Lower Limb Muscle Activity Adjustment and Lactate Variation in Response to Increased Speed with Proportional Resistance in Young Adults

Martín G. Rosario* PT, PhD, CSFI, ATRIC, Daniel Heistand, SPT, Catie Lewis, SPT, Natalie Valdez, SPT, Matthew Nevarez, SPT, Mark Weber PT, PhD, ATC

Texas Woman's University, Physical Therapy Program, Dallas Campus; Texas.

ABSTRACT

Background: Various pathologies require physiotherapists to adjust therapy interventions, some of which are to reducing joint loads while strengthening the lower extremity musculature. Tools such as a sled can be used to accomplish a small load with high-repetition-resistance exercises.

Purpose: This study examined the impact of pushing a sled with regulated resistance on lower limb muscle activation and fatigue while walking and running.

Methods: The neuromuscular activity of the tibialis anterior (TA) and gastrocnemius (GA) muscles of thirty-six young adults were recorded using surface electromyography (EMG) and lactate data from a Nova Biomedical Lactate Plus meter. The sled used was the XPO Trainer, which maintains a steady resistance proportional to the user regardless of the forces applied to accelerate the sled. Baseline lactate was collected and followed by one of three protocols: run, run-push (RP), or walk-push (WP). Each included three trials over a 40 ft distance, during which EMG data were collected per trial, whereas lactate was collected following the completion of the appointed task.

Results: Repeated measures ANOVAs were performed, showing a considerable increase ($P < 0.05$) in lactate levels between the WP and RP groups. Pushing the sled at both WP and RP speeds demonstrated substantial ($P < 0.05$) neuromuscular modifications, primarily in the TA, followed by the GA, in comparison to running.

Conclusion: Pushing a constant resistance sled provoked distinct modifications in the lower limb musculature associated with speed. Running while pushing the sled elicits a higher blood lactate response associated with a longer maximal amplitude and a shorter time for muscle recruitment in the GA and TA muscles, all indicative of endurance-oriented exercise.

Keywords: XPO Trainer, Lactate Levels, Fatigue, Low extremity musculature, Resistance Training, Sled Training. Constant Resistance

*Correspondence to Author:

Martín G. Rosario

Texas Woman's University, Physical Therapy Program, Dallas Campus; 5500 Southwestern Medical Ave. Dallas, TX 75235-7299 Telephone: 241-689-6500

ORCID ID 0000-0001-7505-1329

How to cite this article:

Martín G. Rosario, Daniel Heistand, Catie Lewis, Natalie Valdez, Matthew Nevarez, Mark Weber. Lower Limb Muscle Activity Adjustment and Lactate Variation in Response to Increased Speed with Proportional Resistance in Young Adults. International Journal of Sports Medicine and Rehabilitation, 2021; 4:18.

eSciPub LLC, Houston, TX USA.

Website: <https://escipub.com/>

1. Introduction

Resistance training (RT) is a form of exercise commonly employed in fitness and health regimens as a result of its thoroughly established multitudinous benefits for people of all ages, including morphological, neuromuscular, and functional improvements (Lopez et al., 2018). While there are a variety of methods to perform RT, approaches to interventions will differ based on each subjects' goals and capabilities. For instance, to increase maximal gait speed, aspects of balance, and strength among those above the age of 55, evidence suggests implementing RT with low loads and high repetitions (Nicholson et al., 2014). Coincidentally, low load-high repetition RT is most regularly utilized in physical therapy because it is crucial to minimize the forces acting on impaired joints.

Another form of RT is using a sled; when operating a sled, the user relies on their ability to either push or pull against resistance. Kawamori et al. (2014) found that when pushing a sled weighing a fraction of the participants' body weight, individuals experience increased horizontal force production with additional resistance, thus increasing the aggregate demand on the body in comparison to traditional unweighted running. This finding is fundamental for sled training in that therapists must be aware of the extent of resistance needed to increase force production, as muscle fatigue will likely play a role when training with this resistance load. Therefore, although it is a useful RT tool, the employment of a sled in interventions will depend on the physical capabilities of the user, generating several limitations and precautions for the participant and the therapist.

One of the limitations of a typical sled is the inability to identify specific neuromuscular training patterns. The XPO-sled trainer, however, is a novel device proven to achieve neuromuscular

adaptations and gait kinematic modifications in users while pushing at two different gait speeds (Rosario MG, 2020; Rosario & Mathis, 2020). This particular XPO trainer provides low resistance that increases proportionally to the participant's speed, which can be utilized for motor coordination and control training. Rosario MG (2020) found direct proportionality between participants' increases in speed and their faster neuromuscular recruitment time, suggesting that while speed does matter, pushing against any type of constant resistance will increase neuromuscular activation and cause faster recruitment. Both neuromuscular adaptation and gait modification factors are essential in strengthening or improving endurance in lower extremity muscles based on the amount of resistance and speed imposed by a constant resistance sled. In their research, Rosario MG and Mathis (2020) proposed that pushing a sled with constant resistance should be considered for interventions with the goal of focusing on the motor control of each step for improve gait pattern symmetry, as this type of sled allows for greater gait cycle time at slower speeds through decreased stride length, velocity, and cadence.

A substantial factor to consider is the aspect of muscle fatigue in RT, and the extent of this fatigue while using a constant resistant sled is worthy of examination. While muscle fatigue levels can be measured by both electromyography (EMG) and lactate levels, these measurements are not necessarily associated with one another. Research findings demonstrate that while lactate levels are involved in muscle fatigue, the relationship between lactate levels and mean power frequency (MPF) during or following exercise are not significant (Tenana et al., 2010). However, it should be noted that fatigue is not necessarily a goal or wanted benefit from exercise, and Folland et al. (2002) found a notable increase in

strength from using strength training methods that induce low-level muscle fatigue to be nearly parallel to methods intended to cause maximal muscle fatigue. This finding suggests that the preconceived notion of high-level muscle fatigue as a prerequisite to increasing strength should be refuted.

As previously established, low-load, high-repetition-resistance exercise is essential for strength training without an extensive muscle fatigue factor. However, although investigations related to fatigue measures with varying resistance have taken place, it is not yet determined research regarding the impact of constant resistance on muscle fatigue. Therefore, this study assessed

muscle activation and fatigue via EMG and lactate levels when pushing a sled with constant resistance while both walking and running. The ongoing research will use the XPO Trainer, a novel sled constructed to provide continuous resistance proportional to each user. The sled produces incremental reciprocal resistance rates adjusted to both the user and their acceleration (Rosario MG, 2020). The outcomes of this investigation will provide a more thorough perspective on how to tailor RT programs adequately, employing tools such as the constant resistance sled, especially for those who are easily fatigued.

2. Methods

Table 1: Demographic data of all participants

Characteristics	Study Participants n= 36
Age	24.6 +/- 3.6 years
Gender	Male= 11; Female = 25
Height (inches)	M= 66.3+/-3.9
Weight (pounds)	154.6+/-33.1
Post-Walking Lactate Levels	2.35 +/- 1.4 mmol/L
Isometric Muscle Contraction TA	82.6+/-33.0
Isometric Muscle Contraction GA	88.7+/-40.1

There were 11 men and 17 women recruited to this study, with an average age of 24.58 years +/-3.58 years (Table 1). The individuals were screened for eligibility based on our inclusion/exclusion criteria; those who were deemed eligible then signed the informed consent form before participating.

After signing the consent form and undergoing a cardiovascular assessment, electromyography (EMG) surface electrodes were placed. When applicable, the areas on which the EMG surface electrodes were to be placed on participants were shaved with a razor. The participants then had the EMG surface electrodes placed by the

principal investigator or the co-principal investigator on the following muscles of the participants' dominant leg: quadriceps, hamstrings, tibialis anterior (TA) and gastrocnemius (GA).

Following the placement of the EMG surface electrodes, a baseline walk of 34 feet was performed, during which fatigue/lactate levels were measured. Immediately after the participant walked, they were seated in order to have their lactate levels tested. Participants were then instructed to wash their hands with an antibacterial wipe prior to blood collection, and the digit of choice was further cleaned with an alcohol pad. Once the digit was cleaned, lactate was measured by pinching the side of the fourth or fifth digit with a lancet-needle to collect a drop of blood, known as the finger-stick collection method, after which a bandage was then placed on the finger where the sample was collected. The research team wore latex gloves at all times while collecting blood samples. Participants were asked before the finger-stick collection if they had any *latex allergy* or if they had any blood disorders. After the procedure was complete, the lancet needle was properly disposed of in a sharp container.

Gait Protocol: The XPO trainer used in this study for the push protocols was a sled that weighed 60-lbs and measured 43" H × 43.5. L × 35" W. The participants were first instructed to push the XPO trainer at a distance of 40 feet at two different speeds: (1) walking and (2) sprinting as a warm-up. Once the participant completed this warm-up, they performed only one of the following three protocols: the walk push protocol (WP), the sprint push protocol (RP), and sprint protocols.

In the walk-push protocol, participants walked for 40 feet while pushing the XPO trainer. The EMG sensors were turned on by the investigator prior to instructing the participants to "start," initiate

the protocol. Once they reached the 40 feet mark, the participant was told to "stop" and walk back to the starting position, while a member of the research team returned the XPO trainer back to the starting point. The participants repeated this process twice more for a total of three trials. In the sprint push protocol, participants sprinted for 40 feet, pushing the XPO trainer. The EMG sensors were turned on by the investigator prior to instructing the subject to "start," initiate the protocol. The participants were instructed to push the sled as hard and fast as they were able to. Once they reached the 40 feet mark, the participant was told to "stop" and walk back to the starting position, while a member of the research team returned the XPO trainer back to the starting point. The participants repeated this process twice more for a total of three trials.

In the sprint protocol, participants sprinted 40 feet without using the XPO trainer. The EMG sensors were turned on by the investigator prior to instructing the participants to "start," initiate the protocol. The subject was instructed to sprint as hard and fast as they were able to. Once they reached the 40 feet mark, the participant was told to "stop" and walk back to the starting position. The participants repeated this twice more for a total of three trials.

Finally, in all three protocols, fatigue/lactate levels were measured for a second time using the same finger-stick collection method while following the same procedures as before. This time, however, the blood sample was collected and performed with the finger stick method on a different finger than before, though still the fourth or fifth digit of either hand.

Instruments and equipment:

Neuromuscular data will be recorded by electromyography (EMG) using a surface electrode system (Delsys, Inc. Boston, MA). The EMG activity of the quadriceps, hamstring, tibialis

anterior and gastrocnemius muscles of the lower extremities were collected at 1,000 Hz with the electrodes placed similar to the Rosario MG 2020 study.

Lactate data was measured using a Nova Bio-medical Lactate Plus meter.

Data Analysis

The EMG data were filtered and rectified to normalize the maximal voluntary contraction (MVC) values to the muscle activations for each participants' task. After we filtered the data, they were later gathered in spreadsheets. The time for each gait task (in seconds) was normalized to the task's proportion (0-100%). In the current study, the highest (maximal) and lowest (minimal) activation points for each muscle (all trials) with their corresponding timing percentages during the gait cycle were identified and organized in spreadsheets. An average of each data point was tallied, and the means were then placed into

the SPSS Statistics Analysis 25 system for a repeated-measures ANOVA test.

This study investigated the influence of the sled's resistance on neuromuscular timing variables (onset, time to peak [TP], decay, and duration) during different tasks for the TA and GA while running, WP, and RP. For the neuromuscular timing analysis, this study used SPSS (version 25) with a repeated-measure ANOVA to compare the means for all neuromuscular time variables.

Statistical p-value of < 0.05 was considered statistically significant for all variables of interest.

3. Results

Table 1 shows the demographic characteristics of all participants in the study, including age, sex, height, weight, post-walking lactate levels, and amount of isometric muscle contraction for the tibialis anterior and gastrocnemius.

Table 2a: Comparisons of EMG variables among tasks. Results of repeated measure ANOVA performed comparing run and WP/RP. Significance level set at $p \leq 0.05$.			
Tibialis Anterior	Means and SD	Means and SD	P Value
	Onset Run: 5.0 +/- 1.2	WP: 6.9 +/- 1.7 RP: 5.7 +/- 1.7	0.01 0.88
	TP Run: 1.0 +/- 0.5	WP: 1.4 +/- 0.4 RP: 0.7 +/- 0.3	0.05 0.41
	Decay Run: 0.7 +/- 0.2	WP: 0.9 +/- 0.3 RP: 0.8 +/- 0.3	0.13 0.41
	Duration Run: 1.6 +/- 0.5	WP: 2.4 +/- 0.5 RP: 1.6 +/- 0.5	0.01 0.67
Gastrocnemius	Means and SD	Means and SD	P Value
	Onset Run: 5.1 +/- 1.0	WP: 7.5 +/- 1.8 RP: 5.6 +/- 2.2	0.01 1.00

	TP Run: 0.7 +/- 0.2	WP: 1.0 +/- 0.4 RP: 0.6 +/- 0.3	0.15 1.00
	Decay Run: 0.9 +/- 0.2	WP: 1.0 +/- 0.3 RP: 0.8 +/- 0.3	1.00 0.32
	Duration Run: 1.4 +/- 0.3	WP: 1.6 +/- 0.6 RP: 1.2 +/- 0.4	0.99 0.88
^WP=Walk and Push, RP=Run and Push, S.D.=Standard Deviation			

Table 2b: Comparisons of EMG variables among tasks. Results of repeated measure ANOVA performed comparing RP and WP. Significance level set at $p \leq 0.05$.

Tibialis Anterior	Means and SD	Means and SD	P Value
	Onset RP: 5.6 +/- 1.7	WP: 6.9 +/- 1.7	0.19
	TP RP: 0.7 +/- 0.3	WP: 1.4 +/- 0.4	0.001
	Decay RP: 0.8 +/- 0.3	WP: 0.9 +/- 0.3	1.00
	Duration RP: 1.6 +/- 0.5	WP: 2.4 +/- 0.5	0.01
Gastrocnemius	Means and SD	Means and SD	P Value
	Onset RP: 5.6 +/- 2.2	WP: 7.5 +/- 1.8	0.05
	TP RP: 0.6 +/- 0.3	WP: 1.0 +/- 0.4	0.05
	Decay RP: 0.8 +/- 0.3	WP: 1.0 +/- 0.3	0.15
	Duration RP: 1.2 +/- 0.4	WP: 1.6 +/- 0.6	0.11
^WP=Walk and Push, RP=Run and Push, S.D.=Standard Deviation			

Table 3a: Comparisons of EMG amplitude among tasks. Results of repeated measure ANOVA performed comparing run and WP/RP. Significance level set at $p \leq 0.05$.

Tibialis Anterior	Means and SD	Means and SD	P Value
	MAX % TIME Run: 70.3 +/- 16.0	WP: 63.7 +/- 15.5 RP: 52.7 +/- 18.6	0.34 0.05

	MAX AMP Run: 94.9 +/- 44.5	WP: 65.7 +/- 20.4 RP: 104.3 +/- 52.5	0.92 0.57
	MIN % TIME Run: 7.0 +/- 15.8	WP: 40.9 +/- 29.3 RP: 18.7 +/- 22.5	0.001 0.26
	MIN AMP Run: 20.6 +/- 4.7	WP: 17.9 +/- 6.3 RP: 16.1 +/- 9.7	0.37 0.15
	AVG AMP Run: 52.4 +/- 21.1	WP: 31.7 +/- 9.6 RP: 37.2 +/- 14.1	0.05 0.05
Gastrocnemius	Means and SD	Means and SD	P Value
	MAX % TIME Run: 65.3 +/- 16.8	WP: 58.7 +/- 13.5 RP: 50.8 +/- 19.6	0.34 0.05
	MAX AMP Run: 189.2 +/- 130.7	WP: 97.6 +/- 37.4 RP: 159.2 +/- 79.9	0.05 0.43
	MIN % TIME Run: 31.1 +/- 32.7	WP: 48.9 +/- 26.2 RP: 16.5 +/- 20.5	0.17 0.21
	MIN AMP Run: 20.5 +/- 9.1	WP: 15.7 +/- 7.7 RP: 16.8 +/- 9.1	0.19 0.33
	AVG AMP Run: 201.9 +/- 94.6	WP: 31.8 +/- 13.6 RP: 56.5 +/- 25.2	0.01 0.01
^WP=Walk and Push, RP=Run and Push, S.D.=Standard Deviation			

Tibialis Anterior	Means and SD	Means and SD	P value
	MAX % TIME RP: 52.7 +/- 18.6	WP: 63.7 +/- 15.5	0.12
	MAX AMP RP: 104.3 +/- 52.5	WP: 65.7 +/- 20.4	0.68
	MIN % TIME RP: 18.7 +/- 22.5	WP: 40.9 +/- 29.3	0.05
	MIN AMP RP: 16.1 +/- 9.7	WP: 17.9 +/- 6.3	0.54
	AVG AMP RP: 37.2 +/- 14.1	WP: 31.7 +/- 9.6	0.76
Gastrocnemius	Means and SD	Means and SD	P Value

	MAX % TIME RP: 50.8 +/- 19.6	WP: 58.7 +/- 13.5	0.25
	MAX AMP RP: 159.2 +/- 79.9	WP: 97.6 +/- 37.4	0.09
	MIN % TIME RP: 16.5 +/- 20.5	WP: 48.9 +/- 26.2	0.001
	MIN AMP RP: 16.8 +/- 9.1	WP: 15.7 +/- 7.7	0.21
	AVG AMP RP: 56.5 +/- 25.2	WP: 31.8 +/- 13.6	0.93
^WP=Walk and Push, RP=Run and Push, S.D.=Standard Deviation			

Table 4a: Comparisons of lactate levels among tasks. Results of repeated measure ANOVA performed comparing Run and WP/RP and WP with RP. Significance level set at p≤0.05.			
Lactate Levels	Means and SD	Means and SD	P Value
	Run: 4.03+/-1.95	WP:3.05+/-0.9	0.48
		RP:4.8+/-1.95	0.80
	WP:3.05+/-0.9	RP:4.8+/-1.95	0.05
^WP=Walk and Push, RP=Run and Push, S.D.=Standard Deviation			

Table 4b: Comparisons of resting lactate levels among groups tasks. Results of repeated measure ANOVA performed comparing Run and WP/RP and WP with RP. Significance level set at p≤0.01.			
Lactate Levels mmol/L	Means and SD	Means and SD	P Value
	Run: 1.8+/-0.57	WP:2.9+/-2.04	0.22
		RP:2.4+/-1.0	1.00
	WP:2.9+/-2.04	RP:2.4+/-1.0	1.00
^WP=Walk and Push, RP=Run and Push, S.D.=Standard Deviation			

Table 2a illustrates the results of the neuromuscular activity of the GA and TA during the run tasks described in relation to WP and RP. During WP, the TA exhibited significant differences in delay onset, prolonged TP, and increased duration when compared to the run task. On the other

hand, GA exhibited a delay in onset in the WP compared to the run.

Table 2b reveals the outcomes of the neuromuscular activity of GA and TA during the two sled tasks, WP and RP. TA exhibited a shorter TP and duration in RP compared to WP.

Additionally, during RP, GA showed a shorter onset with a quicker TP than WP.

Table 3a displays the comparison of TA and GA muscle amplitude and time (percentage) for the run/WP and run/RP tasks. TA and GA exhibited a quicker onset of maximal muscular amplitude activation during RP. Additionally, the run tasks provoke a greater amplitude on the TA and GA compared to the RP and WP. Distinctively, TA presented a longer time minimally active compared to the run tasks. The GA exhibited a similar maximum amplitude among the run and RP tasks. Furthermore, for the same distance, GA showed minor muscle activation during WP compared to the run.

Table 3b illustrates the comparison of TA and GA muscle amplitudes and times (percentages) for the WP and RP tasks. RP, the sled provokes a quicker onset of muscle activation in the TA and GA. All other variables were comparable among pushing tasks.

Table 4a shows the comparison of lactate levels among the run, WP, and RP tasks. A significant ($P < 0.05$) increase in lactate levels was observed between the walk-push (WP: 3.05 ± 0.9 mmol/L) and run-push (RP: 4.8 ± 1.95 mmol/L) activity. No other significant differences ($P > 0.05$) were found in lactate between the tasks. Table 4b shows a comparison between resting lactate levels among the group tasks. No significant differences were noted.

IV Discussion

This study intended to assess the fatigue and adaptations of lower limb musculature, with regard to timing and activation, in response to healthy young adults pushing a constant resistant sled while walking (WP) and sprinting (RP). Three main findings were discovered from this investigation pertaining to the modifications of neuromuscular activation, increased lactate levels with speed, and variations of the

gastrocnemius (GA) and tibialis anterior (TA) musculature amplitude while pushing the sled.

Neuromuscular Activation. The first main finding of this study depicts timing modifications of the TA and GA, while WP or RP. This outcome illustrates that sled resistance, while either walking or running, can be utilized to promote muscle activation over short distances. During WP, the sled can facilitate prolonged recruitment of other musculatures, such as the TA, rather than solely the pushing muscles, such as the GA. During RP, TA exhibited a faster time to peak activation (TP) over a shorter period of time (duration) in comparison to WP. These findings indicate that when one's goal is to strengthen the musculature while avoiding muscle fatigue, our recommendation is to push the sled at faster speeds over short distances. Contrarily, when endurance is indicated, pushing the sled at slower speeds over short distances is our proposal.

In connection with these findings, Rosario MG (2020) stated that the sled can be utilized for motor coordination and control training of both the GA and TA, while Kawmori et al. (2014) found that pushing a sled with a force of 30% body mass increased net horizontal and propulsive impulses in comparison to unresisted sprinting. These adaptations are due to the sled having an increased ground contact time, as well as requiring a larger force in order to initiate movement compared to sprinting without such resistance. In the current study, the use of resistance, regardless of RP or WP, produced significantly greater results than the act of solely running, as the addition of resistance increases force production. It has been suggested that an individual could utilize the increased force production created when pushing a sled while walking in order to improve endurance, as well as to increase lower extremity strength (Rosario MG, 2020). Our analysis further promotes the concept of

XPO trainer resistance sled as a distinguished tool that can be utilized, under appropriate conditions, in physical therapy practices for certain patient populations, especially when utilizing WP. The results of this study also confirm that the notion that neither high resistance nor speed is necessary to produce significant results in neuromuscular activation (Folland et al., 2002). Clinicians should acknowledge and employ the principle of fatigue when deciding between RP and WP when designing a program that promotes true neuromuscular and functional improvements in their patients. Future studies should focus on neuromuscular activation of the more proximal musculature, such as those of the hip and trunk.

GA and TA amplitudes and time percentages for the amplitude. Our second main outcome portrays that pushing the resistance sled provokes less muscular amplitude in the GA and TA when compared to solely running (Table 3a). The reduced amplitude seen in both muscles indicates that there is lessened demand for muscular recruitment while pushing the sled; a possibility for this outcome is that the sled elicited mainly proximal muscle recruitment, such as the gluteus maximus muscles, rather than the distal muscles. Contrary to our results, Kawamori et al. (2014) found that the force of exertion is greater when towing a sled in comparison to sprinting without a sled; however, their study utilized ground reaction force to determine the performance effort required from the participant in each condition rather than the EMG-based muscular amplitude used in the current investigation. Future studies should assess the relationship between muscle amplitude and ground reaction forces while pushing this particular constant resistance sled.

Amplitude data between the WP and RP sled tasks in this investigation were also compared;

this data demonstrating that RP provoked a quicker onset of maximal GA and TA amplitudes than those seen during WP. This earlier onset depicted by the GA and TA muscles is often used as a neuromuscular retraining strategy for various populations, as seen in older adults (Guadagnin, EC 2019). However, the faster recruitment of maximal amplitude while RP also implies that there is a faster onset of muscle fatigue in comparison to WP, despite previous studies not finding a connection between mean power frequency (MPF), measured by EMG analyses, and fatigue during dynamic exercise in trained cyclists (Tenana et al., 2010). We contend that in untrained individuals, maximal amplitudes during a given dynamic exercise with repeated exposures should lead to changes in muscle activation and faster onset of fatigue levels (Hamlyn, Behm, & Young, 2007), culminating in the significant increase in lactate levels found in the WP and RP participants, as depicted in Table 4. From these findings, we recommend walking while pushing a constant resistance sled to increase muscle strength while simultaneously avoiding muscle fatigue. Alternatively, we propose an increase in speed while pushing the sled when the aim is muscular endurance, in order to reach the optimal fatigue threshold and target endurance.

Lactate Assessment. The third primary outcome of this investigation pertains to our findings from assessing lactate and muscle fatigue in comparison to those of Rosario MG(2020). This outcome indicates that lactate levels were higher in RP participants than in run or WP, as seen in Table 4a, in which the results illustrate that RP produced the most fatigue in participants among the three protocols, while WP had the smallest average lactate levels, equating to this protocol eliciting the least amount of fatigue. The distinction between these results can lead to muscle

training and resistance training protocols, especially when fatigue is a factor that is necessary to be considered. Our findings indicate that in order to either provoke fatigue or promote endurance, a constant resistance sled should be used while running. Contrarily, to promote strengthening while avoiding fatigue, a WP protocol should be employed.

Previous studies have proposed that high resistance is not invariably required to yield significant musculature and strength gains (Folland et al., 2002), as low-resistance exercise protocols have the ability to achieve comparable results, analogous to those seen in our WP. Therefore, although utilizing the WP protocol with the XPO trainer sled in physical therapy settings is optimal for numerous reasons, it is also beneficial because of its ability to challenge the patient without excessive metabolic accumulation.

In the ongoing inquisition, participants' resting lactate levels had an average value of 2.35 ± 1.4 mmol/L, which is higher than what has been previously reported as normal lactate levels at rest, which are 1.3 mmol/L (Aduen et al., 1994). However, the baseline lactate levels in this study were not detectable as they were in the study by Aduen et al. (1994); therefore, the inability to obtain similar resting lactate levels in our participants makes this aspect a constraint of our examination. We believe there are two factors that may have contributed to this constraint: 1) participants had walked prior to the blood collection, measuring their baseline lactate levels, and second, there were two lactate measurements per participant in accordance with our protocol. Nevertheless, we were consistent with all assessments and physical activity levels for each participant. Future research should focus on understanding the impact of pushing a constant resistant sled, although we suggest investigating the effects of participants pushing the sled over

greater distances, following a more significant resting period, and with participants who lead sedentary lifestyles to further interpret the impact on lactate levels while operating such a sled.

V Conclusion

The purpose of this research was to examine muscle activation and fatigue measures through EMG and lactate levels while both walking and running while pushing a constant resistance sled. First, this investigation discovered that the WP protocol could facilitate proper muscular recruitment, regardless of velocity, which corroborates the notion held that high resistance is not required for an individual to develop a considerable impact on neuromuscular activation. It has been previously assumed that only the RP protocol has the ability to yield substantial neuromuscular activation; however, the use of resistance, regardless of speed (RP or WP), has shown considerable muscle recruitment in comparison to the act of running alone, which is a direct result of the resistance increasing overall force production (Kawmori et al., 2014). Second, the amplitude assessment in this study revealed that running without pushing the sled elicited greater GA and TA muscle responses than those found in the WP and RP protocols.

Additionally, the maximum amplitude during RP was prolonged in comparison to that during WP, which ultimately led to fatigue. Finally, the lactate estimate identified that of the three protocols included in this study, the WP protocol produced the lowest levels of fatigue. This identification should prove to be beneficial for clinicians in designing and planning programs for patients whose fatigue levels need to be considered.

This study had several limitations. First, the distance in which participants were asked to complete the tasks was only 40 feet; while this distance could be replicated by physical therapists, it is a limited distance that may not produce a

substantial variation in lactate levels. Second, this study was only authorized to monitor blood lactate levels twice; it would have been desirable to analyze the lactate levels three times to obtain a more thorough resting lactate level in addition to the post-walking and post-task lactate levels that were collected. Third, this study did not have the participants execute a strenuous task in order to distinguish the effects of fatigue, as well as compare results from that task to those of the sled; rather, each participant completed the same task for three trials prior to measuring lactate levels.

Future investigations should focus on the musculature of proximal areas, such as the hip and back, to adequately understand the muscles involved in pushing a constant resistance sled, such as the one presented in this study. Prospective examinations should also choose a resting lactate measurement aside from the two this investigations took, although we recommend that future investigators draw more lactate readings throughout the trials. The addition of one or more lactate measures would provide a more detailed and accurate assessment of participants' lactate levels throughout the study, leading to an overall greater comprehension of the impact of a constant resistance sled on this factor. Conducting a further inquiry that utilizes a longer runway, along with the inclusion of a single strenuous task to determine the impact of fatigue-inducing task's impact, similar to maximal cardiovascular testing, would be ideal. Additionally, it would be beneficial to explore the implications of muscle activation and muscle fatigue at different distances and on varying surfaces, such as ramps.

The present investigation demonstrated that when working with the XPO trainer sled, clinicians in physical therapy settings should acknowledge and employ the principle of fatigue,

along with their patients' desired outcomes, when choosing between the RP and WP protocols to design a program that promotes true neuromuscular and functional improvement in their patients. When utilizing the sled to increase strength in patients without inducing fatigue, increased speed over shorter distances should be prescribed, although slower speeds over shorter distances should be directed when the desired outcome for the patient is endurance without prompting the onset of muscle fatigue.

Declaration

Funding: This research study was funded by the TWU Center for Student Research.

Conflicts of interest/Competing interests: Authors report no conflict or competing interest.

Ethics approval: IRB approval TWU protocol # 20091

Consent to participate: The participant gave signed consent for this report

Authors' contributions: All authors contributed to the study conception and design.

References

- [1] Aduen, J., Bernstein, W. K., Khastgir, T., Miller, J., Kerzner, R., Bhatiani, A., Lustgarten, J., Bassin, A. S., Davidson, L., & Chernow, B. (1994). The use and clinical importance of a substrate-specific electrode for rapid determination of blood lactate concentrations. *Jama*, 272(21), 1678-1685.
DOI: 10.1001/jama.1994.03520210062033
- [2] Borotikar, B. S., & Sheehan, F. T. (2013). In vivo patellofemoral contact mechanics during active extension using a novel dynamic MRI-based methodology. *Osteoarthritis and cartilage*, 21(12), 1886-1894.
DOI: 10.1016/j.joca.2013.08.023
- [3] Cohen, Z. A., Roglic, H., Grelsamer, R. P., Henry, J. H., Levine, W. N., Van Mow, C., & Ateshian, G. A. (2001). Patellofemoral stresses during open and closed kinetic chain exercises: an

- analysis using computer simulation. *The American journal of sports medicine*, 29(4), 480-487. DOI: 10.1177/03635465010290041701
- [4] DeMers, M. S., Pal, S., & Delp, S. L. (2014). Changes in tibiofemoral forces due to variations in muscle activity during walking. *Journal of orthopaedic research: official publication of the Orthopaedic Research Society*, 32(6), 769–776. DOI: 10.1002/jor.22601
- [5] Guadagnin, E.C., Barbieri, F.A., Simieli, L., & Carpes, F.P. (2019). Is muscular and functional performance related to gait symmetry in older adults? A systematic review. *Archives of Gerontology and Geriatrics*, 84, 1-6. doi: 10.1016/j.archger.2019.103899.
- [6] Folland, J. P., Irish, C. S., Robert, J. C., Tarr, J. E., & Jones, D. A. (2002). Fatigue is not a necessary stimulus for strength gains during resistance training. *British Journal of Sports Medicine*, 36(5), 370–373. DOI: 10.1136/bjsm.36.5.370
- [7] Hamlyn N, Behm DG, Young WB. Trunk muscle activation during dynamic weight-training exercises and isometric instability activities. *J Strength Cond Res*. 2007 Nov;21(4):1108-12. doi: 10.1519/R-20366.1. PMID: 18076231. Kawamori, Naoki & Newton, Robert & Nosaka, Ken. (2014). Effects of weighted sled towing on ground reaction force during the acceleration phase of sprint running. *Journal of sports sciences*, 32(12) DOI: 10.1080/02640414.2014.886129
- [8] Lopez, P., Pinto, R. S., Radaelli, R., Rech, A., Grazioli, R., Izquierdo, M., & Cadore, E. L. (2018). Benefits of resistance training in physically frail elderly: a systematic review. *Aging clinical and experimental research*, 30(8), 889-899. DOI: 10.1007/s40520-017-0863-z
- [9] Nicholson, V. P., McKean, M. R., & Burkett, B. J. (2015). Low-load high-repetition resistance training improves strength and gait speed in middle-aged and older adults. *Journal of science and medicine in sport*, 18(5), 596-600. DOI: 10.1016/j.jsams.2014.07.018
- [10] Rosario, M. G. (2020). Neuromuscular timing modification in responses to increased speed and proportional resistance while pushing a sled in young adults. *European Journal of Human Movement*, 44, 50-66. DOI: 10.21134/eur-jhm.2020.44.544.
- [11] Rosario, M.G., & Mathis, M. (2020). Lower limb muscle activation and kinematics modifications of young healthy adults while pushing a variable resistance sled. *Journal of Human Sport and Exercise*. DOI: 10.14198/jhse.2021.164.06
- [12] Roos, P. E., Barton, N., & van Deursen, R. W. (2012). Patellofemoral joint compression forces in backward and forward running. *Journal of biomechanics*, 45(9), 1656-1660. DOI: 10.1016/j.jbiomech.2012.03.020
- [13] Rossom, S., Smith, C., Thelen, D., Vanwanseele, B., Assche, D., & Jonkers, I. (2018). Knee Joint Loading in Healthy Adults During Functional Exercises: Implications for Rehabilitation Guidelines. *Journal of Orthopaedic And Sports Physical Therapy*, 48(3), 162–173. DOI: 10.2519/jospt.2018.7459
- [14] Saxby, D. J., Modenese, L., Bryant, A. L., Gerus, P., Killen, B., Fortin, K., Wrigley, T. V., Bennell, K. L., Cicuttini, F. M., & Lloyd, D. G. (2016). Tibiofemoral contact forces during walking, running and sidestepping. *Gait & posture*, 49, 78-85. DOI: 10.1016/j.jbiomech.2012.03.020
- [15] Tenan, M. S., McMurray, R. G., Blackburn, B. T., McGrath, M., & Leppert, K. (2011). The relationship between blood potassium, blood lactate, and electromyography signals related to fatigue in a progressive cycling exercise test. *Journal of Electromyography and Kinesiology*, 21(1), 25-32. DOI: 10.1016/j.jelekin.2010.09.002