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An Investigation of the Sled Push Exercise: Quantification of Work, Kinematics, and Related Physical Characteristics

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An Investigation of the Sled Push Exercise: Quantification of Work, Kinematics, and Related Physical Characteristics

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by

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ABSTRACT

An Investigation of the Sled Push Exercise: Quantification of Work, Kinematics, and Related Physical Characteristics

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The purpose of this dissertation was to describe the basic characteristics of performing resisted sprint training using a push sled for the enhancement of sport performance. Specifically, this dissertation served to: 1.) quantify the frictional forces involved between a push sled and an AstroTurf® surface at 6 loads, 2.) derive an estimation of mechanical work performed during sled push training, 3.) outline the velocity characteristics of 3 sled pushing loads scaled to the athletes body mass for comparison against their sprinting ability and 4.) determine the interrelations of fitness characteristics to the ability to sprint under heavy resistance.

The following are major findings of this dissertation. 1.) Coefficients of static friction (0.53 – 0.37) and dynamic friction (0.35 – 0.28) were calculated at multiple loads for the AstroTurf® surface. 2.) A direct near perfect relationship exists between total system load of the sled and the forces required to initiate and maintain movement of the sled. Although a direct measurement of force would be more precise and account for changes in velocity, the total system load may be a more practical alternative for daily use. 3.) Statistically significant changes in velocity characteristics were observed within each sled pushing load as well as when comparing each load to sprinting. Decrements in peak velocity ranged from about 40%-51% when comparing resisted to unresisted

sprinting. Load increments of 25% body mass were heavy enough to cause statistically significant differences in velocity characteristics. 4.) Statistically significant correlations were observed in anthropometry, sprinting ability, jumping ability, and strength to sled pushing. The results indicate that larger athletes, who can not only produce greater force but produce those forces rapidly, in addition to excelling at jumping and sprinting compared to their peers demonstrate the ability to move faster against heavy loads and slow down less from unresisted conditions. The strongest athletes demonstrated statistically nonsignificant differences in peak velocity drop off when compared to their weaker counterparts; however, small to moderate effect sizes (*d* = 0.27 – 1.02) were observed indicating a practical difference between strength levels in peak velocity and peak velocity drop off.

DEDICATION

This work is dedicated to my parents, who have demonstrated their greatest lessons through their actions. Thank you for showing me to approach life with a furious intensity, demonstrate patience and composure, and persevere through raw willpower and grit.

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CHAPTER 1

INTRODUCTION

Introduction

The adoption of resisted sprint implements have become an ever increasing tool used to optimize speed development. Within sports where the ability to sprint toward and away from the opponent relates to competitive success, many strength and conditioning coaches are embracing sled towing and sled pushing in hopes to improve athlete performance. Resisted sprint modalities are speculated to improve sport performance through enhancements in factors such as strength, power, and metabolic conditioning; however, such enhancements remain largely uncorroborated with empirical evidence. Additionally, there is little evidence in how these training methods should be appropriately prescribed, how much mechanical work is being performed, and how much physiological strain is being placed on the athlete. As such, the ability to appropriately program resisted sprinting within a periodized training plan is limited.

Resisted sprinting and virtually all other forms of resisted movement training are expressions of the principle of specificity. Training specificity is often misinterpreted to imply that in order to perform an activity, the training involved should mimic the activity across all variables. While in some cases this may be beneficial, only trying to simulate the activity exactly as it appears could potentially leave out other critical training methods for inducing adaptation. Specificity does not imply that any given variables of training and competition are exactly alike but rather deals with the level of association between them. When variables are highly associated, they are said to share a high degree of specificity. Similarly the term “transfer of training effects” relates to this idea of training specificity but describes the degree of performance enhancement resulting from a given training method (Stone, Stone, & Sands, 2007). Specificity is not limited to just muscle morphology, architecture, and metabolism but to other neuromuscular aspects as well. The development of maximal strength and power are highly related to nervous system control of motor unit recruitment, firing frequency and synchronization, and inter-muscular coordination (Cormie, McGuigan, & Newton, 2011).

Resisted movement training (which can include resisted sprinting) can be associated with training specificity. It is thought to enhance transfer of training effects by overloading a sporting movement in such a way that cannot be achieved through normal unresisted practice of that movement (Young, 2006). Examples might include track sprinters towing a sled behind them during a sprint or offensive lineman repeatedly hitting or driving a weighted blocking sled. Although these and other methods may look similar to the activity they are seeking to improve, several key factors must first be considered for developing mechanical specificity and optimal transfer of training effects: The complexity of the movement, body position, joint range of movement and accentuated regions of force production, types of muscle actions, average and peak forces, rates of force development, acceleration and velocity parameters, and the ballistic nature of the movement (Stone et al., 2007).

With these factors considered, a variety of implements have been developed or used to provide resistance during sprints. These include but are not limited to the use of pulleys, parachutes, weighted vests, elastic bands, and pushing or towing sleds or motor vehicles. Although all these implements provide their own unique biomechanical challenges to overcome, ultimately they are all used in an attempt to overload the sprint movement with additional resistance in the vertical or horizontal orientation.

A recent review by Hrysomallis (2012) described the potential benefits of resisted sprint training as related to sprint performance. However the author does allude to the fact that resisted sprint training appears to offer no additional benefits to that of unresisted sprint training (Hrysomallis, 2012). These inferences may call into question the usefulness of the further addition of resistance to speed training, especially considering that developing other physical characteristics such as strength and explosiveness though other means will likely have a positive effect on sprinting ability (Israetel, 2013). Although sprinting ability, particularly over shorter distances, appears to be a key performance characteristic for most sporting activities, it alone may not fully justify the use of resisted-sprint or movement training (Cummins, Orr, O'Connor, & West, 2013; Dwyer & Gabbett, 2012; Lockie, Murphy, Knight, & Janse de Jonge, 2011; Spinks, Murphy, Spinks, & Lockie, 2007).

Currently there is little scientific evidence describing the physiological effects or the potential adaptations of performing the sled push exercise. While traditionally push sleds have been used in the development of multi-person blocking or scrummaging, single person sled variations have now emerged onto the market, which has lead to a variety of novel training methods. Some strength and conditioning coaches suggest using these implements due to their unique biomechanical challenge, as well as the potential to carry a great deal of mechanical specificity to many sporting movements (Jenkins & Palmer, 2012; Zemke & Wright, 2011). Others suggest that due to the lack of a loaded eccentric muscle action, these methods might be useful in reducing training-related fatigue (Jenkins & Palmer, 2012; West et al., 2014). Similar methods have found resisted implement training to be metabolically taxing and considered a high-intensity form of training (Berning, Adams, Climstein, & Stamford, 2007; West et al., 2014).

Because these resisted implement training methods are metabolically challenging and appear to hold mechanical specificity to many sporting movements, push sleds have made their way off the field and into the weight room. The suggested use of the sled push exercise has appeared to span the entire range of bio-motor abilities and physical characteristics and have been applied to promote strength, power, speed, conditioning, or what has often been described anecdotally as a ‘finisher’ at the end of a training session. While sled towing is a well-established method of training sprint acceleration, very little is actually known about the application of a push sled to an athlete’s training program. Findings from similar methods of resisted implement training suggest that because of the concentric only nature of the movement, high metabolic cost, and similar biomechanical characteristics to many sporting movements the sled push may be used as an alternative method to develop high intensity intermittent endurance for sports like American football, rugby, and others where high intensity activity is not limited to just running or sprinting.

The purpose of this dissertation was to further describe the sled push exercise in the following areas: the frictional forces involved between the push sled and an AstroTurf® surface at six loads, suggest a basic estimation of mechanical work being performed during this exercise based on the data collected, the velocity characteristics of three heavy loads scaled to the athletes body mass (for comparison against their unresisted sprinting ability), and the interrelations of fitness characteristics to the ability to sprint under heavy resistance.

Operational Definitions

1. Resisted Sprinting: a form of sprinting in which the body must move against and overcome an external force in addition to body mass. This can be achieved through a variety of implements such as towing sleds, pushing sleds, parachutes, weighted vests, and resistance bands
2. Push Sled: a type of sled that is positioned in front of the user and is pushed forward through contact with the arms or shoulders as the user moves forward.
3. Tow Sled: a type of sled that is positioned behind the user and is dragged forward by a harness as the user moves forward.
4. High-Intensity Interval Training (HIIT): a form of physical conditioning involving repeated bouts of near maximal, maximal, or supra-maximal activity interspersed with periods of incomplete recovery.
5. Sled: a simple device for providing resistance to pushing or pulling movements. A sled typically consists of a flat surface or set of skis that remain in contact with the ground. The resistance is controlled by how much weight is loaded on to the sled, which will proportionately change the frictional forces between the sled ground surfaces. The sled is typically attached to the user by either a body harness or through specific handles on the sled where the user is meant to push through contact with the upper extremities.
6. Completion Time (CT): The time it takes from start to finish covering a given distance. For the purpose of this investigation, completion time will always be in reference to a distance of 10 m.
7. Peak Velocity (PV): The highest velocity achieved throughout a given test.
8. Average Velocity (AV): The average velocity from start to finish throughout a given test.
9. Time to Peak Velocity (TTPV): The time it takes from the onset of the test to achieve the PV.
10. Static Jump (SJ): A type of jump performed where the subject begins at a knee angle of 90 degrees and jumps strait into the air without a countermovement initiating the jump
11. Countermovement Jump (CMJ): A type of jump performed where the subject begins standing upright and when ready to jump initiates a downward countermovement to a self-selected depth and jumps strait into the air.
12. Coefficient of Friction (μ): a value representing the ratio of the force of friction between two objects and the force pressing them together (normal force).

13. Static Friction: the friction between objects that are not moving relative to each other.
14. Dynamic Friction: the friction between objects that are moving relative to each other.
15. Strength: the ability to generate and/or sustain maximal and submaximal forces.

CHAPTER 2

COMPREHENSIVE REVIEW OF LITERATURE

Resisted Sprinting

Though there appears to be no direct benefit in overall sprint performance, some evidence suggests that resisted sprints may provide improvements in the initial acceleration phase of sprinting over short distances (<20m) (Hrysomallis, 2012; Lockie, Murphy, & Spinks, 2003; Spinks et al., 2007; Zafeiridis et al., 2005). Unresisted sprinting however appears to produce superior results in distances greater than 20m (Kristensen, van den Tillaar, & Ettema, 2006; Zafeiridis et al., 2005). This may suggest that the resisted sprint shares similar force velocity characteristics to unresisted sprinting during acceleration phases. However resisted sprints may deviate too far in force, velocity, and technical characteristics near or at maximal velocity. Another possible benefit of the resisted sprint may come from a more effective transfer of propulsive impulses instead of improvements in the athlete's strength or power characteristics.

Specifically in sled towing, coaches have traditionally recommended using lighter loads (<10% body mass) , believing that this loading maintains sprint mechanics and does not reduce maximal sprint velocity by more than 10% (Alcaraz, Palao, & Elvira, 2009; Kawamori, Newton, Hori, & Nosaka, 2013; Lockie et al., 2003; Spinks et al., 2007). This has led to further debate about the priorities of overload versus mechanical specificity in programming resisted sprint training, as these training principles may be weighed differently across different sports. For example, alterations in sprint technique due to loading for a track sprinter may be deleterious to performance. However rugby players often have one or more limbs impeded from movement so alterations in technique may not have as great an impact. Furthermore, a track and field sprinter may need to sprint a broad range of distances all of which are unresisted, whereas a rugby player will predominantly make shorter sprints often against the resistance of other players.

Kawamori and colleagues (2013) recently compared the use of heavier and lighter loads during sled towing in field sport athletes for 8 weeks of training. The loads for each group were assigned to reduce unresisted sprint velocity by 30% and 10% for the heavy and light groups respectively. They found that both groups were able to improve 10m sprint times. However, only the heavier sled group was able to improve 0-5m times as well (Kawamori et al., 2013). These findings suggest that previous notions about the “10%" rule may be misunderstood in their application and that heavier resisted sprints may enhance sprint acceleration better than lighter or unresisted sprints. Although strength measures were not reported, it is possible that the improvements observed in sprint times could also be attributed to increases in strength characteristics.

Cottle, Carlson, and Lawrence (2014) further bolster the findings by Kawamori and colleagues (2013) through the study of ground reaction forces. In this study ground reaction forces were compared across an unresisted condition, a 10% body mass condition, and a 20% body mass condition from a standing, staggered-foot start using sled towing. The findings indicated statistically significant increases in both sled conditions from the unresisted condition in propulsive ground reaction force impulses scaled to body mass ($p < 0.001$); however, the 20% body mass load also produce statistically significantly greater propulsive ground reaction impulses scaled to body mass than the 10% body mass condition. Additionally, the 20% body mass load was also found to have a statistically significant increase in vertical ground reaction force impulse scaled to body mass from the unresisted condition ($p \leq 0.05$). Neither sled condition produced statistically different propulsive ground reaction forces scaled to body mass or propulsive rates of force development scaled to body mass. The authors noted that because an increase in rate of force production was not observed in either load and neither would provide evidence for increased sprint start power. They speculated that the 20% load may help increase strength characteristics, but other training modalities should be used to increase propulsive power and sprint start explosiveness (Cottle et al., 2014).

Though it appears that resisted sprint training may have a beneficial effect on unresisted acceleration ability, the relationships between many of the underlying variables remain unclear. A study by Okkenen and Häkkinen (2013) further investigated these relationships by comparing the biomechanics of unresisted sprinting from the blocks to sled towing, countermovement jumps, and squatting movements. Using nine male track and field athletes (four sprinters, three decathlonists, one long jumper, and one triple jumper) undergoing force-time, electromyography, and kinematic analysis, the authors were able to identify distinct similarities and differences between sled towing and sprinting. Statistically significant correlations were found between the 10m sprint from a block start and sled towing at a load of 10% of body mass in completion time ($r = 0.733$) and averaged EMG of the vastus lateralus muscle ($r = 0.783$). Completion time and force production times for the resisted conditions were longer than the unresisted conditions, resulting in larger impulses and lower step frequencies consistent with previous literature. Another finding of note was that during the block phase, the phase of force production toward the starting blocks, sled towing resulted in an 80% increase in integrated EMG and about a 40% increase in average EMG in the gluteus maximus muscle, whereas the bicep femoris muscle actually decreased in EMG values. Although the angular velocities for the resisted condition were generally lower at the knee, hip, and ankle, the minimal and maximal angles were similar. The author's speculated that because the sled towing conditions showed mechanical specificity to blocked start conditions, effective transfer of training effects could be expected (Okkonen & Hakkinen, 2013).

Further evidence was provided by Alcaraz (2012) who was possibly the first to outline the training adaptations from a resisted sprint training program on well trained athletes (Alcaraz, Elvira, & Palao, 2012). In this study 30 national level track and field athletes (male n = 20, female n = 10) consisting of 24 sprinters, 2 long jumpers, and 4 decathletes performed a 4-week combined strength, jumping, and resisted sprint training program at a load resulting in a 7.5% decrease in peak sprinting velocity. A separate group performed the same training but sprinted without additional resistance and was used as comparison. Sprint kinematics, strength, and jumping ability were assessed after training to determine the effect of the training intervention. Results indicated statistically significant improvements in the resisted group in sprint velocity from 15-30m and in the unresisted from 30-50m with no change in overall maximal sprint velocity in either group. Both groups saw statistically significant improvements in 1RM smith machine half squats. Both groups also saw statistically significant improvements in mechanical power during half squats at relative percentage of their 1RMs, with resisted groups at 45% and 70% and unresisted groups at 30% of 1RM half squat. Jumping ability remained largely unchanged within and between groups, with the unresisted group having a statistically significant group difference pre-to posttraining in relative force production at 100ms. Although these differences are difficult to attribute to any one element of the training, this was an attempt to maintain external validity of the sport training itself, as strength and conditioning programs are virtually always implemented with multiple components.

The findings by Alcaraz appear to confirm previous suggestions that for more well trained athletes this type of training may enhance acceleration ability (Hrysomallis, 2012). Less highly trained athletes may see a strength training type effect from sprinting against heavy load due to the large propulsive impulses. However this is merely a result of training status as many fitness characteristics can improve at the onset of training.

Physical Characteristics of Sprinting Ability

Strength may be one of the most important fitness characteristic to an athlete's ability to rapidly accelerate. Strength characteristics have been able to differentiate high and low performers in both sprinting and jumping ability indicating that the strongest athletes typically perform these tasks better than their weaker counterparts (Israetel, 2013; Kraska et al., 2009). Maximal squat strength both absolutely and relatively scaled has shown to be a strong correlate to short distance sprinting ability (Chelly et al., 2010; Lockie et al., 2011; McBride et al., 2009). It would appear that the ability to generate large maximal forces, especially when scaled to bodyweight, is a critical factor in the ability to accelerate. However the expression of strength is not limited to just maximal forces but rather a variety of other variables such as rate of force development (RFD), peak power output (PPO), and different force velocity characteristics as well.

Similar to measures of maximal strength, the ability to produce large forces in high velocity activities such as jumping have also been related to sprinting ability. Young, McLean, and Ardagna (1995) showed that one of the strongest correlates ($r = 0.80$, $p = 0.0001$) of maximal sprinting speed was the force applied (scaled relative to body weight) at 100 ms during the concentric phase of a loaded jump. Similarly the best correlate ($r = 0.86$, $p = 0.0001$) of starting performance (2.5 m) was the peak force generated during a jump from a 120° knee angle (Young et al., 1995). Similarly, Marques et al. (2014) examined the relationships of a loaded countermovement jump with 10m sprint times. Their findings indicated statistically significant correlations between average bar velocity ($r = -0.578$, $p < 0.001$), peak bar velocity ($r = -0.63$, $p < 0.001$), peak force ($r = -0.469$, $p < 0.001$), mean power ($r = 0.579$, $p < 0.001$), and peak power ($r = 0.636$, $p < 0.001$) with 10m sprint performance (Marques & Izquierdo, 2014). This was also confirmed in a study by Israetel (2013) examining the interrelations of fitness characteristics in NCAA Division 1 athletes consisting of Women’s Volleyball, Baseball, Men’s Soccer, and Women’s soccer athletes. His findings also indicated that fastest 20m sprinters typically had statistically significantly higher unloaded countermovement jump heights and peak power outputs (scaled to body mass) than their weaker counterparts. In fact, the stronger group jumped 21% higher than the weaker group, indicating that the expression of strength is not limited to activities with slow maximal loading but can be expressed throughout an entire force velocity spectrum. Thus, the collective strength and power characteristics seem to be highly related to the ability to accelerate and perform sprint related tasks.

High Intensity Interval Training

Traditionally one of the primary uses of sled pushing has been the development of metabolic conditioning in sports like American football. High intensity interval training (HIIT) is one of the foundational approaches to sport conditioning. Although no true universal definition exists, HIIT generally consists of near maximal, maximal, or even supra-maximal bouts of exercise followed by intermittent recovery to target specific metabolic pathways and mimic the demands of game play. HIIT interventions generally have been found to be just as effective, if not more effective, in variables such as maximal oxygen consumption, hydrogen ion buffering capacity, time to fatigue, and time trial performance as traditional endurance training methods (Esfarjani & Laursen, 2007; Laursen, Blanchard, & Jenkins, 2002; Laursen, Shing, Peake, Coombes, & Jenkins, 2002). One of the additional benefits of HIIT results from the reduced total training volume necessary to get comparable skeletal muscle adaptations to that of traditional endurance training (Burgomaster et al., 2008). This however comes at the cost of higher intensity training sessions and the corresponding fatigue that comes with it (Midgley, McNaughton, & Wilkinson, 2006). Accordingly the need for coaches and athletes to understand how to implement these techniques appropriately is critical to not only optimal performance enhancement but fatigue management as well.

HIIT training has been suggested to have a positive effect on mitochondrial biogenesis, $VO2_{max}$, fat oxidation, glycogen utilization, muscle buffering capacity, citrate synthase (CS) activity, and cytochrome C oxidase activity (Burgomaster et al., 2008; Gibala & McGee, 2008; Hoffmann Jr, Reed, Leiting, Chiang, & Stone, 2013; Laursen & Jenkins, 2002; Laursen et al., 2002; Little, Safdar, Wilkin, Tarnopolsky, & Gibala, 2010; Weston et al., 1997). HIIT interventions have also shown similar intracellular signaling responses to that of traditional endurance training, stimulating the AMPK and p38 MAPK signaling pathways (Gibala et al., 2009).

There does appear to be a significant effect of training age on the adaptability to HIIT. Contrary to what has been seen in untrained athletes, it appears highly trained or skilled athletes typically produce more peripheral adaptations and very small changes in aerobic fitness. This is well demonstrated and discussed in a review done by Midgley et al. (2006) summarizing a number of different running based HIIT programs and their corresponding changes in $VO2_{max}$. Changes typically range from 0.7-5.4 $ml \cdot kg^{-1} \cdot min^{-1}$ and more often than not fail to reach statistical significance though may be a practical change for athletes and coaches. An interesting finding by Weston et al. (1997) indicated that skeletal muscle buffering capacity may also play a major in role in well trained athletes. In this study subjects performed 6 weeks of HIIT consisting of six-eight repetitions of cycling at 80% of peak power output for 5-minute intervals with 1 min of recovery. They found that hydrogen ion tolerance increased from 17.9mmol H+ to 34.1mmol H+ with improvements in 40km time trial, peak power output, time to fatigue @ 150% peak power output and no change in phosphofructokinase or citrate synthase enzyme activity. The results indicate that HIIT may have enhanced the muscles ability to perform and sustain maximal and/or submaximal work, and it was suggested that skeletal muscle buffering capacity may be an important determinant of performance in highly trained athletes. Similar results found by Lauresn et al. (2002) investigating the addition of several different supra-maximal cycling HIIT interventions to an existing low intensity endurance program. This was compared to a control group that only performed low intensity exercise. It was found that all HIIT groups were able to improve 40km time trial performance and peak power output more than the control group and two groups improved maximal oxygen uptake more than the control group.

It appears that HIIT interventions, regardless of training status, improves an athlete’s ability to produce maximal work, sustain a high percentage of submaximal work either continuously or intermittently, and better resist fatigue during high intensity bouts. The mechanisms responsible for promoting these increased abilities appear to be heavily dependent on the training status of the athlete and the type of HIIT used (sub-max, max, supra-max). HIIT programs can be optimized to promote the necessary cardiovascular, metabolic, and muscular adaptations of game play by manipulating intensity, volume/duration, and work to rest ratios.

Running and cycling based interventions have been extensively researched with a wide variety of programming and evaluation methods. These types of interventions, particularly cycling, are easily quantified and can be accurately implemented using watts, speed, cadence, and distance. Typically these interventions are evaluated using $VO2_{max}$, peak power output, lactate threshold, muscle buffering capacity, metabolic enzyme activities, time trial performance, repeated sprint ability, anaerobic capacity, and time to exhaustion. Additionally these methods hold a high degree of external validity to the performance outcomes of many sports due to their similarities in agonist muscles and mechanical specificity. For these reasons very little research exists on the use of nonrunning or cycling based interventions. However due to the ease of evaluation, implementation, and overall effectiveness of running and cycling HIIT programs, the need for investigation into other modalities has not been entirely warranted.

Physiological Responses to Resisted Implement Training

Though implement training has been a staple in many sports such as track and field for years, more creative uses of loading and implement devices have arisen in other sports largely due to the advents of Strongman and Crossfit™. Anecdotal evidence seems to support the use of these exercises in promoting the high intensity intermittent endurance of high force output movements. However the scientific validity remains yet to be determined. Some initial findings have shed some light on the demands of these exercises. However to the author's current knowledge no research has been done on using these techniques to promote sport specific conditioning.

Although no current literature exists on the physical demands of a heavy sprint style sled push, similar studies have arisen to base an early theoretical understanding on the expected training responses and outcomes. One of the most comparable findings came from Berning et al. (2007) who investigated the metabolic cost of pushing and pulling a 1960kg motor vehicle over a distance of 400m. Six subjects consisting of powerlifters, rugby players, and bodybuilders with at least 5 years of periodized resistance training performed a maximal push and tow of the motor vehicle over a distance of 400m per trip. It was found that even within a short distance of about 50m, subjects had reached about 44% of $VO2_{max}$ and 90% of maximum heart rate. By the end of each trial subjects had reached about 68% of $VO2_{max}$, 97% of maximum heart rate and blood lactate values of 16.1±-1.3 $mmol\cdot L^{-1}$. They concluded that this type of training "is an exhausting training technique that requires a very high anaerobic energy output and should be considered an advanced form of training" (Berning et al., 2007, p.856). Though this is an extreme example of resisted sprint training because of the heavy weight rolling implement and relatively long distance traveled, this study suggests that this type of training has largely anaerobic metabolic demands. This is not unlike traditional sprint training, which relies predominantly on the phosphagen and glycolytic pathways for energy production, whether performed in single or repeated bouts (Bishop, Girard, & Mendez-Villanueva, 2011).

There appears to be a tradeoff: a greater overload comes at the cost of decreased specificity to unresisted sprinting and vice versa. The question however should not be whether this tradeoff is good or bad but how to optimize this relationship for sport performance. This was further explored in a study by Keogh et al. comparing the kinematics of acceleration phase sprinting and the strongman style heavy sled pull. In this study six resistance trained males experienced in the sled pull exercise performed three sets of 25m sled pulls with a load of 171.2kg. Cameras were placed for kinematic analysis at the first 5m and last 5m to examine the acceleration phase and maximal velocity phases respectively. The results indicated statistically significant differences between acceleration and maximal velocity phases. However the heavy sled pull shared many kinematic similarities to the acceleration phase of unresisted sprinting with the exceptions of shorter stride lengths and lower rates, longer ground contact times, and an increased horizontal trunk lean. Additionally the results indicated that the slowest trials were characterized by lower stride rates and shorter lengths than the fastest trials, suggesting that large ground reaction forces and propulsive impulses are critical for heavy sled pulling performance (Keogh, Newlands, Blewett, Payne, & Chun-Er, 2010). So it would appear that even under very heavy loads resisted sprinting still holds much of biomechanical specificity to that of unresisted sprinting during acceleration. The use of a heavier training load as seen in the study by Keogh et al. may be more appropriate for sports like (American) football and rugby where collisions, driving, and heavy pushing or dragging may be taking place. They speculated that this type of training may improve acceleration ability in sprinting as well as the ability to make and break tackles in contact sports (Keogh et al., 2010).

The hypothesis presented by Keogh is strengthened when also considering that in many field sports, athletes are not able to execute perfect sprint technique due to various extremity immobilizations such as dribbling, ball carrying, tackling, and breaking tackles and have to resist against large forces. Additionally the average distance per sprint is typically too short to achieve maximal velocity (Coughlan, Green, Pook, Toolan, & O'Connor, 2011; Cummins et al., 2013; Dwyer & Gabbett, 2012; Roberts, Trewartha, Higgitt, El-Abd, & Stokes, 2008; Vigne, Gaudino, Rogowski, Alloatti, & Hautier, 2010). Though loads of 170kg may not be warranted for all athletes, this and other studies have shown potential benefits of using implement training loads greater than the traditional ‘10%’ approaches.

Similarly West et al. (2014) examined the metabolic, hormonal, biochemical, and neuromuscular responses to a backward sled drag training session loaded with 75% body mass. They found after five sets of 2x20m maximal sled drags (120s rest between sets) blood lactate levels increased from baseline levels of 1.7±0.5 $\text{mmol}\cdot\text{L}^{-1}$ to 12.4±2.6 $\text{mmol}\cdot\text{L}^{-1}$ immediately following the training session and remained elevated at 60 minutes before returning to baseline after 3 hours posttraining. This indicated a large metabolic stress placed on the athlete performing the sled dragging training session. Pre- and postcountermovement jump analysis indicated a similar trend in peak power output, dropping below baseline immediately post-training and returning to baseline 3 hours posttraining indicating only an acute impairment of neuromuscular function from training. No statistical differences were seen from pre- to posttraining in creatine kinase levels, indicating little skeletal muscle damage resulting from training. West and colleagues further speculated that because of the concentric-only nature of the exercises, this type of training may elicit favorable training responses in strength-trained athletes This was based on their findings indicating the that sled training stressed multiple physiological systems while only impairing neuromuscular function for 3 hours with little associated muscle damage. Due to the high metabolic cost and relatively short-lived neuromuscular impairment, this type of training may be used as a supplementary method to traditional concentric-eccentric methods such as sprinting (West et al., 2014). Other coaches and professionals have begun using implement training not only for resisted sprinting, but a variety of other exercises to take advantage of the concentric-only nature of these modalities (Jenkins & Palmer, 2012).

Determination of Frictional Forces

The challenge from resisted sprinting elements such as pushing or towing sleds results from overcoming the frictional forces between the sled and running surface. Although several studies have looked at various biomechanical changes resulting from different loading schemes (Alcaraz et al., 2012; Alcaraz, Palao, Elvira, & Linthorne, 2008; Alcaraz et al., 2009; Clark, Stearne, Walts, & Miller, 2010; Cronin, Hansen, Kawamori, & McNair, 2008; Harrison & Bourke, 2009; Kawamori et al., 2013; Lockie et al., 2003; Murray, 2007; Okkonen & Hakkinen, 2013; Spinks et al., 2007), only two have actually attempted to quantify the frictional forces involved under different loads and surface types (Andre, Fry, Bradford, & Buhr, 2013; Linthorne & Cooper, 2013). Simply put the magnitude of frictional forces, whether static or dynamic, is equal to the product of the normal force of the sled and coefficient of friction (static or dynamic) for the sled and the respective surface it's moving across. This can be expressed by the following equations:

$$\mu_s = F_s \cdot R^{-1}$$

Where μ_s is the coefficient of static friction, F_s is the static horizontal force, and R is the normal contact force. The normal contact force will be equal to the load multiplied by 9.81 the acceleration due to gravity. (Andre et al., 2013)

$$\mu_d = F_d \cdot R^{-1}$$

Where μ_d is the coefficient of dynamic friction, F_d is the static dynamic force, and R is the normal contact force. The normal contact force will be equal to the load multiplied by 9.81 the acceleration due to gravity (Andre et al., 2013).

For sled towing the normal force will be proportional to the weight of the sled when the surface is level and the tow cord is held at a constant angle (Linthorne & Cooper, 2013). It would seem logical that this relationship between the normal force and the total weight of the sled would be consistent across all forms of sled training on a level surface whether it was being pushed, towed, or dragged assuming conditions remain constant.

Although it may appear to be common knowledge, different surface types will produce different coefficients of friction, and thus different frictional forces per the same given load. This could lead to different loads needed to produce the same training stimulus across different surface types. To the author's current knowledge, there is no universally accepted method of quantifying a training load from sled work or other resisted implements. This knowledge could better help coaches not only assign training loads but track them more effectively as well. This was confirmed in a study by Linthorne and Cooper (2013) showing that differences in the coefficients of friction existed between a synthetic athletics track, a natural grass rugby pitch, a 3G football pitch, and an artificial grass hockey pitch. The findings indicated that each surface type resulted in slightly different 30m sprint completion times. The fastest was observed on the Rekortan athletics track (3.91 ± .025s) with increase of 0.05, 0.10, and 0.37s slower for the natural grass rugby pitch, artificial grass hockey pitch, and 3G football pitch respectively. The coefficient of friction was found to be independent of the velocity of the sled when towing across the Rekortan track. Multivariate regression analysis showed the majority of the variation in friction force could be explained by the weight of the sled ($R^2 = 0.983$, $p < 0.001$) with only 0.1% of the variance attributed to towing velocity ($R^2 = 0.001$, $p = 0.09$). Additionally the completion times for 30m sled towing increased linearly with increasing sled weight.

Within the question of how to assign training loads lies another important consideration when dealing with resisted sprint training, how to account for static and dynamic frictional forces of different surfaces. Because the load of the resisted sprint is a product of the total weight of the implement used and the frictional coefficient of the surface, being able to quantify frictional coefficients of the training surface itself is a crucial step in further understanding resisted sprint training. In an introductory study by Andre et al. the authors sought to establish a reliable protocol for determining frictional forces during a sled pull. In this study a winch was attached to a sled mounted force transducer via nylon tether to drag a sled across a floor under three different loads for 10 trials each, for a total of 30 trials. Statistically significant differences were found in both static and dynamic frictional forces between loads, indicating that average static and dynamic horizontal frictional forces increased as the load increased. Coefficient of variation scores ranged from 1.0% to 3.7% for the each of the 10 trials performed per load, indicating this was a reliable method for determining frictional constants and horizontal forces (Andre et al., 2013). One possible limitation to this approach is the absence vertical and resultant vector quantities that would be present in a normal sled drag or push training session. With this information, coaches may be better able to appropriately assign loads and estimate training load to this type of training across different surface types.

Conclusions

The ability to quantify training loads from all areas of strength and conditioning, technical, and tactical practice of sport is an integral part of sport science. Sport scientists have the additional burden of translating and condensing a variety of these training related variables into values that are both usable and meaningful while also having universal units of measure. If such an estimation of training load was developed, coaches and sport scientists could more easily integrate resisted sprint training methods into an annual plan as well as the fatigue management system.

Although little is still known about using heavy resisted implements for sprint training, a few trends can be seen. This type training seems to come at a large metabolic cost to the athlete, likely as a result of high force generation isolated mainly to the lower extremities, similar to traditional sprinting. Moreover, some of these methods even appear to share kinematic similarities in movement patterns to unresisted sprinting, with the major differences including longer ground contact times, increased trunk lean, and often the inability to use the upper extremities for assistance. These training methods also consist virtually of concentric muscle actions, and because of the lack of a resisted eccentric muscle action, these methods may cause less structural damage to the working muscles (Jenkins & Palmer, 2012; West et al., 2014).

Arguably the most important factors when analyzing these training methods might be their force and velocity characteristics. The amount of load used will impact the ground reaction forces, propulsive impulses, and velocities the athlete can achieve during the training session. Although a heavy sled push may carry a great deal of movement pattern specificity to a movement like blocking, the load should not be so heavy or so light that it compromises the velocity and acceleration characteristics of the sport. Transfer of training effects for unresisted sprinting are often velocity dependent, and it would seem logical that within sporting movements requiring an athlete to sprint or make maximal efforts against heavy resistance that an optimal range of loads and velocities exist to enhance transfer of training effects (Young, 2006).

With these factors in mind, the author speculates that resisted sprint training using push sleds will likely serve two major training outcomes: Developing speed and acceleration ability for sporting movements seen in American football, rugby, and winter sliding sports, and developing power maintenance and/or high intensity intermittent endurance for the same previously mentioned sports.

CHAPTER 3

FRICTION, WORK, AND VELOCITY CHARACTERISTICS OF RESISTED SPRINTING USING A WEIGHTED PUSH SLED

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Abstract

Purpose: The purpose of this investigation was twofold: the first to quantify the static and dynamic frictional forces and coefficients of a commonly used AstroTurf® training surface and the steel skis of Prowler 2® training sled at different loads. The second was to describe the velocity characteristics of performing sled pushing at three relatively heavy loads and compare those values to sprinting. **Methods:** For the first objective, six loads (39.9, 59.9, 79.9, 99.9, 119.9, 139.9kg) on a sled were towed manually by the investigator with a vinyl-coated cable and an inline load cell. Two trials were performed for each load, peak and average force data was collected from the load cell. For the second objective, twelve male East Tennessee State University Rugby club athletes (age 21.9 ± 2.6 years, rugby experience 3.2 ± 2.1 years, height 177 ± 6.3 cm, weight 80.6 ± 12.5 kg) were recruited for this study. Testing consisted of two 10m sled push trials at each load of 75, 100, and 125% body mass, and two 10m sprints. Completion time, peak velocity, average velocity, and time to peak velocity were calculated. One-way ANOVAs with paired sample t-tests were used to determine statistical differences within loads. Effect size of differences were calculated using Cohen's *d*. **Results:** Static friction coefficients ranged from 0.53 – 0.37 and dynamic friction coefficients ranged from 0.35 - 0.28. Peak static friction forces ranged from 206.1 - 505.1N and average dynamic friction forces ranged from 135.2 - 386.1N. Peak velocities of sled pushing ranged from 4.16 – 3.39 $m \cdot s^{-1}$ with 40 – 51% drop off from sprinting. Statistically significant differences with moderate to large effect sizes in velocity characteristics were observed within the three sled loads (d = 0.64 – 1.88), as well as between the sled pushing and sprinting conditions (d = 6.97 – 9.27). **Conclusions:** The

friction coefficients between the steel sled skis and AstroTurf® surface are comparable to other artificial grass surfaces. Statistically significant decreases in peak and average velocity can occur from load increments of 25% body mass during sled pushing. Coaches and sport scientists should manipulate training loads to best simulate the activities encountered in their respective sports.

Introduction

Resisted sprint training has become an increasingly popular training method in sport. Traditionally, methods for this type of training have come in two forms: towing sleds where the athlete is harnessed at the waist or shoulders to small flat sled weighted against the ground which is towed behind them, or pushing sleds where the athlete engages a larger sled either using the arms or shoulders and drives it forward. Push style sleds can be found in large multi-person sleds such as blocking or scrummaging sleds seen in American football and rugby respectively. Additionally smaller individual based sleds such as tackling sleds in American football, push track sleds in bobsled and winter sliding sports, and even smaller one man push training sleds are used for sport training.

All of these sleds require that the athlete overcome the forces of friction between the sled and contact surfaces in order to accelerate the sled forward. The amount of friction generated is mainly dependent on the coefficient of friction (μ) in static (μ_s) and dynamic (μ_d) conditions, as well as the normal force being applied to the system. In the case of sled pushing the coefficients of friction are specific to the skis on the bottom of the sled in use and the training surface used to push on. These can be calculated by the following equations:

$\mu_s = F_s \cdot R^{-1}$

Where μ_s is the coefficient of static friction, F_s is the static horizontal force, and R is the normal contact force. The normal contact force will be equal to the load multiplied by the acceleration due to gravity (9.806 $m \cdot s^{-2}$) (Andre et al., 2013).

$$\mu_d = F_d \cdot R^{-1}$$

Where μ_d is the coefficient of dynamic friction, F_d is the static dynamic force, and R is the normal contact force.

Linthorne and Cooper (2013) calculated μ_d values for several different surface types including a Rekortan athletics track (0.58 ± 0.01), a natural grass rugby pitch (0.45 ± 0.01), an artificial grass 3G football pitch (0.35 ± 0.01), and an artificial grass hockey pitch (0.21 ± 0.01) (Linthorne & Cooper, 2013). They found that when subjects performed an unloaded 30m sprint, each surface resulted in slightly different sprint completion times. Likewise when the subjects performed resisted sprints via sled towing, the frictional forces were also different on each surface per the same loads (0, 5%, 10%, 15%, 20%, 25%, and 30% of subjects body mass). Thus given the same level of effort, distance, and system load the surface type used in sled pushing could result in practical differences when performed across different surface types. Quantifying the frictional characteristics of the training surface could potentially help coaches and athletes understand how the training surfaces used will compare to each other, and possibly make adjustments if necessary.

Similarly the amount of force required to move the sled will have a direct impact on the peak velocities the athlete can achieve while sprinting. Traditionally in sled towing loading recommendations have followed a “10%” rule, in that the load of the sled does not exceed 10% of body weight or result in a 10% or more reduction in peak velocity (P. E. Alcaraz et al., 2009; Lockie et al., 2003; Spinks et al., 2007). This recommendation is rationalized by a detrimental effect of change in sprint technique with increasing load. Others have found that the use of heavier loads may be just as beneficial in improving sprinting ability (Cottle et al., 2014; Kawamori et al., 2013). This argument is strengthened when considering sports like American football and rugby, where athletes often make resisted sprint efforts through tackling, scrummaging, blocking, and breaking tackles against resistance with sub-optimal technique due to their limbs or trunk being immobilized. This also is true in winter sliding sports such as bobsled and skeleton, where athletes must sprint with arms immobilized against a heavy load.

Assigning training loads for sled and implement based training has varied considerably between studies. The most common methods are to scale the training load to achieve a predetermined percentage drop in maximal velocity or as a percentage of the athletes body mass, though others have used absolute training loads as well (Berning et al., 2007; Cottle et al., 2014; Harrison & Bourke, 2009; Kawamori et al., 2013; Keogh et al., 2010; Okkonen & Hakkinen, 2013; West et al., 2014). Although no universal definition of magnitude currently exists, based on the current literature a heavy sled load will be considered loads greater than 20% of the athletes body mass, as these have been shown to cause statistically differences in sprint technique, ground reaction forces, and percentage drop in peak velocity (P. E. Alcaraz et al., 2008; P. E. Alcaraz et al., 2009; Cottle et al., 2014; Harrison & Bourke, 2009; Kawamori et al., 2013; Keogh et al., 2010; Okkonen & Hakkinen, 2013).

Questions remain as to how much load is appropriate to maintain specificity of training. Although several studies have outlined different loads and velocity reduction in sled towing, at the current time there is little to no evidence outlining these load velocity relationships for sled pushing. Therefore the purpose of this investigation is twofold: the first to calculate the coefficients of friction for a commonly used AstroTurf® training surface and a Prowler 2® push sled at different loads as well as the respective force values necessary to generate movement. The second is to quantify the velocity characteristics of performing a sled push resisted sprint at different relative loads and compare those to sprinting.

Methods

Experimental Approach

This first portion of this investigation was to determine μ_s and μ_d for the turf surface and steel sled skis under multiple different loads. The ability to quantify the peak and average frictional forces involved can help coaches and investigators further understand how much work is being performed during this activity. All testing was performed on an AstroTurf® (Textile Management Associates, Inc., Dalton, GA) surface.

The second portion of this investigation was to determine how the loading affects kinematic variables during a sled push. In order to assess the effects of different loads during the sled push across athletes with different body masses and heights, loading was scaled according to athlete's body mass. Hand placement was set as a relative percentage of the subject's standing height. Completion time, peak velocity, and average velocity were calculated for each trial for comparison. Peak velocity and completion time were also compared across sled loads and with sprinting which was collected as part of a separate testing session using the same athletes.

Determination of Frictional Forces

No athletes were recruited for the first portion of this study, the investigator performed all analyses. An LC101 500 load cell (Omega Engineering, Stamford, CT) was attached to a Prowler 2® (Williams Strength, West Columbia, SC) sled weighing 39.9kg and the stock steel skis with the loading poles attached. The load cell was tethered to the sled using a vinyl coated steel cable. The signal from the load cell was amplified using a DMD465 amplifier (Omega Engineering, Stamford, CT) and analyzed using an Xplorer GLX analyzer (PASCO, Roseville, CA) sampled at 100 Hz. Loads were calculated as the total mass of the sled plus the external load added to the sled.

Six loads were towed for the study: 39.9 kg (unloaded), 59.9 kg, 79.9 kg, 99.9 kg, 119.9 kg, and 139.9 kg. The sled was manually towed by the investigator a distance of 5 m using another section of vinyl coated steel cable in a direction parallel to the turf surface. Two trials were performed for each load for a total of 12 trials.

For each trial static force (F_s) was determined by the peak force achieved during the trial. Dynamic force (F_d) was determined by averaging the force values from one second after the time peak force was achieved for one full second. The coefficient of static friction (μ_s) was calculated by dividing F_s by the normal force of the sled (the load multiplied by 9.81). The coefficient of dynamic friction (μ_d) was calculated by dividing F_d by the normal force of the sled.

Athletes

The athletes of this investigation were 12 male East Tennessee State University Rugby club athletes (age 21.9 ± 2.6 years, rugby experience 3.2 ± 2.1 years, height 177

± 6.3 cm, weight 80.6 ± 12.5 kg). Athletes all had at least one year of Rugby playing experience and were free of any disabling injuries or illness. One athlete dropped out between the sled pushing session and the following week when the sprint was collected. Therefore an n = 12 was used for the descriptive sled pushing data set, and an n = 11 was used for the comparison of sled pushing and sprinting. All athletes read and signed informed consent documents prior to participation in this study. This study was approved by the Institutional Review Board of East Tennessee State University.

Anthropometry

Height was measured to the nearest 0.5 cm using a digital stadiometer (Cardinal Scale Manufacturing Co., Webb City, MO) without shoes. Body mass was measured on a certified digital scale (Tanita B.F. 350, Tanita Corp of America Inc., Arlington Heights, IL) calibrated to the nearest 0.1 kg.

Warm Up

Before starting the specific warm up protocol, the athletes performed their normal dynamic team warm up. After this, athletes performed two 10m sled warm up sprints at a load of 100% body mass. The first trial was set at 50% of maximal effort and the second at 75% of maximal effort.

Sled Testing

Athletes performed two maximal effort 10m sled pushes at three different loads for a total of six trials. The loads were set at 75%, 100%, and 125% of the athlete’s body mass rounded to the nearest 1kg. These values were chosen based on the investigators anecdotal observations in commonly assigned training loads. Hand placement was standardized at 40% of standing height similar to Wu et al. (2007), with the superior portion of first web space between the thumb and index fingers placed at height on the loading poles. The 40% standing height body position was found to produce large peak scrummaging forces in rugby players. Elbows were flexed with the shoulders in line with the placement of the hands(Figure 1). Trials were performed in order of increasing body mass. Athletes rested passively after each trial until the sequence was restarted.

Figure 1

Body positioning on the sled

Kinematic data for completion time, peak velocity, and average velocity were collected using a Photron^{tm} Model 1280 high speed camera (Photron USA, Sand Diego, CA) located 32.1m away in a perpendicular direction from the center of the sprinting lane at a rate of 60 Hz. A marker was place on the front of the sled and tracked for the 10m distance. Displacement was tracked at 60 frames per second and exported into a time series data set. A seven point moving average was applied to the displacement data to create a velocity-time curve. Peak velocity (PV) was calculated as the highest velocity achieved during the trial. Average velocity (AV) was calculated by taking the average of velocity curve data points from the onset of movement until completing the 10m distance. A four meter reference value was used to calibrate the camera. High speed video analysis was performed using ProAnalyst software (Xcitex, Woburn, MA).

Sprint Testing

A 10 m sprint was collected one week after the sled pushing session. Athletes were given 50% and 75% of maximal effort warm up trials before performing two maximal effort 10 m sprints. Athletes used a self-selected two point stance starting from a static position before performing the sprint. Percentage drop in peak velocity was calculated by the relative change from the peak velocity obtained from the sprint to the peak velocity of the sled push at the given load. Data was collected using an Optogait analyzer (Microgate, Bolzano, Italy). Sprint testing was carried out on the same AstroTurf ® (Textile Management Associates, Inc., Dalton, GA) surface.

Statistical Analyses

A Pearson correlation matrix was generated with the mean force values, friction coefficients, and total system loads. All velocity calculations were performed using a seven point moving average to reduce noise. Peak velocity was calculated as the highest velocity achieved during the trial and average velocity was calculated from the start until completing the 10m distance. Four one-way analyses of variance (ANOVA) were used to examine between-load differences. A paired-sample t-test was used as a post hoc test to identify where statistical differences occurred. Because four ANOVAs were used, the critical alpha level was adjusted using Bonferroni adjustment from p = 0.05 to p = 0.0125 to control for an increased chance of type I error. Similarly, Bonferroni adjustment was applied to the critical alpha level of p = 0.05 for the post hoc paired sample t-tests.

Additionally, two one-way ANOVAs with a paired-sample t-test as a post hoc test were used to examine differences between sled pushing and sprinting. Bonferroni adjustment was also applied and the critical alpha level was reduced from p = 0.05 to 0.025 for the ANOVAs and to 0.0125 for the post hoc paired sample t-tests. Greenhouse-Geisser corrections were used for any variables that failed to meet the assumption of sphericity. Reliability for each variable from the high speed camera analysis was calculated using intraclass correlation coefficients. All statistical analyses for intraclass correlation coefficients, completion time, peak velocity, average velocity, and time to peak velocity were performed using SPSS (Version 21, IBM, Armonk, NY). Calculations for coefficients of variation and Cohen's *d* were calculated used Excel

(Microsoft Excel 2010, Microsoft Corporation, Redmond, WA). Variables were considered to be reliable and included for analysis having an ICC ≥ 0.70.

The strength of relationships as measured by the Pearson product-moment correlation coefficients were evaluated using the following scale: r = 0.0-0.1 (trivial); r = 0.1-0.3 (small); r = 0.3-0.5 (moderate); r = 0.5-.07 (large); r = 0.7-0.9 (very large); r = 0.9-1.0 (nearly perfect) (Hopkins, 2002). Practical importance of Cohen's *d* were evaluated using the following scale: d < 0.2 (trivial); d = 0.2-0.6 (small); d = 0.6-1.2 (moderate); d = 1.2-2.0 (large); d = 2.0-4.0 (very large) (Hopkins, 2002).

Results

All friction and force variables were found to be reliable (*ICC* = 0.961 – 0.999) between the first and second trial. An inverse relationship was observed between μ_s and μ_d with total system load. Table 1 lists descriptive data from these trials. The coefficients of friction calculated represent the interaction of the stock skis from the Prowler 2® sled and the AstroTurf® surface.

Table 3.1

Descriptive and Reliability data from Frictional Trials

	39.9kg	59.9kg	79.9kg	99.9kg	119.9kg	139.9kg
	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD
PF (N)	206.1 ± 11.7	280.9 ± 0	343.1 ± 5.87	388.8 ± 0	480.1 ± 0	505.1 ± 11.7
AF (N)	135.2 ± 2.2	191.7 ± 0.76	238.4 ± 3.9	275.1 ± 14.6	325.5 ± 16.8	386.1 ± 8.2
μ_s	0.53 ± .03 (*CV* = 5.7%)	0.48 ± 0 (*CV* = 0%)	0.44 ± 0.01 (*CV* = 1.7%)	0.4 ± 0 (*CV* = 0%)	0.41 ± 0 (*CV* = 0%)	0.37 ± 0.01 (*CV* = 2.3%)
μ_d	0.35 ± .01 (*CV* = 1.6%)	0.33 ± 0 (*CV* = 0.39%)	0.3 ± 0.01 (*CV* = 1.6%)	0.28 ± 0.01 (*CV* = 5.3%)	0.28 ± 0.01 (*CV* = 5.2%)	0.28 ± 0.01 (*CV* = 2.1%)

SD = Standard Deviation, CV = Coefficient of Variation, PF = Peak Force, AF = Average Force

Statistically significant correlations were found between system load and PF (*r* = 0.993, $p < 0.001$), AF (*r* = 0.998, $p < 0.001$), μ_s (*r* = -0.959, p = .002) and μ_d (*r* = -0.931, p = 0.007). These would be considered nearly perfect correlations according to Hopkins (Hopkins, 2002).

Statistically differences were observed between sprinting and sled pushing in PV and CT. Descriptive and reliability measures can be in table 2. Large percentage drops (40-51%) in sprinting peak velocity were observed at each sled pushing load. Drop offs of 5-10% in sled pushing PV were also observed between each relative body mass load (Table 3).

Table 3.2

Descriptive and Reliability Data from Sled Pushing and Sprinting

Sled Pushing (n=12)	ICC	Mean	SD	CV
Completion Time 75 (s)	0.88	3.17	0.36	11.30
Completion Time 100 (s)	0.96	3.39	0.37	10.78
Completion Time 125 (s)	0.94	3.74	0.43	11.61
Peak Velocity 75 ($m \cdot s^{-1}$)	0.93	4.16	0.45	10.86
Peak Velocity 100 ($m \cdot s^{-1}$))	0.97	3.74	0.41	10.84
Peak Velocity 125 ($m \cdot s^{-1}$)	0.94	3.40	0.37	10.86
Time to Peak Velocity 75 (s)	0.85	2.87	0.38	13.18
Time to Peak Velocity 100 (s)	0.77	2.88	0.48	16.61
Time to Peak Velocity 125 (s)	0.71	3.23	0.50	15.32
Average Velocity 75 ($m \cdot s^{-1}$)	0.90	3.21	0.32	9.84
Average Velocity 100 ($m \cdot s^{-1}$)	0.97	2.96	0.29	9.70
Average Velocity 125 ($m \cdot s^{-1}$)	0.94	2.68	0.28	10.39
Sprinting (n=11)	ICC	Mean	SD	CV
Completion Time (s)	0.98	01.63	0.13	8.19
Peak Velocity ($m \cdot s^{-1}$)	0.89	7.10	0.48	6.78

75 = load of 75% body mass, 100 = load of 100% body mass, 125 = load of 125% body mass, ICC = intraclass correlation coefficient, SD = standard deviation, CV = coefficient of variation

Table 3.3

Percentage Drop in Peak Velocity from Sprinting for Each Sled Load

	75% BM	100% BM	125% BM
	Mean ± SD	Mean ± SD	Mean ± SD
% PV Drop from unresisted sprint	40 ± 4	46 ± 4	51 ± 4
% PV Drop from 75% BM		10 ± 4	18 ± 5
% PV Drop from 100% BM			9 ± 3

BM = body mass, SD = standard deviation, PV = peak velocity

High speed video analysis showed statistically significant differences in completion time ($F(2,22) = 50.9$, $p < 0.001$) , peak velocity ($F(1.1,12.3) = 102.3$, $p < 0.001$), average velocity ($F(2,22) = 92.5$, $p < 0.001$), and time to peak velocity ($F(2,22) = 9.213$, $p = 0.001$) across different sled loads. Descriptive kinematic data for each sled load is listed in table 2. Moderate to large effect sizes (d = 0.64 - 1.88) were observed in all paired load differences in completion time, peak velocity, and average velocity, and time to peak velocity at 75-125% body mass and 100-125% body mass (Table 4)

Table 3.4

Differences Across Loads in Sled Push Performance (n=12)

Completion Time (s)		Mean	SD	Std. Error	CI Lower	CI Upper	df	P value (2-tailed)	Cohen's *d*
Pair 1	75 - 100	-0.23	0.2	0.06	-0.39	-0.06	11	0.002*	0.64
Pair 2	75 - 125	-0.58	0.24	0.07	-0.78	-0.43	11	< 0.001*	1.49
Pair 3	100 - 125	-0.35	0.15	0.04	-0.47	-0.24	11	< 0.001*	0.89
Peak Velocity (m·s^{-1})									
Pair 1	75 - 100	0.42	0.17	0.05	0.28	0.55	11	< 0.001*	0.98
Pair 2	75 - 125	0.76	0.25	0.07	0.56	0.97	11	< 0.001*	1.88
Pair 3	100 - 125	0.35	0.11	0.03	0.26	0.43	11	< 0.001*	0.89
Time to Peak Velocity (s)									
Pair 1	75 - 100	-0.01	0.27	0.08	-0.23	0.21	11	0.877	0.03
Pair 2	75 - 125	-0.37	0.39	0.11	-0.68	-0.05	11	0.007*	0.91
Pair 3	100 - 125	-0.35	0.34	0.1	-0.63	-0.78	11	0.004*	0.8
Average Velocity (m·s^{-1})									
Pair 1	75 - 100	0.25	0.14	0.04	0.13	0.36	11	< 0.001*	0.83
Pair 2	75 - 125	0.52	0.17	0.05	0.39	0.66	11	< 0.001*	1.79
Pair 3	100 - 125	0.28	0.08	0.02	0.21	0.34	11	< 0.001*	0.97

** Statistically significant at the adjusted α = 0.017, 75 = load of 75% body mass, 100 = load of 100% body mass, 125 = load of 125% body mass, CI = confidence interval*

Statistically significant differences were also observed in completion time (*F* (1.4, 13.8) = 280.4, *p* < 0.001) and peak velocity (*F* (1.6, 15.7) = 657.5, *p* < 0.001) when the sprint was compared with the sled loads. Large effect sizes (d = 6.98 - 9.27) were observed in all paired load differences in completion time and peak velocity (Table 5).

Table 3.5

Differences Between Sprinting and Sled Push Performances (n=11)

Completion Time (s)		Mean	SD	Std. Error Mean	CI Lower	CI Upper	df	P value (2-Tailed)	Cohen's *d*
Pair 1	0 - 75	-1.45	0.17	0.05	-1.61	-1.29	10	< 0.001*	8.5
Pair 2	0 - 100	-1.7	0.31	0.09	-1.98	-1.42	10	< 0.001*	6.98
Pair 3	0 - 125	-2.05	0.37	0.11	-2.38	-1.71	10	< 0.001*	7.24
Peak Velocity ($m \cdot s^{-1}$)									
Pair 1	0 - 75	2.85	0.37	0.11	2.51	3.19	10	< 0.001*	6.97
Pair 2	0 - 100	3.28	0.38	0.11	2.93	3.62	10	< 0.001*	8.28
Pair 3	0 - 125	3.64	0.41	0.12	3.26	4.01	10	< 0.001*	9.27

** Statistically significant at the adjusted α =0.0125, 0 = unresisted sprinting, 75 = load of 75% body mass, 100 = load of 100% body mass, 125 = load of 125% body mass, CI = confidence interval*

Discussion

Determination of Frictional Forces

The results of the frictional analysis are consistent with the previous research done by Andre et al. (2013). There is an inverse relationship for μ_s and μ_d with total system load, whereas peak and average forces increase linearly with total system load. This indicates that with increasing load on the sled, more minimal force is required by the athlete to initiate and maintain sled movement. The μ_d values for the AstroTurf® surface and sled skis (0.35 - 0.28) are consistent with that of similar data for an artificial grass 3G football pitch and a towing sled (0.35 ± 0.01) (Linthorne & Cooper, 2013). Additionally the inverse relationship between the friction coefficients observed and the total system load was consistent with the data from Andre et al. (2013), and is possibly due to deformation of the surface. The same results may not be observed for harder surfaces such as asphalt. Coefficient of variation values had a broader range than that seen in the study by Andre (1.0 – 3.7% vs 0 – 5.7%), and this is likely due to the fact that in this study the sled was dragged manually and a winch was by Andre. These values however indicate that reliable measures of friction coefficients can be achieved with only two trials per load and without the use of additional machinery.

Although the forces observed in this experiment are much lower than what has been reported in similar studies looking at maximal isometric scrummaging force ranging from about 1063 – 1370N, the values observed in the present study should be interpreted as more ‘minimal’ values of force required to move or maintain movement of the sled (Quarrie & Wilson, 2000; Wu, Chang, Wu, & Guo, 2007). The values observed do not account for additional forces because the athlete will very likely be producing higher peak and average forces at a given load when the sled is moving faster than the minimal speed to move the sled. However, this makes calculating a training load more difficult for a coach or sport scientist without knowing the actual force values involved. Although it can be done and measured precisely, the impracticality of set up, equipment needed, and complicated analysis makes it an unlikely choice for day to day training. Although speculative, because of the very high correlations ($r = 0.99$) observed between peak and average forces and total system weight, it would seem possible that the system weight itself may be the most practical measure for estimating loads with this type of training for athletes and coaches.

Therefore for estimating work and training loads two main methods are recommended:

Average force (N) x distance traveled (m) x number of repetitions = Total work (J)

Total system mass (kg) x distance traveled (m) x number of repetitions = Total work (kgm)

The first method should be used for precise measurements such as continuing scientific experimentation using a load cell, strain gauge, or similar device. The latter method should be used for day to day training purposes. Although probably not as precise, the latter method also gives comparable units to resistance training volume load (weight lifted x number of reps x number of sets), making it more universal and practical to use for coaches and sport scientists. Although the first method would account for changes in velocity, the findings from previous studies indicate that velocity only accounts for about 0.1% of the variation in frictional forces given the same distance traveled and effort, which makes a practical argument against its necessity (Linthorne & Cooper, 2013).

The ability to estimate training loads from sled pushing or similar of types of training may be may have been an underrated or overlooked part of the overall athlete training plan. Just as athletes and coaches prescribe and track variables like distance covered, rates of perceived exertion, volume loads, durations, training impulses (TRIMPs), and heart rate zones from other forms of training like weight training, practice sessions, and running sled training too should have a quantifiable prescription used for training and monitoring. This could be beneficial in not only developing a periodized annual training plan, but in the athlete fatigue management program as well as limited research has shown this type of training to be physically taxing and should not be overlooked (West et al., 2014).

Kinematics of Sled Push Resisted Sprinting

The results from the kinematic analysis indicate that with increasing relative load, there is a corresponding drop in peak and average velocities resulting in higher completion times(Table 2). From unresisted to 75% body mass, peak velocity dropped off on average about 40% and up to 51% when compared to 125% body mass. Although logical, the data show that resisted loads of 75, 100, and 125% body mass provide a statistical and practical difference from unresisted sprinting. Even between the sled loads themselves, statistical differences with moderate-to-large effect sizes (*d* = 0.64 – 1.88) were found in completion time and peak and average velocities, indicating that 25% body mass increments are both statistically and practically significant differences in loading.

The differences in the resisted and unresisted sprints also indicate large statistical and practical differences in velocity characteristics. Very large effect sizes (*d* = 6.97 – 9.27) were seen from each sled load compared to the unresisted sprint in completion time and peak velocity. These large effects sizes are largely in part due to the increase in load, however they are also likely due to biomechanical differences in technique. In the unresisted condition, the athletes were allowed to run freely with full use of arms and legs, whereas in each sled condition the athlete's arms were fixed at a low position relative to their standing height and had to push against a load.

So for sled pushing which variable should be emphasized in training, the load or the velocity? A better question might be 'which physical or performance based characteristics are we trying to improve?' Although many non-sport-specific adaptations can occur in less or non-trained athletes, well-trained athletes generally need to target specific bio-motor abilities and performance characteristics sequentially in order to maximize performance potential (Bompa, 2009). Keeping this in mind, the authors suggest that heavy sled push-style sprints be implemented for two main applications: the development of 1) speed and acceleration ability and 2) high intensity intermittent endurance (HIIE).

Though muscle strength and force producing characteristics are a vital component in developing sprint acceleration, evidence also suggests that velocity specific neurological adaptations such as improved intermuscular coordination, increased central drive, and increased rate coding also play a crucial role in enhancing transfer of training effects (Cormie, McGuigan, & Newton, 2010; Kristensen et al., 2006; McBride, Triplett-McBride, Davie, & Newton, 2002a; W. B. Young, 2006). A study by McBride et al. (2002) compared the effects of jump squats at 30% and 80% of the one repetition maximum (1RM) of the squat exercise. The results for the lighter group indicated statistically significant improvements in peak power and peak velocity during squat jumps at 30, 55, and 80% of 1RM, as well as in the 1RM itself. This group also demonstrated statistically non-significant improvements in 20m sprint times. The results for the heavy group showed statistically significant improvements in peak force and peak power in squat jumps at 55 and 80% 1RM, as well as in the 1RM itself, but also had statistically significantly slower 20m sprint times. Both groups yielded statistically significant increases in EMG from that of the control group (McBride et al., 2002a). Although the heavier jump group was able to produce more forceful jumps at heavier loads, this did not translate as effectively as the lighter group into unresisted sprinting possibly indicating velocity specific neuromuscular adaptations.

The findings from this study seem to be in agreement with previous findings suggesting a "10%" rule, however little is still known on the outcomes of various loading schemes. Loads of 20% body mass have also been found to produce statistically significantly larger ground reaction forces than an un-weighted and 10% body mass condition (Cottle et al., 2014), leading to more questions of how much is too much or too little. It would appear that assigning loads relative to body mass alone may not be the most appropriate approach, but rather using loads relative to velocity and acceleration characteristics to the sport itself may provide enhanced transfer of training effects. Future research outlining the velocities at additional loads relative to body mass may help outline loads for a variety of sporting movements.

The second proposed application to this type of training is improving high intensity intermittent exercise endurance through local metabolic factors such as hydrogen ion buffering capacity, enzyme activities, and substrate utilization. This would be most appropriate for activities consisting of large horizontal forces completed at relatively low velocities such as blocking or rushing in American football or scrummaging, rucking, and mauling in rugby (Milburn, 1993; Quarrie & Wilson, 2000; Wu, Chang, Wu, & Guo, 2007). Though no evidence currently exists on the efficacy of this type of training on HIEE, similar methods provide insight on the metabolic cost of accelerating heavy implements. One of the first studies exploring metabolic training responses looked at the effects of pushing and towing a 1960kg motor vehicle over a distance of 400m. Results indicated by the end subjects had reached about 44% of maximal oxygen consumption, 90% of maximum heart rate, and blood lactate values of 16.1 ± 1.3 mmol·L^{-1} (Berning et al., 2007).

A similar, arguably more practical approach was examined by West et al. (2014). They examined metabolic, hormonal, biomechanical, and neuromuscular responses to a backward sled drag training session. Subjects performed five sets of 2x20m maximal effort sled drags at 75% body mass blood lactate levels increased from baseline levels of 1.7 ± 0.5 mmol·L^{-1} to 12.4 ± 2.6 mmol·L^{-1} immediately following the training session and remained elevated at 60 minutes before returning to baseline after 3 hours post training. No statistical differences were seen from pre to post exercise in blood creatine kinase levels, indicating little skeletal muscle damage resulting from training. They further speculated that because of the concentric-only nature of the exercises, short lived impairment of neuromuscular function, and little damage to the muscle tissue that this type of training may elicit favorable training responses in strength-trained athletes (West et al., 2014) .

Practical Applications

The use of complex instrumentation and analyses for this type of training may not be warranted for day-to-day use. Because of the strong relationship between the load and the force required to move the sled, the use of devices such as load cells and strain gauges should be reserved for scientific investigation and not for training purposes. Additionally because of the strong relationship between completion time and peak and average velocity, measuring all of these variables might be redundant. Measuring completion time alone with a stop watch or timing system would be a sufficient form of assessment without complex instrumentation.

To calculate a training load, we suggest using:

Work (kgm) = Total system mass (kg) x Distance (m) x Number of Repetitions

Although not as precise as directly measuring force output, this approach can provide units of work comparable to traditional resistance training units of volume and can be universally and easily implemented.

Increases in loading of 25% body mass can cause significant reductions in peak velocity when performing resisted sprints. Performing a push sled resisted sprint using loads of 75-125% body mass can cause reductions in peak unresisted sprinting velocity ranging from 40-51%. Coaches and sport scientists must understand the force and velocity characteristics of the sport and determine how much drop in peak velocity is appropriate during training for a given sport or sporting movement. The use of heavier loads may be more appropriate in developing HIEE for sporting movements such as blocking and scrummaging, however velocity characteristics are likely a critical factor for the development of speed and acceleration.

Further investigation into the use of push sled sprints and their applications to HIEE are still warranted. This type of training may be more appropriate than unresisted running or sprinting to specific positions in sport like American football and rugby due to larger similarities in force and velocity characteristics.

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CHAPTER 4

INTERRELATION OF FITNESS CHARACTERISTICS AND HEAVY RESISTED SPRINTING

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Abstract

Purpose: The purpose of this investigation was to determine which fitness qualities in the areas of anthropometry, unresisted sprinting ability, jumping ability, and strength characteristics are related to performing resisted sprint tasks. A secondary purpose was to determine if strength-related differences can be observed within male University club rugby athletes. **Methods:** The athletes of this investigation were eleven male East Tennessee State University Rugby club athletes. The test battery consisted of anthropometry measurements of age (21.9 ± 2.5 years), height (177.4 ± 6.3cm) , weight (80.6 ± 12.5kg), body composition (11.1 ± 4%) , and body circumferences, a 10m sprinting test (completion time (CT0), peak velocity (PV0), and ground contact time (GCT)), vertical jumping tests (peak force (PF), peak power (PP), peak velocity (PV), jump height (JH), and net impulse), and strength characteristics (maximum isometric force, rates of force development (RFD), forces at 50, 90, 200, and 250ms, time to peak force), and 10m sled push test at 75, 10, and 125% (75, 100, 125) body mass loads (completion time (CT), time to peak velocity (TTPV), peak velocity (PV), and average velocity (AV)). Pearson product-moment correlation coefficients were used to statistically determine relationships between fitness qualities and sled pushing ability. Athletes were split into a strongest and weakest group for comparison. Independent sample t-tests were used to determine statistical differences between the strongest and weakest groups. Effect size was measured using Cohen's *d.* **Results:** Statistically significant relationships were observed between all fitness qualities. Anthropometry values of height, arm circumference, and body mass were statistically correlated with sled pushing (r = -0.64 - 0.74). Statistical relationships in sprinting completion time,

peak velocity, and ground contact time were observed with sled pushing (r = -0.69 - 0.65). Strength qualities (r = -0.79-0.73) and vertical jumping ability (r = -0.77-0.77) were also statistically related with sled pushing. Statistically non-significant differences were observed in peak velocity and peak velocity drop off between the strongest and weakest groups, however small to moderate effect sizes were observed in peak velocity at 100% body mass (*d = 0.93)*, peak velocity at 125% body mass (*d = 1.02)*, peak velocity drop off from 0 to 100% body mass (*d = 0.37)*, and peak velocity drop off from 0 to 125% body mass (*d* = 0.52). **Conclusions:** The datum indicates that strength power characteristics are highly related to resisted sprinting ability. Larger, stronger, and more powerful athletes will likely move faster and slow down less under heavy resistance. Coaches and sport scientists should consider strength and explosive qualities as training foci for athletes who must perform heavily resisted sprint movements.

Introduction

Resisted movement training, such as resisted sprinting, is thought to have a high degree of training specificity and transfer of training effects by overloading a sporting movement in such a way that cannot be achieved through normal unresisted practice of that movement (Young, 2006). This can be seen for example in track sprinters towing a sled behind them during a sprint, or with offensive lineman repeatedly hitting or driving a blocking sled. Although these and other methods may look like the activity they are seeking to improve, several key factors must first be considered for developing mechanical specificity and optimal transfer of training effects: the complexity of the movement, body position factors, range of movement and accentuated regions of force production, types of muscle actions, average and peak forces, rates of force development, acceleration and velocity parameters, and the ballistic nature of the movement (Stone et al., 2007).

One of the most common methods of this type of training has been sled towing, which appears to have a beneficial effect on sprint acceleration ability, but not necessarily maximal speed (Harrison & Bourke, 2009; Hrysomallis, 2012; Spinks et al., 2007). Along with this idea of improving specificity, velocity and technique characteristics of sprinting have also been considered, leading to the traditional ‘10%’ recommendations of resisted sprinting (Alcaraz et al., 2009; Cormie et al., 2010; Kawamori et al., 2013; Kristensen et al., 2006; Lockie et al., 2003; Spinks et al., 2007; Young, 2006). This however may not be appropriate for sports where sprints are performed against heavy resistance and technique is inherently sub-optimal due to the impediment of limbs such as American football, rugby, and sled sports such as bobsled or skeleton. This thought has led to the development of push sled training methods used to imitate sporting movements such as blocking, tackling, scrummaging, and other similar movements, where the athletes must push forward with maximal or near maximal efforts often at the expense of body position or sprint technique. Although many have examined transfer of training effects for unresisted sprinting, very little is still known about how resisted sprint training can be implemented into strength and conditioning programs, and to the authors' current knowledge no direct training studies on sled pushing currently exist.

Assigning training loads for sled and implement based training has varied considerably between studies. The most common methods are to scale the training load to achieve a predetermined percentage drop in maximal velocity or as a percentage of the athletes body mass, though others have used absolute training loads as well (Berning et al., 2007; Cottle et al., 2014; Harrison & Bourke, 2009; Kawamori et al., 2013; Keogh et al., 2010; Okkonen & Hakkinen, 2013; West et al., 2014). Although no universal definition of magnitude currently exists, based on the current literature a heavy sled load will be considered loads greater than 20% of the athletes body mass, as these have been shown to cause statistically differences in sprint technique, ground reaction forces, and percentage drop in peak velocity (Alcaraz et al., 2008; Alcaraz et al., 2009; Cottle et al., 2014; Harrison & Bourke, 2009; Kawamori et al., 2013; Keogh et al., 2010; Okkonen & Hakkinen, 2013).

Strength is one of the foundational fitness characteristics of jumping and sprinting ability (Argus, Gill, & Keogh, 2011; Chelly et al., 2010; Cormie et al., 2010; Delecluse et al., 1995; Israetel, 2013; Kraska et al., 2009; Kukolj, Ropret, Ugarkovic, & Jaric, 1999;

Lockie et al., 2011; Marques & Izquierdo, 2014; McBride et al., 2009; Smirniotou, Katsikas, Paradisis, Argeitaki, & Zacharogiann, 2008; Stone et al., 2003; Wisloff, Castagna, Helgerud, Jones, & Hoff, 2004; Young, 2006; Young et al., 1995). Although strength has also been attributed to jumping ability under resistance, there is little to no evidence identifying key fitness characteristics of performing resisted sprint tasks. It would seem logical based on the existing large body of literature supporting the development of maximal strength to improve unresisted sprint performance that strength would also be a key fitness characteristic in performing resisted sprint tasks. Therefore the purpose of this investigation is to determine which fitness characteristics in the areas of anthropometry, unresisted sprinting, jumping ability, and strength characteristics are related to performing resisted sprint tasks. A secondary purpose will be to determine if strength-related differences can be observed within male University club rugby athletes.

Methods

Experimental Approach

In order to investigate the relationships between the athletes physical qualities and sled pushing ability the athletes performed a test battery consisting of anthropometrics, a general warm up, 10m sprinting ability, vertical jumping ability, and maximal isometric strength performed in order respectively. Data collection was split into two sessions separated one week apart. The first session consisted of sled pushing and the second session consisted of the test physical qualities test battery. Correlations and were used to determine statistical relationships.

Athletes

The athletes of this investigation were 11 male East Tennessee State University Rugby club athletes. Athletes all had at least one year of Rugby playing experience. One subject injured his hand at rugby practice within the week between the two data collection sessions. This subject performed all of the tests with the exception of the isometric mid-thigh pull. Therefore an n = 12 was used for sled pushing, an n = 11 was used for anthropometrics, sprinting, and jumping and an n = 10 was used for maximal isometric strength testing. All athletes read and signed informed consent documents prior to participation in this study. This study was approved by the Institutional Review Board of East Tennessee State University.

Body Composition Anthropometry

Height was measured to the nearest 0.5cm using a digital stadiometer (Cardinal Scale Manufacturing Co., Webb City, MO) without shoes. Body mass was measured on a digital scale (Tanita B.F. 350, Tanita Corp. of America Inc., Arlington Heights, IL). Body composition was estimated via seven site skinfold technique (*ACSM's guidelines for exercise testing and prescription, 2006*) using a skinfold caliper (Lange, Beta Technology Inc., Cambridge, MD) to the nearest two millimeters. Body circumferences were measured using a measuring tape to the nearest millimeter at the calf, thigh, hip, waist, arm flexed, arm relaxed, and chest.

Warm Up

To begin the general warm up protocol athletes first performed 25 jumping jacks followed by a set of five un-weighted mid-thigh pulls with a standard 20 kg barbell

(Werksan USA, Moorestown, NJ). This was followed by three additional sets of five repetitions at 60 kg.

Sprint Testing

Athletes were given 50% and 75% of maximal effort warm up trials before performing two maximal effort unresisted 10 m sprints. Athletes used a self-selected two point stance starting from a static position before performing the sprint at a self-selected start. All trials were performed on an AstroTurf® artificial grass surface. Sprinting variables collected were ground contact time (GCT), peak velocity (PV0), and completion time (CT0). Data were collected using an Optogait analyzer (Microgate, Bolzano, Italy). Reliability for sprint variables were assessed using the intra-class correlation coefficient and the coefficient of variation.

Vertical Jump Testing

Each subject performed two maximal static (SJ) and countermovement (CMJ) jumps in an un-weighted condition (0) using a nearly weightless polyvinyl chloride pipe, then a weighted condition using a 20kg barbell (20). For each jump the barbell was placed on the neck below the seventh cervical vertebra, with hands fixed on the barbell to remove any arm swing. Two warm up jumps were performed prior to the maximal-effort jumps, the first at 50% and the last at 75% of maximal effort.

For the SJ athletes were instructed to squat down to an approximate 90° knee flexion angle, which had been previously established using a manual goniometer. This position was held for three seconds before receiving a countdown of “3, 2, 1 jump.” The same procedures were applied to the CMJ, except that the CMJ began standing upright and was performed in one continuous movement. Jumping variables collected were jump height (JH), net impulse, peak force (PF), peak velocity (PV), and peak power (PP). All jumps were performed using a dual force plate set up (two separate 45.5 cm x 91 cm) (RoughDeck HP, Rice Lake, WI) and were sampled at 1,000 Hz. All jump trials were recorded and analyzed using a program designed with LabVIEW (ver. 2010, National Instruments, Austin, TX).

Strength Testing

Strength was assessed using an isometric mid-thigh pull which was completed in a custom designed power rack with a dual force plate set up (two separate 45.5 cm x 91 cm) (RoughDeck HP, Rice Lake, WI) and sampled at 1,000 Hz. The apparatus and standard body positioning were based on previously established methods (Kraska et al., 2009). Bar heights were set for each individual subject to correspond with a knee angle of 125° ± 5° and a hip angle of 175° ± 5°. Athletes were fixed to the bar at the hands using lifting straps.

Each subject performed two warm up trials at 50% and 75% of maximal effort before performing two maximal isometric contractions with one minute of rest between trials. The athletes were instructed to “pull as fast and as hard as possible”. Trials were excluded and repeated if a visible countermovement was present. Strength variables collected were peak force (mPF), allometrically scaled peak force, peak force per kilogram body mass, time to peak force (mTtoPF), force at 50ms (mF50), force at 90ms (mF90), force at 200ms (mF200), force at 250ms (mF250), rate of force development (RFD) over 50ms (mRFD50), RFD over 90ms (mRFD90), RFD over 200ms (mRFD200), RFD over 250ms (mRFD250), and RFD over peak force (mRFDPF). The force and rate of force development values were chosen based on previous literature supporting these time windows to potentially influence the ability to accelerate an implement or body , relate to 10m sprinting ability in rugby players, having similar sprint ground contact times in rugby players, and as makers of general explosiveness (Khamoui et al., 2011; Lacey, Brughelli, McGuigan, & Hansen, 2014; Stone, Stone, & Sands, 2007; West et al., 2011). The trials were averaged and analyzed using a customized LabVIEW software (ver. 2010, National Instruments, Austin, TX) program.

Sled Testing

Sled data were collected one week prior to the physical qualities test battery. The same group of athletes performed two maximal effort 10 m sled pushes at three different loads for a total of six trials. The loads were set at 75%, 100%, and 125% of the athlete's body mass rounded to the nearest 1kg. These values were chosen based on the investigators anecdotal observations in commonly assigned training loads. Hand placement was standardized at 40% standing height similar to Wu et al. (2007), with the superior portion of first web space between the thumb and index fingers placed at height on the loading poles. The 40% standing height body position was found to produce large peak scrummaging forces in rugby players. Elbows were flexed with the shoulders in line with the placement of the hands. Trials were performed in order of increasing body mass. Athletes rested passively after each trial until the sequence was restarted. All trials were performed on an AstroTurf® artificial grass surface.

Data were collected using a Photron^{tm} Model 1280 high speed camera (Photron USA, Sand Diego, CA) located 32.1m away in a perpendicular direction from the center of the sprinting lane at a rate of 60 Hz. A four meter reference value was used to calibrate the camera. Displacement was tracked at 60 frames per second and exported into a time series data set. A seven point moving average was applied to the displacement data to create a velocity-time curve. Sled variables collected were completion time (CT), peak velocity (PV), time to peak velocity (TTPV), and average velocity (AV) each at 75% of body mass (75), 100% of body mass (100), and 125% body mass. PV was calculated as the highest velocity achieved during the trial. AV was calculated by taking the average of velocity curve data from the onset of movement until completing the 10m distance. High speed video analysis was performed using ProAnalyst software (Xcitex, Woburn, MA).

Statistical Analyses

Data collected from anthropometry, sprinting, jumping, and strength testing were correlated with the sled pushing variables a using the Pearson product moment correlation coefficient (*r*). Statistically significant correlations were reported. The strength of relationships as measured by the Pearson product-moment correlation coefficients were evaluated using the following scale: r = 0.0-0.1 (trivial); r = 0.1-0.3 (small); r = 0.3-0.5 (moderate); r = 0.5-.07 (large); r = 0.7-0.9 (very large); r = 0.9-1.0 (nearly perfect) (Hopkins, 2002).

Analyses comparing sled velocities amongst the strongest and weakest groups were also carried out. Athletes were separated into strongest (n=3) and weakest (n=3) based on maximal isometric peak force. Independent sample t-tests were used to determine differences between strong and weak groups. Intraclass correlation coefficients and coefficients of variation *(Microsoft Excel 2010, Microsoft Corporation, Redmond, WA)* were calculated to assess reliability for sled pushing, sprinting, strength, and jumping measures. Effect size of the differences were calculated by Cohen's *d* *(Microsoft Excel 2010, Microsoft Corporation, Redmond, WA)*. Practical importance of Cohen's *d* were evaluated using the following scale: $d < 0.2$ (trivial); $d = 0.2\text{-}0.6$ (small); $d = 0.6\text{-}1.2$ (moderate); $d = 1.2\text{-}2.0$ (large); $d = 2.0\text{-}4.0$ (very large) (Hopkins, 2002). All statistical analyses for reliability, anthropometry, sprinting, jumping, strength, and sled testing were performed using SPSS (Version 21, IBM, Armonk, NY). Significance was determined a priori ($\alpha < 0.05$). Variables were considered to be reliable and included for analysis having an ICC ≥ 0.70.

Results

All sled pushing and sprinting variables were found to be sufficiently reliable (ICC = 0.71-0.98). Differences were observed between sled pushing and sprinting in PV (3.40 - 7.10$\text{m}\cdot\text{s}^{-1}$) and CT (1.63 - 3.74s) and each relative body mass load (Table 4.1).

Table 4.1

Descriptive and Reliability Data from Sled Pushing and Sprinting

Sled Pushing (n=12)	ICC	Mean	SD	CV
Completion Time 75 (s)	0.88	3.17	0.36	11.30
Completion Time 100 (s)	0.96	3.39	0.37	10.78
Completion Time 125 (s)	0.94	3.74	0.43	11.61
Peak Velocity 75 ($m \cdot s^{-1}$)	0.93	4.16	0.45	10.86
Peak Velocity 100 ($m \cdot s^{-1}$))	0.97	3.74	0.41	10.84
Peak Velocity 125 ($m \cdot s^{-1}$)	0.94	3.40	0.37	10.86
Time to Peak Velocity 75 (s)	0.85	2.87	0.38	13.18
Time to Peak Velocity 100 (s)	0.77	2.88	0.48	16.61
Time to Peak Velocity 125 (s)	0.71	3.23	0.50	15.32
Average Velocity 75 ($m \cdot s^{-1}$)	0.90	3.21	0.32	9.84
Average Velocity 100 ($m \cdot s^{-1}$)	0.97	2.96	0.29	9.70
Average Velocity 125 ($m \cdot s^{-1}$)	0.94	2.68	0.28	10.39
Sprinting (n=11)	ICC	Mean	SD	CV
Completion Time (s)	0.98	1.63	0.13	8.19
Peak Velocity ($m \cdot s^{-1}$)	0.89	7.10	0.48	6.78
Ground Contact Time (s)	0.85	0.17	0.01	7.45

75 = load of 75% body mass, 100 = load of 100% body mass, 125 = load of 125% body mass, ICC = intraclass correlation coefficient, SD = standard deviation, CV = coefficient of variation

CT75 was statistically significantly correlated with PV75 ($r = -0.934$, $p < 0.001$) and AV75 ($r = -0.987$, $p < 0.001$). CT100 was statistically significantly correlated with PV100 ($r = -0.903$, $p < 0.001$) and AV100 ($r = -0.99$, $p < 0.001$). CT 125 was statistically significantly correlated with PV125 ($r = -0.765$, $p = 0.004$) and AV125 ($r = -0.988$, $p < 0.001$).

Time to peak force, RFD at 50ms, 90ms, and at peak force were found to be insufficiently reliable (ICC = 0.17 - 0.63) and were excluded from further analyses. Peak force, force at 50, 90, 200, and 250ms, and rate of force development over 200 and 250ms were found to be sufficiently reliable (ICC = 0.89 - 0.98) (Table 4.2).

Table 4.2

Descriptive and Reliability Data for Strength Measures

Strength (n = 10)	ICC	Mean	SD	CV
Peak Force (N)	0.98	4311.75	734.01	17.02
Time to Peak Force (s)*	0.2	3274.45	1280.25	39.1
Force at 50ms (N)	0.91	1411.73	336.55	23.84
Force at 90ms (N)	0.89	1874.39	531.17	28.34
Force at 200ms (N)	0.98	2931.34	698.98	23.85
Force at 250ms (N)	0.97	3275.32	700.31	21.38
Rate of Force Development over 50ms ($N{\cdot}s^{-1}$)*	0.43	4942.92	3487.72	70.56
Rate of Force Development over 90ms ($N{\cdot}s^{-1}$)*	0.63	7886.72	4477.47	56.77
Rate of Force Development over 200ms ($N{\cdot}s^{-1}$)	0.96	8833.81	2504.82	28.35
Rate of Force Development over 250ms ($N{\cdot}s^{-1}$)	0.94	8442.95	2034.02	24.09
Rate of Force Development over Peak Force ($N{\cdot}s^{-1}$)*	0.17	1211.54	930.85	76.83

**=* *Variable was excluded from further analysis, ICC = intraclass correlation coefficient, SD = standard deviation, CV = coefficient of variation*

Jump data was found to be sufficiently reliable for all variables (ICC = 0.83 – 0.99) (Table 4.3).

Table 4.3

Descriptive and Reliability Data for Vertical Jump Measures

Vertical Jump (n = 11)	ICC	Mean	SD	CV
Unloaded SJ Jump Height (m)	0.94	0.31	0.05	15.75
Loaded SJ Jump Height (m)	0.98	0.24	0.05	21.00
Unloaded CMJ Jump Height (m)	0.99	0.35	0.07	19.83
Loaded CMJ Jump Height (m)	0.98	0.26	0.05	20.24
Unloaded SJ Peak Force (N)	0.99	1882.11	323.34	17.18
Loaded SJ Peak Force (N)	0.98	1985.06	299.83	15.10
Unloaded CMJ Peak Force (N)	0.98	1985.06	284.15	14.31
Loaded CMJ Peak Force (N)	0.98	2152.33	357.33	16.60
Unloaded SJ Peak Velocity ($m \cdot s^{-1}$)	0.96	2.67	0.17	6.36
Loaded SJ Peak Velocity ($m \cdot s^{-1}$)	0.83	2.41	0.22	9.08
Unloaded CMJ Peak Velocity ($m \cdot s^{-1}$)	0.99	2.78	0.22	8.00
Loaded CMJ peak Velocity ($m \cdot s^{-1}$)	0.99	2.48	0.19	7.66
Unloaded SJ Peak Power (W)	0.99	4231.37	927.61	21.92
Loaded SJ Peak Power (W)	0.97	4153.75	926.37	22.30
Unloaded CMJ Peak Power (W)	0.99	4367.38	805.12	18.43
Loaded CMJ Peak Power (W)	0.99	4284.40	745.49	17.40
Unloaded SJ Net Impulse (N·s)	0.99	204.46	37.98	18.58
Loaded SJ Net Impulse (N·s)	0.98	222.41	43.93	19.75
Unloaded CMJ Net Impulse (N·s)	0.99	214.29	40.19	18.75
Loaded CMJ Net Impulse (N·s)	0.99	230.02	39.38	17.12

ICC = intraclass correlation coefficient, SD = standard deviation, CV = coefficient of variation, SJ = static jump, CMJ = countermovement jump

Height was found to be statistically significantly correlated to completion time at 75% (r = 0 .646, p = 0.032), time to peak velocity at 125% (r = 0.742, p = 0.009), and time to peak velocity at 75% (r = 0.702, p = 0.016). Percent drop in peak velocity from 100 to 125% was statistically significantly correlated with arm flexed (r = -0.667, p = 0.025), arm relaxed (r = -0.64, p = 0.034), and body mass (r = -0.629, p = 0.038). Age was also statistically significantly correlated with time to peak velocity at 100% (*r* = 0.611, *p* = 0.046).

Peak velocity of sprinting had statistically significant relationships with completion time at 75% (*r* = -0 .693, *p* = 0.018), peak velocity at 75% (*r* = 0 .618, *p* = 0.043), and average velocity at 75% (*r* = 0 .653, *p* = 0.029). Sprinting completion time (CT0) was statistically significantly correlated with time to peak velocity at 75% (*r* = 0 .649, *p* = 0.031). Negative statistically significant relationships (*r* = -0.615, *p* = 0.044) were seen between ground contact time (GCT) and percent drop in peak velocity from 100 to 125% body mass.

Statistically significant relationships (r = 0.61 - 0.77) between jumping and sled variables were observed. Large relationships between sled pushing and jumping peak force (r = 0.62 - 0.64) and jumping peak power (r = 0.61 - 0.65) were observed across all jumps and conditions. Large to very large relationships between sled pushing and jump height (r = -0.63 - 0.75) and jumping peak velocity (r = 0.62 - 0.77) were observed across all jumps and conditions (Table 4.4).

Table 4.4

Vertical Jumping Correlates to Sled Pushing

		SJ0JH	SJ0PF	SJ0PV	SJ0PP	SJ20JH	SJ20PV	CMJ0JH	CMJ0PV	CMJ0PP	CMJ20JH	CMJ20PF	CMJ20PV	CMJ20PP
CT75	Pearson *r*	-0.70		-0.74	-0.61	-0.63	-0.66	-0.66	-0.75	-0.63	-0.74		-0.77	-0.63
	p	0.02		0.01	0.05	0.04	0.03	0.03	0.01	0.04	0.01		0.01	0.04
TTPV75	Pearson *r*	-0.64		-0.63					-0.63		-0.67		-0.67	
	p	0.03		0.04					0.04		0.02		0.03	
AV75	Pearson *r*	0.75		0.77	0.64	0.66	0.63	0.65	0.74	0.64	0.73		0.77	0.65
	p	0.01		0.01	0.04	0.03	0.04	0.03	0.01	0.03	0.01		0.01	0.03
%PV0to75	Pearson *r*											-0.63		
	p											0.04		
CT100	Pearson *r*			-0.68										
	p			0.02										
AV100	Pearson *r*			0.65										
	p			0.03										
PV125	Pearson *r*		0.62											
	p		0.04											
AV125	Pearson *r*		0.64	0.62	0.61									
	p		0.03	0.04	0.05									
%PV0to125	Pearson *r*											-0.63		
	p											0.04		

CT = completion time, TTPV = time to peak velocity, AV = average velocity, %PV = percentage drop in peak velocity, SJ = static jump, CMJ = countermovement jump, JH = jump height, PF = peak force, PV = peak velocity, PP = peak power, 0 = unloaded condition, 20 = 20kg loaded condition, 75 = load of 75% body mass, 100 = load of 100% body mass, 125 = load of 125% body mass

Statistically significant relationships (r = 0.64 - 0.79) between sled pushing and strength variables were observed. Large relationships were observed between CT100 and rate of force development over 200 and 250ms, AV100 and force at 200 and 250ms, and AV125 and force at 50ms (r = 0.64 - 0.65). Very large relationships were observed between CT100 and force at 50, 90, 200, and 250ms, and AV100 and force at 50 and 90ms (r = -0.71 - -0.79) (Table 4.5).

Table 4.5

Strength Correlates to Sled Pushing

		CT100	AV100	AV125
Force at 50ms (N)	Pearson *r*	-0.79	0.73	0.65
	p	0.01	0.02	0.04
Force at 90ms (N)	Pearson *r*	-0.73	0.70	
	p	0.02	0.03	
Force at 200ms (N)	Pearson *r*	-0.71	0.64	
	p	0.02	0.05	
Force at 250ms (N)	Pearson *r*	-0.71	0.64	
	p	0.02	0.05	
Rate of Force Development over 200ms ($N \cdot s^{-1}$)	Pearson *r*	-0.65		
	p	0.04		
Rate of Force Development over 250ms ($N \cdot s^{-1}$)	Pearson *r*	-0.64		
	p	0.05		

CT100 = completion time at 100% body mass load, AV = average velocity at 100% body mass load, AV125 = average velocity at 125% body mass load

Independent sample t-tests determined no statistically significant differences between the strongest and weakest rugby players. Small to moderate effect sizes were observed between strongest and weakest rugby players in PV75, PV100, and PV125 (d = 0.27 - 1.02). Small effect sizes were observed in percentage drop in PV0 from 100 and 125% body mass (d = 0.37 - 0.52) (Table 4.6).

Table 4.6

Differences in Peak Velocities Amongst Strongest and Weakest Groups

	Strongest		Weakest				
	Mean	SD	Mean	SD	*p*	*d*	Observed Power
PV75	4.36	0.32	4.30	0.01	0.76	0.27	0.04
% Drop in PV0 to 75	39.33	7.51	39.33	0.58	1	0.0	
PV100	3.96	0.16	3.76	0.26	0.31	0.93	0.14
% Drop in PV0 to 100	45.0	6.25	47.0	4.58	0.68	0.37	0.05
PV125	3.65	0.09	3.36	0.39	0.28	1.02	0.16
% Drop in PV0 to 125	49.33	5.51	52.33	6.11	0.56	0.52	0.07

SD = standard deviation, PV = peak velocity, 0 = unresisted sprint condition, 75 = load of 75% body mass, 100 = load of 100% body mass, 125 = load of 125% body mass

Discussion

Correlates to Sled Push Resisted Sprinting

The first major finding of this investigation is that large statistically significant correlations were observed between the sled pushing variables and the anthropometric, sprinting, jumping, and strength testing variables. These relationships will be discussed in further detail. It should also be noted that very large statistically significant correlations (r = -0.903 to -0.990, $p < 0.001$) were observed between the velocity characteristics and completion times of all the sled loads. This would indicate that measuring peak velocity, average velocity, and completion time may be redundant, as they are all highly interrelated. Although this may appear to be common sense, this provides a more practical basis of assessment for coaches in that complex instrumentation and analysis may not provide more insight than simply measuring completion time using a stopwatch or timing gate system. Additionally it would seem logical that variables that relate to completion time therefore would also indirectly relate to velocity characteristics as well.

The strong relationships seen in the anthropometric measures individually do not imply any clear relationships. It would appear that athletes who are larger or have more body mass will possibly slow down less when sprinting under resistance, however athletes who are older and taller will possibly move slower and take longer to reach peak velocities. This could possibly be a result of the heavier players being better trained. Previous research has suggested that an optimal height range may exist for world-class caliber sprinting, and athletes who are taller or shorter (1.68-1.91m male, 1.52-1.82m female) may see respective decrements in their performance (Uth, 2005). A similar range may exist for sled pushing tasks, where athletes who are too short or tall may experience technical changes resulting in reduced stride lengths or decreased force production capabilities. The relationship between time to peak velocity at 100% body mass and age is contradictory to literature supporting age and experience as predictors of not only team selection, but also having a beneficial relationship to biomechanically similar sporting movements such as tackle attempts, tackles completed, and proportion of tackles missed (Gabbett, Jenkins, & Abernethy, 2011a; Gabbett, Jenkins, & Abernethy, 2011b). Age is also associated with physical maturation, making the observation of older rugby players generally reaching peak velocity slower seem unusual within this population of collegiate rugby players. Although time to peak velocity at 100% body mass met reliability inclusion criteria for this study, its variability (ICC = 0.77, CV = 16.61%) may have contributed to the observed relationship with age and may be excluded from future studies.

Sprinting peak velocity and completion time collectively were statistically significantly related to peak velocity, average velocity, time to peak velocity, and completion time at 75% body mass, but not to the heavier relative loads. Several studies have indicated that there may be velocity specific adaptations to sprint training (Alcaraz et al., 2009; McBride, Triplett-McBride, Davie, & Newton, 2002b; Young, 2006), and the correlations observed in this study may indicate that there may also be velocity dependent relationships between resisted and unresisted sprinting. This would indicate that unresisted sprinting ability alone may not be representative of an athlete’s ability to accelerate or resist drops in velocity against heavier loads. A statistically significantly negative relationship was observed between ground contact time, and percent drop in peak velocity from 100 to 125% body mass, possibly indicating that generating larger propulsive impulses through increased contact time may help in preventing large velocity decreases under heavy load. This is consistent with previous findings indicating that heavier loads result in increased ground contact time (Keogh et al., 2010) and larger propulsive impulses (Cottle et al., 2014). However increasing ground contact time is generally contradictory to training goals and recommendations for improving sprint accelerations in field sports by reducing ground contact times (Lockie et al., 2003). The authors speculate this observed relationship between ground contact time and percent drop in peak velocity from 100 to 125% could potentially be a result of changes in technique used to push the sled as the load increased, though this was not measured as part of the investigation.

Associations similar to previous findings on jumping and unresisted sprinting were found between jumping and resisted sprinting (Marques & Izquierdo, 2014; W.

Young et al., 1995). Jump height, peak power, and peak velocity for both unloaded and loaded static and countermovement jumps were statistically significantly correlated with completion time and average velocity at 75% body mass. For the heavier loads unloaded static jump peak velocity (SJ0PV) was only statistically significant relationship observed for average velocity and completion time at 100% body mass, and SJ0PV, SJ0PP, and SJ0PV were also statistically significantly related to average velocity at 125% body mass. Strong negative relationships were also observed in 20kg countermovement jump peak force and percent drop in peak velocity from both 0 to 75% and 0 to 125% body mass. Peak velocity and jump height regardless of jump or load appeared to be the most related variables to time to peak velocity across all sled loads.

The results of the vertical jumping relationships are similar to findings done by Israetel (2013) with NCAA Division 1 athletes. In this dissertation, Israetel found that in a sample of Women's Volleyball, Baseball, Men's Soccer, and Women's Soccer athletes the fastest sprinters have statistically significant relationships between 20m sprint times and unloaded countermovement jump height and peak power scaled to body mass (Israetel, 2013). Similarly Marques and Izquierdo found statistically significant relationships between 10m sprint time and countermovement jump peak velocity, peak force, and peak power (Marques & Izquierdo, 2014). This may indicate that the jumping variables closely related to unresisted sprinting seem to have a similar relationship to resisted sprinting as well. It would appear that athletes who are better jumpers may be better able to sprint faster under heavier resistance.

Of the strength variables measured, force at 50ms appeared to be the strongest correlate in terms of magnitude and frequency with sled pushing. Explaining 62.4, 53.3, and 42.4% of the variance in CT100, AV100, and AV125 respectively, the amount of isometric force that can be generated in 50ms appears to be an indicator of how fast an athlete will be able to sprint under resistance. Additionally forces at 50, 90, 200, and 250ms had very large correlations with CT100, and large to very large correlations with AV100 possibly indicating that athletes who can both produce large forces, and produce them rapidly are probably better able to maintain high sprint velocities under heavier resistance. The notion of a time or rate component is also supported by the large correlations observed in rate of force production over 200 and 250ms explaining 42.3 and 41% of the variance in CT100 respectively.

These findings are consistent with much of the literature supporting the importance of strength on sprinting ability Young, 2006; Young et al., 1995). Israetel (2013) also described strength characteristics and their relationship to sprinting ability in NCAA Division 1 athletes. His findings indicated that the faster sprinters were able to produce higher isometric forces per body mass and higher RFD values over 90ms than their weaker counterparts (Israetel, 2013). Other evidence has supported other dynamic measures of strength such as jumping and squatting ability and have shown strong relationships with short distance sprinting ability, indicating that strength is a vital component in developing sprint speed (Lockie et al., 2011; McBride et al., 2009; Young et al., 1995). This relationship seems to hold true when sprinting against heavy external resistance, which could relate to sporting activities such as making or breaking tackles, blocking, scrummaging, and similar movements.

Strongest vs Weakest Comparisons

Although no statistically significant differences were observed, small-to-moderate effect sizes were observed in the differences in peak velocity and peak velocity fall-off between the strongest and weakest athletes (Table 11). This data suggests that the stronger rugby players were able to move loads relative to their body mass faster and slow down less than their weaker counter parts. This comparison, along with the observed correlations to strength variables, provides a reasonable justification that training plans designed for athletes who must sprint and move against heavy resistance should look to emphasize maximal strength outcomes.

Kraska et al. (2009) investigated the relationship between strength characteristics and differences between weighted and un-weighted jumps. Their findings indicated that stronger athletes have less fall-off in vertical jump height when going from un-weighted to weighted jumps than their weaker counterparts. Additionally, statistically significant negative correlations were observed between percent decrease in SJ and CMJ jump height and isometric peak force, forces at 50ms, 90ms, and 250ms, and isometric rate of force development (Kraska et al., 2009). Their findings indicate that athletes who both produce large forces and produce them rapidly are better able to resist changes from heavier loads during jumps. Similar relationships were observed in the current study, in that the strongest athletes typically were able to achieve higher peak velocities under resistance as well as slow down less under heavy resistance. These findings combined with the results from the current study suggest that strength and power characteristics seem to be a foundational component in an athlete’s ability to perform explosive movements under external resistance.

One of the limitations of this study is having a low sample size. Although studies in sport and exercise sciences traditionally use smaller sample sizes than that of biomedical sciences, having a low sample size does limit the amount of statistical power and the number of tests that can be used for analysis. In the current study, correlations were used to determine the most powerful and statistically significant relationships between fitness qualities and sled pushing ability. However the findings do not imply that the variables reported were the most important, or that other non-statistically significant variables are not also meaningful, rather that the variables reported were the most statistically powerful in this investigation. Other tests such as factor analysis and discriminant analysis may provide deeper insight into which fitness characteristics collectively relate to sled pushing, or which fitness qualities will differentiate high and low performers. These tests were not used in this investigation due to the large pre-requisite sample sizes needed to perform these tests. Similarly the data comparing the within group differences in strength at such a sample size can realistically only be interpreted as a trend and basis for future investigation.

Practical Applications

Because velocity characteristics and completion time for this type of training are so highly inter-related, day-to-day assessment can be achieved without the use of complex instrumentation. Measuring completion time for a given distance with a stop watch may be a more practical alternative for coaches and sport scientists for most training purposes.

Although many fitness characteristics are related to the ability to sprint under heavier resistance, the results of this investigation suggest that larger, stronger, more powerful athletes will be more likely better able to move quickly under heavy load, and slow down less from unresisted to resisted conditions. Athletes who excel at jumping and sprinting tasks will be more likely better able to move at high velocities under resistance and stronger athletes will slow down less from heavier loads. For sports like American football, rugby, and bobsled where the ability to move quickly under resistance is a common characteristic of the sport, the development of both maximal strength and power are likely warranted foci within athlete training plans.

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CHAPTER 5

SUMMARY AND FUTURE INVESTIGATIONS

The purpose of this dissertation was to further describe sled push resisted sprinting for sport training in the areas of friction, work, velocity characteristics, and related physical characteristics. The findings indicate that the minimal forces required to initiate or sustain movement of the sled on an AstroTurf® surface are likely directly related with the total system weight of the sled and any additional weight added to it. For practical purposes the total system weight could possibly be used to indirectly estimate the amount of force required to perform the resisted sprint. Additionally the use of force measuring devices may not be necessary for day-to-day training purposes to calculate training loads, rather just the total system weight and the distance covered.

Sled pushing using loads of 75%-125% body mass will cause significant decreases in peak velocity when compared to sprinting. For sports and activities where this reduction is common due to increased resistance, and the technical components may not be critical factors in skill execution, sled pushing potentially could provide a unique training stimulus. For sports where sprints are highly technical and unresisted, this reduction in velocity and technique may compromise transfer of training effects. Even between the 75%, 100%, and 125% body mass loads, increments of 25% body mass are enough to cause a statistically significant drop in peak velocity.

Heavy sled pushing shares similar relationships with the physical characteristics of sprinting. Athletes who are strong, explosive, and can reach peak forces quickly are more likely to move faster under heavy loading and slow down less relative to their unresisted sprint. Thus training outcomes for sporting activities such as blocking, scrummaging, rushing, tackling, and mauling should emphasize strength and power characteristics in their respective training plans.

Though limited evidence currently exists on sled pushing, the author speculates the outcomes for sled push training should generally revolve around 1.) Development of power and short distance acceleration ability and 2.) The maintenance of power and acceleration during high intensity repeated efforts. Again keeping in mind force-velocity characteristics of the sport in mind, as this may be of benefit for an American football offensive lineman developing high intensity intermittent endurance in their blocking ability, but probably not for a basketball point guard. Future investigations should compare sled pushing with force-velocity characteristics of similar sporting movements such as blocking and scrummaging determine what degree of training specificity can be achieved. Additionally investigations on the metabolic cost of performing sled pushing in sport training might shed better insight into its role as a conditioning tool.

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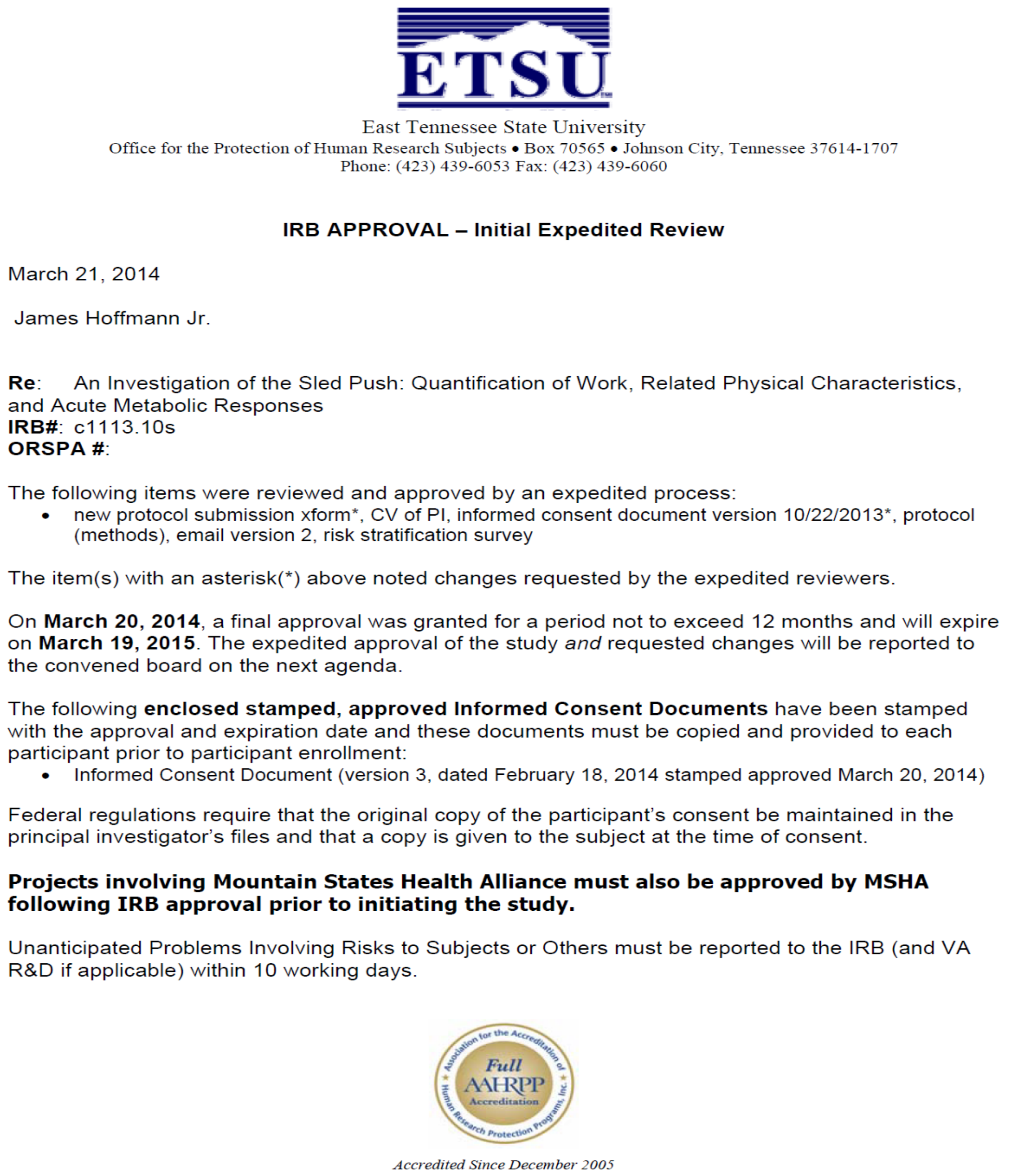
APPENDIX

ETSU Institution Review Board Approval



ETSU
East Tennessee State University
Office for the Protection of Human Research Subjects • Box 70565 • Johnson City, Tennessee 37614-1707
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IRB APPROVAL – Initial Expedited Review

March 21, 2014

James Hoffmann Jr.

Re: An Investigation of the Sled Push: Quantification of Work, Related Physical Characteristics, and Acute Metabolic Responses
IRB#: c1113.10s
ORSPA #:

The following items were reviewed and approved by an expedited process:

- new protocol submission xform*, CV of PI, informed consent document version 10/22/2013*, protocol (methods), email version 2, risk stratification survey

The item(s) with an asterisk(*) above noted changes requested by the expedited reviewers.

On **March 20, 2014**, a final approval was granted for a period not to exceed 12 months and will expire on **March 19, 2015**. The expedited approval of the study *and* requested changes will be reported to the convened board on the next agenda.

The following **enclosed stamped, approved Informed Consent Documents** have been stamped with the approval and expiration date and these documents must be copied and provided to each participant prior to participant enrollment:

- Informed Consent Document (version 3, dated February 18, 2014 stamped approved March 20, 2014)

Federal regulations require that the original copy of the participant's consent be maintained in the principal investigator's files and that a copy is given to the subject at the time of consent.

Projects involving Mountain States Health Alliance must also be approved by MSHA following IRB approval prior to initiating the study.

Unanticipated Problems Involving Risks to Subjects or Others must be reported to the IRB (and VA R&D if applicable) within 10 working days.

Association for the Accreditation of Human Research Protection Programs, Inc.
Full AAHRPP Accreditation

Accredited Since December 2005

Proposed changes in approved research cannot be initiated without IRB review and approval. The only exception to this rule is that a change can be made prior to IRB approval when necessary to eliminate apparent immediate hazards to the research subjects [21 CFR 56.108 (a)(4)]. In such a case, the IRB must be promptly informed of the change following its implementation (within 10 working days) on Form 109 (www.etsu.edu/irb). The IRB will review the change to determine that it is consistent with ensuring the subject's continued welfare.

Sincerely,
Stacey Williams, Ph.D., Vice Chair
ETSU Campus IRB

cc: William A Sands

VITA

JAMES J. HOFFMANN JR

Education:	Ph.D. Sport Physiology and Performance – Concentration in Sport Physiology, East Tennessee State University, Johnson City, Tennessee, 2014
	M.S. Applied Exercise Physiology, University of Illinois at Chicago, Chicago, Illinois, 2011
	B.S. Biochemistry, University of Illinois at Chicago, Chicago, Illinois, 2009
	Glenbard South High School, 2004
Professional Experience:	Doctoral Fellow: ETSU Weight Room Supervisor, East Tennessee State University, 2013-2014
	Graduate Assistant Sport Scientist and Strength and Conditioning Coach for ETSU Men's Golf, Tennis, Rugby, and Basketball, East Tennessee State University, 2011-2014
	Research Assistant, East Tennessee State University, 2012

Publications: Hoffmann, J. J.,Jr, Reed, J. P., Leiting, K., Chiang, C. Y., & Stone, M. H. (2014). Repeated sprints, high-intensity interval training, small-sided games: Theory and application to field sports. *International Journal of Sports Physiology and Performance, 9*(2), 352-357