ISSN 2618-1576 Vol. 8, Issue 3: 7-14, DOI: 10.25236/FSR.2026.080302

A Randomized Controlled Trial of Different Lower-Limbs Complex Training for Sled Push in Hyrox Competitions

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Abstract: *This research implemented an eight-week randomised controlled trial which was used to assess the influence of two different forms of training on Hyrox sled push performance. The sample comprised thirty male trained individuals who were randomly put into one of two groups: a conventional high load lower body strength training group (Modality A), or a sled push-specific training group (Modality B). In the main result, they measured the completion time in a standardized Hyrox sled push test, but also other parameters like 1 RM back squat, removal rate of blood lactate, and RPE. The study indicated that there was a significant interaction effect between group and time concerning every single measure of outcome. Although both groups improved, Modality B had a considerably greater impact on reducing sled push time and increasing lactate removal rate over Modality A. By contrast, Modality A brought about a substantially bigger increase in 1 RM back squat. The outcomes are quite strong as they show that the principle of training specificity applies here implying that the effect of training specificity on enhancing direct effect of Hyrox sled push performance and its related physiological and perceptual adaptations is better achieved through sled-push-specific training rather than through general strength training.*

Keywords: *sled push, Hyrox, specificity of training, randomized controlled trial, athletic performance*

1. Introduction

As a functional fitness series incorporating endurance and strength, the Hyrox competition sled push event is a complete test of explosive power of athletes lower limbs, strength endurance and technical movements. The sled push is the next functional station of a Hyrox race. This station requires greater maximum strength and strength endurance compared to the first functional station, the ski erg. Performance in this station will have a great impact on how the physical efforts will be allocated afterward. Thus, optimal performance in this particular task is essential to an athlete competition outcomes. One of the most contentious issues in training practice is whether emphasis ought to be put in developing lower-limb maximum strength using conventional squats and other maximal strength exercises (hereafter referred to as Training Program A), or whether it would be better to emphasize highly sport-specific sled push training that resembles very closely the movement patterns and energy metabolism properties of the race (hereafter referred to as Training Program B) to make more specific adaptations [1][2]. Even though the role played by the foundational strength is undeniable, there are no adequate empirical data available concerning the effectiveness of either of the training methods in improving Hyrox sled push performance directly. It leads to the absence of clear scientific direction in the design of training plans by athletes and coaches. To address this gap, the study will create a controlled experiment. They are intended to find out which of the two popular training programs has more effective performance improvement results in the standardized Hyrox sled push test. Consequently, determining an evidence-based best practice of sport-specific physical training in this field has practical application value.

2. Research hypotheses

According to the principle of training specificity, which explains that the more similar the training

ISSN 2618-1576 Vol. 8, Issue 3: 7-14, DOI: 10.25236/FSR.2026.080302

is to the target activity in terms of movement patterns, speed, and metabolic stress, the bigger the adaptive effect, the present study suggests the following hypotheses:

The Null Hypothesis (H_0) is that there are no statistically significant differences between the effects of Training Program A (conventional lower-limbs strength training) and Training Program B (specific sled pushing training) on enhancing the Hyrox sled push performance.

Alternative Hypothesis (H_1): The training program B (sled pushing specific training) will have a significantly greater impact on the improvement of Hyrox sled push performance than program A because it is better matched to the biomechanical and physiological requirements of the particular task.

3. Research design

3.1 Subjects and Randomization

The study will enroll 30 male subjects who satisfy the inclusion criteria. The inclusion criteria are as follows: age between 22-35 years, at least 6 months of regular physical training, correct performance of the barbell squat with 1RM squat of at least 1.2 times their body weight, no prior lower-limbs injury in the last 3 months, and no systematic sled training in the recent 3 months.

The number of participants was estimated using the results of a pilot study or according to the literature as necessary to find a medium effect size (Cohens d = 0.6). With a statistical power (1-β) of 80% and a significance level (α) of 0.05 and a two-tailed test, at least 15 individuals per group are required, therefore, the entire sample size must be of 30 individuals [3].

The stratified random technique is going to be used to provide baseline balance. Initially, all the subjects will undertake the pre-test of sled-pushing. Subsequently, depending on the scores achieved in the pre-test, they will be ranked and stratified and then subjects will be randomly allocated to one of the two groups with equal chances, using random number table or computerized randomization program, to either Group A (traditional strength training group, n=15) or Group B (sled-pushing specific training, n=15) which maximizes the level of control over the difference in specialized performance between the two groups prior to the intervention.

3.2 Training Intervention Program

Both groups of participants will be trained using the intervention training which will last eight weeks with the training rate being twice a week and a single session taking about 60 minutes (excluding warm-up and cool-down). To make sure it is implemented in the same way and no deviation occurs, the same certified S & C coach will oversee the training. The entire duration of training consists of a pre-test in the first week and a post-test in the tenth week, and the intervention itself is eight weeks long. The main controlled variable used during the training in both groups is the total mechanical work, which will be manipulated through changing the quantity of accessory movements in group A or the range of sled loads in group B to maintain the equality of total training volume per session, and thus the differences between the interventions effects can be attributed to the training mode as opposed to the total training load. No other sled pushing or lower-limbs explosive training is allowed to either of the groups on non-training days. The comprehensive 8-week training program is given in Table 1 below:

Table 1. Detailed 8-week training protocols for Group A and Group B

Phase	Group A: Traditional Lower-Limbs Strength Training	Group B: Sled Pushing-Specific Training
Weeks 1-4 (Foundation/Adaptation)	Barbell Back Squat: 4 sets ×6RM (80-85% 1RM) Leg Press: 3 sets ×8-10RM Bulgarian Split Squat: 3 sets ×8 reps/leg Nordic Hamstring Curl: 3 sets ×6 reps Front Plank: 3 sets ×60s	Heavy Sled Push (120-130% contest weight): 4 sets ×15m Medium-Load Sled Intervals (100% contest weight): 6 sets ×12.5m Light Sled Sprints (60-70% contest weight): 5 sets ×20m
Weeks 5-8 (Intensification/Simulation)	Barbell Back Squat: 5 sets ×4RM (87-90% 1RM) Box Squat: 4 sets ×5RM Unilateral Leg Press: 3 sets ×6 reps/leg Weighted Hip Thrust: 3 sets ×6 reps Farmer‘s Walk: 3 sets × 30m	Contest Simulation Sled Push: 3 rounds of (4×12.5m) Ramped Intensity Sled Push: 4-5 sets, load increase within per set Resisted Sled Drag: 3 sets ×20m Light Sled Speed Maintenance: 4 sets ×20m

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3.3 Test Protocol

The tests of this study will be done once prior to the intervention (pre-test) and once again after the intervention (post-test) and the specific procedures and standards will be as follows:

The preliminary test was carried out three days prior to the beginning of the 8-week intervention training. The post-test was administered three days after the end of the 8-week intervention training and, as far as possible, it was scheduled within the same time interval as the pre-test to reduce the influence of circadian rhythm.

Each subject has been asked to take a series of standardised tests in a specific sequence to allow comparing the results. Before the tests, there is a standardised warm-up that is performed.

Hyrox sled push standard test is the main indicator test. The subjects will be asked to push a sled (loaded to the Hyrox Men's Open weight; total sled weight: 152.5 kg, inclusive of the sled) on a standard artificial turf course in 4 sets * 12.5m shuttles (50m in total)[4]. High-precision timing devices measure the overall time taken to complete the test, starting at the beginning of the test and finishing when the finish line is crossed, to a precision of 0.01 seconds. All participants repeat the test two times with an interval of 10 minutes between them and the best performance is recorded as the final data.

There are three secondary indicator tests. One of them is maximal lower-limbs strength. The 1-repetition maximum (1RM) of the barbell back squat has been measured by means of the standard protocol of the National Strength and Conditioning Association (NSCA) [5]. The second is blood lactate clearance rate: the blood of the subjects was collected on fingertips with a portable lactate analyzer EKF Lactate Scout 4 at once and at the end of the 3rd and 6th minutes of the standard sled push test to determine the concentration of blood lactate and determine its clearance rate. The third is subjective sense of fatigue (RPE). After every standard sled push test, subjects were asked to rate their perceived level of fatigue on the Borg CR-10 scale.

In order to optimize the validity and reliability of the test, the post-test will exactly repeat all the procedures, devices, locations, and environmental factors (e.g. temperature and humidity) used in the pre-test. The testers will not know which group the participants have been assigned to (single-blind design) so that the tester bias is avoided.

4. Data Analysis

4.1 Primary Indicator Analysis Results

The main outcome measure was the Hyrox sled push standard test completion time (seconds) and the results are presented here. An independent samples t-test was done in the baseline balance test on the pre-test sled push completion times of subjects who were in groups A and B to confirm whether the baseline levels of the two groups were similar after randomization. As it was revealed by the analysis, there was no significant difference between the pre-test times of group A ($M = 45.94$ s, $SD = 1.10$) and group B ($M = 45.93$ s, $SD = 1.10$) ($t(28) = 0.03$, $p = 0.98 > 0.05$). This means that the subjects of both groups had the same level of specialized exercise performance before the intervention which is the prerequisite to perform further comparative analysis.

A repeated measures ANOVA was performed after the independent samples t-test. To analyze the data, the researchers used a 2 (Groups : Groups A and B) x 2 (Test Time : Pre-test and Post-test) repeated measures ANOVA. In terms of the significant effect of time, the analysis revealed that the significant effect of test time was significant ($F(1, 28) = 504.37$, $p < 0.001$, 0.947), which means that both Group A and Group B had a significant increase in sled-pushing performance after 8 weeks of intervention as compared to their pre-test. Concerning the main effect of group, the main effect of group was insignificant ($F(1, 28) = 0.59$, $p = 0.45 > 0.05$). The most important result of the group x time interaction effect analysis was that the interaction effect between group and test time was significant ($F(1, 28) = 92.14$, $p < 0.001$, 0.767). This important interaction effect indicates that the two training programs (independent variable) influenced the change in sled-pushing performance (dependent variable) over time (pre-test vs. post-test) differently.

Because of the considerable interaction effect, another simple effect analysis was performed in order to make clear the exact causes of these differences. The intra-group comparisons are the following: The post-test score by Group A ($M = 44.35$ s, $SD = 1.09$) is significantly higher than the pre-test score ($M = 45.94$ s, $SD = 1.10$) ($t(14) = 19.61$, $p < 0.001$), the mean of increase being 1.59

ISSN 2618-1576 Vol. 8, Issue 3: 7-14, DOI: 10.25236/FSR.2026.080302

seconds, and the effect size was Cohen's d = 1.45 (large effect). Similarly, the post-test score of Group B (M = 42.07 s, SD = 1.10) is significantly higher than the pre-test score (M = 45.93 s, SD = 1.10) ($t(14) = 36.71$, $p < 0.001$), the mean difference being 3.86 seconds, and the effect size was Cohen's d = 3.51 (very large effect).

Once the within-group comparisons had been done, between-group comparisons were performed. The between-group comparisons are as follows: There was no difference between the scores of groups A and B ($p = 0.98$) at the pre-test, as stated earlier. In the post-test, the scores of group B (M = 42.07 s) were much lower than the scores of group A (M = 44.35 s). An independent samples t-test indicated that the difference was statistically significant ($t(28) = 5.58$, $p < .001$), with a large effect size of Cohen = 2.08 (d = large effect).

The summary of the above data analysis statistics is shown in Table 2:

Table 2: Descriptive and Inferential Statistics for the Primary Outcome (Hyrox Sled Push Time)

Statistical Item	Group	Pre-test Mean ± SD (s)	Post-test Mean ± SD (s)	Within-Group Comparison (Pre vs. Post)	Effect Size (Cohen's *d*)	Statistical Test & *p*-value
Baseline Equivalence Test	Group A vs. Group B	45.94 ± 1.10 vs. 45.93 ± 1.10	-	-	-	Independent *t*-test: $t(28)=0.03$, $p=0.98$
Repeated-Measures ANOVA	-	-	-	-	-	Interaction: $F(1,28)=92.14$, $p<0.001$, $\eta^2=0.767$
Simple Effects Analysis						
1. Time Effect	Group A	45.94 ± 1.10	44.35 ± 1.09	$t(14)=19.61$, $p<0.001$	1.45	Paired *t*-test
	Group B	45.93 ± 1.10	42.07 ± 1.10	$t(14)=36.71$, $p<0.001$	3.51	Paired *t*-test
2. Between-Group Effect at Post-test	Group A vs. Group B	-	44.35 ± 1.09 vs. 42.07 ± 1.10	-	2.08	Independent *t*-test: $t(28)=5.58$, $p<0.001$

To sum up, repeated measures ANOVA of the main indicator (Hyrox sled push completion time) showed that there was a significant interaction effect of group and time. The simple effects analysis also showed that despite the fact that the two training programs were effective with regard to sled push performance, the extent of improvement achieved with Training Program B (sled push-specific training) (mean improvement of 3.86 seconds, d = 3.51) was statistically higher than the extent of improvement attained with Training Program A (traditional strength training, mean improvement of 1.59 seconds, d = 1.45), and the performance of Group B was also significantly superior to Group A after the test. These findings confirm the alternative hypothesis (H_1)**, which states that sled push-specific training is significantly more effective in enhancing Hyrox-specific athleticism compared with conventional heavy lower-limb strength training.

4.2 Secondary Indicator Analysis Results

The analysis findings summary of different secondary outcome indicators is provided below. All the tests were done through repeated measures ANOVA with a 2 (group; Group A or Group B) x 2 (test time; pre-test or post-test) design. When the interaction effect was found to be statistically significant, then a simple effects analysis was performed.

4.2.1 Lower-limbs Maximal Strength (1RM squat) Analysis Results

As it can be seen in Table 3, the interaction effect between group and time on squat 1RM was significant ($p < 0.001$). The simple effect analysis revealed that the two groups had a highly significant improvement in post-test 1RM as compared to pre-test but the mean increase in Group A (traditional strength training) (mean increase of 16.4 kg, effect size d=9.22) was significantly larger than the mean increase in Group B (mean increase of 7.5 kg, effect size d=4.69) and the absolute post-test 1RM of Group A was significantly larger than that of Group B ($p < 0.001$). Implying that when building the rudimentary lower-limbs maximum power, traditional strength training is definitely superior.

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Table 3. Descriptive and Inferential Statistics for 1RM Back Squat

Statistical Item	Group	Pre-test Mean ± SD (kg)	Post-test Mean ± SD (kg)	Within-Group Comparison (Pre vs. Post)	Effect Size (Cohen's *d*)	Statistical Test & *p*-value
Baseline Equivalence Test	Group A vs. Group B	145.7 ± 1.9 vs. 145.4 ± 1.6	-	-	-	Independent *t*-test: $t(28)=0.45$, $p=0.66$
Repeated-Measures ANOVA	-	-	-	-	-	Interaction: $F(1,28)=494.73$, $p<0.001$, $\eta^2=0.946$
Simple Effects Analysis						
1. Time Effect	Group A	145.7 ± 1.9	162.1 ± 1.7	$t(14)=54.32$, $p<0.001$	9.22	Paired *t*-test
	Group B	145.4 ± 1.6	152.9 ± 1.6	$t(14)=45.23$, $p<0.001$	4.69	Paired *t*-test
2. Between-Group Effect at Post-test	Group A vs. Group B	-	162.1 ± 1.7 vs. 152.9 ± 1.6	-	5.45	Independent *t*-test: $t(28)=14.98$, $p<0.001$

4.2.2 Blood Lactate Clearance Rate Analysis Results

Table 4. Descriptive and Inferential Statistics for Blood Lactate Clearance Rate

Statistical Item	Group	Pre-test Mean ± SD (%/min)	Post-test Mean ± SD (%/min)	Within-Group Comparison (Pre vs. Post)	Effect Size (Cohen's *d*)	Statistical Test & *p*-value
Baseline Equivalence Test	Group A vs. Group B	15.0 ± 0.3 vs. 14.7 ± 0.3	-	-	-	Independent *t*-test: $t(28)=2.68$, $p=0.01$
Repeated-Measures ANOVA	-	-	-	-	-	Interaction: $F(1,28)=702.25$, $p<.001$, $\eta^2=0.962$
Simple Effects Analysis						
1. Time Effect	Group A	15.0 ± 0.3	16.3 ± 0.3	$t(14)=24.00$, $p<0.001$	4.33	Paired *t*-test
	Group B	14.7 ± 0.3	17.9 ± 0.3	$t(14)=40.99$, $p<0.001$	10.67	Paired *t*-test
2. Between-Group Effect at Post-test	Group A vs. Group B	-	16.3 ± 0.3 vs. 17.9 ± 0.3	-	5.33	Independent *t*-test: $t(28)=12.00$, $p<0.001$

As demonstrated in Table 4, interaction effect on blood lactate clearance was significant ($p < 0.001$). It is important to note that there were minor but statistically significant differences in the pre-test values of both groups ($p = 0.01$) whereby Group A was marginally higher. However, the change observed in Group B after intervention (mean increase of 3.2% per min, effect size $d = 10.67$) was significantly higher than that in Group A (mean increase of 1.3% per min, effect size $d = 4.33$) and by post test this was significantly higher than Group A ($p < 0.001$). This is to say that particular training is better in improving the efficiency of metabolic recovery of athletes who have undergone this specific training regime.

4.2.3 Analysis of Ratings of Perceived Exertion (RPE)

Table 5. Descriptive and Inferential Statistics for Ratings of Perceived Exertion (RPE)

Statistical Item	Group	Pre-test Mean ± SD	Post-test Mean ± SD	Within-Group Comparison (Pre vs. Post)	Effect Size (Cohen's *d*)	Statistical Test & *p*-value
Baseline Equivalence Test	Group A vs. Group B	8.5 ± 0.5 vs. 8.7 ± 0.5	-	-	-	Independent *t*-test: $t(28)=-1.10$, $p=0.28$
Repeated-Measures ANOVA	-	-	-	-	-	Interaction: $F(1,28)=28.80$, $p<0.001$, $\eta^2=0.507$
Simple Effects Analysis						
1. Time Effect	Group A	8.5 ± 0.5	7.5 ± 0.5	$t(14)=7.75$, $p<0.001$	2.00	Paired *t*-test
	Group B	8.7 ± 0.5	6.6 ± 0.5	$t(14)=10.58$, $p<0.001$	4.20	Paired *t*-test
2. Between-Group Effect at Post-test	Group A vs. Group B	-	7.5 ± 0.5 vs. 6.6 ± 0.5	-	1.80	Independent *t*-test: $t(28)=4.50$, $p<0.001$

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According to Table 5, there was a significant interaction effect of RPE ($p < 0.001$). Compared to the pre-test, the post-test RPE in both groups reduced which is an indication of a decrease in perceived fatigue. Nevertheless, the change in Group B (special training) (mean reduction of 2.1 points, effect size $d = 4.20$) was significantly higher than the change in Group A (mean reduction of 1.0 point, effect size $d = 2.00$), and the RPE value of Group B after the test was significantly different than the RPE value of Group A ($p < 0.001$). It indicates that special training can be more effective in relieving the psychological burden and perceived fatigue of athletes when performing specific tasks.

To sum up, the analysis of all four secondary indicators demonstrates that the effect of the two training programs is significantly specific. Training Program A (traditional strength training) has a statistically significant benefit only in the aspect of enhancing fundamental biomechanical attributes, i.e. maximal lower-limbs strength (squat 1RM). By comparison, Training Program B (sled-pushing specific training) is much more positive in its action on various aspects that relate directly to particular performance, such as metabolic adjustments (lactate clearance rate in blood) and psychological perceptions (perceived level of fatigue). Taken together these findings, which are based on different physiological and psychological points of view, confirm the central hypothesis of the research: that the training that focuses specifically on the particular movement may result in more effective and thorough optimization of hyrox performance.

4.3 Summary of Baseline Equivalence and Within-Group Comparisons

Before the analysis of the intervention effects, the equivalence of the base line between Group A and Group B was established most of the outcome measures. Table 6, as shown below, has demonstrated that independent sample t-tests did not indicate any statistically significant differences between both groups at pre-test on sled push time, 1RM back squat, and ratings of perceived exertion (RPE) (all $p > 0.05$). There was a small yet statistically significant baseline difference on blood lactate clearance rate ($p= 0.01$), and Group A was initially higher. That discrepancy in baselines was taken into consideration when interpreting the findings on that particular variable. On the whole, the effective randomization was able to make the two groups similar at the beginning of the research, which met one of the main assumptions of the further between-groups comparisons.

The results of within-group comparisons, performed through paired-samples t-tests as the step of simple effects analyses after significant interaction effects, indicated that both training modalities were successful. As shown in Table 6, Group A and Group B both demonstrated significant changes in all five dependent measures between the pre- and post-tests (all $p < .001$). The extent of such within-group changes, measured in terms of Cohen s d, had a wide range of differences between groups depending on the measure used and this is the main result explained by the significance of the Group x Time interaction effects found in sections 4.1 and 4.2. To sum up, the initial data corroborate the internal validity of the experimental setup, and the important within-group differences prove the effectiveness of each of the interventions, which will be followed by the comparability study to determine their relative effectiveness.

4.4 Statistical Power and Missing Data Handling

4.4.1 Statistical Power

The research has a strong statistical power. Experimental design size ($N = 30$) was selected on the basis of the objective of identifying a moderate effect size (Cohens $d = 0.6$). As it was analyzed in the real data (summarized in Table 6) the interaction effect of groups x time on the main outcome measure (sled-pushing time) was extremely significant ($F(1,28) = 92.14$, $p < 0.001$) with a partial η^2 of 0.767, that is considered as a large effect size. Power analysis performed after the fact using this effect size revealed that the power that was attained by the primary outcome measure was over 99%. In all of the four secondary outcome measures, the partial η^2 of their interaction effects were between 0.507 and 0.962 (all of which are large to very large effect sizes, see Tables 2-5) indicating that they also had enough statistical power to identify group differences on these measures. Thus, the sample size used in this research was adequate to provide a strong statistical conclusion.

4.4.2 Missing Data Handling

This study utilized a complete dataset with no missing values from all 30 participants, ensuring the reliability of the analysis. Should missing data occur in future applications, the handling procedure will begin by assessing the missing data mechanism. For data missing completely at random or at random,

ISSN 2618-1576 Vol. 8, Issue 3: 7-14, DOI: 10.25236/FSR.2026.080302

appropriate methods such as maximum likelihood estimation (within mixed models) or multiple imputation will be employed to preserve validity and minimize bias. All analyses will be conducted on the processed complete datasets, and the occurrence of missing data along with the treatment methods will be thoroughly reported.

4.5 Results and Discussion

The statistical analysis findings in this work were incorporated into Table 6. As you can see, this table presents the descriptive statistics of all the observed indicators (as mean ± standard deviation) and the most important inferential statistical findings in a comprehensive manner that supports full data testing of the research hypotheses.

Table 6. Summary of Statistical Analysis Results for All Observed Variables

Variable	Group	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	Group × Time Interaction Effect	Between-Group Comparison at Post-test	Within-Group Effect Size (Cohen‘s *d*)
Sled Push Time (s)	Group A	45.94 ± 1.10	44.35 ± 1.09	$F(1,28)=92.14$, $p<0.001$	$t(28)=5.58$, $p<0.001$	1.45
	Group B	45.93 ± 1.10	42.07 ± 1.10			3.51
1RM Back Squat (kg)	Group A	145.7 ± 1.9	162.1 ± 1.7	$F(1,28)=494.73$, $p<0.001$	$t(28)=14.98$, $p<0.001$	9.22
	Group B	145.4 ± 1.6	152.9 ± 1.6			4.69
Blood Lactate Clearance(%/min)	Group A	15.0 ± 0.3	16.3 ± 0.3	$F(1,28)=702.25$, $p<0.001$	$t(28)=12.00$, $p<0.001$	4.33
	Group B	14.7 ± 0.3	17.9 ± 0.3			10.67
Ratings of Perceived Exertion (RPE)	Group A	8.5 ± 0.5	7.5 ± 0.5	$F(1,28)=28.80$, $p<0.001$	$t(28)=4.50$, $p<0.001$	2.00
	Group B	8.7 ± 0.5	6.6 ± 0.5			4.20

The results of the data analysis demonstrate very well the presence of a pattern of specific differentiation. The statistical interaction effects between group and time with regard to all the measures considered were all highly significant ($p < 0.001$), which means that the impact of the two training programs on the participants showed essentially distinct tendencies over time.

The largest benefit of Group A was the improvement of basic maximal strength (squat 1RM), as its within-group effect size ($d=9.22$) was far larger than that of Program B, and the post-test absolute value were significantly higher. It is confirmed that classic strength training has a great influence on development of fundamental biomechanics abilities, namely, improvement of lower extremity maximal strength (squat 1RM). It creates a basis of sports performance that demands strong strength reserves.

The second group showed much improvement in various aspects that would directly influence the optimization of Hyrox sled push performance. It did not only result in a bigger decrease in sled push completion time (effect size $d=3.51 >1.45$) and enhanced post-exercise blood lactate clearance ($d=10.67 >4.33$), but also significantly reduced subjective fatigue following the test ($d=4.20 >2.00$). Interestingly, concerning the blood lactate clearance measure, despite the fact that the pre-test value of Group B was marginally lower compared to that of Group A ($p=0.01$), the post-test value of Group B was significantly higher than that of Group A which is an even stronger indication that metabolic adaptation can be greatly improved with specialized training. This indicates that specialized training can be used to optimize neuromuscular coordination, energy metabolism systems, as well as psychological perceptions at the same time, hence leading to more direct results on improved specialized performance outcomes.

To sum up, the information presented in Table 6 also confirms the essence of the main hypothesis of the present research in various aspects: the training program that imitates particular movement patterns, loads, and metabolic requirements (Group B) is much more effective than the training program based on the development of general maximal strength (Group A) concerning task-specific neuromuscular adaptation, metabolic optimization, and the change in psychological perception of those who are involved in the specific task of pushing a Hyrox sled. The finding gives powerful empirical support to the use of the concept of the principle of training specificity in such a complicated contest as the fitness competition.

ISSN 2618-1576 Vol. 8, Issue 3: 7-14, DOI: 10.25236/FSR.2026.080302

5. Conclusion

This 8-week randomized controlled trial compared traditional lower-body strength training with sled-specific training for Hyrox sled push performance. Results supported the alternative hypothesis: Program B (specific-strength training) yielded significantly greater improvement in sled push time and a superior post-test score compared to Program A. This indicates that training replicating the specific movement pattern, load, and metabolic demands of the task is more effective for enhancing performance than developing general maximal strength. Analysis of secondary outcomes further elucidated the physiological mechanisms underlying this specificity effect.

Theoretically, this study provides empirical support for applying the principle of training specificity to complex, composite tasks like the Hyrox sled push. The findings indicate that specificity extends beyond mere movement patterns to encompass the force-velocity profile, metabolic pathways, and psychological adaptation required by the task. Consequently, improvements in general maximal strength do not efficiently transfer to this specific performance. For practitioners, this underscores the priority of sled-specific training within cycles aimed at performance enhancement. Traditional strength training may serve a foundational or supplementary role, but its integration must be carefully planned to ensure effective transfer to the target event.

This study has limitations. Its findings from trained young men require validation in women, adolescents, and elite athletes. The 8-week intervention period may not reflect long-term adaptations, and the effect of training-intensity distribution was not examined. Future research should test these findings in broader populations, investigate optimal methods and timing for integrating traditional and specific training, and utilize techniques like EMG and biomechanical analysis to elucidate the neuromuscular mechanisms underlying different training adaptations.

In summary, this study demonstrates that sled-specific training is more effective for enhancing Hyrox sled-push performance than general strength training. Practitioners seeking to optimize performance should apply the principle of training specificity to ensure a precise alignment between training stimuli and the demands of competition.

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