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Sled-Pull Training Improves Maximal Horizontal Velocity in Collegiate Men and Women Soccer Players

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Abstract The force velocity profile (FvP), which details the capacity to sprint and accelerate, is a determinant of success in soccer. To date, no data exist that details the FvP of male and female collegiate Division I soccer players. Further, there is limited insight on how training interventions may modify the FvP of either males or females. **Purpose:** The aim of this investigation was to compare FvP between collegiate male and female athletes and assess the efficacy of an 8-week sled pull training intervention. **Methods:** Seventeen male (20.17±1.38 yrs) and 12 female (19.75±1.05 yrs) soccer players participated in an 8-week sled pull training intervention. FvP was measured prior, during, and after training using a 30m sprint to assess maximal horizontal force (F_0), maximal horizontal speed (V_0), and maximal power output (P_{max}). **Results:** The intervention improved 30m sprint times of men by 11.86% (pre: 4.35±0.17s, post: 4.27±0.17, $p<0.05$) and women by 5.1% (pre: 5.01±0.18s, post 4.96±0.20, $p<0.05$). This was reflected by an improvement V_0 in both men (pre: 7.98±0.36 m/s, post: 8.09±0.35 m/s, $p<0.05$) and women (pre: 6.73±0.26 m/s, post 6.84±0.31 m/s, $p<0.05$). However, the intervention did not improve F_0, P_{max}, or early acceleration. **Conclusions:** An 8-week sled pull training intervention improves 30m sprint times and V_0 in both male and female collegiate athletes but does not improve F_0 and P_{max}. Thus, the sled pull intervention should be modified or paired with other training that specifically targets force and power development.

Keywords Force-velocity profiles, Sled-pull training, Soccer

1. Introduction

Early acceleration during sprint running is critical in many individual and team sports (i.e. soccer). Horizontal force generation is a key in determinant of sprint and acceleration performance [1], which may translate to on-field success. Cross sectional data in men and women demonstrate players at higher levels of play have better sprint performance [2], highlighting the need for effective interventions that improve acceleration and overall sprint performance.

Lower extremity power can be profiled using multiple sprint trials to produce a linear force-velocity relationship [3,4]. The theoretical *x*- and *y*-axis intercepts of this relationship characterize the theoretical maximum force at zero velocity (maximal net horizontal ground reaction force, F_0) and the maximum velocity at zero force (v_o), representing the maximum mechanical capacity of the individual [5]. Power can then be computed as the product of force and velocity ($P = F * v$), with the relationship between power and velocity fitted with quadratic equations [5] and the peak of the power-velocity relationship representing maximum power (P_{max}). P_{max} is widely measured as it is a criterion of performance among athletes and should be a training goal of strength and conditioning coaches. Additionally, the maximum ratio of force (RF_{max}), which is a ratio of the step-averaged horizontal component of the ground reaction force to the corresponding resultant force [1], is another mechanical characteristic of sprint performance that can provide insight into biomechanical limitations of athletes.

Resisted sled pull training improves sprint performance, particularly during the early acceleration phase, by overloading horizontal force capacities [6-8]. Petrakos and colleagues [7] determined light-to-moderate loads (12 to 43% of body mass, BM) are effective in improving sprint performance, with heavy loads (>60% BM) specifically improving initial acceleration due to high resistive forces and low velocity. Subsequent research suggests sled pull training with heavier loads (69-96% BM) maximizes peak power [9], which demonstrates the limits of the neuromuscular system during explosive activities and improves sprint acceleration [10]. Very-heavy sled training increased maximal horizontal force production in amateur soccer players while simultaneously improving sprint performance [11]. Additionally, a 6-week resisted sled-pull training program using 80% BM improved

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sprint acceleration force, velocity, power, and performance in junior Australian footballers [12] further supporting the implementation of such a training program. Very-heavy loads enable the athlete to produce more force in a forward direction throughout the sprint by reducing the velocity of the athlete [13]. Altogether, the literature reinforces the utility of very-heavy sled pull training for increasing horizontal power.

Much of the research demonstrating improvements in acceleration and horizontal force from resisted sled pull training was conducted in men [11,12,14]. There is limited knowledge on the effects of resisted sled training on sprint performance and power in women. Only recently, a study investigated the acute physiological and perceptual responses to a single session of resisted sled sprint training in males and females demonstrating similar responses [15]. However, there are no long-term comparisons of sled pull training adaptations between men and women. Therefore, the aim of this study was to determine the effects of a very-heavy sled training program on sprint performance and the force-velocity profile of both men and women collegiate soccer players. A secondary aim was to examine sex-specific effects of the training program on force-velocity (F-v) profiles of the soccer players.

2. Methods

2.1. Subjects

Forty-four soccer players, 23 men and 21 women, were recruited from an NCAA Division I soccer team during the non-competitive season (i.e. spring). Subjects were required to have completed 80% of the resisted sled-pull training sessions, not have acquired any injury that may have impeded with their ability to participate in the intervention and had to complete all three testing sessions. Of the 44 athletes recruited, 15 men (20.18 ± 1.38 yrs, 182.47 ± 7.87 cm, 79.78 ± 8.87 kg) and 11 women (19.69 ± 1.03 yrs, 166.57 ± 4.27 cm, 62.71 ± 8.22 kg) met aforementioned inclusion criteria and were thus included in the analyses. The Institutional Review Board approved the testing protocol and informed consent documentation was obtained from all participants prior to enrolling in the study.

2.2. Methodology

Participants were familiarized with the sled pull intervention one week prior to implementation (load was gradually increased). The sled pull intervention involved two phases: loading and maintenance. During the loading phase, subjects completed six reps of 20-meter sled pull sprints with 80% BM of resistance twice per week. This loading phase lasted four weeks, followed by a one-week taper before mid-intervention testing (4:1 mesocycle arrangement).

After mid-intervention sprint testing, subjects entered the maintenance phase, during which the subjects completed six reps of 20-meter sled pull sprints with resistance equivalent to 50% of their body weight. This maintenance phase also lasted four weeks and was followed by a one-week taper before post-intervention testing.

All sled-pulls during the training intervention occurred on a cement surface while wearing training shoes. At least 48 hours recovery time was provided between training days. Sled load, sprint distance, and rest intervals of at least 3 minutes remained constant for each participant throughout each sled pull training intervention phase.

Each sled-pulling training session started with a standardized RAMP protocol warm-up of about 12-15 minutes that targeted the main muscle groups of the upper and lower extremities. This was followed up with plyometric training, which focused on horizontal jumps, emphasizing acceleration force production through broad jump and bound variations. Athletes then conducted sled pulling intervention. After the sled pulling intervention, athletes participated in traditional strength training in the gym. Strength training involved linear progressions of the barbell squat and bench press movement with additional accessory exercises. Athletes were familiarized with the plyometric and strength training programs throughout previous sport seasons.

Concurrently, the athletes were also engaged in soccer practice four to five days each week. Practices that occurred on the same days each week as the sled pull intervention were completed after the training sessions.

2.3. Assessments

Sprint testing occurred the week prior to the intervention (pre), one week after the loading phase (mid), and one week after the maintenance phase (post). Each testing assessment followed the same protocol as described below.

Prior to sprint testing, participants completed a standardized warm-up led by the strength coach professional followed by two build-up sprints (80 and 90% of self-determined maximal sprint velocity) to prepare the athletes for testing. Sprint testing was conducted on synthetic turf in the morning between 0600 – 0800. Participants wore comfortable clothing and cleats, which they were asked to replicate each day of testing to prevent influencing subsequent data collections. Temperature and atmospheric pressure were also collected each day.

2.4. Force-Velocity Profiles

To generate F-v profiles, timing gates [16] (Brower TC System; Draper, Utah, USA) were placed at 5, 10, 15, 20, 25, and 30 meters to collect the sprint times at each distance [17]. Timing gates were placed at a vertical height at approximately the center of mass similar to previous studies [14,18]. Each subject completed the 30-meter sprint twice from a standing split stance with a minimum of 5 minutes of recovery given between sprints. Participants were instructed to sprint through the last set of timing gates to ensure deceleration was avoided.

To determine F-v profiles, we adapted methods from a modelling paper detailing the optimal F-v profile for sprint performance [19].

Briefly, the maximum velocity (v_{max}), and the acceleration time constant (1) were estimated by fitting the mono-exponential function

$$v(t) = v_{max}\left(1 - e^{-t/h}\right) \quad (1)$$

to the raw time-distance data for each sprint using least-squares regression.

V_{max} and acceleration time constants were used to calculate the theoretical maximal velocity and force (v_0 and F_0, respectively). F_0 was then calculated as the ratio of V_{max} to the acceleration time constant. V_0 was calculated using the following equation:

$$v_0 = \frac{1}{2kc}\left(1 - \sqrt{1 - 4kcv_{max}}\right) \quad (2)$$

The parameter k is known as a runner's aerodynamic friction coefficient [20], which can be calculated as:

$$k = 0.5\rho A_f C_d \quad (3)$$

where

$$\rho = 1.293 \cdot Pb \cdot 760^{-1} \cdot 273 \cdot (273 + T)^{-1} \quad (4)$$

is the air density, determined from the atmospheric Pb (in Pa) and temperature T (in ℃) conditions in the location where athlete trials are conducted,

$$A_f = 0.2025 \cdot H^{0.725} \cdot W^{0.425} \cdot 0.266 \quad (5)$$

is the frontal cross-sectional area of the athlete, which can be approximated using the height H (in m) and weight W (in kg) of an athlete, and C_d is the drag coefficient, at a constant value of 0.9.

Maximal mechanical power output (P_{max}) was calculated as the product of F_0 and 25% of v_0. v_0 and F_0 were used as intercepts to generate individual linear force-velocity (F-v) profiles. Data processing and calculations were completed using MATLAB (version R2021b for Windows).

The percentage of forward direct of motion compared to the total force production (RF_{max}) is calculated by

$$RF_{max} = \frac{F_0}{\sqrt{F_0^2 + g\hat{}2}} \cdot 100\% \quad (6)$$

where $g = 9.8 m/s^2$ is the gravitational constant.

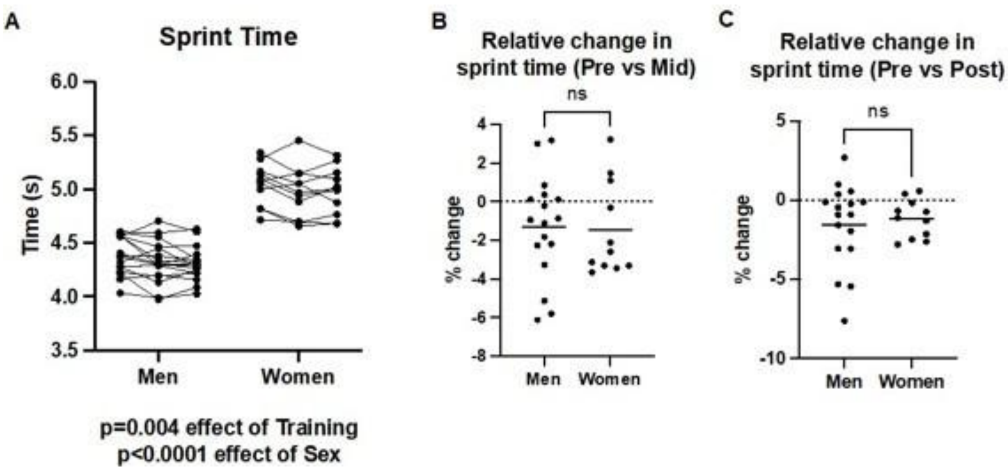
Early acceleration values are calculated for each profile as $a_5 = 5 / (t_5)^2$ and $a_{10} = 10 / (t_{10})^2$ where t5 and t10 are the times collected at the 5- and 10-meter gates, respectively.

2.5. Statistical Analyses

Data are presented as the mean ± SD. Out of 156 sprint trials, 6 sprint tests were outliers, either due to missing timing gate values or excessive errors in the model fitting (SSE > 7) and thus excluded from analysis. At each time point, v_0, F_0, P_{max}, RF_{max} from the two sprint profiles were averaged for each participant. A Two-Way ANOVA with repeated measures was conducted to assess the effect of sex, training, and the interaction of the two factors. Tukey post-hoc tests were conducted when there was a significant main effect. To test if the relative change in sprint time was different between men and women, an unpaired Students t-test was conducted. A One-Way ANOVA was conducted to test if there was an effect of training on peak force generation in either the right or left leg. Statistics were performed using GraphPad Prism (version 9.4.1 for Mac, GraphPad Software, San Diego, California USA). Significance was set a priori at $p < 0.05$.

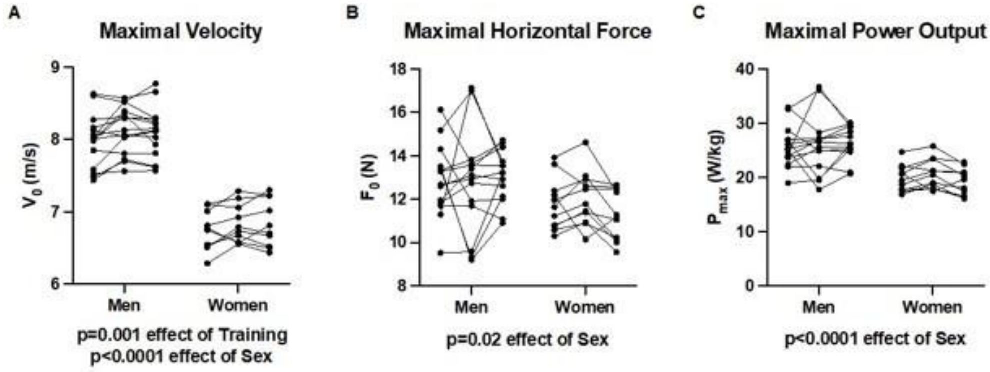
3. Results

Results from the 30m sprint and F-v profiles are summarized in Table 2.



Training had a significant main effect (p=0.0008) on both men and women. Training significantly improved sprint times in women during the loading phase, though men had faster sprint times than women throughout the intervention (p<0.0001) (A).
There were no sex-specific differences in the improvement in sprint times in response to the whole training intervention (B) or during the loading phase (C). However, during the maintenance phase, women had a greater relative increase in sprint times compared to men (p=0.0185) (D).

Figure 1. Change in sprint performance



Training had a significant main effect on maximal horizontal velocity in both men and women (p=0.0008), with post-hoc testing revealing significantly greater (p<0.05) velocities in men after the loading and maintenance phases com- pared to baseline (A). Compared to women, men had greater maximal horizontal velocity (p<0.0001), horizontal power (p=0.0117), and power output (p<0.0001; A, B, and C).

Figure 2. Force-velocity profiles throughout intervention

3.1. 30-meter Sprint Time

The sled-pull training intervention significantly decreased (p=0.004) 30-meter sprint times in both men and women. In men, 30-meter sprint times decreased from 4.38 ± 0.17s to 4.32 ± 0.20s to 4.31 ± 0.16s at pre-, mid-, and post-intervention, respectively (Figure 1A). In women, sprint times decreased from 5.05 ± 0.20s to 4.97 ± 0.24s to 4.99 ± 0.22s (Figure 1A). Post-hoc testing revealed that sprint times were significantly different between pre- and mid-timepoints (p=0.02; Figure 1B) and pre- and post-timepoints (p=0.004; Figure 1C). However, there were no differences in sprint times between mid- and post-timepoints (p=0.99).

There was no difference (p=0.874) in the mean ± SD change in sprint time between men (-1.31 ± 2.69%) and women (1.47 ± 2.42%) at the midpoint (Figure 1B). Similarly, improvements in sprint times at post time point were also not different (p=0.682) between men (-1.55 ± 2.65%) and women (-1.20 ± 1.20%) (Figure 1C).

However, the effect size of training (Cohen's *d*) between pre and post sprint times was 0.424 for men and 0.285 for women. Additionally, men had significantly lower sprint times than women at each timepoint (p<0.0001) (Figure 1A).

3.2. Early Acceleration

Early acceleration did not reflect the changes in velocity. There was no significant difference in acceleration from 0 m to 5 m (p=0.712) and 0 m to 10 m (p=0.870) in both groups. In women, however, there was a significant decrease in early acceleration from 0 m to 5 m (p=0.008). The men showed no significant training-induced changes in early acceleration.

3.3. Force Velocity Profiles

Improvements in sprint times were reflected by training-induced increases (p=0.001) in V0 in both men and women (Figure 2A). In men, V0 increased from 7.98 ± 0.37 m/s to 8.13 ± 0.32 m/s to 8.10 ± 0.35 m/s. In women, V_0 increased from 6.77 ± 0.28 m/s to 6.85 ± 0.26 m/s to 6.88 to 0.34 m/s. Again, post-hoc testing revealed that V0 increased from pre to mid (p=0.003), but not from mid to post (p=0.989) but remained greater than pre-values (p=0.004). The effect size of training on V0 was 0.333 for men and 0.353 for women.

There was no effect of training on either F_0 (p=0.722) or P_{max} (p=0.679) (Figures 2B and 2C). Men had significantly greater V_0 (p<0.0001), F_0 (p=0.02), and P_{max} (p<0.0001) than women (Figures 2B and 2C). Training did not affect RF_{max} in men (p>0.05) but did decrease in women (p=0.063) as a result of the intervention.

4. Discussion

The purpose of the study was to determine the effects of a very-heavy sled training program on sprint performance and the force-velocity profile of both men and women collegiate soccer players and examine sex-specific effects of the training program. The primary outcome is that the 8-week sled-pull training program similarly decreased sprint times in both male and female athletes. Sled-pull training also increased v_0 in both sexes. Surprisingly, there was a decrease in early acceleration from 0 m to 5 m and RF_{max} in women, but no statistically significant changes measured in men. Additionally, the training program did not change F_0 or P_{max}. These results demonstrate that incorporating very-heavy sled pulls during traditional off-season training can improve sprint performance in both men and women.

The current study used an 8-week training program that was broken into two phases: loading and maintenance. Four weeks of very heavy sled pull training (80% BM) followed by 4 weeks of maintenance (50% BM) decreased 30-meter sprint times in both men and women collegiate soccer players, which may translate to on-field success in competition. Prior research has observed improvements in sprinting after 6-week [12] and 8-week [11,14] programs. The current study demonstrates 4 weeks of the very-heavy training phase improved sprint times in 66% and 81% of the men and the women, respectively. This is particularly relevant for collegiate athletics as strength coaches have limited, structured contact with athletes per NCAA guidelines, which precludes employing longer duration training programs.

The lack of difference in sprint times from mid to post indicates that the maintenance load of 50% BM was sufficient to prevent loss of improvements seen through the loading phase. By the end of the full 8-week training intervention, 80% of men and 91% of women improve- ment their sprint time. Rodríguez-Rosell et al. [21] demonstrated that 40% BM and 60% BM induces sprint improvements after an 8-week training program which supports the use of 50% BM as a load for maintenance after training with 80% BM. However, we observed that most women lost some improvements when transitioning from the loading to maintenance phase. In men, there were likely no additional adaptations once the load was reduced. However, the reduced load was a sufficient stimulus to prevent detraining. To our knowledge, the present study is among the first to include a maintenance phase and demonstrate the sex-specific effects of its use.

Surprisingly, early acceleration remained unchanged for all athletes (0 m to 5 m and 0 m to 10 m) with women showing significant decreases in early acceleration from 0m to 5 m (p=0.008). These data contrast prior research which demonstrated that sled-pulling improved early acceleration [6-8]. However, particularly for women, it is likely that the 80% BM resistance caused kinematic changes in sprinting technique that resulted in reduced early acceleration. When towing a sled with 20% BM, male sprinters demonstrated a decrease in stride length in the early acceleration phase of a sprint [22] which sup- ports prior research that 32% BM reduced stride length 24% [23]. Furthermore, Pareja-Blanco and colleagues [24] demonstrated a significant decrease in stride length when conducting resisted sprinting at 80% BM compared to lighter loads in elite male rugby players. Conversely, heavy resisted sled pulling (57-73% BM) did not induce significant kinematic changes in male and female junior running sprinters while significantly improving 30 m sprint times [25]. These dichotomous results could be a result of age and sport. In general, when sprinting, an individual tends to increase stride length initially while also increasing stride frequency to accelerate [26]. Therefore, a potential adaptation from the heavy-load training program may have been a reduction in stride length which inadvertently reduced early acceleration ability. However, the above-mentioned studies were conducted acutely and mostly in men and may not be generalizable to the results of the women soccer athletes. Future research is warranted to determine any kinematic changes in women as a result of the heavy, sled-pull training program.

Improvements in sprint performance are typically reflected in force, velocity, acceleration, and power mechanical characteristics of the sprint. The increase in v_0 (theoretical maximum velocity) in the athletes support the improvement in sprint times. Most athletes improved from pre to mid (men ES: 0.333; women ES: 0.353) but not mid to post, following the same pattern of sprint performance. Edwards and colleagues (2022) similarly demonstrated ~3% improvement in v_0, while others measured ~1% improvements in v_0 alongside sprint performance improvements [11]. However, there was a lack of significant difference in P_{max} and F0 in the present study. Previously, Cahill et al. [14] demonstrated moderate effects (ES: 1.03) on P_{max} post-intervention, which was further supported by other investigations that also reported small but significant improvements (9.07% [12]; 5.3% [11]) in P_{max}. We speculate that because the very-heavy loads reduce velocity during training [21,24], the 80% BM chosen in the present study impaired training power output and subsequent P_{max}. The lack of change in F0 measurements of this intervention contradict prior research which measured a ~6% increase [11,12,14]. Furthermore, RF_{max} decreased in women and was unchanged in men, which is not in line with prior studies. The difference in findings is likely due to sex, training history, age, sport participation of the participants as well as protocol. Prior studies used eight weeks of sled pull training with progressive increases from six to nine repetitions [14] or remained constant with five repetitions [11]. Six weeks of sled pull training with eight repetitions improved mechanical characteristics of sprint performance [12]. However, the present study only included six repetitions each session throughout each four-week phase, which may not have been enough stimulus to induce mechanical force and power changes.

While the present study significantly improved sprint performance, it is not without limitations which should be considered when interpreting our results. While testing occurred at the same time at each measurement time-point, the testing occurred outdoors which could have influenced sprint results. However, temperature, pressure, and wind speed were not differently and thus unlikely to have impacted results of the study. It is also possible the low training volume during the loading phase of the study (eight sessions) was an insufficient stimulus to elicit mechanical characteristic changes of sprint performance. The lowest training volume previously to produce significant changes was 10 sessions [12]. Additionally, all athletes continued to perform their normal sport-specific training programs and strength and conditioning activities in addition to the sled-pull training intervention, which could have impacted the results. However, the training completed was continuous from the prior season and not novel to the athletes, whom all had at least two years of previous resistance and soccer training experience. Therefore, the results of the present study can be attributed to the addition of the sled-pull training.

5. Conclusions

Four weeks of heavy sled pull training significantly improved sprint performance in men and women soccer athletes. These improvements were maintained through the maintenance phase of the program where the resistance was reduced from 80% BM to 50% BM. Mechanical characteristics of sprint performance returned mixed results with an improvement in v_0, but either no changes or decreases in other measures, particularly for women. Future studies should be conducted to investigate optimal loading strategies and training volume for both men and women soccer athletes.

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