Declaration of Helsinki (World Medical Association, 1997).

Measurements and Procedures

Prior to the conduct of the five physical assessments, operators self-reported their age in years and height in centimetres. Self-report of these metrics is common in this population and has been found to be reliable (Dawes, 2019). Additionally, each participant was weighed on a scale both loaded and unloaded with the results recorded in kilograms to the nearest 100 grams.

The five physical assessments undertaken were the RUSH, a 2.4km unloaded run, a 5km unloaded run, a 2km loaded walk, and / or a 10km loaded walk. While all members from all units completed the RUSH, there were variations in the other tests with some units only completing either the 2.4km unloaded run, 5km unloaded run, or 2km and 10km loaded events. The research team were not involved in the decisions as to which tests were conducted at the units. All events were completed in the same week with the RUSH completed first and other assessments later in the week and separated by at least 24 hours. The protocols for each test are described below.

The RUSH has been described previously in the literature (Strader et al., 2020; Thomas et al., 2019) but is briefly summarized here. The RUSH assessment comprised of explosive sprints, prone crawls and casualty drags over 10 and 20m distances alternating directions 180 degrees whilst wearing full operational PPE and carrying a primary weapon. At commencement the operators were required to sprint to the first 10m cone then drop into a tactical crawl position, cradling their weapon in a safe manner as they rapidly crawled 10m to an 80kg mannequin, commonly referred to as a dummy. Participants were then required to stand, pick up the dummy under the arms, and walk backwards as fast as possible to the original 10m cone with their rifle slung. Throughout the course the operators were required to achieve a number of static kneeling shooting positions aiming their rifle at a circular target standing 185cm heigh at a distance of 30m. In each case the operators had to align their weapon system with the target as quickly as possible and illuminate the target with the visible red light laser designator affixed to the weapon. Progression could only continue once targeting had been confirmed by instructional staff. At the completion of the first dummy drag and completion of the kneeling unsupported firing position the dummy drag was repeated for a further 10m to the starting position. Once achieving target alignment the operator stood, pivoted 180 degrees and sprinted to the centre 10m cone, repeating the kneeling and target application process. This process of sprinting, changing direction, kneeling and target acquiring continued for an additional 10m (reaching the end), then a continuous 20m (back to the start) before the operators again picked up the dummy and dragged it 20m without stopping. After again adopting the kneeling shooting position, the operator proceeded to sprint 20m to the starting mark. The RUSH course depicted in Figure 1 was conducted indoors in an open gymnasium training space on non-slip dry flooring.

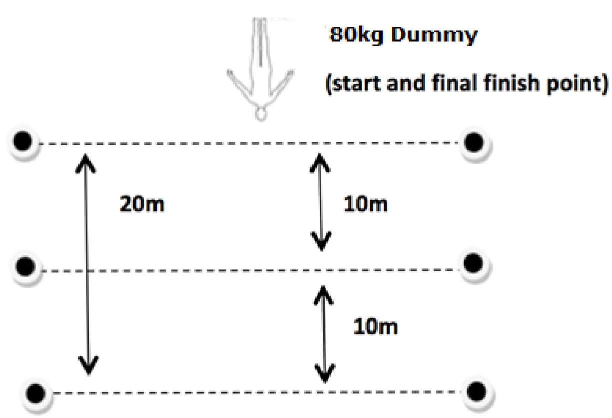

Figure 1. Schematic RUSH test set up.

If the operators stopped voluntarily, fell over, or the instructor ceased the activity due to concerns over the operator's health or safety, the test was ceased, and then restarted after a short rest (minimum of 3 minutes).

All operators were familiar with the test and performed the test once as fast as possible. Each of the operators were dressed based on their role and scope within the PTG. Load for each participant was based on the unit's jurisdictional 'high level' load out requirement (20-25kg) inclusive of their combat rifle (SR15 weighing 3.6kg - unloaded). Prior to the testing, operators underwent a formal warm up and equipment check as per their role.

For the loaded events, the PTG officers undertook the assessments dressed in their standard issue operational boots, fatigues, PPE, pack, and unloaded primary weapon. For the 2.4km event the officers were required to wear their operational PPE, including plate carrier, to a combined weight of 17.5kg and for the 10km March the officers were required to wear their operational issue backpack with a weight of 25kg. For those PTG units who volunteered to complete these two events, the events were undertaken at each of the jurisdictional policing agencies PTG unit base headquarters. The marches were conducted on set courses in these locations over flat ground on a mixture of surfaces, bitumen, concrete pavement, grass and hard dirt or soil looped tracks. These distances are standard practiced distances for these units, and all have dedicated routes regularly used as part of their occupational physical training, barrier assessments, and recruitment selection processes. The officers were requested to complete each of the distances to the best of their ability and were allowed to march or shuffle jog during the activity which replicated operational contexts. The exact locations of these assessment routes were not disclosed due to security provisions given the location of the training areas being in proximity to, if not within, the confines of the unit's bases. As part of the testing protocol however each route was required to be measured and marked utilizing Garmin Oregon 600t handheld GPS system (Garmin, Kansas City, USA) to ensure accuracy and the timed duration of each individual event was recorded by the qualified instructional staff using a handheld timer provided to all the units (Junsed 50, Hart Sport timer, Aspley, Brisbane, Australia). Each operator's completion time for the events was recorded in an excel spreadsheet and provided retrospectively to the researchers who then checked the data and converted the time to seconds.

The 2.4km and 5km timed events respectively were likewise undertaken at each of the jurisdictional PTG unit's base location for each volunteering unit. Each operator was dressed in their standard physical training clothing, traditional, sports shorts, t-shirt or singlet, running shoes-joggers, and sports socks. These events were undertaken unloaded, with no equipment worn or weapon carried. The operators were instructed to run the set distance as fast as possible. The routes, distance measures, supervision and time recording were precisely replicated for the loaded events as described above. All times were recorded in the manner described above.

Statistical analyses

The data were initially provided in a Microsoft Excel (Microsoft Office, 2016) spreadsheet, then transferred to the IBM Statistical Package for Social Sciences (SPSS) Statistics (IBM Corp., 2017) software program for analysis. Time was converted from mins: secs to secs for all timed variables. Once data were descriptively analysed, normality was assessed using the Shapiro-Wilk test. Correlations between the RUSH and timed events (2.4km and 5 km unloaded, and 2km and 10km loaded) were determined through either a Pearson's Correlation for normally distributed data or a Spearman's Rho for non-normally distributed data. For the strengths of correlations 0-0.19 was considered very weak, 0.2-0.39 as weak, 0.4-0.69 as moderate, 0.7-0.89 as strong, and 0.9-1.0 as very strong (Fowler et al., 1998). Alpha levels were set at 0.05 a priori.

Results

Of these 145 male operators for which data were obtained, 89 operators completed the unloaded 2.4 km run, 17 operators completed the unloaded 2 km run, 17 operators completed the 2 km loaded march, and 18 operators completed the 10 km loaded march. Only 6 operators completed more than one of the distance events completing both the 2.4 km and 5 km unloaded runs. Data for 9 operators who completed the RUSH did not have corresponding distance event results due to their operational requirements. Descriptive data is provided in Table 1.

Table 1. Descriptive data for all variables collected

Variable	Min-Max	Mean ± SD
Age (yrs) (n=145)	25.0 – 60.0	36.2 ± 6.5
Height (cm) (n=145)	165.0 – 206.0	182.3 ± 6.6
Body Weight (kg) (n=145)	68.0 - 122.0	91.1 ± 10.5
Occupational Load (kg) (n=145)	14.0 - 31.4	19.5±2.9
Percentage Body Weight (%) (n=145)	13.7 - 31.2	21.5 ± 3.7
RUSH time (secs) (n=145)	74.0 – 161.0	1:47 ± 00:15
2.4km time (min:secs) (n=89)	1:14-2:41	953.2 ± 217.7
5km time (secs) (n=17)	1808 - 3090	2518.1 ± 372.1
Loaded 2km (secs) (n=18)	720.0 – 1080-2	857.0 ± 86.9
10km time (min:secs) (n=18)	83.01-90	86:45 ± 2:24

As data were not normally distributed a Spearman's Rho correlation was conducted with results presented in Table 2 below. The only distance assessment significantly (p=0.041) correlated with RUSH times was the unloaded 2.4km run, although this relationship was weak (r=0.217). No other variables were significantly related.

Table 2. Spearman's Rho correlations between variables.

Variable	2.4km time	5km time	Loaded 10km time	Loaded 2km time
RUSH(secs)	.217*	-0.075	0.370	0.213

Note: *Significant at p < 0.05, **Significant at p < 0.05

Discussion

The aim of this study was to determine relationships between RUSH performance and other longer duration assessments used by PTG units, be they unloaded or loaded. It was hypothesized that the RUSH would not be significantly correlated to longer duration assessments currently used by units. This hypothesis was partly proven. While no significant relationships were found between the RUSH and the unloaded 5km run, 2km loaded march, or 10km loaded march, a significant, albeit weak correlation (r=0.217), with the 2.4km unloaded run was found. These findings indicate that the RUSH primarily evaluates specific, task-focused components of fitness that are not strongly associated with performance in longer-duration events. Given that the operational demands of special operations units frequently encompass both short-duration, high-intensity tasks and, extended load carriage missions (Irving et al., 2019), it is important to consider literature that examines the distinct physical requirements associated with each of these occupational modalities (Maupin et al., 2018).

Research suggests that special operations law enforcement personnel may exhibit distinct muscular force profiles and engage different energy systems depending on the specific demands of their operational tasks (Carlson & Jaenen, 2012; Decker et al., 2022; Maupin et al., 2018; Talaber et al., 2022). In a review of the fitness profiles of specialist police officers, Maupin et al., (2018) reported that these personnel possess levels of strength, power, and both anaerobic and aerobic capacity that, in some cases, are comparable to those observed reported in elite athletes. Notably, the authors also highlighted the absence of standardized physical assessment protocols capable of encompassing all these fitness domains within this population. This observation is supported by Zulfiqar et al., (2021) who found that law enforcement agencies generally favor a battery of discrete fitness assessments rather than a single comprehensive measure. Similarly, Orr et al., (2021) described the broad spectrum of fitness requirements for tactical personnel and, correspondingly, the wide variety of assessment methods employed to evaluate them. Further, Orr et al., (2021) emphasized the inclusion of occupationally relevant specialist physical assessments within tactical populations. As such, incorporating an occupationally relevant assessment such as the RUSH into a broader suite of assessments appears appropriate to reflect the demands placed on specialist tactical police.

Although the RUSH assessment is relatively new, limited research has evaluated its application within specialist police selection processes. Notably, one study reported that RUSH performance did not differentiate between successful and unsuccessful candidates during a selection course, with mean completion times being similar to those reported in this study (1:52 min:secs vs. 1:47 min:secs) (Thomas et al., 2019). In contrast, performance on a 2.4km loaded march significantly distinguished between these groups, suggesting that the latter test may have greater predictive utility for selection outcomes. At first glance, this finding of selection outcomes appears inconsistent with the weak but statistically significant correlation observed in the present study between RUSH performance and the unloaded 2.4km run. However, this difference likely reflects the distinct physiological demands of the two assessments and suggests that these two tests support different physical requirements. The weak correlation between the RUSH and the unloaded 2.4km run may therefore only reflect the shared anaerobic fitness component which can be seen in distance runs (Tharp et al., 1997). The weakness of this relationship may likewise limit the transferability to the longer duration events reported in this study.

As such, the weak relationships between RUSH performance and the 2.4km run does not support that the two tests measure equivalent occupational capabilities. These findings are consistent with those reported by Lockie et al., (2018). who investigated correlations between California's Work Sample Battery Test (WSBT) for law enforcement officers (which included a 99 yard obstacle course (99OC), a 74.84kg victim body drag, chain link fence barrier, solid wall climb and 500 yard run), and various fitness measures inclusive of a 2.4km unloaded run, push ups, sit ups, pull ups, a vertical jump, and a 201m run. Akin to the findings reported in this paper, a weak correlation was found between the 99OC and the 2.4km run ($r=0.026$, $p<0.01$), while measures of strength and short distance sprints were more strongly associated ($r=-0.33$ to 0.48, $p<0.05$) with the 99OC. These results further support the premise that assessments such as the RUSH are more reflective of task specific strength and anaerobic power than that of general aerobic capacity.

Within law enforcement, the use of occupationally relevant obstacle courses to assess physical assessments in general duties officers is common practice (Beck et al., 2015; Birzer & Craig, 1996; Dawes et al., 2022; Koedijk et al., 2020; Mangione et al., 2023; Rhodes & Farenholtz, 1992; Stanish et al., 1999; Weiner et al., 1988). These courses typically involve short bursts of sprinting interspersed with functional tasks such as jumping over barriers, scaling high fences, and victim drags. Such assessments are designed to be both anaerobic and aerobic in nature, reflecting the intermittent high-intensity efforts and sustained physical output required during operational engagements (Lockie et al., 2018; Lockie, Moreno, Cesario, et al., 2021). Many of these obstacle courses are completed without rest and range in duration from 4 minutes onwards. For example, the Physical Abilities Test (PAT) must be completed in 4m:15s (Lindsay et al., 2021; Rhodes & Farenholtz, 1992), the Physical Abilities Requirement Evaluation (PARE) must be completed in ≤4m:45s (Seguin, 2015) and the New Zealand Police Physical Competency Test (PCT) applies a timed standard to ensure operational relevance, (time not listed) (Dawes et al., 2022). As such the repeated, high-intensity efforts with substantial anaerobic contribution and task skill components become increasingly reliant on the aerobic system as the duration extends (Lockie et al., 2023; Rhodes & Farenholtz, 1992; Seguin, 2015). In contrast the WSBT conducted in California Law Enforcement separates each task into discrete components (Lockie et al., 2018). Within the same WSTB, the final 500 yard pursuit run, demonstrated a large correlation with the 2.4km run ($r=0.57$, $p<0.05$), consistent with greater aerobic demand over the longer bout (Lockie et al., 2018). Likewise, in a 400-m police physical competency test that strings multiple tasks together without rest, Lockie et al., (2023) found that the 2.4km run correlated strongly with completion time ($r_s=0.70$, $p<0.001$) and explained 42% of the variance in completion times. Earlier work by Stanish et al., (1999) examining the Royal Canadian Mounted Police's PARE demonstrated that performance was influenced by a combination of muscular strength, muscular endurance, agility, and aerobic power. Specifically upper-body strength, explosive leg power, and agility explained 79% of PARE time variability among male applicants (Stanish et al., 1999). Consistent findings in broader police populations further support the predictive value of muscular endurance, and explosive leg power, and of aerobic fitness in simulated duty tasks of increasing durations (Teixeira et al., 2019).

The key distinction between these established assessments and the RUSH is in the integration of occupational load, none of the aforementioned tests required officers to perform tasks while wearing full standard occupational loads, this is of importance to note as wearing of occupational loads as light as 5kg is known to reduce officer mobility (Carlton et al., 2014; Joseph et al., 2018), power output (Orr et al., 2019; Thomas et al., 2017), speed (Dicks, 2019; Dicks & Pettitt, 2021), and agility (Joseph et al., 2018; Thomas et al., 2017).

The absence of significant relationships between the RUSH and loaded long duration events is unsurprising given the distinct physical characteristics underpinning these tasks. Robinson et al., (2018) investigated the relationship between strength, power, and aerobic fitness on 5km load carriage performance (load = 25kg). While strength and power variables were significantly correlated with load carriage performance, aerobic fitness displayed the strongest and most significant correlation ($r=-0.712$, -0.709 and -0.711 for trials respectively). These findings are supported by Feigel et al., (2024) who likewise found aerobic fitness to be the best predictor of soldier performance when completing a 2km loaded march. Conversely, tasks included in the RUSH, such as the victim drag, have found to be more strongly associated with elements of strength (Feigel et al., 2024) as have short distance sprints (5,10,20m) and elements of power (Dawes et al., 2015). The results and supporting evidence therefore suggest that a loaded march and RUSH task, representative of two leading PTG officer job tasks, require and assess different elements of fitness and are distinct from each other, reinforcing their complementary utility in physical assessment. These findings underscore the importance of implementing a multifaceted assessment battery capable of capturing the full spectrum of tactical performance requirements. This approach aligns with the recommendations of Zulfiqar et al., (2021) and Orr et al., (2021) who advocated for evaluation frameworks which reflect the diverse physiological demands of tactical performance.

Limitations

The data collection was reliant on the contributing specialist units undertaking the testing in their specific geographical location. Due to the large distance between each of the nine tactical group headquarter locations and time constraints, travel to each venue to quality assure the testing protocols was not possible. Accuracy in data collection was reliant on the individual instructional staff at each jurisdiction location. However, all assessors had received training in implementing the RUSH assessment and a standardized protocol was provided. Another limitation was the inconsistent completion of assessments across units; not all operators undertook every test due to time constraints and the voluntary nature of data collection. Finally, no morphological data were available. However, while morphological characteristics are known to influence fitness test outcomes in law enforcement (Janković & Koropanovski, 2024), the RUSH is a based on occupational requirements and tasks that are required to be completed regardless of morphology, age, or sex/gender (Orr et al., 2021).

Practical Implications

The findings of this study indicate that RUSH performance is not associated with longer duration loaded events, which are also recognized as being of importance to PTG officers. On this basis, the RUSH can be confidently used as a complementary assessment which evaluates distinct elements of fitness not currently assessed by other longer duration events. Its inclusion within a specialist police fitness battery can augment the existing longer duration loaded march assessments as a comprehensive physical capability assessment within specialist police.

***Acknowledgment*:** Appreciation is extended to all the participating specialist tactical operations law enforcement unit commands for supporting the research initiatives and further to all the PTG officers, physical training instructors and strength and conditioning specialists who partook and assisted in this project.

Conflict of interest: The authors acknowledge no conflicts of interest.

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SPORTLOGIA
Scientific-Expert Journal of Anthropological Aspects of Sports, Physical Education and Recreation

Submitted: 03/12/2025
Accepted: 19/01/2026
Online first: 03/02/2026
UDK: 572.511.087:796.323.2.077.2-055.2

Original article

Relationships Between Countermovement Jump-Derived Variables, Eccentric Hamstring Strength, and Agility Performance in Elite Female Basketball Players

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Abstract

This study investigated whether agility performance in elite female basketball players could be predicted from countermovement jump (CMJ) force–plate metrics, eccentric hamstring strength, and anthropometric characteristics. Forty-five athletes competing in Iceland's top division completed assessments of CMJ kinetics using dual force platforms, eccentric knee-flexor strength via the Nordic Hamstring Exercise, and reactive agility performance through the Y-Agility Test. A multiple linear regression model was applied to assess the predictive value of CMJ-derived variables and eccentric hamstring force on total test time. The model demonstrated a high coefficient of determination (R^2 = 0.959), indicating that the predictors collectively explained 96% of the variance in agility times. However, none of the individual predictors reached statistical significance ($p > 0.20$), suggesting no meaningful relationships between CMJ or Nordic metrics and agility performance. These results emphasize that reactive agility is a distinct physical quality, influenced by multifactorial determinants such as neuromuscular coordination, horizontal braking efficiency, and perceptual–cognitive factors not captured by traditional CMJ or isolated strength assessments. Practically, coaches should avoid presuming direct transfer between improvements in vertical jump or eccentric hamstring capacity and agility performance. Instead, training programs should incorporate agility-specific drills that integrate reactive decision-making and sport-relevant movement patterns. Future research should include larger samples and multidimensional models to better understand agility determinants in female populations.

Keywords: neuromuscular performance, injury prevention, jumping assessment, lower limb strength, sport-specific conditioning

Citation: Irving, S., Schram, B., Pope, R., Robinson, J., & Orr, R. (2026). Relationships between an occupationally relevant specialist police physical assessment and unloaded and loaded longer duration events. *Sportlogia. 22(*1), 30-37 https://doi.org/10.63356/spl.2026.003

Introduction

Agility is defined as “a rapid whole-body movement with change of velocity or direction in response to a stimulus” and is considered important for many sports (Sheppard et al., 2006). Agility and rapid changes of direction (COD) are fundamental to basketball performance, where athletes must accelerate, decelerate, and redirect movement over short distances (Ben Abdelkrim et al., 2010; Scanlan et al., 2014). In elite female basketball, successful defensive closeouts, offensive drives, and recovery actions depend heavily on the ability to generate explosive force within the first few meters and to decelerate under control before changing direction (Spiteri et al., 2015). Unlike sprint-based sports where maximal velocity is achieved over longer distances, basketball-specific agility emphasizes early acceleration and braking capacity, including the need to prepare athletes for maximal decelerations as well as accelerations. Accordingly, braking (deceleration) capacity is a key component of basketball movement demands.

To assess reactive agility, testing must include an external stimulus to challenge athletes’ visual scanning and decision-making abilities (Oliver & Meyers, 2009). Repeated CODs, accelerations, and decelerations are considered essential components of basketball performance (Brini et al., 2021). During a game, basketball players may perform between 550 and 1000 changes of direction (COD) depending on their playing position (Drinkwater et al., 2008).

While COD performance has been studied in basketball, there is a noticeable lack of research investigating agility—particularly in female basketball players—and its relationship with force–time derivatives or eccentric hamstring capacities. Vencurik et al. (2019) examined the relationship between reactive agility and lower-body speed and power, finding only a weak correlation between Y-agility test performance and countermovement jump (CMJ) height. However, their analysis was limited to jump height as a single output variable. Daveena et al. (2019) reported that jump-derived power—particularly approach jump, relative standing broad jump, and power relative to body mass—was strongly associated with linear sprint and COD speed among Division I collegiate women’s basketball players. While highlighting the importance of stretch-shortening cycle efficiency and relative power, their study did not include force–time characteristics, limiting insight into underlying neuromuscular performance.

Čaušević et al. (2021) examined the relationship between agility, sprint, and vertical jump performance in young basketball players. They found shared physical demands across these qualities, emphasizing the need to train them concurrently. However, their use of the T-test as an agility measure is limited, as it does not include external stimuli and thus does not fully represent reactive agility.

Eccentric hamstring capacity contributes to faster change-of-direction performance, as athletes with greater eccentric peak force and rate of force development tend to achieve shorter ground contact times and greater control during deceleration–acceleration transitions. Studies in basketball and other team sports have shown correlations between Nordic hamstring strength, eccentric knee flexor torque, and COD speed (Smajla et al., 2022).

Recent evidence suggests that eccentric lower-limb capacity—particularly eccentric hamstring (braking) ability—is a key determinant of COD and agility performance in female court athletes. Cross-sectional studies show that faster female basketball players generate greater eccentric force and impulse during COD tasks, and measures of eccentric muscle capacity are significantly associated with COD speed (Spiteri et al., 2015). Interventions using eccentric overload methods, such as flywheel training, have demonstrated improvements in sprint and COD performance in female basketball players, supporting a causal role for eccentric capacity in on-court movement performance (O’Brien et al., 2020).

Advanced athlete monitoring technologies allow for more comprehensive assessment of basketball performance demands. The VALD SmartSpeed system enables precise measurement of agility and COD performance, such as the Y-test, while ForceDecks quantify kinetic and kinematic variables from CMJ tests, and NordBord measures eccentric hamstring strength. Integrating these systems provides a holistic understanding of how neuromuscular, anthropometric, and eccentric strength qualities underpin agility performance (Chen et al., 2023).

The Y-agility test was selected to assess basketball-specific agility by incorporating both rapid acceleration/deceleration and reactive change of direction in response to a visual stimulus. This test replicates typical on-court movements such as defensive slides and offensive cuts and includes a perceptual–cognitive component that differentiates reactive agility from pre-planned COD ability.

To date, no study has comprehensively examined the predictive value of force–time characteristics from CMJ testing and eccentric hamstring performance on Y-agility test outcomes among female basketball players.

Therefore, the purpose of this study was to examine to what extent agility performance could be predicted from anthropometric characteristics, CMJ force–plate variables, and eccentric hamstring strength in elite female basketball players competing in Iceland's top division. We hypothesized that eccentric knee flexor strength and braking-related force–time metrics would be stronger predictors of short-distance reactive agility performance than traditional vertical jump variables.

Methods

Experimental approach to the problem

A cross-sectional design was employed to assess the relationship between CMJ-derived variables, eccentric hamstring strength, and agility performance. All assessments were performed within a single testing session in a controlled indoor environment. Participants completed a standardised warm-up consisting of light jogging, dynamic stretching, and submaximal jump and sprint drills before testing commenced.

Participants

Forty-five elite female basketball players (age: 23.4 ± 3.1 years; height: 177.2 ± 6.3 cm; body mass: 69.5 ± 7.1 kg) competing in the Icelandic top division volunteered for this study. All participants were injury-free for at least six months prior to testing and engaged in regular basketball and strength training as part of their team programs. Written informed consent was obtained from all participants. The study protocol was approved by the institutional ethics committee and conducted in accordance with the Declaration of Helsinki.

Measurements and Procedures

Countermovement Jump (CMJ)

CMJ performance was assessed using a force platform (VALD Performance, Brisbane, Australia), using protocol of Johnson et al (2025) sampling at 500 Hz. Participants performed three maximal CMJs with hands on hips to minimize arm swing influence, separated by 10 seconds of rest. The following variables were extracted: jump height (Impulse-Momentum method, cm), concentric mean force ($N \cdot kg^{-1}$), concentric mean velocity ($m \cdot s^{-1}$), eccentric mean force ($N \cdot kg^{-1}$), eccentric peak velocity ($m \cdot s^{-1}$), reactive strength index modified ($m \cdot s^{-1}$), vertical velocity at takeoff ($m \cdot s^{-1}$), peak net takeoff force ($N \cdot kg^{-1}$), lower-limb stiffness ($N \cdot m^{-1}$), braking and concentric phase durations (ms). The average value of three attempts was taken into further analysis.

Eccentric Hamstring Strength

Eccentric hamstring strength was assessed using the Nordic Hamstring Exercise (NHE) with a validated testing device (VALD Performance, Brisbane, Australia). The NordBord system (VALD Performance) was used to assess eccentric hamstring strength, as previous studies have reported high reliability (ICC > 0.85) and moderate-to-strong concurrent validity compared with other hamstring strength assessment techniques, supporting its use in applied and research settings (Claudino et at. 2021). Participants completed three maximal repetitions of the NHE at a controlled tempo, and the average value was used for analysis. The following variables were included in the analysis: maximal torque (Nm) in the Nordic Hamstring exercise, average force (N) during the eccentric phase, maximal Impulse (Ns) generated throughout the movement.

Agility Test

Agility performance was assessed using a Y-agility test (Callaghan, 2014) implemented with the SmartSpeed System (VALD Performance, Brisbane, Australia). After an initial 5 m acceleration, athletes responded to a randomly illuminated cue, directing them to change direction to the left or right. The SmartSpeed timing gates recorded both the total completion time, the 0–5 m and the 5-10 m split times. Participants completed two trials, and the best performance was used for analysis.

Statistical analyses

Descriptive statistics (mean ± SD) were calculated for all variables. Linear regression model was constructed with total agility time. Assumptions of normality, linearity, and multicollinearity were checked. Regression coefficients (Estimate), standard errors (SE), 95% CI, t-values, p-values, along with model fit indices (R^2 and adjusted R^2). Effect sizes: Standardized regression coefficients (β) are reported for each predictor. The overall regression effect size was Cohen's f^2 = 10.63, calculated from R^2 = 0.914 $f^2 = R^2/(1-R^2)$, indicating a large effect (0.02 small, 0.15 medium, 0.35 large). Statistical significance was set at $p < 0.05$. All analyses were conducted using Jamovi (Version 2.3.28) and verified in R for robustness.

Results

Table 1 shows the descriptive statistics for all variables. Normality of data distribution was assessed using the Shapiro–Wilk test. The residuals of the linear regression model were normally distributed (Shapiro–Wilk W = 0.964, p = 0.583). No significant deviations from normality were observed.

Table 1. Descriptive data for all variables collected

Variables	Mean	SD
Body Height [cm]	175.5	7.9
Body Weight [KG]	72.4	9.0
Jump Height (Imp-Mom) [cm]	27.4	5.8
Concentric Mean Force / BW [N/kg]	18.4	1.4
Concentric Mean Velocity [m/s]	1.3	0.1
Eccentric Mean Force / BW [N/kg]	9.9	0.5
RSI-modified [m/s]	0.3	0.0
Vertical Velocity at Takeoff [m/s]	2.3	0.2
Eccentric Peak Velocity [m/s]	-0.9	0.3
CMJ Stiffness [N/m]	7254.7	3776.9
Concentric Mean Power / BM [W/kg]	23.5	3.1
Lower-Limb Stiffness [N/m]	5087.3	2448.5
Peak Takeoff Acceleration [m/s^2]	13.0	2.1
Force at Zero Velocity / BM [N/kg]	20.9	3.2
Braking Phase Duration [ms]	301.2	104.5

Variables	Mean	SD
Braking Phase Duration:Concentric Duration [%]	111.9	30.1
Concentric Impulse-100ms [N s]	80.3	23.4
Maximal Torque (Nm)	126.2	27.7
Average Force (N)	263.5	50.0
Nordic Curle Max Impulse (Ns)	3750.5	1727.3

A linear regression analysis was performed to examine whether anthropometric characteristics, countermovement jump (CMJ) force–plate variables, and eccentric hamstring strength could predict Y-agility test performance in elite female basketball players. The overall regression model demonstrated a very strong fit, accounting for approximately 96% of the variance in agility performance ($R = 0.979$, $R^2 = 0.959$).

However, none of the individual predictors significantly contributed to explaining variability in agility performance (all $p > 0.20$). Key relevant variables such as jump height (Estimate = –1.280, SE = 0.509, p = 0.24), eccentric mean force per body weight (Estimate = –1.107, SE = 0.522, p = 0.28), reactive strength index modified (Estimate = 10.150, SE = 6.554, p = 0.36), and eccentric peak velocity (Estimate = –0.430, SE = 2.050, p = 0.86) did not show statistically significant relationships with Y-agility test results. A complete summary of model coefficients and 95% confidence intervals is presented in Table 2.

Table 2. Model Coefficients for Y test total.

			95% Confidence Interval			
Predictor	Estimate	SE	Lower	Upper	t	p
Intercept	13.615	30.59	-375.07	402.303	0.44	0.73
Body Height [cm]	0.024	0.031	-0.372	0.42	0.77	0.58
Body Weight [KG]	-0.082	0.072	-1.004	0.838	-1.14	0.45
Jump Height (Imp-Mom) [cm]	-1.28	0.509	-7.752	5.19	-2.51	0.24
Concentric Mean Force / BW [N/kg]	-1.442	1.759	-23.798	20.914	-0.82	0.56
Concentric Mean Velocity [m/s]	-7.38	13.956	-184.714	169.953	-0.52	0.69
Eccentric Mean Force / BW [N/kg]	-1.107	0.522	-7.745	5.53	-2.11	0.28
RSI-modified [m/s]	10.15	6.554	-73.133	93.435	1.54	0.36
Vertical Velocity at Takeoff [m/s]	22.709	8.934	-90.815	136.23	2.54	0.23
Eccentric Peak Velocity [m/s]	-0.43	2.05	-26.478	25.617	-0.21	0.86
CMJ Stiffness [N/m]	0.000174	0.000468	-0.005	0.006	0.37	0.77
Concentric Mean Power / BM [W/kg]	0.996	1.268	-15.121	17.113	0.78	0.57
Lower-Limb Stiffness [N/m]	-0.000679	0.000782	-0.01	0.009	-0.86	0.54
Peak Takeoff Acceleration [m/s^2]	0.023	0.116	-1.45	1.498	0.2	0.87
Force at Zero Velocity / BM [N/kg]	-0.49	0.367	-5.159	4.178	-1.33	0.4
Braking Phase Duration [ms]	0.005	0.009	-0.115	0.126	0.59	0.65
Braking Phase Duration:Concentric Duration [%]	-0.026	0.033	-0.454	0.4	-0.8	0.57
Concentric Impulse-100ms [N s]	0.089	0.063	-0.723	0.901	1.39	0.39
Maximal Torque (Nm)	-0.01	0.012	-0.166	0.146	-0.81	0.56
Average Force / BW (N/kg)	0.399	0.515	-6.152	6.952	0.77	0.58
Maximal Impulse (Ns)	0.000024	0.000087	-0.001	0.001	0.27	0.82

Despite high R^2 indicating strong collective model fit, the lack of significant predictors suggests that the model's explanatory power is not driven by the individual CMJ or hamstring strength variables. This may reflect multicollinearity issues or insufficient statistical power due to sample size. These results indicate that agility, at least as measured by the Y-test in this cohort, cannot be explained by the selected CMJ-derived or eccentric hamstring variables.

Stiffness variables were interpreted according to the mechanical demands of the assessed tasks. CMJ stiffness represents a task-specific force–displacement characteristic derived from the countermovement jump and is strongly influenced by individual movement strategies, countermovement depth, and eccentric braking behavior, making it particularly relevant for agility and jump performance. Lower-limb stiffness reflects a more global spring-mass property of the lower extremities and is more closely related to sprint performance, where elastic energy reutilization and efficient force transmission are critical. The relatively large standard deviations observed for both stiffness variables reflect their sensitivity to inter-individual differences in anthropometrics, neuromuscular coordination, and movement strategy, as well as the fact that they are derived variables rather than direct performance measures.

Discussion

The primary objective of this study was to examine the extent to which agility performance can be predicted from anthropometric characteristics, CMJ force–plate variables, and eccentric hamstring strength among elite female basketball players. We hypothesised that eccentric strength of the knee flexors and braking-related metrics would be stronger predictors of short-distance agility performance than traditional vertical jump height measures. However, the findings revealed that none of the investigated variables predicted agility performance, despite an apparently strong model fit. This supports the notion that agility represents a distinct and independent physical quality—not reducible to vertical jump performance or isolated hamstring strength metrics.

Agility in sport comprises not only biomechanical but also cognitive components, including decision-making, visual scanning, anticipation, and pattern recognition (Horníková & Zemková, 2022). During braking and cutting tasks, the hamstrings act predominantly eccentrically to control hip flexion and knee extension, absorbing and dissipating momentum to stabilize the limb during the deceleration phase. Withrow et al. (2008) found that this eccentric action reduces anterior tibial translation and load on the ACL while improving mechanical efficiency during transitions from braking to propulsion. Strong eccentric hamstring capacity therefore enables athletes to achieve shorter ground contact times and better control of deceleration–acceleration transitions—both crucial in Y-test style agility tasks. Studies by Smajla et al. (2022) and Bright et al. (2023) reported positive associations between Nordic hamstring strength and COD or reactive-agility outcomes and demonstrated that eccentric-focused training can improve COD performance.

Taken together, these findings emphasize that eccentric hamstring strength is fundamental for high-level agility because it: (1) controls deceleration mechanics, (2) reduces knee loading and anterior cruciate ligament (ACL) injury risk—especially critical for female athletes who exhibit higher ACL injury rates, and (3) enables faster, more efficient direction changes. A recent editorial by Bright at al. (2023) highlighted that examining eccentric hamstring performance (e.g., Nordic test metrics) in relation to Y-test agility outcomes can clarify how lower-limb neuromuscular control transfers to practical agility performance—particularly relevant in elite female basketball, where deficits in eccentric control significantly influence performance and injury risk (Barrera-Domínguez et al., 2024).

The present findings are particularly relevant for female basketball players, whose performance demands include frequent defensive shuffles, sharp directional changes, and rapid reactive movements to opponents' actions. Consistent with previous literature, only weak-to-moderate correlations have been reported between vertical jump metrics and agility outcomes in female athletes (Spiteri et al., 2020). This suggests that while

CMJ testing is informative for assessing lower-body power, it cannot serve as a surrogate marker of agility. Agility training should therefore be treated as an independent component of conditioning programs, with specific emphasis on reactive drills, perceptual–cognitive challenges, and court-specific movement patterns.

The contradiction between the high R^2 value and the lack of significant predictors requires methodological reflection. Factors such as small sample size and multicollinearity among CMJ variables may have inflated the model's fit without yielding meaningful or generalizable predictor effects. Additionally, the inclusion of a large number of interrelated CMJ variables likely contributed to unstable coefficient estimates. Future research should address these limitations by incorporating larger samples, applying dimensionality reduction techniques (e.g., principal component analysis), and focusing on fewer, theoretically relevant predictors.

The lack of predictive value from CMJ and hamstring strength metrics aligns with current literature emphasising the multifactorial nature of agility. Agility relies on the interplay of physical attributes such as strength and power, neuromuscular coordination, braking efficiency, and perceptual–cognitive factors including decision-making and reaction to external stimuli. Therefore, single-metric approaches (e.g., jump height) are insufficient to capture the full scope of agility performance.

Conclusion

This study demonstrated that CMJ-derived hamstring strength and lower-limb performance metrics do not significantly predict Y-agility test performance in elite female basketball players. Despite the regression model's high R^2 value, none of the examined variables contributed meaningful explanatory power. These findings suggest that agility should be considered an independent physical quality influenced by neuromuscular, biomechanical, and perceptual–cognitive factors rather than vertical jump performance alone.

From a practical standpoint, strength and conditioning coaches should not assume that improvements in CMJ or hamstring strength will automatically lead to enhanced agility. Instead, agility should be trained and assessed directly using sport-specific drills that incorporate decision-making, reactive movements, and rapid braking and reacceleration demands.

This study was limited to elite female basketball players in Iceland, which may restrict generalisability to other populations. Future research should include analysis of separate phases of this specific movement (Y-agility test), integrate biomechanical analysis of COD tasks, and explore nonlinear modelling approaches to capture the multifactorial nature of agility. It is recommended that future investigations consider broader predictive models including horizontal force production, sprint mechanics, and perceptual–cognitive factors, with specific emphasis on female athletes where knowledge gaps are more prominent.

Conflict of interest: There was no conflict of interest associated with this study, and no external funding was received.

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SPORTLOGIA
Scientific-Expert Journal of Anthropological Aspects of Sports, Physical Education and Recreation

Submitted: 27/04/2025
Accepted: 06/06/2025
Online first: 24/03/2026
UDK: 796.01/.09:[531/533:621.22

Original article

Relationships between Vertical Jump Measurement via a Jump Mat and Jump-and-Reach Device: Implications for Testing in Occupational Health and Wellness Settings

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Abstract

Different equipment (jump mat [JM], jump-and-reach [JAR] device) can be used to measure the countermovement vertical jump (VJ). Physical space may dictate whether organizations (e.g., first responder wellness programs) can use either equipment, or in some instances, may need to use both. It would be beneficial to determine whether VJ predictive equations can be generated such that data is comparable between assessments using device-specific protocols. Sixty-one physically-active subjects (35 males, 26 females) completed three VJ trials each measured by the JM, JAR device, and the JM and JAR device simultaneously (using the JAR technique; JM–JAR and JAR–JM). A four-way repeated measures ANOVA with Bonferroni post hoc compared the average and best VJ trials across the four jump conditions ($p<0.05$). Pearson's correlations ($p<0.05$) calculated between-jump relationships between the conditions. Scatter plots and predictive regression equations for the VJ measured separately (JM, JAR) and simultaneously (JM–JAR, JAR–JM) were derived. For the average and best trials, JM jump height was greater than all other jumps, JM–JAR was greater than JAR and JAR–JM, and JAR was greater than JAR–JM ($p<0.001$). All correlations were significant (r=0.943-0.981). The predictive equations had ~90% explained variance for the average and best trials, with the separate JM and JAR equations slightly stronger (JM and JAR: r^2=0.8967-0.9064; JM–JAR and JAR–JM: r^2=0.8958-0.8745). Even though greater VJ heights were recorded by the JM, given the strong relationships, it is possible to calculate a JAR device measure from a VJ performed on a JM, and vice-versa.

Keywords: countermovement jump, health and wellness, occupational health, performance testing, Vertec, vertical jump

Citation: Lockie, R.G. (2026). Relationships between Vertical Jump Measurement via a Jump Mat and Jump-and-Reach Device: Implications for Testing in Occupational Health and Wellness Settings. *SportLogia. 22(*1), 38-50. https://doi.org/10.63356/spl.2026.004

Introduction

Lower-body power is essential for many tasks that are present in tactical occupations (Lockie et al., 2021b) and sports (Lockie et al., 2016). As a result, lower-body power is an important quality to measure and develop in athletes and tactical personnel. Vertical jump (VJ) tests are often used to extrapolate lower-body power (Lockie et al., 2014), although there has been criticism of using jump height as a metric for this fitness quality (Morin et al., 2019). Nonetheless, jump height has great application for tactical populations. Tactical personnel may need to climb and clear obstacles as part of their profession (e.g., police officers may need to clear fences when pursuing a suspect) (Lockie et al., 2022b). Obstacles will not change their height relative to the power produced by an officer (Lockie et al., 2022b), so absolute jump performance is still relevant for tactical personnel, notwithstanding athletes as well (e.g., basketballers performing a lay-up with a 10-foot [3.05-m] tall hoop). Moreover, VJ assessments are relatively easy to administer (Lockie et al., 2018b), and provide a valid assessment of an individual's physical capacity (Burr et al., 2007).

Different equipment can be used to measure VJ performance, including jump mats (JM) (Lockie et al., 2016), jump-and-reach (JAR) devices (Lockie et al., 2018a), force plates (Buckthorpe et al., 2012), photoelectric cells (Glatthorn et al., 2011), linear position transducers (Wadhi et al., 2018), and smartphone applications (Yingling et al., 2018). JM and JAR devices have been frequently used in research and by professional organizations, and have relatively similar prices (JM: ~$800; JAR devices: ~$1000), and are very practical and easy to use (Lockie et al., 2018b). Nonetheless, there are differences in how VJ performance is measured via these two pieces of equipment. The use of a JM involves the performance of a maximal jump and landing on a mat, with VJ height calculated from flight time via projectile motion equations (McFarland et al., 2016) (Figure 1). A JAR device involves displacing vanes and finding the difference between standing reach height and the maximal jump height, typically with a one-armed reach (Figure 2) (Lockie et al., 2014; Lockie et al., 2018b). The actions of the upper-body can vary; the hands can be positioned on the hips throughout the jump to limit the contribution of the upper-body, or they can be used during the countermovement to add momentum to the jump (Walsh et al., 2007). If the goal is maximum jump height, then the arms should be incorporated into the jump (Lees et al., 2006).

Figure 1. The vertical jump performed with a jump mat. (A) Countermovement. (B) Flight. (C) Landing.

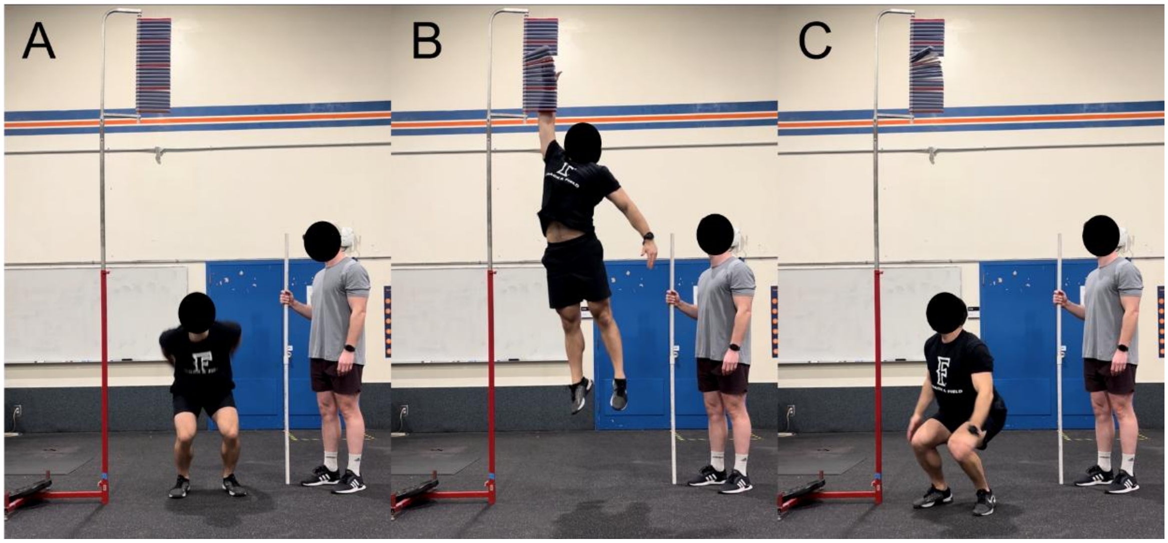


Figure 2. The vertical jump performed with a jump-and-reach device. (A) Countermovement. (B) Flight and Reach. (C) Landing.

Physical space (i.e., the space/room available for fitness testing) can be an influencing factor as to whether an organization can use a JM or JAR device. This is a particular concern for tactical organizations such as police or fire departments, where space can often be at a premium (Lockie et al., 2021a). Restricted, or lack of, space could be problematic for companies that could collect data across multiple sites, such as organizations that provide health and wellness programs for first responders. A component of health and wellness programs often include health and fitness assessments, and data can be compiled over a number of years (Lockie et al., 2022c). If data collection procedures need to change, it would be beneficial to utilize data from previous years, regardless of collection method. Moreover, different law enforcement organizations may use different methods to measure the VJ (Myers et al., 2019). It would be beneficial to determine whether accurate predictive equations can be generated such that data is comparable with different methods of assessment (i.e., VJ measured by a JM or JAR device).

There has been some analysis of this in the literature (Buckthorpe et al., 2012; Leard et al., 2007). Leard et al. (2007) compared VJ performance measured by a JM and JAR device to a 3-camera motion analysis system, with measurement occurring on the same jumps performed with a JAR technique. However, as noted previously, the JM technique can be (and is typically) performed with both arms moving during the countermovement and without the subsequent single-arm reach at peak height (Lees et al., 2006; McFarland et al., 2016; Walsh et al., 2007). Buckthorpe et al. (2012) analyzed jumps performed by healthy adults with a JM and JAR device with a criterion method device of a force plate but did not directly compare the VJ measured by a JM and JAR device. Nuzzo et al. (2011) compared the jump performance of university students recorded by a JM and JAR device simultaneously and found that greater maximum jump heights were recorded by the JM (men: JM = 57.3 ± 9.0 centimeters [cm]; JAR device: 49.8 ± 9.1 cm; women: JM = 38.3 ± 6.0 cm; JAR device = 31.7 ± 5.9 cm). However, the jump technique used by Nuzzo et al. (2011), which was a countermovement followed by a two-hand reach to contact the JAR device, is not typical and may not be optimal for either the JM or JAR device. It would be beneficial to directly compare VJ height measured via both devices and procedures specifically used in tactical populations (i.e., a jump technique that is theoretically used to optimize the VJ for each device), including a jump mat (Dawes et al., 2019a; Dawes et al., 2019b; Lockie et al., 2019c) and JAR device (Beck et al., 2015; Collins et al., 2022; Hernandez et al., 2021; Lockie et al., 2019a; Lockie et al., 2018a). This research could assist with developing fitness profiles for VJ performance and lower-body power, that may be measured in different ways at different sites due to logistical considerations. This type of analysis could also allow for comparisons across tactical organizations that may use different VJ data collection procedures.

Therefore, the purpose of this study was to determine the differences, relationships, and predictive equations produced by VJ height measured by a JM and JAR device using protocols specific to each device. An additional point of analysis was to determine whether the differences, relationships, and predictive equations generated from the same jump performed on a JM with a JAR device (i.e., simultaneous measurement; the participant performed a maximal jump and reach on a JAR device while taking off from and landing on a JM) (Leard et al., 2007; Nuzzo et al., 2011), was similar to jumps performed with a JM and JAR device with their specific protocols. It was hypothesized that VJ height measured by a JM and JAR device would be significantly different whether measured separately or simultaneously (Buckthorpe et al., 2012; Leard et al., 2007; Myers et al., 2019). It was further hypothesized that there would be significant relationships and predictive equations for VJ height measured by a JM or JAR device separately or simultaneously, although the relationships and predictive equations would be stronger for the jumps measured simultaneously.

Methods

Design

A cross-sectional analysis was conducted on physically-active men and women who performed three trials each of the VJ measured by a JM, JAR device, and JM and JAR device simultaneously. This study has a focus on VJ data collection procedures from tactical research (although there is clear application for athletic testing). Accordingly, as per previous research, civilians were used as a surrogate population for research for tactical personnel (Lockie et al., 2019b; Lockie et al., 2020b; Mala et al., 2015; Stevenson et al., 2017). A four-way repeated measures analysis of variance (ANOVA) compared the average and best VJ trials recorded from the JM, JAR device, and JM and JAR device simultaneously. Pearson's correlations and predictive regression analyses were used to document relationships between VJ height measured by the four jump conditions.

Participants

Sixty-one physically-active participants (age: 24.20 ± 3.78 years; height: 1.70 ± 0.11 m; body mass: 74.16 ± 14.15 kg), including 35 males (age: 24.41 ± 3.46 years; height: 1.76 ± 0.10 m; body mass: 81.11 ± 13.66 kg) and 26 females (age: 23.90 ± 4.25 years; height: 1.63 ± 0.07 m; body mass: 64.80 ± 8.26 kg) were recruited for this study. Participants were recruited via word-of-mouth from the university campus where the study was conducted. To satisfy inclusion criteria, participants self-reported whether they completed the minimum recommended physical activity for cardiorespiratory and musculoskeletal fitness as detailed by the American College of Sports Medicine (Garber et al., 2011), and were free from injuries that could influence study participation. As stated, previous research has used civilians as a surrogate population for research directed towards tactical populations (Lockie et al., 2019b; Lockie et al., 2020b; Mala et al., 2015; Stevenson et al., 2017). That formed part of the reason why physically-active participants were recruited for this study. Further, the recruitment from the general population allowed for a proportion of males and females with different physical capabilities to be analyzed (Lockie et al., 2020b; Stevenson et al., 2017). Previous research has used 39-135 participants to conduct similar research to that from the current study (Buckthorpe et al., 2012; Leard et al., 2007; Lockie et al., 2022b; Yingling et al., 2018), and the current sample size fell within this range. G*Power software (v3.1.9.2, Universität Kiel, Germany) was used to confirm post hoc that the sample size of 61 was sufficient for a within factors, repeated measures ANOVA such that data could be interpreted with a small effect level of 0.1 (Hopkins, 2004), and a power level of 0.99 when significance was set at 0.05 (Faul et al., 2007). For documenting relationships between the VJ performed with different methodologies, G*Power software confirmed post hoc that the sample size of 61 was sufficient for a correlation, point biserial model, and ensured the data could be interpreted with a moderate effect level of 0.35 (Hopkins, 2004), and a power level of 0.81 when significance was set at 0.05 (Faul et al., 2007). The institutional review board approved the study (HSR-18-19-586), all participants received a clear explanation of the procedures. This included the risks and benefits of participation, and written informed consent was obtained.

Measurements and Procedures

Data was collected in one ~40–45-minute session. Participants were informed to wear athletic clothing and shoes that they would typically use for training (i.e., sneakers). All testing was conducted in the university's Human Performance Lab, which had rubberized flooring. Prior to testing, participants signed an informed consent form and completed a physical activity readiness questionnaire. Participants removed their shoes so height could be measured using a stadiometer (Detecto, Webb City, MO, USA), and body mass could be measured by an electronic digital scale (Model HBF-510, Omron Healthcare, Kyoto, Japan). After this, participants put their shoes back on and completed a dynamic warm-up that lasted approximately 8-10 minutes. All participants completed the same dynamic warm-up prior to the testing session, which comprised of skips with arm swing, side jacks with arm swing, lunge to rotation with hamstring stretch, pigeon stretch, A-skips, cariocas, and five bilateral base drops with arm swing.

The procedures for this study were adapted from previous research (Buckthorpe et al., 2012; Nuzzo et al., 2011). To counterbalance the sample, participants alternated whether they completed the VJ with the JM or JAR device first. All participants completed the VJ that was performed with the JM and JAR device simultaneously last in the testing order. This was because the focus of the study was documenting the relationships between the VJ measured with the specific protocols for the JM (Dawes et al., 2019a; Dawes et al., 2019b; Lockie et al., 2019c) and JAR device (Beck et al., 2015; Collins et al., 2022; Hernandez et al., 2021; Lockie et al., 2019a; Lockie et al., 2018a) as they have been completed previously in tactical research. For each set of jumps, participants completed two warm-up or practice jumps using the specific procedures for the device (i.e., JM, JAR device, or JM and JAR device combined). This helped prepare the participants for the required maximal effort jumps, and also allowed the researchers to correct any flaws in VJ technique (Nuzzo et al., 2011). Following this, participants completed three VJ trials with the particular device, with rest times of 60 seconds allocated between jumps (Buckthorpe et al., 2012; Nuzzo et al., 2011).

Jump Mat (JM)

Established procedures were used to measure the VJ with the JM (Just Jump, Probotics Inc., Huntsville) (Dawes et al., 2019a; Dawes et al., 2019b; Lockie et al., 2019c). The procedures used in this study also have high reliability (intra-class correlation coefficients > 0.9; coefficient of variation ≤5%) (Nuzzo et al., 2011). The participant initially stood on the jump mat keeping their heels on the floor, before completing a countermovement and jumping as high as possible (Figure 1). No preparatory step was used, and no restrictions were placed on the countermovement range. Participants were instructed to use their arms during the jump, as the arms would generally be used when jumping during a match to add angular momentum (Walsh et al., 2007). Participants were instructed to maintain straight legs during the flight, before landing on both feet with flexion of the hips, knees, and ankles. Within the software for the mat, jump height was estimated from flight time via the following equation: *Jump Height (m) = (½ x acceleration due to gravity [-9.81* $m{\cdot}s^2$*] x [total flight time ÷ 2]*^{2}*)*.

Jump-and-Reach Device (JAR)

As for the JM device, established protocols were used to measure jump height via the JAR device (Vertec Jump Trainer, Perform Better, West Warwick, RI) (Beck et al., 2015; Collins et al., 2022; Hernandez et al., 2021; Lockie et al., 2019a; Lockie et al., 2018a). The protocol used in this study has very high test-retest reliability ($r > 0.99$) (Beck et al., 2015). The participant started by standing side-on to the JAR device on their self-reported dominant side, reached upward as high as possible, and fully elevated the shoulder to displace as many vanes as possible. The participant's heels were to remain in contact with the ground during the reach. The last vane moved became the zero reference. The participant then jumped as high as possible, with no preparatory step, and jump height was recorded from highest vane moved (Figure 2). No restrictions were placed on the countermovement range. VJ height was calculated in inches by subtracting the standing reach height from the jump height, before being converted to cm.

Jump Mat and Jump-and-Reach Device Combined

The final jump trials were performed with the jumps measured simultaneously by the JM and JAR device. The procedures for the jump were the exact same as for the JAR device (Beck et al., 2015; Collins et al., 2022; Hernandez et al., 2021; Lockie et al., 2019a; Lockie et al., 2018a), except participants were also required to take off and land on the JM (Figure 3). The mat was positioned on the floor adjacent to the JAR device and below the vanes (Leard et al., 2007; Nuzzo et al., 2011). If the participant did not land centrally on the mat (i.e., one foot also contacted the ground), the trial was disregarded and reattempted. Data recorded from these methods was defined as JM–JAR (jump measured from the JM) and JAR–JM (jump measured from the JAR device).

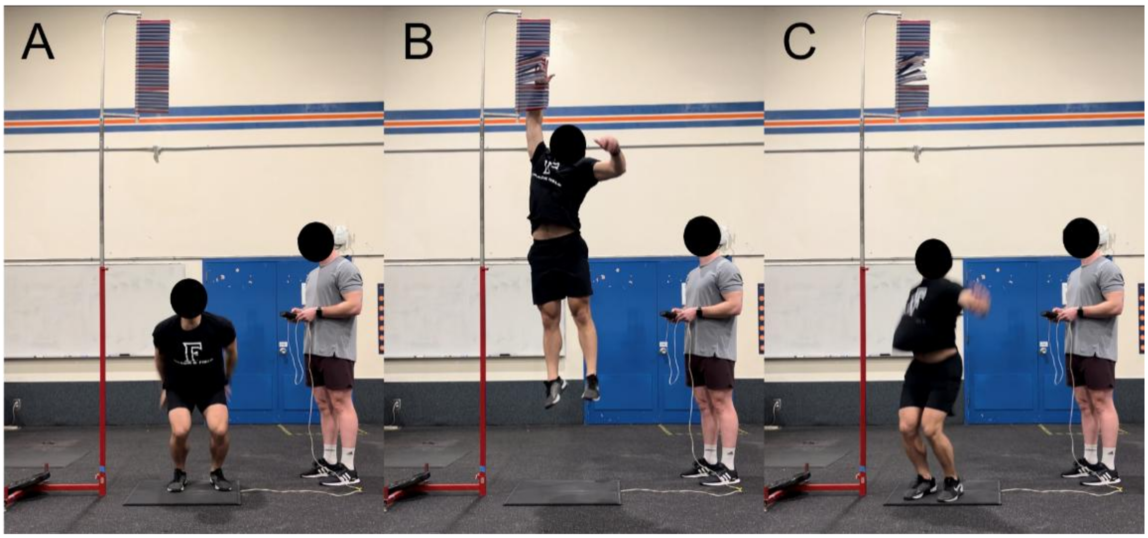


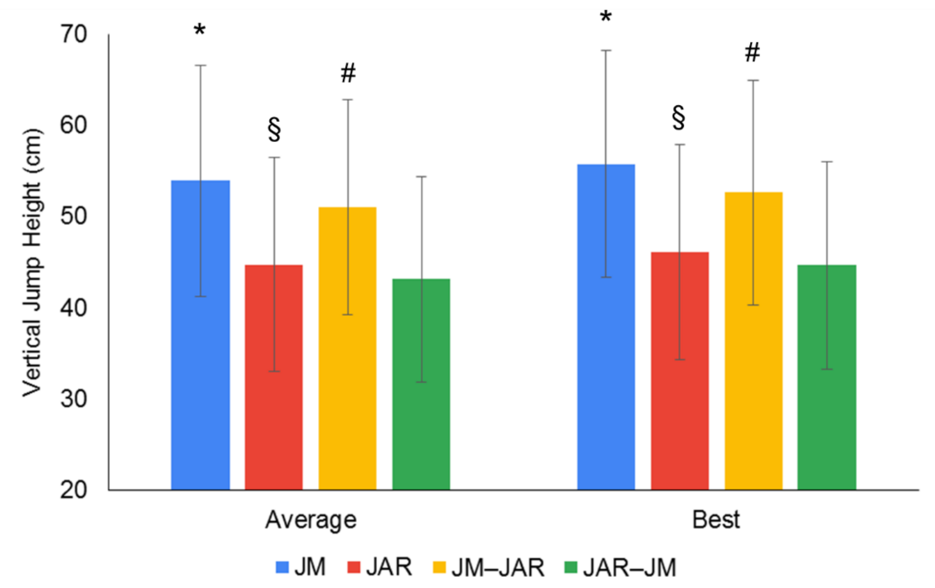
Figure 3. The vertical jump performed with a jump-and-reach device and jump mat simultaneously. The vertical jump performed with a jump-and-reach device. (A) Countermovement. (B) Flight and Reach. (C) Landing.

Statistical Analyses

All statistical analyses were computed using the Statistics Package for Social Sciences (Version 29.0; IBM Corporation, New York, USA) and Microsoft Excel (Microsoft Corporation, Redmond, Washington, USA). Descriptive statistics (mean ± standard deviation [SD]) were calculated for VJ height across the four different conditions (i.e., JM, JAR, JM–JAR, and JAR–JM). Males and females were combined in the sample. Normality of the data was evaluated by the Kolmogorov-Smirnov test and visual analysis of Q-Q plots. Analysis was conducted on the average from the three trials from each condition, as well as the best trial. A four-way repeated measures ANOVA, with Bonferroni post hoc for multiple comparisons, was used to compare the average and best VJ trials across the four jump conditions. Significance was set as $p < 0.05$. Pearson's correlations ($p < 0.05$) calculated between-jump relationships between the JM, JAR, JM–JAR, and JAR–JM. The correlation strength was designated as: an r between 0 to ±0.3 was small; ±0.31 to ±0.49, moderate; ±0.5 to ±0.69, large; ±0.7 to ±0.89, very large; and ±0.9 to ±1 near perfect for relationship prediction (Hopkins, 2006). Lastly, scatter plots were produced in Microsoft Excel for the VJ measured separately (JM and JAR) and simultaneously (JM–JAR and JAR–JM). A line of best fit and predictive regression equations were produced for each scatter plot.

Results

The Kolmogorov-Smirnov test data indicated all jump variables were normally distributed ($p = 0.200$), which was also confirmed upon observation of the Q-Q plots. Thus, parametric statistics were used in this study. The VJ data is shown in Figure 4. There was a significant main effect for the average ($F_{(3,58)} = 141.157$, $p < 0.001$, $\eta_p^2 = 0.880$) and best ($F_{(3,58)} = 145.502$, $p < 0.001$, $\eta_p^2 = 0.883$) jumps. Pairwise comparisons indicated that there were significant ($p < 0.001$) differences between all the jumps whether it was the average or best trial. For both the average and best trials, JM jump height was greater than all other jumps, while the JM–JAR was greater than the JAR and JAR–JM. The JAR was greater than the JAR–JM. For the average values, the VJ recorded separately by the JM was 21% greater than that from the JAR device. When the VJ was measured simultaneously, there was an 18% difference.



* Significantly ($p < 0.001$) greater than the JAR, JM–JAR, and JAR–JM.
\# Significantly ($p < 0.001$) greater than the JAR and JAR–JM.
§ Significantly ($p < 0.001$) greater than the JAR–JM.

Figure 4. Descriptive data (mean ± SD) for the average and best vertical jump recorded from three trials performed by physically-trained men and women ($N = 61$) and measured by a jump mat (JM), jump-and-reach (JAR) device, and jump mat and jump-and-reach device simultaneously (JM–JAR and JAR–JM).

All correlations were significant with near perfect relationships for both the average (Table 1) and best (Table 2) VJ trials across the jump conditions. Figure 5 displays the scatter plot and regression equations for the VJ recorded from the JM–JAR and JAR–JM. There was 89.58% and 87.45% explained variance for the average and best trials, respectively. Figure 6 displays the scatter plot and regression equations for the VJ recorded from the JM and JAR. The explained variance was slightly higher for the JM and JAR relationships, with 89.67% and 90.64% explained variance for the average and best trials, respectively. The equations to predict VJ height for the JAR based on JM performance, and vice-versa, were:

$$JAR_{Average} = (0.875 \times JM_{Average}) - 2.4356$$

$$JM_{Average} = (JAR_{Average} + 2.4356) \div 0.875$$

$$JAR_{Best} = (0.9018 \times JM_{Best}) - 4.1544$$

$$JM_{Best} = (JAR_{Best} + 4.1544) \div 0.9018$$

Table 1. Correlations (*r*) between the average vertical jump height measured from three trials performed by physically-trained men and women ($N = 61$) and measured by a jump mat (JM), jump-and-reach (JAR) device, and jump mat and jump-and-reach device simultaneously (JM–JAR and JAR–JM). All relationships were significant at $p < 0.001$.

	JM	JAR	JM–JAR
JAR	0.947		
JM–JAR	0.955	0.958	
JAR–JM	0.943	0.981	0.946

Table 2. Correlations (*r*) between the best vertical jump height measured from three trials performed by physically-trained men and women ($N = 61$) and measured by a jump mat (JM), jump-and-reach (JAR) device, and jump mat and jump-and-reach device simultaneously (JM–JAR and JAR–JM). All relationships were significant at $p < 0.001$.

	JM	JAR	JM–JAR
JAR	0.952		
JM–JAR	0.946	0.955	
JAR–JM	0.931	0.978	0.935

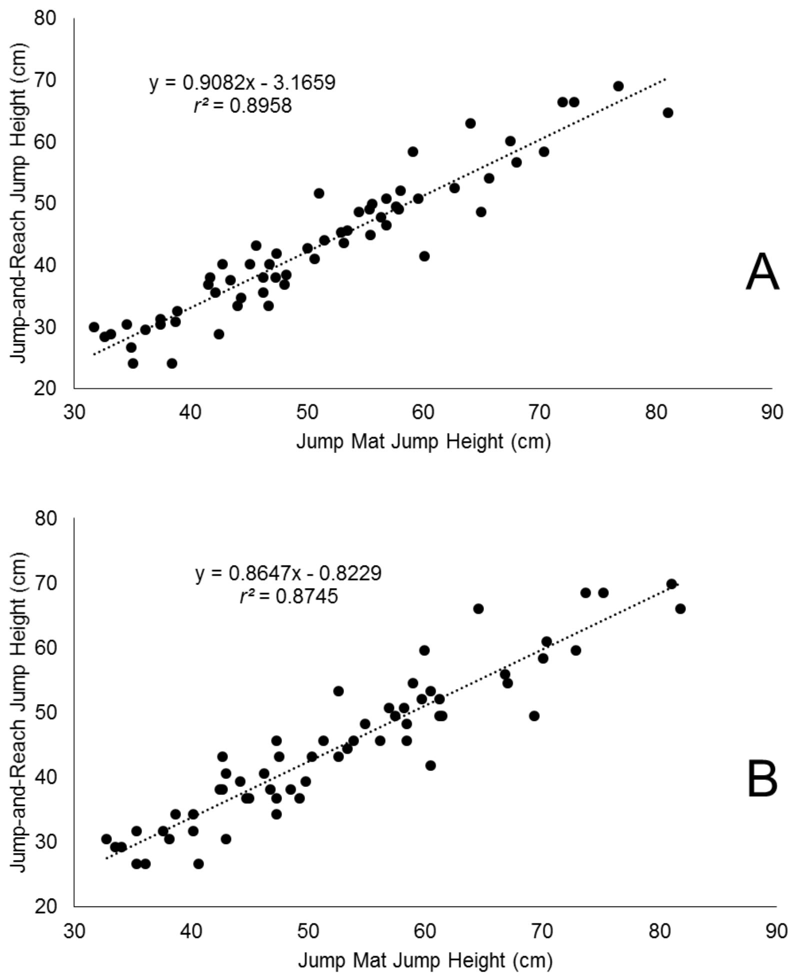


Figure 5. Scatter plot and regression equations for the average (A) and best (B) vertical jump recorded from three trials performed by physically-trained men and women ($N = 61$) and measured by a jump mat and jump-and-reach device simultaneously (JM–JAR and JAR–JM).

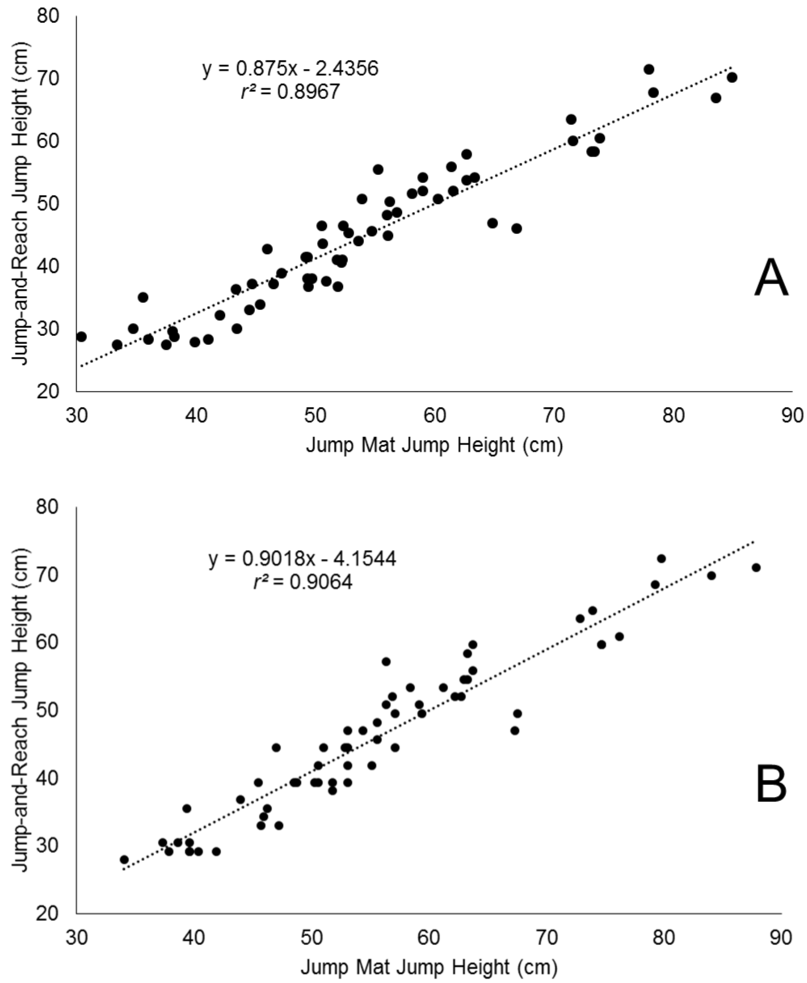


Figure 6. Scatter plot and regression equations for the average (A) and best (B) vertical jump recorded from three trials performed by physically-trained men and women (*N* = 61) and measured by a jump mat (JM) and jump-and-reach (JAR) device.

Discussion

This study investigated the differences, relationships, and predictive equations produced by VJ height measured by a JM and JAR device separately or simultaneously (i.e., the VJ was measured by the JM and JAR device at the same time). It was hypothesized that VJ height measured by a JM and JAR devices would be significantly different and that there would be significant relationships and predictive equations for VJ height measured by the JM or JAR devices. The results generally supported these hypotheses. Similar to previous research (Leard et al., 2007; Nuzzo et al., 2011), a greater VJ was recorded by the JM compared to the JAR device. There were near perfect correlations between the jumps measured across all conditions, and the explained variance for the average and best trials when comparing jumps from the JM and JAR device measured either separately or simultaneously was also very high (r^2 = 0.8745-0.9064). As will be discussed, these results have implications for practitioners who use either a JM or JAR device in their testing, and how they could calculate VJ measurements to predict performance in the other device.

Measuring VJ performance with the JM resulted in the highest jump height. This was expected given the technique required for the jump (i.e., the JM involved a maximal jump without a reach) as well as the projectile motion calculations used to derive the final metric. Flight time recorded via a JM may be longer than other devices such as a force plate, which contributes to a greater derived VJ (Whitmer et al., 2015). Further, reach displacement can influence jump heights recorded via a JAR device (Ferreira et al., 2010), and poor reach technique could negatively impact the final jump height that is recorded. Leard et al. (2007) and Nuzzo et al. (2011) found 10-21% greater jump heights recorded by a JM compared to a JAR device, which was comparable to the current study (18-21%). There was a study that found contrasting findings (Whitmer et al., 2015). In an analysis of 35 college students, Whitmer et al. (2015) found no significant differences between jumps measured from a JM or JAR device (~50 ± 12 cm vs. ~48 ± 11 cm), although the VJ recorded by the JM was approximately 4% greater. Nonetheless, the data from the current study suggested that VJ height recorded from a JM will generally be greater than that from a JAR device. If organizations and staff have to use different devices across different locations, the VJ data they record cannot be directly compared. A correction factor or predictive equation would need to be used to calculate comparable data (within the context that the data has been calculated rather than directly measured).

In support of the potential for the use of predictive equations, the results from this study indicated that the average and best jumps were highly correlated (near perfect relationships above 0.90). Previous research has also documented correlations above 0.90 for jumps recorded from a JM and JAR device (Whitmer et al., 2015). These near perfect relationships occur even though different jump techniques were used for the JM and JAR device. Thus, an individual who has a good VJ as measured by the JM should also have a good VJ when measured by a JAR device. The significant relationships were reflected in the predictive equations generated for both the average ($JAR_{Average} = (0.875 \times JM_{Average}) - 2.4356$; $JM_{Average} = (JAR_{Average} + 2.4356) \div 0.875$) and best ($JAR_{Best} = (0.9018 \times JM_{Best}) - 4.1544$; $JM_{Best} = (JAR_{Best} + 4.1544) \div 0.9018$) VJ, which both had explained variances of approximately 90%.

Practitioners could use these equations in several different scenarios. For example, these equations could also be used by practitioners who wish to compare their personnel to those from other organizations, even though they may have used different jump methodologies to collect their data (Myers et al., 2019). Historical VJ data could still be used, even if coaches must change their jump testing equipment due to spacing or cost considerations. One of the factors behind conducting this study is that some health and wellness organizations, researchers, and practitioners who work with first responders will often need to travel to different locations to conduct their testing. Physical space is often at a premium; some testing locations could accommodate a JAR device, while others may not (Lockie et al., 2021a). Moreover, some first responder organizations will purchase and use a JM (Dawes et al., 2019a; Dawes et al., 2019b; Lockie et al., 2019c), while others may only have JAR devices (Collins et al., 2022; Hernandez et al., 2021; Lockie et al., 2019a; Lockie et al., 2018a). The equations documented in this study could allow for greater flexibility in data interpretation, as calculations could be made such that JM or JAR device jump data could be converted and analyzed. However, caution should still be exercised when using data derived from predictive equations, and the error that may exist. For example, as noted the JM uses a projectile motion equation within internal software to calculate jump height (McFarland et al., 2016). Using a predictive equation to then estimate a JAR device measure would involve using a calculation upon a calculation. One situation where this could be impactful is that some first responder health and wellness programs may offer rewards or incentives based on their fitness test performance (Lockie et al., 2022a; Lockie et al., 2022c). There could be errors associated with using calculations to estimate VJ performance, so staff should make their decisions for rewards or incentives within this context.

A novel part of this study included the measurement of a VJ performed with a JM and JAR device simultaneously, using the typical technique for the JAR device. This did result in an atypical movement when considering the JM measurement (i.e., jumping and reaching for a target on the JM, as opposed to just a maximal jump), although a similar jump has been performed in other research (Nuzzo et al., 2011). As previously stated, Nuzzo et al. (2011) used a two-hand rather than one-hand reach, although the one-hand reach has been suggested as the more appropriate technique for accurate jump measurements (Ferreira et al., 2010). Regardless, there was still a significant difference between the jump height measured by the JM and JAR device when performed simultaneously. There were near perfect relationships between the JM–JAR and JAR–JM (and with the JM and JAR) average and best jump measurements. Interestingly, the explained variance between the JM–JAR and JAR–JM were slightly lower than that for the JM and JAR (average: 89.58% vs. 89.67%; best: 87.45% vs. 90.64%). Thus, the predictive relationships for the JM and JAR were good even with different jump techniques performed at different times. If anything, the results from this study suggest practitioners should use the most appropriate technique specific to the device used to optimize jump performance (i.e., when using a JM, use a countermovement and free arm swing; when using a JAR device, use a countermovement and one-arm reach).

There are study limitations that should be noted. There are potential issues with using VJ height as a metric for power (Morin et al., 2019). However, and as noted, jump height is often used by tactical organizations for both cadets/recruits (Dawes et al., 2019b; Lockie et al., 2019a; Lockie et al., 2020a) and in-service personnel (Dawes et al., 2023; Lockie et al., 2022c). Furthermore, absolute jump performance is important for the completion of job tasks (e.g., clearing an obstacle) (Lockie et al., 2022b). Therefore, the results from this study have clear application. Other devices (e.g., force plates) could provide more accurate measurements of jump performance (Buckthorpe et al., 2012; Ferreira et al., 2010). Regardless, the devices used in this study are common in the field and more affordable and time efficient for many organizations (Lockie et al., 2018b), especially police and fire departments. The sexes were combined in this study. It is possible that different relationships and predictive equations could exist specific to men and women. Nonetheless, the focus of this study was to focus on the test output (i.e., VJ height) measured by each device. The sample for the study was physically-active men and women, although application to first responders and tactical professionals was discussed. Even with tactical professionals being drawn from the general population (as the study participants were), it is possible that tactical personnel could produce different jump data and relationships. Nevertheless, the physical qualities important for a task such as the VJ should be similar whether they are performed by tactical personnel or the general population (Lockie et al., 2019b; Lockie et al., 2020b; Stevenson et al., 2017). As a result, the JM and JAR device relationships and predictive equations should still be applicable.

Conclusion

The results from this study demonstrated that the JM typically recorded higher average and best VJ trials, which may be a function of the technique during the jump (i.e., arm drive with countermovement, with no need to reach for a target) and use of projectile motion equations to calculate jump height. However, there were near perfect relationships between a VJ measured by a JM or JAR device, and regression equations could be explained with approximately 90% variance. Thus, an individual with a good VJ as measured by a JM should also have a good VJ when measured by a JAR device. These results have applications for practitioners, especially those involved with tactical or first responder organizations where fitness testing can be conducted across multiple sites with different equipment. It is possible to produce predictive equations where a JAR device measure can be derived from a VJ performed on a JM, and vice-versa. This study presented equations for average and best VJ trials that could be used for this process. Practitioners could also consider developing their own predictive jump equations specific to their personnel. However, any decisions made using predicted VJ performance (i.e., provisions or restriction of rewards as part of a health and wellness program) should be exercised within the context that the results have been calculated and not necessarily directly measured.

Acknowledgements: The authors acknowledge Marci Guzman for her support of this research and the subjects for their contribution to the study. This research project received no external financial assistance. None of the authors have any conflict of interest.

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SPORTLOGIA
Scientific-Expert Journal of Anthropological Aspects of Sports, Physical Education and Recreation

Submitted: 29/04/2026
Accepted: 15/06/2026
Online first: 25/06/2026
UDK: 796.332-055.1:159.947.5.072

Original article

Speaking the Same Game: An Analysis of Evidence-Informed Communication Training on Coaching Behaviors and Collegiate Soccer Performance

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Abstract

Background: In the high-pressure environment of collegiate soccer, effective communication is vital for tactical execution, yet it often remains intuitive rather than intentional, leading to increased cognitive load for players. This study addresses the research gap linking structured communication training to objective on-field performance measures.

Methods: A quasi-experimental, longitudinal design was used to evaluate a nine-month communication curriculum involving three coaches and ten collegiate student-athletes. Data were collected using the Coaching Behavior Questionnaire (CBQ) and the Game Performance Assessment Instrument (GPAI). Results: Results indicated a statistically significant shift from directive "Informing" behaviors to non-directive "Supporting" and "Exploring" behaviors in coaches. Players showed significant improvements across all GPAI metrics, with total scores increasing from 66.50 to 94.80. Conclusions: This study demonstrates that transitioning from intuitive to intentional communication successfully bridges the gap between coaching behaviors and execution on the pitch. Reducing unnecessary cognitive load through "narrative need" and the "deep inquiry", coaches can accelerate trust and familiarity, increasing player technical and tactical performance. The "Skeletal Model" therefore provides a scalable, evidence-based framework to optimize relationship-building and player performance.

Keywords: Evidence-informed pedagogy, athlete temperament, cognitive load theory, coaching behavior questionnaire (CBQ), instructional inquiry, tactical development

Citation: Hinchman, S.T., Taylor, D.C., Shawver, S., Lange, J.E., O'Brien, M. (2026). Speaking the Same Game: An Analysis of Evidence-Informed Communication Training on Coaching Behaviors and Collegiate Soccer Performance. *Sportlogia. 22(*1), 60-70. https://doi.org/10.63356/spl.2026.007

Introduction

In the pressure-filled environment of collegiate soccer, a coach's effectiveness is traditionally measured via tactical mastery and the development of team cooperation. This development relies on a complex partnership between a coach's technical knowledge and a foundation of relational variables—specifically trust, familiarity, and openness—that serve as the necessary conduits for all instruction (Bayraktar et al., 2025). When the relationship foundation is solid and secure between a player and a coach, effective communication is the primary means of translating tactical theory into on-field execution (Zubić, 2024).

Despite this, communication in coaching is often overlooked and treated as intuitive rather than intentional, evidence-based practice (Collins et al., 2016; Lath et al., 2021; Roberts et al., 2020). The reliance on intuitive coaching can create a hurdle to player development (Lindsay & Spittle, 2024), as unstructured communication practices can unintentionally overload and saturate a player's cognitive load, thereby impeding development (Davis et al., 2024).

When student-athletes have to sort through too much instructional "noise," it begins to eat up the mental space needed to make quick in-game decisions, resulting in a gap between what the coach is asking for and what actually shows in the player's performance (Moran et al., 2023). The current literature reveals a clear gap in this area; while existing research shows that coach training can shift verbal interactions and strengthen coach-athlete relationships (Haugan et al., 2021), no studies to date have examined targeted, communication-focused training curricula while simultaneously measuring outcomes using both the Coaching Behavior Questionnaire (de Haan & Nilsson, 2017) and the Game Performance Assessment Instrument (Oslin et al., 1998) within a soccer context.

To address this disconnect and reduce the impact of excessive cognitive demand, a targeted eight-month intervention was conducted in 2025 as part of an ongoing longitudinal study. The intervention introduced four specific training modules—Coaching as Persuasion, the Three Lanes Concept, The Power of Inquiry, and Looping—designed to move the coaching staff away from intuitive communication habits and toward more intentional, evidence-informed communication strategies. By evaluating the value of this curriculum, the present study sought to determine whether structured shifts in coaching behaviors—specifically in the Informing and Supporting categories—correlate with improved player performance results, while also examining the potentially moderating role of individual player temperament.

This study examines coach-player communication within collegiate athletics. The specific problem is that coaching tactical instructions are often more intuitive than intentional, increasing student-athletes' cognitive load and limiting tactical performance. This challenge is reflected in the gap between the directives the coach provides and the execution in high-pressure moments. The existing literature leaves important questions unanswered. There is a clear lack of research linking communication-focused training to objective performance measures, namely the Coaching Behavior Questionnaire (CBQ) and the Game Performance Assessment Instrument (GPAI), within a longitudinal soccer context. By addressing this gap, the present study offers a framework designed to improve both instructional efficiency and athletic performance.

The purpose of this study was to examine the impact of a nine-month communication training intervention on coaching behaviors and player performance for a Midwestern collegiate soccer team. The independent variable is the 2025 communication training curriculum (Coaching as Persuasion, Three Lanes Concept, The Power of Inquiry, and Looping). The dependent variables are coaching behaviors, as measured by the CBQ, and player tactical performance, as measured by the GPAI. Individual player temperament as measured by the Personality Plus test (LPP), by Florence Littauer (Littauer, 1992) was examined as a moderating variable controlling for baseline performance.

Research Questions and Hypotheses

Research Question One (RQ1): What is the impact of the communication training program on coaching behavior categories as measured by the CBQ?

Null Hypothesis ($H_{ø1}$): There is no statistically significant difference in coaching behavior categories following the implementation of the communication training program.

Alternative Hypothesis (H_{a1}): There is a statistically significant difference in coaching

Research Question Two (RQ2): What is the effect of the communication training program on player tactical performance metrics as measured by the GPAI?

Null Hypothesis ($H_{ø2}$): There is no statistically significant difference in player tactical performance metrics following the implementation of the communication training program.

Alternative Hypothesis (H_{a2}): There is a statistically significant difference in player tactical performance metrics following the implementation of the communication training program.

Research Question Three (RQ3): To what extent does player temperament influence post-intervention tactical performance scores when controlling for baseline performance levels?

Null Hypothesis ($H_{ø3}$): There is no statistically significant effect of player temperament on post-intervention GPAI scores when controlling for baseline performance.

Alternative Hypothesis (H_{a3}): There is a statistically significant effect of player temperament on post-intervention GPAI scores when controlling for baseline performance.

Materials and Methods

Experimental Approach

The study employed a quasi-experimental design to evaluate the effectiveness of an evidence-based communication intervention. This study conducted during the fifth year of a longitudinal investigation into a collegiate soccer program, examined coaching communication. Coaching communication behaviors and player performance were measured using a pre-test/post-test design throughout the 2025 season, following the 9-month training program.

Participants

A Midwestern college soccer program (*n* = 13) was used as the population in this study. Participants included *n* = 3 coaches and *n* = 10 sample student athletes. The coaching staff consisted of *n* = 1 head coach and *n* = 2 assistant coaches. The student-athletes comprised *n* = 10 field players, all new additions to the soccer team during the 2025 school year. This study was approved by the IRB (No. 24111202). Informed consent was obtained. Figure 1 illustrates the longitudinal progression of the study, mapping the recruitment of the participant cohort through the four specific communication training modules and the corresponding assessment timeline from March to December.

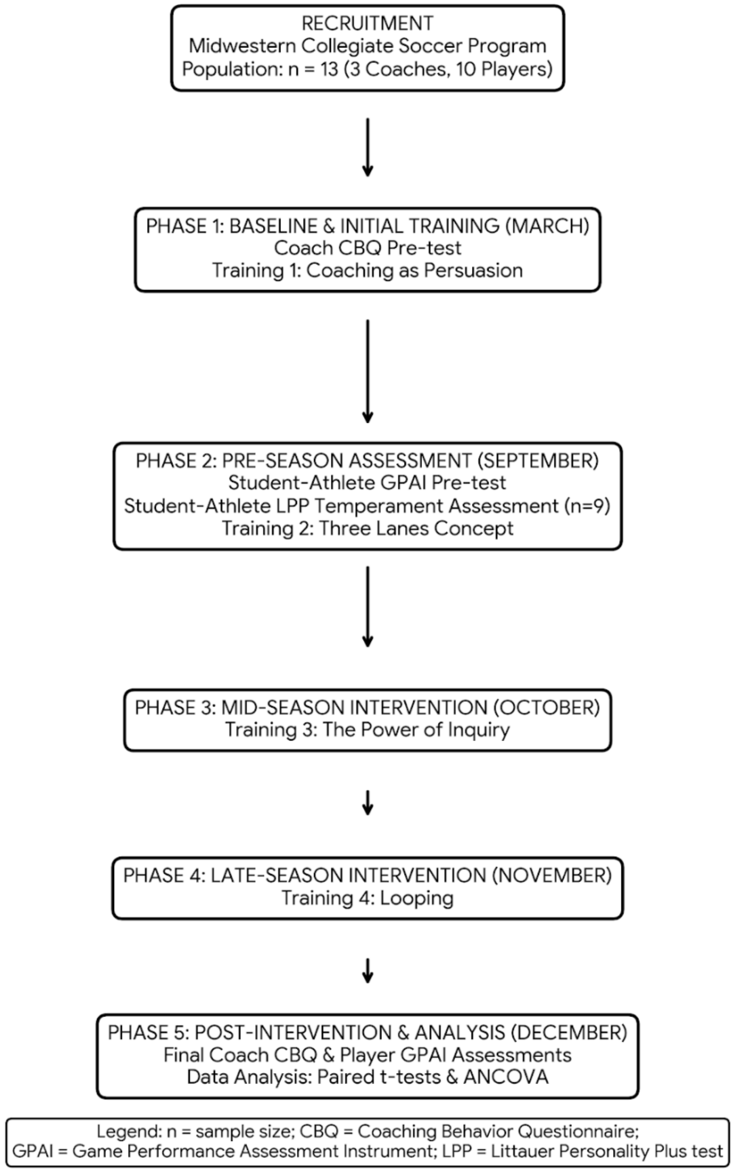

Figure 1. Participant flow and study progression timeline.

Measurements and Procedures

Coaching Behavior Questionnaire (CBQ): The CBQ was used as a self-assessment tool for the coaching staff to measure their perceived instructional styles. The instrument contains 18 forced-choice questions, each with four statements, in which participants allot exactly 10 points, for a total of 72 items. It assesses six coaching behavior dimensions falling under two larger dimensions:

1. Directing Behaviors: Prescribing, Informing, and Confronting.
2. Non-directing Behaviors: Supporting, Exploring, and Releasing.

The CBQ is a validated instrument that measures change in the proportions of directive and non-directive behaviors.

Game Performance Assessment Instrument (GPAI): Player tactical performance was assessed using the GPAI (Oslin et al., 1998), as in previous studies (Hinchman et al., 2023; 2024). The head coach served as the sole observer, rating the nine students on six performance variables: teamwork/support, position/direction, trapping, dribbling, passing, and total performance. Each variable was assessed using a 20-point rating rubric:

0–4: Below expectations

5–9: Needs improvement

10–15: Meets expectations

16–20: Exceeds expectations

Temperament Assessment (LPP): The students-athletes' temperaments were assessed using the LPP (Littauer, 1992). The LPP identifies the four primary temperaments (Sanguine, Choleric, Melancholy, Phlegmatic). The LPP was administered to 9 of the 10 student-athletes to measure their basic temperament characteristics as a mediating variable in their performance.

Intervention

The 9-month intervention occurred from March 2025 to December 2025. Coach responses to the CBQ were collected at the pretest (March 2025) before the training began. The data on the student athletes' responses to the GPAI were collected three times over the course of the season, allowing changes in performance to be tracked. However, to fit the pretest-posttest design of the current study, only the first (pre) and last (post) GPAI assessment data were used in the analyses.

During the intervening periods (March and December CBQ self-assessments), a total of four training sessions were undertaken by the coaching staff:

Module 1: Coaching as Persuasion: This module reconceptualized coaching as a means of persuasive influence, emphasizing the crucial importance of trust and empathy in moving an athlete toward a state of self-regulated performance. Coaches were prompted to structure their sessions to enhance their athletes' self-coaching abilities rather than to provide directive instruction. One aspect of the module was "Narrative Need", which taught how important it was for coaches to explain to their student-athletes exactly what was required of them and avoid any incorrect or limited perceptions of what they were doing. The "COP" Model (Case, Observe, Profile) was introduced to help coaches understand players' "egocentric anchors." The coaches were trained in the "Chameleon Effect" to build identification and trust, using linguistic tools such as Barnum Statements and Rainbow Ruses to foster a deep personal understanding.

Module 2: Three Lanes Concept: Coaches were trained to categorize communication into three distinct streams:

1. The Practical Lane: Focuses on tactical facts, strategy, and logistics.
2. The Emotional Lane: Focuses on empathy and acknowledging players' feelings to establish trust.
3. The Social Lane: Focuses on belonging, addressing a player's reputation and fit within the team hierarchy.

Module 3: The Power of Inquiry: This module addressed the "Why Trap," where closed-ended or accusatory questioning triggers defensive postures. Coaches were trained to use "Deep Inquiry"—open-ended questions focusing on underlying thoughts rather than mistakes. This shift is designed to move players from the "Emotional/Defensive" system into the "Rational/Analytical" system, reducing cognitive demand.

Module 4: Looping: This module introduced coaches to the 'Looping' process as the mechanism that makes the athlete 'feel heard' which consisted of two actions: Step one involves listening to, then reflecting and summarizing the athlete's problem in the coach's own words and, step two is asking for validation ("Did I hear that correctly?")

Self-reported CBQ posttest measures were administered in December 2005, following completion of the training curriculum.

Statistical analyses

To address RQ1, a series of paired-samples t-tests were conducted to evaluate the impact of the eight-month communication training program on the six behavioral categories of the Coaching Behavior Questionnaire (CBQ). The analysis compared self-assessment scores collected in March 2025 (pretest) to those collected in December 2025 (posttest). Similarly, to address RQ2, a series of paired-samples t-tests were conducted to evaluate changes in player tactical performance across six metrics: Teamwork/Supporting, Position/Direction, Trapping, Dribbling, Passing, and Total GPAI. The analysis compared head-coach ratings from the beginning of the season (Interval 1) to the end of the season (Interval 3). To address RQ3, a one-way analysis of covariance (ANCOVA) was conducted to determine the extent to which player temperament influenced post-intervention tactical performance scores (n = 9) while controlling for baseline (pretest) performance levels. The posttest GPAI was the dependent measure, temperament categories were the independent variable, and pretest GPAI was the covariate to control for pretest performance. To estimate the effect size, the partial eta squared (η_p^2) was computed. All statistical analyses were conducted using IBM SPSS Statistics (Version 31.0; IBM Corp., 2025), with the threshold for statistical significance set at $p < .05$.

Results

Statistically significant differences were observed in two of the six behavioral categories: Informing and Supporting. There was a significant decrease in Informing behaviors from pretest to posttest and a significant increase in Supporting behaviors from pretest to posttest. No statistically significant differences were found for Prescribing, Exploring, Confronting, or Releasing (Table 1).

Table 1. Paired Samples T-Test Results for Coaching Behavior Questionnaire (CBQ) Categories.

Category		Pretest *M(SD)*	Posttest *M(SD)*	*t*	*df*	*p* (two-tailed)	Cohen's *d*
Directive	**Prescribing**	30.67(4.04)	30.67(1.53)	0	2	1	0
	Informing	41.00(3.61)	32.67(2.89)	5.735	2	.029*	3.31
	Confronting	34.33(7.02)	30.00(2.65)	0.79	2	0.512	0.456
Nondirective	**Releasing**	20.67(10.69)	26.00(8.72)	-0.828	2	0.495	-0.478
	Exploring	26.67(4.16)	29.67(3.21)	-3	2	.095^	-1.73
	Supporting	26.67(2.08)	31.00(2.65)	-13	2	.006**	-7.51

Note. This table presents the shift in coach self-perceptions across the six behavioral dimensions of the CBQ. *n* = 3. CBQ = Coaching Behavior Questionnaire; *M* = Mean; *SD* = Standard Deviation; *t* = *t*-statistic; *df* = degrees of freedom; *p* = probability value. **Significant at the .05 level.* ***Significant at the .01 level.*

Regarding RQ1, the null hypothesis, which stated there would be no statistically significant difference in coaching behavior categories—was rejected. The alternative hypothesis was supported, as the implementation of the communication training program resulted in significant shifts in both directive (Informing) and nondirective (Supporting) coaching behaviors.

Regarding RQ2, paired-samples *t*-tests revealed statistically significant increases across every tactical performance category, yielding large effect sizes (Table 2). Total GPAI scores increased from pre-season (*M* =

66.50, *SD* = 7.38) to post-season (*M* = 94.80, *SD* = 3.79), $t(9) = –10.30$, $p < .001$, $d = –3.26$. Thus, the null hypothesis was rejected, confirming a statistically significant difference in player tactical performance metrics between the two assessment intervals. The magnitude of the increase was substantial across all categories, particularly within Teamwork, $t(9) = –10.16$, $p < .001$, $d = –3.21$, and Passing, $t(9) = –9.68$, $p < .001$, $d = –3.06$

Table 2. Paired Samples T-Test Results for Game Performance Assessment Instrument (GPAI) Metrics.

Metric	Pretest *M(SD)*	Posttest *M(SD)*	*t*	*df*	*p* (two-tailed)	Cohen's *d*
Teamwork	12.40(2.37)	20.00(0.00)	-10.16	9	<.001	-3.21
Position	13.60(1.26)	18.80(1.93)	-6.5	9	<.001	-2.06
Trapping	13.60(1.90)	19.20(1.69)	-6.24	9	<.001	-1.97
Dribbling	13.60(1.26)	17.20(1.93)	-4.32	9	0.002	-1.37
Passing	13.30(1.70)	19.60(1.26)	-9.68	9	<.001	-3.06
Total GPAI	66.50(7.38)	94.80(3.79)	-10.3	9	<.001	-3.26

Note. This table illustrates changes in player tactical performance metrics between pre-season (September) and post-intervention (December). n = 10. GPAI = Game Performance Assessment Instrument; M = Mean; SD = Standard Deviation; t = t-statistic; df = degrees of freedom; p = probability value; d = Cohen's d effect size. **Significant at the .05 level.* ***Significant at the .01 level.*

To address RQ3, an independent variable consisted of the four Littauer (1992) temperament categories: Sanguine, Choleric, Melancholy, and Phlegmatic (Table 3). The dependent variable was the post-intervention Total GPAI score, and the covariate was the pre-intervention Total GPAI score.

Table 3. Descriptive Statistics for Post-Intervention Total GPAI by Temperament.

Temperament	*n*	*M*	*SD*
Sanguine	1	88	—
Choleric	3	97.33	2.31
Melancholy	3	96	4
Phlegmatic	2	92	0
Total	9	94.67	4

Note. This table presents the mean and standard deviation of total GPAI scores following the nine-month intervention, categorized by player temperaments identified via the LPP. *n* = 9. LPP = Littauer Personality Plus test; GPAI = Game Performance Assessment Instrument; *M* = Mean; *SD* = Standard Deviation.

Preliminary checks were conducted to ensure that the data met the assumptions required for an ANCOVA. Levene's test of equality of error variances was non-significant, $F(3, 4) = 3.80$, $p = .092$, indicating that the assumption of homogeneity of variance was not violated. After adjusting for pre-intervention performance, the main effect of player temperament on post-assessment tactical scores was not statistically significant, $F(3, 4) = 4.63$, $p = .086$, partial $\eta_p^2 = .776$, though it demonstrated a large effect size (Table 4). The covariate, pre-intervention performance, did not significantly predict post-assessment performance in this model, $F(1, 4) = 2.04$, $p = .226$, partial $\eta_p^2 = .338$. Consequently, the null hypothesis was retained. Despite the lack of statistical significance due to the limited sample size (n = 9), the temperament factor accounted for 77.6% of the post-assessment variance. This large effect size suggested that player temperament may share a substantial practical relationship with variations in athlete tactical performance, warranting further investigation with a larger participant cohort.

Table 4. ANCOVA Results for Total GPAI Post-Intervention by Temperament.

Source	*SS*	*df*	*MS*	*F*	*p*	*ηp*2
Pre-GPAI (Covariate)	14.41	1	14.41	2.04	0.226	0.338
Temperament	98.14	3	32.71	4.63	0.086	0.776
Error	28.25	4	7.06			
Corrected Total	128.00	8				

Note. This table presents the results of a one-way ANCOVA examining the impact of player temperament on post-intervention tactical performance, using pre-intervention scores as a covariate. R^2 = .779, Adjusted R^2 = .559. *n* = 9. LPP = Littauer Personality Plus test; GPAI = Game Performance Assessment Instrument; *SS* = Sum of Squares; *df* = degrees of freedom; *MS* = Mean Square; *F* = *F*-statistic; *p* = probability value; η_p^2 = partial eta squared. *Significant at the .05 level.

Discussion

This study was designed to address a problem in US college sports: the reliance on intuition rather than intention in coaching (Roberts et al., 2020; Sheldon, 2018) and communication (Mavor et al., 2010). Ineffective communication can increase student-athletes' cognitive load and limit their development (Bates & McShan, 2025). By providing and examining a communication training curriculum, this study attempted to bridge the gap between the coach's intent and on-field execution, a directed telescope (Van Creveld, 1979) approach. The findings offer a longitudinal blueprint for how intentional and deliberate communication serves as the principal driver behind both athletic performance and development.

The problem identified in this study was the gap between a coach's instructions and player execution on the pitch. The results demonstrate that by replacing an intuitive approach to communication with an intentional framework, coaches can bridge this divide. The statistically significant differences in both coaching behaviors as measured by the Coaching Behavior Questionnaire (CBQ) directly corresponded to improvements in all Game Performance Assessment Instrument (GPAI) categories. This validated the study's primary purpose, proving that communication training can move beyond interpersonal "soft skills" to become a rigorous tool for tactical development.

The study identified that intuitive coaching often leads to an over-reliance on directive "data-dumping," which increases cognitive load. The Informing category of the CBQ—representing directive tactical instruction—showed a significant decrease and a massive effect size (*d* = 3.31). This shift suggests that coaches became more intentional and concise in their delivery. This behavioral change provided the clarity needed for a concurrent and massive shift in player Position/Direction on the GPAI (*d* = -2.06). When coaches removed the "noise" of intuitive, excessive informing, athletes were better able to execute specific tactical positioning.

An integral part of the intervention was the Emotional Lane training, which affirmed players' feelings and developed a sense of trust. These purposeful actions are evident in the statistically significant increase in Supporting scores on the CBQ (*p* = .006, *d* = -7.51). This relational intentionality might even be employed as a direct mediator in on-field situations and is supported by observations of GPAI Teamwork and Supporting Behavior, which earned the highest posttest score (*M*=20.00). These findings suggest that when coaches deliberately validate their players' emotions through the "Emotional Lane," they create a clear path towards collaborative behaviors necessary for elite team cohesion and performance (Li et al., 2024).

The statistically significant improvements in technical execution categories—specifically Passing ($p < .001$) and Dribbling ($p = .002$)—provide empirical evidence of Cognitive Load Theory (Sweller, 1988, 1994) and Dual-Processing Theory (Kahneman, 2011) in action. CLT states that working memory has limited capacity, and instructional design must minimize "extraneous cognitive load" the mental effort spent processing poorly delivered or disorganized information to allow cognitive resources to be dedicated to "germane load," which facilitates actual learning and task execution (Sweller, 1988, 1994).

Intuitive coaching behaviors can strain student-athletes' cognitive load (Bates & McShan, 2025). The higher utilization of the "Informing" category by the coaches (as demonstrated by baseline CBQ scores) has the potential to lead to working memory overload from extraneous information received. By implementing the "Three Lanes" and "Narrative" communication components, coaches can now streamline the dissemination of information. By reducing irrelevant information, more cognitive bandwidth became available to the student-athletes, as evidenced by the statistically significant increase in Total GPAI scores (66.50 to 94.80).

The increase in the Total GPAI score can be further explained by the shift from System 1 to System 2 thinking (22).

> System 1 Thinking: This thinking type represents quick, instinctual, and often emotional processing, which is exemplified in traditional coaching as the "Why" trap (e.g., "Why did you miss that pass?"). Accusatory directives can also trigger a defensive System 1 response, characterized by emotional reactivity and a "shutting down" of analytical capabilities (Kahneman, 2011). This response can create mental friction, as the athlete's brain prioritizes psychological safety over tactical analysis.
>
> System 2 Thinking: This thinking type represents a more rational, slower, and more deliberative approach. The "Deep Inquiry" utilized in Training 3 was specifically designed to bypass the defensive System 1 trigger and engage the athlete's rational faculties (Kahneman, 2011; Stanovich & West, 2000).

The intervention likely created a psychologically safe environment where players could activate their logical, System 2 resources and apply them to solving tactical on-field challenges. This transition is reflected in the Passing and Dribbling GPAI scores, which require both technical skill and rapid analytical decision-making. The intentional shift in coaching behavior—from directive (System 1 triggers) to nondirective (System 2 engagement)—effectively reduced the internal "noise" for the athletes, enabling the significant tactical gains measured during the 2025 season.

Rather than treating student-athletes as "cogs" in a tactical system—a common pitfall in high-stakes collegiate athletics—coaches treated them as individuals to be persuaded. According to Social Influence Theory, persuasion is most effective when messages are "anchored" in the recipient's existing beliefs and values (Cialdini, 2021). Using "Casing, Observing, and Profiling" (the COP model), the coaches aligned their tactical directives with the athletes' internal narratives. This alignment ensured that directives issued in high-pressure match scenarios were met with lower psychological resistance and greater cognitive buy-in.

This intentionality laid the foundation for Relational Trust. According to literature on sport psychology, Relational Trust is considered necessary for high-speed adaptivity (Dirks, 2000). Self-determination and autonomy would be enhanced in athletes who believe their personal temperament and "egocentric anchors" are acknowledged and appreciated. (Deci & Ryan, 2000).

This study fills a clear gap in existing literature by linking communication-focused training to objective performance measures. It provides athletic departments with a rigorous framework to improve both instructional efficiency and player outcomes through intentionality.

From these findings, sports management programs may benefit from introducing "Psychological Persuasion" and "Active Inquiry" (Looping) techniques early in their respective programs. Coaches who can effectively implement the concepts embedded in these modules will be better equipped to manage the cognitive load placed on their athletes, leading to better tactical outcomes.

Although the ANCOVA did not reach statistical significance (p = .086), the very large effect size (ηp^2 = .776) suggests that player temperament (LPP) explains a substantial proportion of the variance in athletes' responses to coaching communication.

The results here suggest that the "Skeleton Model" (Practical, Emotional & Social lanes) is versatile and may be applicable for a variety of athlete personality types. Future research with larger samples is required to define the relationships between temperament and performance and to determine how best to apply the model to different sports environments.

Future Directions

Future research with larger, more diverse participant cohorts is required to further define the relationships between player temperament and performance outcomes. Separate longitudinal studies should investigate the long-term retention of these communication shifts and their applicability across different sports environments beyond collegiate soccer.

Conclusion

In conclusion, this study demonstrates that shifting from intuitive to intentional coaching communication significantly enhances both the efficiency of communication instruction and athletic execution. The use of an intentional communication curriculum, driven by both Cognitive Load Theory (Sweller, 1988, 1994; Kahneman, 2011) and Persuasion (23), delivered to the coaching staff suggests that it has eliminated many of the extraneous mental demands on student-athletes and made the translation of coaching directives into action on the pitch seamless. The statistically significant differences across all the GPAI metrics and the noticeable variations in the CBQ suggest that the "Skeletal Model" provides a framework for communication training in collegiate athletics. The statistically significant differences across all the GPAI metrics and the noticeable variations in the CBQ suggest that the "Skeletal Model" provides a framework for communication training in collegiate athletics. While a player's temperament remains a factor in how humans process information, the positive results of this study suggest that intentionality is an important, trainable leadership skill for sport professionals to maximize performance in high-pressure situations.

Practical Applications

Coaches can utilize "Deep Inquiry" and "Looping" techniques to move players from emotional/defensive reactions to rational, analytical thinking during high-pressure scenarios. The Three Lanes Concept" (Practical, Emotional, and Social) can be used to ensure tactical instructions are balanced with emotional validation and team belonging. Coaches can reduce the volume of directive "data-dumping" (Informing) to free up players' cognitive bandwidth for technical execution and in-game decision-making. The application of the "COP" Model (Case, Observe, Profile) to align tactical instructions with individual player temperaments to increase buy-in

Conflict of interests: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Acknowledgment: The research was approved by the Midwestern State University Institutional Review Board Committee (No. 24111202) on 11/12/2024 (signed by Rodney Fisher, Ph.D., RT(R)(N)(CT)(BD), CNMT Chair, Human Subjects in Research Committee).

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