LITHUANIAN SPORTS UNIVERSITY

AUSTRA SKUJYTĖ

MAXIMIZING POWER ACROSS THE RANGE OF SPRINT VELOCITIES: AN INDIVIDUALISED APPROACH TO ASSISTED SPRINT TRAINING

Doctoral Dissertation

Natural Sciences, Biology (01 B), Physiology (B 470)

Kaunas 2026

This doctoral dissertation was prepared at the Institute of Sport Science and Innovations, Lithuanian Sports University, during the period 2021–2025, in accordance with the Regulations of Doctoral Studies in the Field of Biology at Lithuanian Sports University, with the participation of the University of Tartu (Estonia).

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The doctoral thesis will be defended in the public meeting of the Committee of Biology at 2 p.m. on September 29, 2026, in 218 auditorium of the Lithuanian sports university.
Address: Sporto str. 6, LT-44221 Kaunas, Lietuva.

The dissertation is available at the library of the Lithuanian Sports University.
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LIETUVOS SPORTO UNIVERSITETAS

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GALINGUMO DIDINIMAS ĮVAIRIUOSE SPRINTO GREIČIO DIAPAZONUOSE: INDIVIDUALIZACIJA TAIKANT BĖGIMĄ SU UŽTEMPIMU

Daktaro disertacija

Gamtos mokslai, biologija (01 B), fiziologija (B 470)

Kaunas 2026

Disertacija rengta 2021–2025 metais Lietuvos sporto universiteto Sporto mokslo ir inovacijų institute pagal Lietuvos sporto universiteto dalyvaujant Tartu universitetui biologijos mokslo krypties doktorantūros reglamentą.

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Daktaro disertacija bus ginama atvirame Lietuvos sporto universiteto dalyvaujant Tartu universitetui Gynimo tarybos posėdyje.
Disertacijos gynimo data – 2026 m. rugsėjo 29 d. 14 val. Lietuvos sporto universiteto 218 aud.
Adresas: Sporto g. 6, LT-44221 Kaunas, Lietuva.
Disertaciją galima rasti Lietuvos sporto universiteto bibliotekoje.
Adresas: Sporto 6, LT-44221 Kaunas, Lietuva.

CONTENTS

DEFINITIONS

Sprinting – a high-intensity, short-duration running activity characterized by maximal or near-maximal effort. It is a fundamental component of many sports, requiring rapid acceleration, high maximal velocity, and efficient neuromuscular coordination.

Acceleration Phase – the initial phase of sprinting where the athlete increases velocity from a stationary or low-speed position. It is characterized by longer ground contact times, a pronounced forward lean, and high horizontal force application.

Maximal Velocity Phase – the phase of sprinting during which the athlete reaches and maintains their top speed before deceleration occurs. This phase relies on extremely short ground contact times and high vertical stiffness.

Ground Contact Time – the duration (in seconds or milliseconds) that the foot remains in contact with the ground during each step. Shorter contact times are associated with higher sprinting velocities and efficient force production.

Flight Time – the duration of the airborne phase between consecutive ground contacts. Longer flight times combined with shorter contact times are characteristic of high-speed sprinting.

Stride Length – the horizontal distance covered between successive contacts of the same foot. Stride length reflects the effectiveness of horizontal propulsion and is influenced by force production, mechanics, and limb length.

Stride Frequency – the number of steps taken per second. Stride frequency, in combination with stride length, determines overall sprint velocity.

Force-Velocity Relationship – a biomechanical relationship describing how the maximal horizontal force an athlete can produce decreases as sprinting velocity increases. This relationship provides insights into whether an athlete is force- or velocity-deficient.

Theoretical Maximal Force – the estimated maximal horizontal force an athlete can produce at zero velocity, representing the force capabilities at sprint initiation.

Theoretical Maximal Velocity – the estimated maximal sprinting velocity at which horizontal force production theoretically drops to zero. It reflects the athlete's velocity-oriented capabilities.

Maximal Power Output – the peak mechanical power an athlete can generate, calculated as the product of force and velocity. It represents the optimal combination of force and velocity during sprinting.

Maximal Ratio of Force – the highest ratio of horizontal to resultant ground reaction force during the sprint, indicating how effectively the athlete directs force horizontally at the start of sprinting.

Rate of Decrease in Ratio of Force – the rate at which horizontal force application declines as sprinting velocity increases. A lower rate of decrease in ratio of force reflects the athlete's ability to maintain horizontal force at higher velocities.

Force-Velocity Slope – the slope of the Force-Velocity relationship, representing the balance between force and velocity capacities. A steep negative slope indicates a force-dominant profile, while a flatter slope indicates a velocity-dominant profile.

Resisted Sprint Training – a sprint training method in which external resistance is applied to increase horizontal force production, emphasizing improvements in the acceleration phase.

Assisted Sprint Training – a sprint training method in which external assistance is provided to tow the athlete to supramaximal speeds, emphasizing improvements at the velocity end of the Force-Velocity spectrum.

Supramaximal Speed – running speeds that exceed the athlete's unassisted maximal sprinting velocity, typically achieved through assisted sprint training.

ABBREVIATIONS

AST	Assisted Sprint Training
CI	Confidence Interval
CoM	Center of Mass
CT	Ground Contact Time
CV	Coefficient of Variation
DF	Duty Factor
DRF	Rate of Decrease in Ratio of Force
EMG	Electromyography
F_0	Theoretical Maximal Force
F-V	Force-Velocity
FT	Flight Time
ICC	Intraclass Correlation Coefficient
IMU	Inertial Measurement Unit
MDC	Minimal Detectable Change
Pmax	Maximal Power Output
RFmax	Maximal Ratio of Force
RST	Resisted Sprint Training
SD	Standard Deviation
SEM	Standard Error of the Mean
SF	Stride Frequency
SL	Stride Length
V_0	Theoretical Maximal Velocity

INTRODUCTION

Sprint performance is a key determinant of success in many sports. In track and field, sprinting forms the foundation of events such as the 100-m dash, hurdles, and long jump, where maximal speed and efficient sprint mechanics are essential for competitive excellence. In team sports like football, rugby, and basketball, short bursts of acceleration and the ability to reach top speed quickly often decide game outcomes. A single sprint can determine whether a football player reaches the ball before an opponent, whether a winger breaks through defensive lines, or whether a striker converts a scoring opportunity. The capacity to generate high sprint velocities and maintain them over short distances is therefore a fundamental quality for athletes across diverse sporting contexts (Gualtieri et al., 2023; Lockie et al., 2012).

Achieving world-class sprint performance requires the coordinated development of multiple physical and technical capacities. Sprinting involves rapid production and application of force in very short ground contact times, precise coordination between limbs, and the ability to sustain maximal outputs while minimizing fatigue and injury risk (Morin & Samozino, 2016; Moura et al., 2023; Pietraszewski et al., 2025; Thompson, 2017). The mechanical determinants of sprinting can be broadly divided into force-oriented qualities, which are most evident during the acceleration phase, and velocity-oriented qualities, which dominate during maximal velocity running. Athletes who can generate high horizontal forces at the start, as well as high limb velocities later in the sprint, are typically the most successful. However, individual athletes often display specific strengths or weaknesses along this force-velocity (F-V) spectrum, leading to the need for targeted and individualized training strategies (Buchheit et al., 2014; Morin et al., 2012; Nagahara et al., 2018a; Samozino et al., 2016).

Traditional sprint training methods aim to improve both ends of the F-V spectrum. Resisted sprint training (RST), such as sled towing or uphill running, increases external load to develop force production and horizontal impulse (Alcaraz et al., 2018; Cahill et al., 2020; Dougan et al., 2025; Stavridis et al., 2023). Assisted sprint training (AST), such as downhill running or towing devices, reduces external resistance or actively pulls the athlete forward to achieve supramaximal speeds, thereby stimulating adaptations associated with limb turnover and maximal velocity mechanics (Cecília-Gallego et al., 2022; Gleadhill et al., 2023; Lahti et al., 2020; Myrvang & Van den Tillaar, 2024; Ross et al., 2001). Both approaches have been shown to be effective in specific contexts. Resisted sprinting enhances the early acceleration phase by increasing projection angles and force application, whereas assisted sprinting allows athletes to experience speeds beyond their usual limits, challenging the neuromuscular system to adapt to extremely short ground contact times and faster stride frequencies. When used together, these methods can complement each other, creating a balanced approach to sprint development (Lahti et al., 2020; Myrvang & Van den Tillaar, 2024).

Despite their potential, several challenges remain. Traditional sleds and elastic cords provide resistance or assistance but lack precise control. Environmental factors such as friction, slope, and surface type affect loading, making it difficult to replicate conditions or measure exact outputs (Cross et al., 2019; Cross, Tinwala, et al., 2017; Petrakos et al., 2016; Van den Tillaar, 2020). As a result, training loads are often estimated rather than precisely individualized, limiting both performance improvements and the ability to track progress over time.

The concept of F-V profiling offers a framework for understanding and targeting sprint performance. By plotting an athlete's theoretical maximal horizontal force (F_0) against maximal velocity (V_0), coaches and scientists can identify whether an athlete is force-dominant, velocity-dominant, or balanced. This profile provides insight into which qualities should be emphasized in training (Fernández-Galván et al., 2022; Morin et al., 2019). Force-dominant athletes may excel in the initial 5–10 m but struggle to reach top speed, velocity-dominant athletes may achieve high maximal velocities but lack the explosive force needed for quick starts, while balanced athletes possess a more optimal profile and typically show superior sprint performance across phases (Baena-Raya et al., 2021; Haugen, Breitschädel, et al., 2019; Morin & Samozino, 2016; Samozino et al., 2022).

Previous studies have shown that F-V profiling can guide training decisions. For example, athletes with a force deficit may benefit most from resisted sprint training, while those with a velocity deficit may respond better to assisted sprinting (Cross et al., 2018; Lahti et al., 2020). However, research by Rakovic et al. (2018) and Lahti et al. (2020) suggests that individual responsiveness is variable, and not all athletes improve in predictable ways (Lahti et al., 2020; Rakovic et al., 2018). This variability highlights a crucial gap: the need to refine our ability to predict who will benefit most from each type of sprint training. Adding spatiotemporal measures, such as stride length, stride frequency, ground contact time, and speed maintenance, may improve these predictions (Meng et al., 2024; Murata et al., 2018). In particular, assisted sprints, which achieve higher peak velocities, might reveal aspects of performance not visible in regular sprints, potentially offering more precise diagnostic insights.

Recent technological advancements have addressed many of the limitations of traditional sprint tools. Motorized sprint devices, such as the Sprint 1080 and DynaSpeed, enable precise control of both resistance and assistance. (Chang et al., 2024; Cross et al., 2018; Jiménez-Reyes et al., 2024; Matusiński et al., 2022). They maintain consistent loading independent of environmental factors and provide real-time measurements of force, velocity, distance, and power (Haugen, McGhie, et al., 2019; Lahti et al., 2020). These systems have revolutionized both training and research by allowing coaches to apply individualized programs while simultaneously collecting high-quality performance data. However, many existing systems are expensive and limited to specific settings. The development of portable, versatile solutions has become increasingly important for field-based testing in team sports and for organizations with limited resources.

The Alex7 device, developed in Lithuania, represents one such innovation. While similar to established systems in functionality, Alex7 was designed with an emphasis on portability and accessibility, enabling its use in both elite and grassroots environments. Importantly, it provides both full and partial assistance modes, offering opportunities to explore novel training concepts, such as releasing assistance mid-sprint to preserve natural mechanics. Although the device plays a central role in this dissertation, its inclusion serves a broader purpose: demonstrating how cutting-edge technology can help maximize power across the range of velocities through individualized sprint interventions.

Despite these technological advances, several important gaps remain in the current scientific understanding of sprint performance enhancement. Validation studies of portable motorized devices are still limited, and the accuracy and reliability of newer systems such as the Alex7 must be established before they can be confidently implemented in training or research settings. Furthermore, while full towing has been studied extensively, partial towing, where assistance is released once a target speed is reached, has not been systematically investigated. This approach may help preserve muscle engagement and movement control while still providing exposure to supramaximal velocities, potentially leading to superior neuromuscular adaptations.

In addition, the underlying neuromuscular mechanisms of assisted sprinting remain poorly understood. Few studies have examined how muscle activation patterns and coordination strategies change under different towing conditions (Cecília-Gallego et al., 2022; Mero & Komi, 1987). Finally, although force-velocity profiling is widely used to individualize training, its predictive power could be enhanced by incorporating spatiotemporal and kinematic variables. Such an integrated approach could help coaches better identify individual performance limitations and design more targeted sprint training programs.

Addressing these gaps is essential for bridging the divide between science and practice. A clearer understanding of towing strategies, neuromuscular responses, and predictive profiling tools will provide coaches and practitioners with evidence-based methods to maximize sprint performance while minimizing injury risk.

The aim of this dissertation is to investigate whether individualized assisted sprint training strategies can promote greater neuromuscular adaptations and improve sprint performance across the force-velocity spectrum.

Research Objectives

1. To validate and assess the reliability of a novel motorized device for measuring sprint performance under resisted and assisted conditions.
2. To investigate the acute neuromuscular and mechanical effects of full versus partial towing assistance on muscle activation and sprint kinematics.
3. To evaluate the effects of a six-week assisted sprint training intervention on sprint performance, spatiotemporal variables, and F-V profiles measured during regular sprints in youth football players, and to examine whether baseline variables from these conditions can predict individual responsiveness to training.

Hypotheses

1. The motorized device will provide valid and reliable measurements of sprint performance when compared to a gold-standard reference system.
2. Partial towing assistance will result in greater muscle activation and higher power output compared to full towing at similar supramaximal speeds.
3. Combining spatiotemporal parameters with F-V profiles will enhance the ability to predict which athletes will show the greatest performance improvements following assisted sprint training.

Theoretical and Practical Significance

The present dissertation advances sprint science by providing novel insights into both measurement and training. Theoretically, it establishes a validated, portable motorized device for resisted and assisted sprinting and introduces the first electromyography-based comparison of full and partial towing strategies. It also expands the application of force-velocity profiling to include supramaximal sprinting, integrating spatiotemporal and neuromuscular data to refine our understanding of how different mechanical strategies influence sprint performance and power development.

Practically, these findings translate directly into actionable strategies for coaches and practitioners. The research provides evidence-based methods for precisely monitoring sprint performance, safely exposing athletes to supramaximal speeds using partial assistance, and designing individualized training programs based on F-V and spatiotemporal profiles. This approach supports the optimization of power across the entire velocity spectrum, enhances performance outcomes, and reduces injury risk, ultimately contributing to sustainable athlete development and long-term success in sport.

1. LITERATURE REVIEW

1.1. Introduction to sprint training

Beyond raw speed, the ability to accelerate rapidly and maintain high velocities for short bursts plays a pivotal role in tactical performance. In football, even a fraction of a second gained during a 5–10 m acceleration can determine ball possession or scoring opportunities. Research has consistently demonstrated that sprint ability, especially over distances up to 30 m, is a key predictor of elite performance in team sports, where game-defining moments often occur in constrained spaces (Caldbeck & Dos'Santos, 2022; Lockie et al., 2012; Nagahara et al., 2018a; Nicholson et al., 2020).

Over recent decades, scientific interest in sprint performance has expanded significantly. Advances in biomechanics, physiology, and technology have deepened our understanding of sprinting as a complex neuromuscular task. Sprinting requires athletes to generate extremely high forces and apply them effectively within very short ground contact times (Lockie et al., 2011). Key performance variables such as force, velocity, stride length (SL), stride frequency (SF), contact time (CT), and flight time (FT) are now routinely measured to evaluate sprint mechanics and training adaptations (Howard et al., 2018; Mattes et al., 2014; Morin & Samozino, 2016).

Modern sprint research also emphasizes the role of neuromuscular factors in determining sprint performance. Electromyography (EMG) studies have revealed the timing and intensity of muscle activation patterns during sprinting, providing insights into how muscles coordinate to achieve efficient acceleration and maximal velocity running (Jacobs & Schenau, 1992; Kyröläinen et al., 2005; Pietraszewski et al., 2025; Van Den Tillaar & Gamble, 2017; Yu et al., 2008). These findings have informed training interventions designed to target specific neuromuscular and biomechanical qualities.

As sprinting is a high-intensity activity with significant demands on both force production and velocity expression, contemporary training approaches are built around manipulating external load to stimulate adaptations at different points on the force-velocity spectrum. Two primary strategies dominate this spectrum: resisted sprint training and assisted sprint training (Dougan et al., 2025; Lockie et al., 2012; Myrvang & Van den Tillaar, 2024; Ross et al., 2001).

Resisted sprinting, which adds external horizontal load via sleds, weighted vests, or motorized devices, focuses on improving acceleration by enhancing horizontal force production (Alcaraz et al., 2018; Cusano et al., 2025; Dougan et al., 2025; Morin et al., 2017; Petrakos et al., 2016; Stavridis et al., 2023; Xu et al., 2025). Assisted sprinting, in which the athlete is towed or propelled to supramaximal velocities, targets the velocity end of the spectrum, challenging the neuromuscular system to achieve higher step frequencies and reduced ground contact times (Cecília-Gallego et al., 2022; Chang et al., 2024; Clark et al., 2021; Rumpf et al., 2016; Van Den Tillaar & Gamble, 2018). Both methods have been shown to induce specific neural and muscular adaptations, making them valuable but highly specialized tools in sprint development (Aldrich et al., 2024; Mero & Komi, 1987; Morin et al., 2019). Their effectiveness depends on precise control of loading and careful integration into periodized training plans. Historically, traditional modalities such as sled towing or downhill running were difficult to standardize, leading to inconsistent results (Chang et al., 2024; Matusiński et al., 2021). However, recent technological advances have introduced motorized sprint devices, such as the Sprint 1080 and DynaSpeed, which allow coaches to apply controlled, repeatable resistance or assistance while simultaneously capturing kinematic and kinetic data (Haugen, McGhie, et al., 2019; Lahti et al., 2020; Matusiński et al., 2022).

The emergence of these systems has also transformed research possibilities, enabling real-time measurement of variables such as force, velocity, and power under field conditions. This has allowed researchers to move beyond descriptive studies and into individualized, data-driven sprint training models (Haugen, Breitschädel, et al., 2019; Lahti et al., 2020). By identifying whether an athlete is more force-deficient or velocity-deficient, practitioners can target specific performance limitations through tailored resisted or assisted sprint protocols (Cross, Brughelli, Samozino, & Morin, 2017; Lahti et al., 2020; Morin & Samozino, 2016; Samozino et al., 2008).

Despite these advances, significant questions remain. For instance, while resisted sprinting has been well-studied, assisted sprinting, particularly with partial towing protocols, where assistance is released once a target velocity is reached, has received far less attention. Understanding how different towing strategies influence muscle activation, limb coordination, and injury risk remains a critical gap in the literature (Clark et al., 2021; Nagahara et al., 2018a; Van Den Tillaar, 2021). Similarly, while force-velocity profiling has become an essential diagnostic tool, there is still limited knowledge on how initial F-V characteristics and technical variables predict responsiveness to specific sprint training interventions (Lahti et al., 2020; Rakovic et al., 2018).

1.2. Sprint mechanics

Sprinting is a highly complex motor skill requiring precise coordination between the neuromuscular system and the mechanical forces acting on the body. Performance in sprinting can be understood as the interaction between external mechanics (force application, kinematics, and kinetics) and internal neuromuscular factors (muscle activation patterns, neural drive, and coordination) (Haugen, McGhie, et al., 2019; Vellucci & Beaudette, 2023; Whitacre et al., 2024). These elements are expressed through two primary sprint phases: acceleration and maximal velocity, each with distinct biomechanical and physiological demands (Morin & Samozino, 2016; Nagahara et al., 2018a).

Understanding these phases in detail is essential for designing targeted training interventions and for interpreting the effects of different loading strategies such as resisted and assisted sprinting. This section examines the mechanical and neuromuscular characteristics of sprinting, with a focus on the lower-limb muscle activation patterns underpinning each phase.

1.2.1. The acceleration phase

The acceleration phase begins at the sprint start and continues until the athlete approaches near-maximal velocity. In elite track sprinters, this phase typically extends to 30–50 meters, lasting approximately 4–6 seconds, while in team sports such as football or rugby, the decisive sprint efforts often occur within the first 5–20 meters due to spatial and tactical constraints (Morin & Samozino, 2016; Nagahara et al., 2018a). Regardless of the total sprint distance, early acceleration performance is crucial because it determines whether an athlete reaches a high velocity quickly enough to influence competitive situations (Colyer et al., 2018; Lockie et al., 2012; Moura et al., 2023).

Acceleration requires the athlete to generate large horizontal propulsive forces and maintain an optimal forward body lean to project force effectively against the ground (Kawamori et al., 2013; Morin et al., 2015; Morin et al., 2019). From a practical perspective, this phase is strongly influenced by maximal horizontal force capacity, which represents the athlete's ability to generate high propulsive impulses during the initial steps (Pantoja et al., 2018).

Early acceleration is marked by a pronounced forward trunk lean and lowered center of mass (CoM) to maximize horizontal force projection, longer ground contact times, initially >200 ms, which progressively shorten to approximately 120–140 ms as velocity increases and rapid increases in step length and step frequency, with step length improving most during the first 10 meters and step frequency increasing later as posture becomes more upright (Flanagan et al., 2025; Moura et al., 2023; Nagahara et al., 2018b; Walker et al., 2021).

Nagahara et al. (2018) demonstrated through step-by-step analysis that during the initial strides, back-side mechanics dominate, characterized by powerful hip extension behind the body (Nagahara et al., 2014, 2018a). As the athlete transitions toward upright running, mechanics shift toward front-side dominance, with quicker thigh lift and faster repositioning in front of the CoM (Nagahara et al., 2014).

From a kinetic perspective, the key determinant of acceleration is the ratio of horizontal to total ground reaction force (RF). During the first steps, RF is at its highest, reflecting a strong horizontal force orientation. As velocity builds, RF steadily decreases, a process quantified by the rate of decrease in RF (DRF) (King et al., 2022; Morin et al., 2011; Morin et al., 2012, 2019). This means that the earliest steps are most critical for propulsive impulse generation. Nagahara et al. (2018) confirmed that horizontal propulsive impulse was the strongest predictor of acceleration performance between ~ 55–95 % of maximal sprint speed (Nagahara et al., 2018a). As speed increases, braking impulse becomes more relevant, requiring precise technical execution to minimize energy loss.

Hip extensors (gluteus maximus, hamstrings) generate large concentric forces during early stance to drive propulsion and maintain trunk alignment (Edouard et al., 2018; Morin et al., 2015; Pandy et al., 2021). Knee extensors (quadriceps) resist braking forces at touchdown and extend the knee during push-off (Hamner et al., 2010; Pandy et al., 2021). Ankle plantar flexors (soleus, gastrocnemius) progressively contribute more to propulsion as velocity rises, benefiting from elastic energy storage and release in the Achilles tendon (Pandy et al., 2021; Schache et al., 2019).

Electromyography provides insights into the temporal sequencing and magnitude of muscle activation during acceleration. The gluteus maximus shows sustained, high activation during early stance to drive hip extension and maintain trunk stability (Pandy et al., 2021). The hamstrings are eccentrically active in late swing to decelerate the forward-moving thigh and concentrically active in early stance to extend the hip and generate propulsion (Higashihara et al., 2018; Pietraszewski et al., 2025; Willer et al., 2024). The vastus lateralis and rectus femoris are highly active during early stance, especially during the braking-to-propulsion transition (Bezodis et al., 2008; Pandy et al., 2021). The rectus femoris shows a biphasic pattern, contributing to hip flexion during early swing and knee extension during stance (Pandy et al., 2021). The soleus demonstrates prolonged activation supporting force output during extended ground contacts, while the gastrocnemius assists in propulsion and stabilizes the knee joint (Pandy et al., 2021).

Muscles such as the erector spinae and obliques help maintain alignment and manage rotational forces, while the arms counterbalance leg movement and assist in momentum generation (Hamner & Delp, 2013; Kubo et al., 2010; Yoshimoto et al., 2025). These activation patterns suggest that upper-body actions can shift the balance between force magnitude and the rate of force production (Macadam et al., 2019).

1.2.2. The maximal velocity phase

The maximal velocity phase begins once the athlete reaches peak sprinting speed and continues until deceleration due to fatigue or mechanical breakdown. In elite sprinters, maximal velocity is usually achieved between 50 and 60 meters and sustained for one to two seconds (Healy et al., 2019; Nagahara et al., 2018a).

In most team sports, however, sprints are too short for this phase to be fully realized. Nonetheless, the capacity to reach high top speeds provides a critical competitive advantage, especially in open-field situations such as breakaways or counterattacks (Gualtieri et al., 2023).

At maximal velocity the athlete adopts a tall, upright posture with minimal vertical oscillation of the CoM, ground contact times become extremely short, often 80–90 ms, limiting the window for force application, step frequency peaks, while step length stabilizes relative to late acceleration and efficient front-side mechanics dominate, with rapid thigh recovery and compact heel movement to minimize limb inertia. The foot strikes the ground directly under or slightly behind the CoM, reducing braking forces and allowing immediate transition to propulsion (Čoh et al., 2018; Nagahara et al., 2018a; Walker et al., 2021).

Because ground contact time is so short, maximal velocity sprinting relies more on rapid force application rather than absolute force magnitude. Vertical mean force becomes the most important predictor of speed (Nagahara et al., 2018a). The spring – mass model explains this phase: the ankle-achilles complex acts like a stiff spring, storing and releasing large amounts of elastic energy (Pandy et al., 2021). Leg stiffness and vertical stiffness are critical for maintaining rebound and minimizing energy loss between steps (Nagahara & Zushi, 2017). The plantar flexors, particularly the soleus, must pre-activate before touchdown to regulate stiffness and absorb high impact forces within a fraction of a second (Struzik et al., 2021).

At top speed, EMG studies reveal that the hamstrings are the most highly activated muscles, peaking eccentrically in late swing to decelerate the limb and prevent overextension. Activity often exceeds 100 % of maximal voluntary isometric contraction (Hegyi et al., 2019; McNally et al., 2023; Morin et al., 2019). This phase represents the greatest hamstring injury risk due to the combination of high stretch and high force (Chumanov et al., 2011; Chumanov et al., 2007). The gluteus maximus produces a short, powerful burst during early stance to maintain hip extension and posture stability (Pietraszewski et al., 2025; Yamaguchi et al., 2025). The rectus femoris and other quadriceps are briefly active in early stance to stabilize the knee and resist braking forces (Yamaguchi et al., 2025). The soleus and gastrocnemius show significant pre-activation prior to ground contact, which is essential for regulating leg stiffness and enabling rapid elastic rebound (Williams et al., 2025). The hip flexors drive rapid thigh recovery, which is critical for maintaining step frequency and front-side mechanics (Yamaguchi et al., 2025). The shift from prolonged activation in acceleration to rapid, high-intensity bursts in maximal velocity reflects the transition from a force-dominant to a velocity-dominant neuromuscular strategy (Higashihara et al., 2018; Pietraszewski et al., 2025).

Maximal velocity performance depends on high theoretical maximal velocity, exceptional neural drive and motor unit synchronization, effective use of elastic energy, and efficient inter- and intramuscular coordination (Morin et al., 2012; Morin & Samozino, 2016). Errors such as over-striding, excessive anterior foot placement, or insufficient ankle stiffness increase braking forces and reduce efficiency (Lieberman et al., 2015; Paradisis et al., 2019). Fatigue, especially in the hamstrings and plantar flexors, is a common limiting factor during repeated maximal sprinting bouts (Pimenta et al., 2024; Vial et al., 2023).

1.3. Training interventions

1.3.1. Introduction to sprint-specific secondary methods

Primary sprint training, which includes maximal sprint repetitions, technical drills, and strength and conditioning work, remains the cornerstone of speed development. However, to target specific neuromuscular and mechanical qualities, secondary sprint methods are used to manipulate external load during sprinting. These include resisted sprint training and assisted sprint training, which occupy opposite ends of the force-velocity spectrum (Alcaraz et al., 2018; Cross et al., 2018; Hicks et al., 2023; Jiménez-Reyes et al., 2024; Lahti et al., 2020; Morin & Samozino, 2016).

RST emphasizes the force end of the spectrum by adding external resistance, promoting improvements in horizontal force production and early acceleration. In contrast, AST focuses on the velocity end, enabling athletes to run at supramaximal speeds that cannot be achieved unassisted, challenging stride frequency and neuromuscular coordination (Chang et al., 2024; Lahti et al., 2020; Myrvang & Van den Tillaar, 2024; Ross et al., 2001).

When carefully integrated into a periodized program, these methods complement one another and provide a comprehensive stimulus for sprint performance. RST builds the foundation for powerful acceleration, while AST enhances maximal velocity capabilities and neuromuscular efficiency. Together, they help athletes maximize overall sprint potential (Dougan et al., 2025; Myrvang & Van den Tillaar, 2024; Nagahara et al., 2018a; Van Den Tillaar, 2018).

1.3.2. Resisted sprint training

Resisted sprint training is a method designed to overload the acceleration phase of sprinting by adding external resistance during sprint efforts. This approach is grounded in Newton's second law of motion, where increasing external load requires greater horizontal ground reaction forces to accelerate the body forward (Kawamori et al., 2014; Morin & Samozino, 2016; Samozino et al., 2016). By applying resistance, RST enhances an athlete's ability to produce and orient force horizontally, which is especially important in the initial steps of a sprint (Nagahara et al., 2018a; Pantoja et al., 2018; Sašek et al., 2024).

In team sports such as football and rugby, athletes rarely reach maximal sprint velocity, making acceleration performance particularly relevant for match situations. RST directly addresses this demand by improving the capacity to generate explosive horizontal impulses during the first 5–10 meters (Espasa et al., 2025; Lockie et al., 2012; Petrakos et al., 2016).

Traditional RST modalities include sled towing, weighted vests, parachutes, and uphill running. While these tools are widely used, they are often influenced by environmental factors such as surface friction or slope, making precise load standardization challenging (Alcaraz et al., 2018; Petrakos et al., 2016; Van Den Tillaar, 2020). This limitation has led to the growing use of motorized resistance systems such as the Sprint 1080, DynaSpeed, and Alex7, which deliver controlled resistance independent of velocity and surface conditions (Cusano et al., 2025; Lahti et al., 2020; Myrvang & Van den Tillaar, 2024).

When sprinting under resistance, running velocity decreases, and athletes adapt their technique to overcome the added horizontal load. The magnitude of these adaptations depends on the intensity of resistance applied, typically expressed as a percentage velocity decrement relative to unresisted sprint speed (Cross, Brughelli, Samozino, Brown, et al., 2017; Osterwald et al., 2021). Key kinematic changes include increased ground contact time, especially in the initial steps, allowing for greater impulse production, decreased stride frequency and stride length with more pronounced effects at higher load (Cahill et al., 2020; Lahti et al., 2020; Lockie et al., 2003; Pareja-Blanco et al., 2020), increased forward trunk lean and a lower center of mass to maintain a horizontal projection angle of force and earlier, more forceful hip extension during stance to orient the ground reaction force vector backward (Osterwald et al., 2021).

At the joint and muscle activation level, resisted sprinting mainly alters loading and activation balance rather than creating entirely new roles. Ankle plantar flexors and hip extensors are considered the primary contributors to propulsion during acceleration sprinting, whereas knee extensors mainly provide support and braking functions. The soleus primarily contributes to vertical support, while the gastrocnemius contributes to both vertical support and forward propulsion. In contrast, the quadricep muscles mainly act to stabilize the lower limb and resist braking forces during early stance, supporting forward progression under longer ground contact times (Pandy et al., 2021). EMG studies further suggest that heavier horizontal loads may shift muscular demands toward greater quadriceps (especially vastus medialis/lateralis) and gluteal involvement, while hamstring and calf muscle activity may decrease under load (Deng, 2024). Resisted sprinting appears to redistribute muscular demands according to the magnitude and mode of resistance rather than uniformly increasing activation across all lower-limb muscles (Deng, 2024; Van Den Tillaar & Gamble, 2018). Current EMG evidence suggests that heavier resisted conditions may increase gluteal and quadriceps involvement during stance, while hamstring activity may remain unchanged or even decrease under higher loading conditions (Higashihara et al., 2018; Martínez-Valencia et al., 2015). Increased quadriceps activation may reflect greater demands for braking control, limb stiffness regulation, and force application during prolonged ground contact times (Nagahara et al., 2018a; Osterwald et al., 2021; Pandy et al., 2021). Although ankle plantar flexors continue to contribute substantially to propulsion and vertical support (Pandy et al., 2021), evidence regarding soleus and gastrocnemius activation responses during resisted sprinting remains limited. Collectively, these adaptations reproduce several mechanical characteristics of early acceleration sprinting, including greater horizontal force orientation, increased trunk lean, and longer stance durations (Cahill et al., 2020; Cross, Brughelli, Samozino, Brown, et al., 2017; Osterwald et al., 2021), making RST highly specific to acceleration development (Alcaraz et al., 2018; Lockie et al., 2012; Petrakos et al., 2016).

Long-term RST interventions typically lasting 4–10 weeks, consistently improve short sprint performance, particularly over 0–5 m and 0–10-m distances (Alcaraz et al., 2018; Dougan et al., 2025; Lockie et al., 2012). These improvements are associated with increased theoretical maximal horizontal force, a key determinant of acceleration capacity (Morin & Samozino, 2016; Samozino et al., 2016), improved stride length and technical efficiency during the initial sprint steps, and enhanced horizontal reactive strength, often measured through plyometric tasks such as broad jumps and bounding (Lockie et al., 2012). Additionally, positive changes occur in the force-velocity profile, especially in athletes initially classified as force-deficient (Cross et al., 2018; Lahti et al., 2020). However, RST has limited transfer to maximal velocity performance (> 20 m), reflecting its specificity to early acceleration rather than top-speed running. For this reason, RST should be complemented with high-speed sprinting or AST to develop the velocity end of the spectrum (Myrvang & Van den Tillaar, 2024).

Effective RST depends on precise load prescription. Historically, loads were expressed as a percentage of body mass, but this method does not account for differences in sled friction or surface variability (Petrakos et al., 2016). Modern best practice prescribes loads using % velocity decrement, which represents the reduction in sprint speed caused by resistance relative to unresisted sprinting (Cahill et al., 2019; Cross, Brughelli, Samozino, Brown, et al., 2017).

Light loads about 10 % velocity decrement cause minimal technical disruption and are ideal for reinforcing sprint mechanics while adding slight resistance (Osterwald et al., 2021). Moderate loads from 15 to 20 % velocity decrement target improvements in horizontal force production while maintaining proper technique, whereas heavy loads from 20 to 30 % velocity decrement are used to maximize F_0 development for explosive starts, particularly in team-sport athletes (Ward et al., 2023). Typical training prescriptions include distances of 10–30 m per sprint, a total session volume of 120–300 m, recovery periods of 2–3 minutes between repetitions to maintain maximal effort, and a frequency of 2–3 sessions per week over a minimum of six weeks to achieve measurable adaptations (Alcaraz et al., 2018; Thurlow et al., 2023).

While resisted sprint training is highly effective, excessive resistance levels above 30 % velocity decrement can lead to undesirable technical changes, including overly pronounced forward trunk lean, excessively long ground contact times that diminish stretch–shortening cycle (SSC) utilization, and reductions in stride frequency or stride length (Osterwald et al., 2021). To minimize these risks, technique should be closely monitored, with particular attention to projection angle and limb alignment. Video analysis or real-time device feedback can help ensure that sprint mechanics remain close to those observed during unresisted sprinting (Alcaraz et al., 2008). Motorized devices such as Sprint 1080, DynaSpeed, or Alex7 provide precise load control and immediate feedback, reducing trial-and-error in programming and maintaining movement quality (Cross et al., 2018; Rakovic et al., 2022). When appropriately prescribed, RST is a powerful and highly specific training method for enhancing acceleration. By adding external resistance, athletes are required to generate greater horizontal impulses and improve the technical orientation of force. Over time, consistent exposure to well-designed RST programs leads to substantial gains in early sprint performance, making it particularly valuable for team-sport athletes and sprinters seeking to develop more explosive starts.

1.3.3. Assisted sprint training

While resisted sprint training develops horizontal force production and acceleration capabilities, assisted sprint training addresses the opposite end of the force-velocity spectrum by enabling athletes to run at supramaximal velocities. Supramaximal running is defined as sprinting above the athlete's unassisted maximal velocity, typically between 2–5 % faster and, in advanced contexts, up to 8–10 % faster (Gleadhill et al., 2023; Lahti et al., 2020).

The primary goal of AST is to enhance the neuromuscular and technical qualities required for maximal velocity sprinting. By artificially increasing running velocity and exposing athletes to supramaximal limb speeds, AST alters sprint spatiotemporal characteristics, particularly ground contact time, flight time, and stride length (Cecilia-Gallego et al., 2022; Clark et al., 2021). Acute overspeed sprinting consistently reduces ground contact time and increases stride length, while changes in stride frequency are generally small or inconsistent (Gleadhill et al., 2023; Lahti et al., 2020). Over time, repeated exposure to supramaximal running may contribute to improvements in maximal velocity performance, step frequency, and sprint coordination, particularly when AST is combined with regular maximal sprinting (Mendiguchia et al., 2022). Proposed mechanisms include exposure to higher limb velocities, altered contact dynamics, and neuromuscular stimuli that may refine limb turnover and front-side mechanics; however, the underlying neural adaptations remain largely hypothesized rather than directly confirmed in longitudinal AST studies.

Historically, AST has been implemented through downhill running, tailwinds, or elastic cord towing, but these methods lack precision and are difficult to standardize (Corn & Knudson, 2003; Ebben et al., 2008; Matusiński et al., 2022). Modern motorized towing systems, such as the Sprint 1080, DynaSpeed, and Alex7, now allow precise and repeatable programming of assistance. These devices can be set to provide either constant-force assistance – applying a steady external pull throughout the sprint or velocity-targeted assistance – assisting only until the athlete reaches a set speed, after which the pulling force stops automatically (*partial assistance*). This innovation has revolutionized assisted sprint training by enabling controlled supramaximal exposures with reduced risk of technique disruption (Lahti et al., 2020; Rakovic et al., 2022).

Assisted sprinting acutely alters sprint mechanics and neuromuscular demands. Ground contact times are reduced as external assistance increases forward momentum, leaving less time to apply force during each step. This reduction in contact time may be accompanied by small increases in stride frequency, although speed gains are primarily associated with increased stride length and altered flight-contact dynamics (Chang et al., 2024; Gleadhill et al., 2023; Mero & Komi, 1987). Under moderate levels of assistance, stride length may also increase, allowing athletes to cover more distance per step. These changes support improved front-side mechanics, characterized by faster thigh lift and earlier limb repositioning, which enhance preparation for the next ground contact (Lahti et al., 2020; Mendiguchia et al., 2022).

Neuromuscular responses during assisted sprinting are less consistently established than the associated spatiotemporal changes. Although kinematic adaptations to supramaximal running are relatively well described, evidence regarding specific neuromuscular responses remains more limited and sometimes inconsistent. A recent meta-analysis showed that as sprint speed increases, hamstring and gluteus maximus activation generally rise, with biceps femoris activity peaking during the late swing phase, highlighting the substantial neuromuscular demands associated with high-speed running. As running speed increases toward supramaximal levels, the hamstrings continue to play an important role during late swing for limb deceleration and preparation for ground contact (Mero & Komi, 1987; Nagahara et al., 2018a; Pietraszewski et al., 2025). However, reviews on hamstring injury mechanisms suggest that current biomechanical models and simulations describe muscle stretch, timing, and mechanical loading more effectively than detailed in vivo neuromuscular control, meaning that many neural responses during high-speed sprinting remain incompletely understood. Faster running velocities and shorter contact times may increase eccentric demands on the posterior chain, potentially elevating injury risk if exposure is not appropriately progressed. In addition, lower-limb muscle pre-activation before touchdown is considered important for stiffness regulation, impact absorption, and preparation for rapid force application during high-speed running (Danielsson et al., 2020; Dietz et al., 1979). However, direct EMG evidence regarding specific changes in hamstring, plantar flexor, and quadriceps activation during assisted sprinting remains limited and somewhat inconsistent. Consequently, many proposed neural adaptations associated with AST, including altered motor unit recruitment, improved intermuscular coordination, and refined front-side mechanics, remain partly theoretical and require further longitudinal investigation. Given that a substantial proportion of hamstring injuries occur during high-speed running actions, careful progression of assisted sprint exposure and adequate eccentric strength development remain essential when implementing AST (Gronwald et al., 2022; Jokela et al., 2023; Kamandulis et al., 2023).

Repeated assisted sprint training sessions lead to long-term improvements in sprint mechanics and maximal velocity performance, particularly in athletes with initial velocity deficits. Over time, AST has been shown to increase theoretical maximal velocity by enhancing stride frequency and running efficiency (Lahti et al., 2020). Some studies have also reported reductions in ground contact time and improvements in sprint spatiotemporal characteristics following assisted sprint interventions. Potential neural adaptations may include improved intermuscular coordination, exposure to higher limb velocities, and more efficient force application during maximal speed sprinting, although the precise mechanisms remain incompletely understood (Mero & Komi, 1987; Morin et al., 2019).

However, if the level of assistance is excessive or poorly managed, chronic exposure may reinforce maladaptive mechanics, such as over-striding, excessive braking forces, or a shift toward quadriceps dominance (Matusiński et al., 2022). Using partial towing may help mitigate these risks by allowing athletes to continue actively producing force while still benefiting from overspeed exposure.

Initial exposure to assisted sprint training should generally begin with relatively low supramaximal velocity surpluses to minimize excessive technical disruption and reduce injury risk. Current studies commonly use assisted sprint velocities ranging from approximately 105–110 % of unassisted maximal sprint velocity, although lower surpluses may be appropriate during early familiarization phases or in youth athletes (Gleadhill et al., 2023; Lahti et al., 2020; Matusiński et al., 2022). Recommended sprint distances typically range from 20 to 30 m, using either fully assisted sprinting or combinations of assisted and unassisted running within the same training session (Hicks et al., 2023). Full passive recoveries of approximately 3–6 minutes between repetitions are commonly implemented to maintain high movement quality, maximal sprint intensity, and technical precision during supramaximal running (Matusiński et al., 2022).

Progression should be gradual, with increases in velocity surplus, sprint distance, or training volume carefully individualized according to the athlete's technical competency, sprint mechanics, and training background (Myrvang & Van den Tillaar, 2024). AST is typically integrated 1–2 times per week and is often combined with resisted or unassisted sprint training to balance force- and velocity-oriented adaptations within a periodized sprint program (Hicks et al., 2023). Partial assistance may be particularly beneficial for youth or developing athletes, as well as during transitions from resisted sprint phases toward maximal velocity development, because it allows athletes to maintain active force production while still experiencing supramaximal running speeds (Lahti et al., 2020).

The primary risk of assisted sprint training is hamstring strain, caused by the increased eccentric demands placed on the hamstrings during the late swing phase at supramaximal speeds (Chumanov et al., 2011; Chumanov et al., 2007; Nagahara et al., 2018a). This risk can be reduced by conducting eccentric hamstring strength testing prior to training, ensuring athletes have sufficient lumbopelvic control to maintain proper alignment, using partial towing protocols for safer progression, and closely monitoring running mechanics with high-speed video or real-time device feedback (Andrews et al., 2025; Sancese et al., 2023).

AST is a highly effective method for enhancing maximal velocity performance by exposing athletes to supramaximal running speeds. Modern motorized devices allow for precise control of assistance and the implementation of advanced protocols such as partial towing, which optimize performance improvements while safeguarding long-term neuromuscular health.

1.3.4. Integrating resisted sprint training and assisted sprint training for optimal development

Resisted sprint training and assisted sprint training represent opposite yet complementary ends of the force-velocity spectrum. RST emphasizes horizontal force production and technical projection of force during early acceleration (Dougan et al., 2025). AST targets velocity-oriented qualities by challenging the neuromuscular system at supramaximal running speeds (Lahti et al., 2020). When used together in a structured and periodized manner, these methods provide a balanced approach to sprint development, addressing both acceleration and maximal velocity qualities. This dual strategy allows athletes to progress from producing greater initial horizontal force to refining rapid force application under extremely short ground contact times, ultimately maximizing sprint performance across the entire race distance (Lahti et al., 2020; Morin & Samozino, 2016; Myrvang & Van den Tillaar, 2024).

The integration of resisted sprint training and assisted sprint training should follow a logical progression across the training year, with the emphasis shifting based on the athlete's development stage and competition calendar. In the early pre-season, the focus is on building a strong force foundation using RST with moderate to heavy loads, typically corresponding to a 15–30 % velocity decrement. This phase aims to increase theoretical maximal force and improve horizontal projection angles, laying the groundwork for later phases (Hicks et al., 2023; Lahti et al., 2020; Myrvang & Van den Tillaar, 2024; Ward et al., 2023).

As athletes transition into the mid pre-season, the goal shifts toward blending force and velocity qualities. Training at this stage combines both RST and AST, applied at low resistance and low assistance levels. This balance helps athletes move from strength-oriented work to more speed-specific mechanics, ensuring that gains in force production translate effectively into improvements in sprint performance (Jiménez-Reyes et al., 2024).

In the late pre-season and during the competition phase, the emphasis moves to maximizing velocity expression. Here, AST becomes the dominant method, using partial assistance and a small velocity surplus of + 2–5 % above unassisted sprinting. This approach enhances theoretical maximal velocity, reduces ground contact time, and optimizes neural drive to prepare athletes for peak performance (Agudo-Ortega et al., 2023; Gleadhill et al., 2023).

Finally, during the taper or peak period, training consists of light AST and unassisted sprints. The focus is on fine-tuning coordination and allowing recovery so that athletes can perform at their best during competition. This structured progression ensures that the qualities developed through RST early in the season are effectively transferred into high-speed performance through AST closer to competition, maximizing performance gains and minimizing injury risk (Jiménez-Reyes et al., 2024).

Partial towing assistance has emerged in the literature as a promising way to introduce supramaximal exposures while better preserving natural mechanics and active propulsion than continuous (full) towing. Classical AST methods (downhill running, elastic cords, motorized assistance) help athletes reach higher-than-usual velocities (Clark et al., 2021; Corn & Knudson, 2003; Mero & Komi, 1987), but continuous towing throughout the sprint can reduce voluntary propulsive effort and increase the risk of over-striding or excessive braking if overdosed (Cecília-Gallego et al., 2022; Haugen, McGhie, et al., 2019).

In contrast, partial assistance applies towing only until a target velocity is reached and then releases the athlete, aiming to balance supramaximal exposure with voluntary force production. From a periodization standpoint, this supports a progressive approach. In the early phases of assisted sprint training, partial towing is used to help athletes gradually accommodate to higher limb velocities while maintaining more natural kinematics and muscle activation. As training progresses and athletes develop greater technical proficiency and neuromuscular readiness, occasional full-towing exposures can be introduced to provide a stronger overspeed stimulus (K. Clark et al., 2021; Van Den Tillaar, 2021). This approach mirrors the progressive overload principles commonly observed in both sprint and strength training literature (Petrakos et al., 2016; Ross et al., 2001). Reported benefits of partial assistance include (i) maintaining higher active muscular involvement, which may support long-term adaptation (Cecília-Gallego et al., 2022; Higashihara et al., 2010), (ii) mitigating over-striding/braking issues often seen with continuous towing (Clark et al., 2021; Haugen, McGhie, et al., 2019), and (iii) facilitating smoother transfer back to unassisted sprinting (Ross et al., 2001).

When combining RST and AST within a microcycle, it is essential to carefully monitor technique, as excessive resistance can cause exaggerated forward lean and disrupted stride timing, while excessive assistance may encourage over-striding and increase the risk of hamstring strain (Gronwald et al., 2022; Haugen, McGhie, et al., 2019; Petrakos et al., 2016). Loads should be progressed conservatively, with resistance and assistance increased gradually based on the athlete's readiness and response (Ross et al., 2001). Before introducing heavy or supramaximal exposures, athletes should be screened for hamstring eccentric strength, ankle stiffness, and trunk control to reduce injury risk (Haugen, McGhie, et al., 2019; Kamandulis et al., 2023). Modern motorized systems (e.g., Sprint 1080, DynaSpeed) enable precise control, real-time feedback, and velocity-targeted (partial-release) protocols that can help implement individualized AST safely and effectively (K. Clark et al., 2021; Lahti et al., 2020; Rakovic et al., 2022).

1.4. Force-velocity and power-velocity profiling

Sprinting performance can be understood through the dynamic interaction between force production and running velocity. In the horizontal plane, the most relevant axis for sprint propulsion, this relationship is well described by a linear model in which maximal horizontal force production occurs at zero running velocity and progressively declines as velocity increases (Morin et al., 2012; Morin & Samozino, 2016; Samozino et al., 2016).

At one extreme, an athlete's theoretical maximal horizontal force reflects their capacity to generate large propulsive impulses during the initial steps of acceleration. At the opposite extreme, the maximal velocity represents the athlete's ability to move at very high speeds when horizontal force is minimal. The slope of this relationship provides key information about how rapidly force diminishes with increasing velocity, effectively indicating whether an athlete's performance is constrained more by force production at low speeds or by rapid force application at high speeds (Jiménez-Reyes et al., 2018; Nagahara et al., 2018a; Samozino et al., 2022).

A related concept is the power-velocity (P-V) relationship, where power, calculated as the product of force and velocity ($P = F \times v$), forms a parabolic curve. Power peaks at approximately 50 % of both F_0 and V_0, representing the optimal balance of force and velocity production during sprinting (Cross et al., 2018; Samozino et al., 2012; Samozino et al., 2022). This peak power output (Pmax) reflects the athlete's overall sprint capacity (Haugen, Breitschädel, et al., 2019). However, maximizing performance on the track requires not only a high Pmax but also a force-velocity balance tailored to the athlete's mechanical needs (Samozino et al., 2022).

An optimal F-V slope is individual and sport-specific. Athletes with profiles that deviate significantly from this optimal slope may produce submaximal sprint performances even if their total Pmax is high (Samozino et al., 2022).

For instance, a force-dominant athlete may accelerate rapidly over the first 5–10 meters but lack the neuromuscular capacity to achieve and maintain high top speeds. Therefore, a velocity-dominant athlete may reach high maximal speeds but struggle to generate sufficient early acceleration (Haugen, Breitschädel, et al., 2019; Morin et al., 2012). Understanding these profiles provides coaches and researchers with a diagnostic tool for prescribing targeted interventions, bridging the gap between performance testing and individualized training design.

1.4.1. Force-velocity profile parameters

An F-V profile yields several primary outputs that provide insight into sprint performance (Table 1.1).

Table 1.1 F-V profile parameters, definitions and performance relevance

Parameter	Definition	Performance relevance
F_0	Theoretical maximal horizontal force at zero velocity	Determines initial acceleration capacity
V_0	Theoretical maximal velocity when horizontal force approaches zero	Determines maximal speed potential
Pmax	Peak mechanical power (F × v) at optimal balance of force and velocity	Overall sprint performance indicator
Slope	Rate of decrease in horizontal force as sprint velocity increase	Identifies force- vs. velocity-dominant profile for targeted training
RFmax	Peak ratio of horizontal to resultant force	Quality of force orientation during propulsion
DRF	Rate of decrease in RF with rising velocity	Ability to sustain horizontal force as speed increases

High RF peak is associated with effective horizontal force orientation during the initial acceleration steps, including favorable foot placement relative to the center of mass, appropriate shank positioning, stable trunk-pelvis control, and reduced braking distances (King et al., 2022; Nagahara et al., 2018a). In contrast, DRF reflects the athlete's ability to maintain horizontal force application as sprint velocity increases. A steep DRF is often associated with a premature transition to upright posture, inadequate front-side mechanics, reduced control of braking forces, and difficulty sustaining horizontal propulsion at higher running speeds. These variables are influenced not only by force-generating capacity, but also by technical factors such as posture, coordination, and the timing of braking and propulsive phases during stance (Fernández-Galván et al., 2022; Morin et al., 2011). Consequently, F-V profiling is not purely a mechanical assessment; it acts as an interface between physical capacities and sprint technique, providing a comprehensive picture of sprint performance and helping identify whether performance limitations arise from force production, velocity capacity, or force-application mechanics. (Fernández-Galván et al., 2022; Feser et al., 2021).

1.4.2. Interpreting profiles: force-dominant vs. velocity-dominant

Athletes can be broadly categorized based on their F-V profile slope. Force-dominant athletes have a high F_0 but low V_0, excelling in early acceleration (0–10 m) and short sprints typical of team sports, but they may lack the maximal velocity capacity needed for longer sprints. Velocity-dominant athletes have a high V_0 but lower F_0, allowing them to achieve exceptional top speeds while generating limited initial horizontal force. Balanced athletes have an F-V profile that closely matches the theoretical optimal slope, reflecting well-rounded sprint performance (Haugen, Breitschädel, et al., 2019; Samozino et al., 2022).

Neuromuscular activation patterns also appear to differ according to the mechanical demands of acceleration and maximal-velocity sprinting. During acceleration, greater and more prolonged activation of the hip and knee extensors contributes to horizontal force production, with the hamstrings, gluteal muscles, and quadriceps playing important roles in propulsion and support during stance (Higashihara et al., 2018; Pandy et al., 2021). As sprint velocity increases, the contribution of the plantar flexors becomes increasingly dependent on rapid stretch-shortening cycle function and elastic tendon recoil, particularly through the soleus and gastrocnemius during maximal-velocity running (Lai et al., 2014). Consequently, force-oriented sprinting appears to rely more on sustained proximal extensor force production (Pandy et al., 2021), whereas velocity-oriented sprinting depends more heavily on rapid force transmission, ankle stiffness, and elastic energy utilization through the plantar flexors (Schache et al., 2019).

Lahti et al. (2020) found that initial F-V profiles predicted training adaptation. Force-deficient athletes responded best to resisted sprint training, improving horizontal force production and velocity-deficient athletes improved most with assisted sprint training, enhancing maximal speed qualities (Lahti et al., 2020). This reinforces the importance of profiling not just as a diagnostic tool but as a prescriptive guide for training design.

1.4.3. Training from the profile: individualized strategies

Once an athlete's F-V profile is established, it can guide the selection and progression of training methods. Force-velocity profiling provides a diagnostic framework for identifying the optimal balance between resisted sprint training and assisted sprint training for each athlete. Force-dominant athletes, characterized by high theoretical maximal force and low theoretical maximal velocity, may require greater exposure to AST to enhance maximal velocity and stride frequency, while maintaining sufficient RST to preserve acceleration capacity. In contrast, velocity-dominant athletes, characterized by high V_0 and low F_0, may benefit more from RST to improve horizontal force production and acceleration ability, with AST used more selectively to refine maximal velocity mechanics (Hicks et al., 2023; Rakovic et al., 2018). Lahti et al. (2020) demonstrated that initial F-V profile characteristics strongly influence training adaptations, showing that force-deficient athletes respond best to resisted sprint training, whereas velocity-deficient athletes achieve greater improvements with assisted sprint training. These findings emphasize the importance of individualized, profile-based programming rather than a one-size-fits-all training approach (Lahti et al., 2020). Two main strategies are typically used. The first is a deficit-focused approach, which aims to correct imbalances by targeting the weaker end of the spectrum.

For force-deficient athletes, the emphasis is placed on resisted sprint training with loads prescribed via velocity decrement, typically ranging from 10–20 % for sprinters and up to 30 % for team-sport athletes (Alcaraz et al., 2018; Cahill et al., 2019, 2021). This is complemented with high-force strength training, such as heavy squats and hip thrusts, along with horizontal plyometrics to further raise F_0. Neuromuscularly, this approach extends stance-phase extensor activation and enhances horizontal impulse (Loturco et al., 2018; Williams et al., 2018; Zhang & Li, 2026).

For velocity-deficient athletes, the focus shifts toward high-speed running exposures, including fly sprints and partial assisted sprints at + 2–5 % supramaximal velocity (Myrvang & Van den Tillaar, 2024). Short-contact plyometrics, such as drop jumps and stiff-legged bounds, are also incorporated to improve ankle stiffness and stride frequency (Ramírez-delaCruz et al., 2022).

The second strategy is a strengths-based approach, which focuses on amplifying an athlete's dominant qualities once balance is achieved. Force-dominant athletes continue to refine early acceleration with moderate resistance while maintaining at least one maximal velocity exposure per week. In contrast, velocity-dominant athletes prioritize maximal velocity development through regular assisted sprint training sessions, while maintaining a minimum dose of resisted sprint training to prevent loss of acceleration ability (Lahti et al., 2020).

The timing of training blocks is critical. In the early preparation phases, the focus should be on correcting imbalances. As competition approaches, the emphasis shifts toward refining dominant qualities and integrating both resisted sprint training and assisted sprint training within the same weekly microcycle (Lahti et al., 2020).

Lahti et al. (2020) reported that adaptation peaks may occur several weeks after training ends, emphasizing the need to align training loads with competition timing for optimal performance transfer (Lahti et al., 2020). Regular re-assessment – every 4–6 weeks – is essential because F-V profiles are dynamic and can change due to training, fatigue, or injury (Myrvang & Van den Tillaar, 2024).

1.5. Motorized devices for sprint research and training

The evolution of sprint training methods has been closely tied to advances in technology. Traditional approaches, such as sled towing, parachutes, elastic cords, and downhill running, have long been used to manipulate sprint loading. While effective to some degree, these methods are limited by lack of precision, variability in environmental conditions, and difficulty in standardizing the exact resistance or assistance applied (Lockie et al., 2012).

The introduction of motorized sprint devices marked a major shift in both practice and research. These systems bridge the gap between laboratory-grade measurement precision and real-world, field-based training environments (Haugen, McGhie, et al., 2019). By electronically controlling resistance and assistance, motorized devices provide consistent, programmable loads that are independent of surface friction or athlete technique.

Compared to traditional tools, motorized systems offer several unique benefits for sprint training and analysis. One key advantage is the precision control of external load, as resistance or assistance can be programmed in very small increments, ensuring exact prescription. Unlike sleds, where friction changes with speed and surface, motorized devices maintain a constant load throughout the sprint. Another benefit is the availability of real-time feedback. Metrics such as instantaneous velocity, force, power, and position are displayed immediately, allowing coaches to adjust technique or load on the spot (Cross, Brughelli, Samozino, & Morin, 2017).

These systems are also highly versatile, enabling both resisted and assisted sprinting on the same device. They allow the use of partial-assist and progressive-resistance protocols, which help refine technical execution. In addition, motorized devices integrate training and testing by simultaneously collecting sprint performance data, force-velocity profiles, and kinematic information during regular training sessions. This dual function not only saves time but also enhances the ecological validity of assessments. Finally, their capacity for longitudinal tracking makes it possible to monitor performance adaptations over weeks or even entire competitive seasons, providing valuable insights into athlete development.

Examples of leading systems include Sprint 1080 Motion™ (1080 Motion, Sweden), which is one of the most widely studied motorized sprint devices in sports science research. It uses a servo motor to deliver velocity-independent resistance or assistance, programmable throughout the sprint distance. Common applications include heavy-load resisted sprinting to increase F_0 and light-load assisted sprinting for supramaximal velocity exposures (Lahti et al., 2020). The device has been validated for its accuracy in measuring split times, instantaneous velocity, and force-velocity profiles. Lahti et al. (2020) used the 1080 Sprint to study individualized dosing of supramaximal sprinting (+ 5–10 % velocity surplus), demonstrating improvements in maximal velocity in velocity-deficient athletes.

Another commonly used system is DynaSpeed™ (Ergotest Innovation, Norway), frequently applied in elite track and field and team sports. It offers highly adjustable resistance and assistance, with precise control of loading similar to Sprint 1080. This prevents technique disruption caused by continuous external pulling and helps athletes maintain natural mechanics during overspeed training (Myrvang & Van den Tillaar, 2024). The system integrates with radar timing to provide real-time kinematic analysis and velocity-time curves, supporting both training and biomechanical research.

The MuscleLab Linear Motor (Ergotest Innovation, Norway) is primarily designed for resisted sprinting with a constant horizontal force. It allows for simultaneous measurement of force and velocity, making it particularly useful for sprint profiling. This system is often used alongside other tools for comprehensive biomechanical analysis.

The Alex7 motorized sprint system (Inosportas, Kaunas, Lithuania) was developed to overcome several limitations of existing sprint devices. It is highly portable, designed for quick and easy setup on a standard track or turf, making it practical for coaches and researchers working outside of controlled laboratory environments. The system features dual-mode functionality, offering both constant-force resistance and velocity-targeted assistance within a single unit. A unique partial-assistance feature automatically releases the towing force once the athlete reaches a preset velocity threshold, which helps reduce the risk of over-striding and technical breakdown during supramaximal sprints.

Additionally, Alex7 includes a built-in measurement system that records force, velocity, distance, and time without requiring external timing gates or radar systems. It is also cost-effective, providing a more accessible alternative to high-end devices like Sprint 1080 while maintaining scientific-grade precision. These characteristics make Alex7 ideally suited for individualized sprint training, particularly in field sports where acceleration and deceleration demands vary greatly. It also supports integrated performance monitoring, enabling coaches to track sprint mechanics, spatiotemporal parameters, and adaptations over time, while serving as a valuable tool for applied research studies such as those presented in this dissertation.

While systems like Sprint 1080 and DynaSpeed have been extensively validated, Alex7 was untested when it was first introduced. Without established validity and reliability data, it would not be possible to interpret measurements with confidence, compare findings with other research and integrate Alex7 into individualized sprint training prescriptions. Therefore, the first study focused on confirming the accuracy and repeatability of Alex7 outputs under both resisted and assisted sprint conditions. This was a crucial step before moving on to applied studies using Alex7 as both a training tool and a measurement instrument.

2. METHODS

2.1. Study design

The present dissertation comprises three interconnected studies, each addressing a distinct but related aspect of sprint performance assessment and training using the novel Alex7 motorized device. Collectively, these studies progress from validation of the measurement tool to physiological exploration and finally to practical intervention, providing a comprehensive investigation of resisted and assisted sprinting (Table 2.1).

Table 2.1 Aim and methods of all studies

Study	Aim	Methods
Study 1 – Validity & Reliability of Alex7	Validate and assess the reliability of the Alex7 device under resisted and assisted sprint conditions.	Repeated sprint testing, Alex7 device for controlled assistance and resistance, comparison with reference timing systems, validity and reliability analysis.
Study 2 – EMG & kinematics in assisted sprinting	Investigate lower-limb muscle activation, spatiotemporal parameters, and sprint kinematics across unassisted, partially assisted, and fully assisted conditions.	EMG measurements, Alex7 device for controlled assistance, spatiotemporal and kinematic analysis, with emphasis on phase-specific muscle activity patterns.
Study 3 – Assisted training intervention	Evaluate the effects of a six-week assisted sprint training program on sprint performance, spatiotemporal variables, and force-velocity profiles, and examine whether baseline force-velocity characteristics are associated with individual training adaptations	Randomized controlled trial, assisted sprint training and control groups, pre- and post-testing, force-velocity profiling, statistical modeling to identify responders and non-responders.

2.2. Participants

The three studies included in this dissertation involved different groups of athletes, each selected to match the specific objectives of the respective study. Across all studies, participants were informed of the procedures and potential risks, and written consent was obtained prior to participation. For athletes under 18 years of age, parental or guardian consent was also collected. All studies were conducted in accordance with the Declaration of Helsinki and approved by the Lithuanian Sports University Ethics Committee.

Table 2.2 Number and description of participants within the three studies

Study	Number of Participants	Description of Participants
Study 1 – Validity & Reliability of Alex7	n = 27	Male youth football players competing in top-tier U16 and U18 leagues. Age: 16.5 ± 0.8 yrs; Height: 179.5 ± 6.9 cm; Body Mass: 67.7 ± 8.3 kg. Regular sprint training experience but no prior exposure to motorized towing systems.
Study 2 – EMG & kinematics in assisted sprinting	n = 14 (final n = 13)	Male athletes actively engaged in sprint-based sports. Age: 21.4 ± 1.5 yrs; Height: 1.86 ± 0.07 m; Body Mass: 81.8 ± 8.5 kg. Experienced in sprinting but no previous motorized assisted sprinting experience.
Study 3 – Assisted training intervention	n = 27 (final n = 24)	Male youth football players. Age: 16.5 ± 2.1 yrs; Height: 1.80 ± 0.06 m; Body Mass: 69.3 ± 9.7 kg. Randomly divided into assisted sprint training group (n = 17) and control group (n = 7), with allocation informed by initial force-velocity profile characteristics.

Although the participant groups varied across studies, they shared common characteristics, such as regular exposure to sprint training and competitive match play (Table 2.2). Study 1 included a homogeneous group of trained football players to evaluate the device's accuracy and reliability under realistic sport-specific sprinting conditions. Study 2 focused on a smaller, specialized group with strong technical sprinting ability, ensuring high-quality EMG and kinematic data during assisted sprint trials. Finally, Study 3 involved youth football players to examine the practical application of assisted sprint training within a team setting. The final sample comprised 24 participants. Three players did not complete the intervention: one was released from his soccer academy, one was promoted to a higher league, and one withdrew because of an injury not related to sprints. The study was conducted during the preparation phase for the next season. In this study, all players completed five training sessions during the week comprising three soccer training sessions and two sprint training sessions for the intervention groups followed by strength conditioning for both the intervention and control groups. Adherence to the sprint training program was high, and participants attended an average of 11.6 ± 1.5 sessions out of 12 total sprint sessions available during the intervention period. Participants were instructed to maintain their usual training routine and regular diet throughout the study period.

2.3. Equipment overview

A variety of specialized equipment was used across the three studies to ensure precise measurement of sprint performance, kinematics, and neuromuscular activity. The Alex7 motorized sprint device served as the primary intervention tool, enabling both resisted and assisted sprinting while simultaneously recording mechanical outputs such as force, velocity, and distance, and supporting consistent monitoring of sprint performance across pre- and post-intervention testing in Study 3. Timing gates were employed as a gold-standard reference for sprint performance and were used for F-V profiling calculations, while the OptoJump system provided detailed spatiotemporal analysis of stride characteristics, including ground contact time, flight time, and stride length. For the EMG study, Noraxon wireless EMG sensors captured lower-limb muscle activation patterns during full and partial towing conditions. Additionally, a calibrated digital scale was used to set individualized resistance loads. The specific use of each equipment within the three studies is summarized in Table 2.3.

Table 2.3 Equipment used within the three studies

Equipment	**Study 1: Validity & Reliability**	**Study 2: EMG & Kinematics**	**Study 3: Assisted training intervention**
Alex7 Motorized Sprint Device (Inosportas, Kaunas, Lithuania)	Primary tool for resisted and assisted sprints, while collecting sprint performance data	Applied both full and partial towing assistance while collecting sprint performance data.	Implemented in assisted sprint training and used for monitoring sprint performance and controlled application of assistance during intervention sessions
Timing Gates (Witty, Microgate, Italy)	Gold-standard reference system for validation testing at 0–10 m, 10–20 m, 20–30 m intervals.	Used for recording sprint performance.	Used for pre- and post-testing of sprint performance and F-V profiling calculations.
OptoJump Modular System (Microgate, Italy)	Measured ground contact time, flight time, stride length, and pace during 10–30 m segments.	Measured ground contact time, flight time, stride length, and pace during 10–30 m segments.	Measured ground contact time, flight time, stride length, and pace during 10–30 m segments.
Electromyography System (Noraxon, USA)	—	Recorded lower-limb muscle activation during full and partial towing sprints.	—
Calibrated Digital Scale (Tanita TBF-300, Japan)	Measured participant body mass to set individualized resistance loads (10 % body mass).	—	Measured participant body mass for F-V profiling calculations.

2.4. Procedures

2.4.1. Standardized warm-up and pre-test preparation

Across all three studies, standardized warm-up and preparation protocols were implemented to ensure that participants were physically ready for maximal sprint performance and to minimize the risk of injury. These procedures were also designed to reduce variability in performance caused by inconsistent preparation.

Before every testing or training session, participants completed a 20-minute standardized warm-up consisting of 5 minutes of light jogging, dynamic stretching for the hamstrings, quadriceps, gluteus, and calves, followed by sprint-specific drills such as A-skips, B-skips, high knees, and bounding to activate the relevant muscle groups. The warm-up concluded with four 30-meter progressive accelerations performed at 70 %, 80 %, 90 % and 95 % of perceived maximal effort to prime the neuromuscular system.

Participant preparation included measuring body mass to the nearest 0.1 kg using a calibrated digital scale (except Study 2), checking and calibrating all equipment (Alex7, OptoJump, Witty timing gates, and EMG sensors in Study 2) according to manufacturer guidelines, and providing safety instructions before each session. Additional instructions specific to assisted sprinting included proper handling of towing forces and controlled deceleration following assistance release.

All testing was conducted indoors on a 60-meter rubberized track to control environmental factors such as wind and surface variability. Recovery periods between maximal sprints were standardized to five to six minutes of passive rest, and participants were instructed to avoid intense physical activity for 48 hours before each testing session.

2.4.2. Study 1: Validity and reliability of Alex7

Testing procedures

The 1st study followed a repeated-measures design, with three sprint conditions in a following standardized order (Figure 2.1):

1. Regular sprint (no resistance or assistance),
2. Resisted sprint (10 % body mass load applied by Alex7),
3. Assisted sprint (constant 6 kg towing force).

Testing sessions occurred on three consecutive weeks. The first week was used for familiarization with the resisted and assisted conditions, while the next two weeks involved identical testing sessions to evaluate test-retest reliability and validity of the Alex7 device against the timing gate system. Sessions were scheduled at consistent times of day for each participant to minimize circadian rhythm effects.

Each participant performed two maximal 30-m sprint trials per condition, with a minimum of six minutes of passive recovery between sprints (Figure 2.1). The fastest sprint was retained for analysis. Timing gates were positioned at 0, 10, 20 and 30 m to capture 10-m, 20-m and 30-m splits. The participant began each sprint trial with his lead foot placed 70 cm behind the first photocell to prevent inadvertent triggering of timing in the start position (Kamandulis et al., 2013; Lukonaitienė et al., 2020). The OptoJump system recorded spatiotemporal variables (ground contact time, flight time, stride length, and pace) over the 10–30 m zone. The four fastest consecutive steps were selected from each trial for analysis.

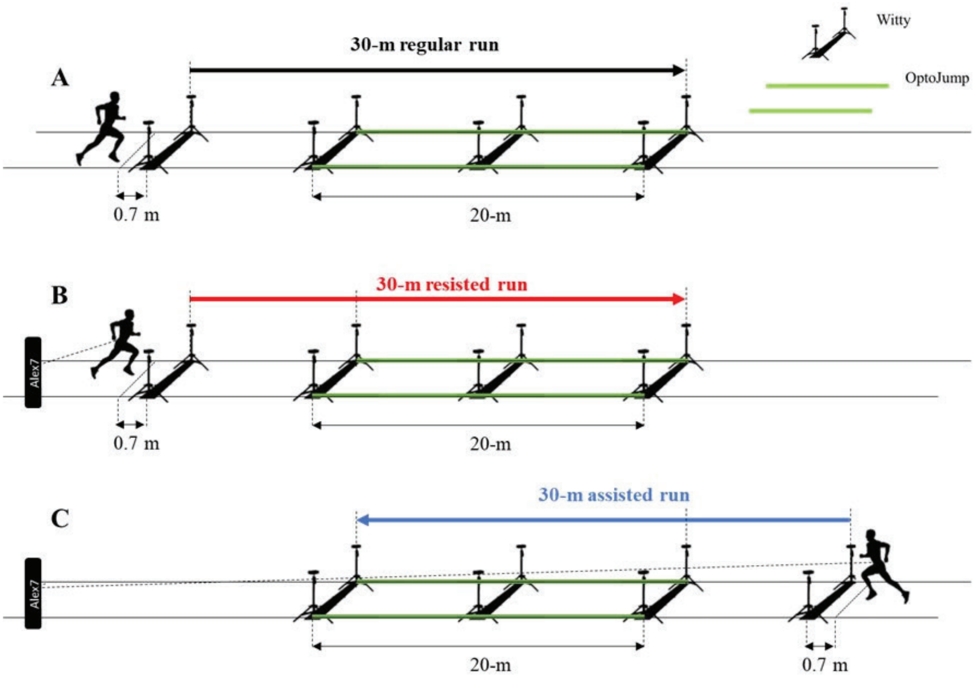


Figure 2.1 Schematic diagram of the experimental testing setup for (A) regular, (B) resisted, and (C) assisted sprint testing

Note: Three different devices (OptoJump, Witty, and Alex7) were used during each trial.

The Alex7 device simultaneously recorded sprint velocity and distance. Timing synchronization was carefully managed: the sprint began 0.7 m behind the first timing gate, and this initial distance was subtracted from the Alex7 data to ensure alignment with gate-based measurements.

For resisted sprints, the Alex7 applied a load equal to 10 % of the athlete's body weight throughout the entire 30-m sprint. For assisted sprints, a 6 kg towing force was applied continuously until the finish line, after which the assistance was automatically released to allow safe deceleration. Primary outcomes included a total sprint time (30 m), 10-m and 20 m split times, kinematic parameters from OptoJump (step length, step frequency, contact time, and flight time) and velocity and distance metrics from Alex7. These data were used to compare the validity of Alex7 against the timing gates and assess its reliability across repeated sessions.

2.4.3. Study 2: Electromyography and kinematics during assisted sprinting

Testing procedures

Testing for Study 2 was performed in a single session, with each athlete completing three sprint conditions (Figure 2.2):

1. Unassisted sprint,
2. Fully assisted sprint (continuous 6 kg towing force throughout the sprint),
3. Partially assisted sprint (towing force applied until the athlete reached a velocity 0.5 m/s below supramaximal speed, corresponding to approximately 95 % of individual maximal assisted speed, then released).

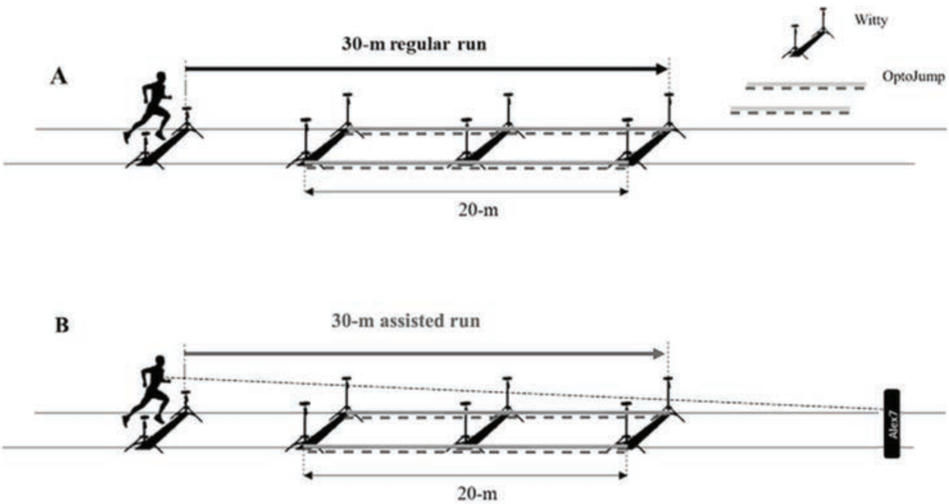


Figure 2.2 Schematic diagram of the experimental testing setup for (A) regular and (B) assisted sprint testing. Three different devices (OptoJump, Witty, and Alex7 run) were used during each trial

The order of conditions was standardized, with athletes first completing the regular run, followed by the fully assisted run, and finally the partially assisted run. Each athlete performed two maximal 30-m sprint trials per condition, with six minutes of passive recovery between sprints to prevent fatigue. The fastest trial per condition was used for analysis.

Timing gates were positioned at 0, 10, 20 and 30 m to capture total sprint time and split intervals. Spatiotemporal parameters – stride length, stride frequency, ground contact time, flight time, and duty factor (DF) – were measured with OptoJump over the 10–30 m zone, with the stride of interest defined as last complete stride before the 30 m finish line, ensuring consistency across all conditions. This approach minimized the inclusion of strides occurring during the immediate post-release transition phase and ensured that the analyzed stride reflected stabilized sprinting mechanics.

Lower-limb kinematics were collected using inertial measurement unit (IMU) sensors positioned on the foot, shank, thigh, and sacrum. Calibration was performed before each trial following manufacturer guidelines, using a standardized N-pose. Data were recorded at a sampling rate of 2000 Hz.

Electromyography recorded activity from the gluteus maximus, rectus femoris, vastus lateralis, semitendinosus, and biceps femoris on the dominant leg. Electrodes were placed according to SENIAM guidelines following skin preparation. EMG signals were sampled at 2000 Hz, band-pass filtered (20–450 Hz), full-wave rectified, and smoothed using a root mean square approach, with the envelope obtained via low-pass filtering at 10 Hz. EMG signals were normalized to the maximal value recorded during unassisted sprints for the stride of interest.

The stride of interest was identified using a validated gait phase detection algorithm, enabling precise synchronization of OptoJump, IMU, and EMG data across conditions.

Primary outcomes included:

- Total sprint time and split times,
- Spatiotemporal metrics (SL, SF, CT, FT, DF),
- Lower-body joint angles,
- Normalized muscle activation profiles across the three conditions.

This design enabled a direct comparison between full and partial towing, providing insight into how different assistance strategies influence sprint mechanics and muscle activation, while also allowing evaluation of neuromuscular responses across unassisted, partially assisted, and fully assisted conditions.

2.4.4. Study 3: Assisted training intervention

Testing procedures

Athletes performed testing sessions under standardized conditions at the same time of the day for both pre- and post-intervention assessments to minimize circadian influences. Each session began with a 20-minute standardized warm-up consisting of jogging, dynamic stretching, sprint drills, and progressive accelerations.

Participants had previous experience with overspeed sprinting using elastic towing (bungee), but none had prior experience with motorized assisted sprinting.

Sprint performance was assessed using two conditions:

1. A 30-meter regular sprint from a standing staggered start.
2. A 30-meter assisted sprint with a constant towing force of 6 kg applied via the Alex7 motorized device (Inosportas, Kaunas, Lithuania).

Each sprint condition was performed twice, separated by five minutes of passive rest, and the fastest trial for each condition was retained for analysis. Sprint times were recorded using a Witty timing gate system (Microgate, Italy), with gates positioned at 0, 5, 10, 15, 20, 25, and 30 m. The first gate was set at 20 cm height to ensure timing began at the initiation of forward movement.

Spatiotemporal variables were collected using the OptoJump Next modular system (Microgate) over the 10–30-m segment. Stride length, stride frequency, ground contact time, and flight time were extracted, and the two fastest consecutive strides within this segment of the fastest trial were analyzed for both the regular and assisted sprint conditions.

F-V profile parameters were calculated from regular sprint trials, using the validated field method described by Samozino et al. (2016), which estimates step-averaged horizontal anteroposterior force, velocity, and propulsive power from split time and anthropometric data through exponential modeling of the velocity–time curve (Samozino et al., 2016). From this modeling, F_0, V_0, Pmax, slope, RFmax, and DRF were derived.

Because the first photocell was positioned directly at the start line and 20 cm above the ground, the timing beam was typically broken only after the athlete had already initiated forward movement. This produced a systematic delay in the recorded start time and consequently an underestimation of early acceleration velocity and force values. To address this misalignment between the true onset of movement and photocell triggering, a time-shift optimization procedure was applied, based on the approach validated by Stenroth (Stenroth et al., 2023) who demonstrated that adjusting split times by an optimized temporal offset substantially improves the reliability and validity of F-V variables when the start instant cannot be captured precisely. Accordingly, a constant time correction was added to all raw split times. Constant time correlation was determined by minimizing the discrepancy between the modeled and observed positions during the exponential fitting. This correction ensured that the reconstructed velocity-time curve originated from true zero velocity conditions and that all F-V variables (F_0, V_0, Pmax, RFmax, DRF, slope) were calculated with the correct temporal alignment. After the corrected split times were obtained, instantaneous step-averaged velocity, horizontal force, and propulsive power were computed according to the procedures outlined in Samozino et al. (2016) (Morin & Samozino, 2016).

Training procedures

Following baseline testing, athletes were divided into two training groups:

– The fully assisted group performed all assisted 30 m. sprints with a constant towing force of 6 kg which corresponded to 8.7 ± 1.2 % of the athletes' body mass.
– Partially assisted group performed sprints where assistance was applied until reaching a predetermined velocity (95 % of individual maximal assisted speed) and then automatically released, allowing the athlete to continue unassisted.

The group allocation was balanced so that both groups had similar average values for theoretical maximal velocity, theoretical maximal force, and F-V slope derived from regular sprint trials, ensuring comparable baseline mechanical profiles between groups.

The intervention consisted of 12 training sessions over six weeks (two sessions per week).

Each session included:

– A standardized warm-up identical to that used in testing,
– Four 30-meter assisted sprints (either fully assisted, either partially assisted – depending on the group) performed at maximal effort,
– Five minutes of passive recovery between sprints to ensure full neuromuscular recovery.

To be considered as having completed the training, athletes were required to attend at least 10 of the 12 scheduled sessions. After the intervention, athletes underwent post-testing following the exact same procedures as baseline.

Data analysis

All three groups were first compared. The two assisted sprint modes showed similar neuromuscular and performance responses; therefore, they were combined into a single intervention group for comparison with the control group, which allowed a more robust estimate of the intervention effect.

To evaluate individual responsiveness, athletes were retrospectively classified as high responders or non-responders based on improvements in their assisted 30-m sprint times. The minimal detectable change (MDC) was calculated as:

$$MDC = 1.96 \times \sqrt{2} \times SEM$$

where SEM is the standard error of measurement derived from two repeated pretest assisted sprint trials (Furlan & Sterr, 2018; Intaruk et al., 2024).

For this study, MDC was 0.13 s. and represented the smallest change exceeding the typical measurement error. A stricter threshold of ≥ 0.19 s, approximately 50 % above the MDC, was used to define high responders (n = 7). Athletes who improved by ≤ 0.13 s were classified as nonresponders (n = 7), whereas athletes with improvements between 0.13 and 0.19 s were excluded from this analysis. This dual-threshold approach was used to distinguish measurement variability from meaningful performance adaptations.

2.5. Statistical analysis

Study 1 – Validation and Reliability

Mean and standard deviation (SD) were presented for all sprint times and kinematic parameters. The Shapiro–Wilk test confirmed normal data distribution. Relative reliability was assessed using two-way mixed interclass correlation coefficients (ICC) for single measures, interpreted as moderate (0.50–0.74), good (0.75–0.89), and excellent (≥0.90) (Koo & Li, 2016). Absolute reliability was assessed with the standard error of the mean (SEM), calculated as SD/√2, and coefficient of variation (CV), computed as SD/mean × 100 %. Pearson's correlation coefficient (r) determined the associations between Alex7 and Witty timing systems, interpreted as large (0.50–0.69), very large (0.70–0.89), nearly perfect (0.90–0.99), and perfect (1.00) (Hopkins, 2000). For criterion-referenced validity, mean difference and CV were calculated, with paired sample t-tests testing the significance of mean differences. Cohen's d was used for effect sizes, interpreted as large (≥ 0.80), medium (0.50–0.79), small (0.20–0.49), or trivial (<0.20) (Fritz et al., 2012). Bland-Altman analyses illustrated agreement between repeated measures for Alex7 and between Alex7 and Witty timing systems (Bland & Altman, 1999). The 95 % confidence interval (CI) of the mean difference determined systematic bias. All statistical analyses were performed using IBM SPSS Statistics (version 28.0, Armonk, NY, USA), with significance set at $\alpha = 0.05$.

Study 2 – EMG and Kinematic Comparisons

Descriptive statistics (mean ± SD) were calculated for each variable. The Shapiro–Wilk test was used to confirm normal distribution of the data. Sphericity was evaluated with Mauchly's test, and the Greenhouse–Geisser correction was applied when this assumption was violated. As the assumptions for parametric tests were met for all spatiotemporal variables, a repeated-measures analysis of variance (ANOVA) was performed for the first stance to identify statistically significant differences between conditions. When significant effects were found, post hoc pairwise comparisons were conducted using multiple t tests for dependent samples with the Benjamini–Hochberg correction.

For analysis of kinematics and muscle activity, a repeated-measures ANOVA was performed on the whole time series using statistical parametric mapping to identify significant differences between conditions. In cases of significant effects, pairwise comparisons were performed using multiple t tests for dependent samples with adjusted significance thresholds. The effect size (Cohen's d) was computed as the difference between group means normalized to the standard deviation of the unassisted running condition (Pataky, 2012).

Effect sizes were calculated for each pair of conditions and for each muscle, and interpreted using conventional benchmarks, where values of approximately 0.20, 0.50, and 0.80 represent small, moderate, and large effects, respectively (Cohen, 1988). These benchmarks are widely used in sports science contexts (Hopkins, 2002).

Statistical analyses were performed using SPSS v25.0 for Windows (IBM, Armonk, NY, USA) and JASP (Version 0.11.1). The level of significance was set at 0.05.

Study 3 – Assisted Training Intervention

All data are reported as means ± SD. Outliers were screened visually (QQ plots, residuals) and by standardized residuals ($|z| > 3$); influential points in regressions were checked via Cook's distance ($> 4/n$). Assumptions of linear regression, including normality of residuals and absence of influential observations, were verified using these diagnostic procedures. Alpha was set at .05 .(Ghasemi & Zahediasl, 2012; Zhu et al., 2012). Analyses were conducted in JASP (version 0.95.1 Intel).

A two-way Analysis of Variance (ANOVA, Group × Time) with repeated measures on the Time factor was conducted to examine differences in dependent variables. When significant interaction effects were observed, post hoc pairwise comparisons were performed using Holm-adjusted multiple comparisons. Effect sizes for ANOVA were reported as partial eta squared (η^2p). This analysis was first performed with three separate groups: control, fully assisted, and partially assisted. A second analysis was then conducted after merging the two assisted groups into a single intervention group to compare them directly with the control group. The variables included were sprint performance outcomes (regular 30-m and assisted 30-m sprint times) and spatiotemporal variables in both sprint conditions (step length, step frequency, contact time, and flight time). Within-group comparisons were evaluated using paired-samples t-tests to identify significant pre-to-post changes within each group and to compare assisted vs. regular sprint conditions at the same time point. Significant pre-to-post differences are marked with an asterisk (*), while differences between assisted and regular sprint conditions are marked with a hash symbol (#) in the tables. These t-tests were complementary to the two-way repeated-measures ANOVA, providing additional clarity on specific pairwise effects.

The independent-samples t test was used to compare the pretest, posttest, and change scores between responders and nonresponders (Δ = post – pre) for both performance and spatiotemporal variables. The performance comparisons included regular and assisted 30-m sprint times, and the spatiotemporal comparisons included step length, step frequency, ground contact time, and flight time during both regular and assisted sprinting. Within-group comparisons between regular and assisted sprinting for the same variables were conducted. A p value < 0.05 was considered to be significant. Effect sizes are reported using Cohen's d, and 95 % CI were calculated where appropriate. Welch's correction was applied when the variances were unequal.

The independent-samples t test was used to compare baseline F-V variables between responders and nonresponders. The analysis included F_0, V_0, Pmax, RFmax, DRF and the slope of the F-V relationship, which were calculated for the regular sprint runs. Effect sizes are reported using Cohen's d, and Welch's correction was applied when the assumptions of equal variances were violated.

3. RESULTS AND DISCUSSION

3.1. Reliability and validity of sprint performance using the Alex7 motorized device

3.1.1. Reliability of the Alex7 device in resisted and assisted conditions

The descriptive statistics for the between-session comparison during the resisted and assisted running split times using the Alex7 are presented in Table 3.1. Running times measured with the Alex7 demonstrated good to excellent test-retest reliability (ICC, 0.83–0.94) in both assisted and resisted conditions. The reliability of the split time tended to be lower in the first part of the course (ICCs of 0.83–0.86 for 0–10 m) in both assisted and resisted conditions. The CV was 0.80–1.43%, and the SEM was 0.01–0.05 s for the time intervals independent of the running condition. In contrast to the other variables, the split time for 10–20 m in the resisted condition improved significantly and consistently from the first testing session to the retest ($p < 0.001$). Notably, this improvement was accompanied by a similar level of reliability as that for the other markers assessed. In addition, Bland-Altman analyses showed no significant systematic bias between repeated measurements except for the 10–20 m split time in the resisted condition ($p < 0.001$, Figure 3.1). The narrow range of limits of agreement on the Bland-Altman plot indicates high stability and low variation between test occasions. Repeatability for most measures was within the 95 % CI.

Table 3.1 Between-session reliability of the Alex7 outcome time and OptoJump kinematic variables

	Test (mean ± SD)	Retest (mean ± SD)	Mean difference ± SD	p =	ICC	ICC (95% CI)	CV (%)	SEM (s)
Running splits								
R 0 – 10 m	2.13 ± 0.09	2.13 ± 0.09	-0.002 ± 0.053	0.890	0.83*	[0.64 to 0.93]	1.24	0.03
R 10 – 20 m	1.65 ± 0.07	1.63 ± 0.07	0.022 ± 0.023	< 0.001	0.92*	[0.53 to 0.98]	1.12	0.02
R 20 – 30 m	1.62 ± 0.08	1.61 ± 0.10	0.007 ± 0.040	0.444	0.90*	[0.77 to 0.96]	1.40	0.02
R 0 – 30 m	5.39 ± 0.24	5.37 ± 0.25	0.027 ± 0.081	0.131	0.94*	[0.86 to 0.98]	0.85	0.05
A 0 – 10 m	1.77 ± 0.08	1.76 ± 0.07	0.013 ± 0.044	0.167	0.83*	[0.63 to 0.92]	1.43	0.03
A 10 – 20 m	1.25 ± 0.05	1.25 ± 0.04	0.003 ± 0.025	0.573	0.86*	[0.70 to 0.94]	0.95	0.01
A 20 – 30 m	1.18 ± 0.05	1.17 ± 0.04	0.006 ± 0.016	0.105	0.94*	[0.85 to 0.97]	0.80	0.01
A 0 – 30 m	4.21 ± 0.18	4.18 ± 0.15	0.022 ± 0.077	0.188	0.88*	[0.74 to 0.95]	1.01	0.04
Kinematic variables								
R Contact time (s)	0.15 ± 0.01	0.15 ± 0.01	-0.002 ± 0.005	0.066	0.88*	[0.73 to 0.95]	2.16	0.00
R Flight time (s)	0.09 ± 0.01	0.09 ± 0.01	0.001 ±0.007	0.596	0.79*	[0.56 to 0.91]	3.93	0.00
R Stride length (m)	3.18 ± 0.14	3.25 ± 0.16	0.069 ± 0.094	0.003	0.74*	[0.31 to 0.90]	1.74	0.06
R Pace (step/s)	4.17 ± 0.20	4.13 ± 0.23	0.044 ±0.127	0.116	0.82*	[0.61 to 0.92]	1.72	0.07
A Contact time (s)	0.12 ± 0.01	0.12 ± 0.01	0.000 ± 0.006	0.951	0.85*	[0.66 to 0.93]	2.82	0.00
A Flight time (s)	0.11 ± 0.01	0.11 ± 0.01	0.003 ± 0.006	0.079	0.79*	[0.55 to 0.91]	3.41	0.00
A Stride length (m)	4.13 ± 0.18	4.19 ± 0.20	0.059 ±0.090	0.005	0.85*	[0.57 to 0.94]	1.40	0.06
A Pace (step/s)	4.28 ± 0.23	4.23 ± 0.22	0.044 ± 0.128	0.124	0.83*	[0.63 to 0.93]	1.70	0.07

Notes: ICC, interclass correlation coefficient (* $p < 0.001$); CI, confidence interval; CV, coefficient of variation; SEM, standard error of the mean; R, running with resistance; A, running with assistance.

Stride length differed between the two testing sessions for both the resisted and assisted sprints ($p < 0.05$, Table 3.1) but not for other kinematic variables. Almost all kinematic variables showed good test–retest reliability (ICC, 0.79–0.88), except for a moderate value for stride length (ICC, 0.74) in the resisted sprint and an excellent value for running speed in the assisted sprint (ICC, 0.94). In general, the ICCs for almost all variables were slightly higher in the assisted than the resisted sprints.

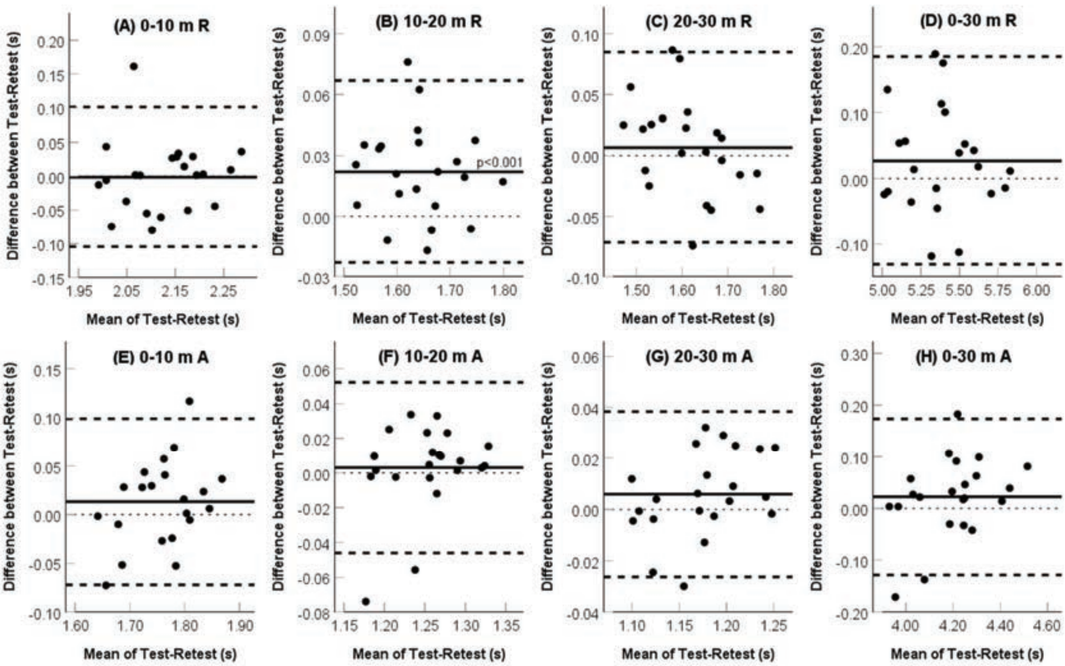


Figure 3.1 Bland–Altman analysis of test–retest sprint times derived from Alex7

Notes: The plot differences were obtained by subtracting the retest value from the test value. Thick black solid line – mean difference between the two tests; thick black dashed lines – 95 % limits of agreement; thin black dashed line – zero value.

3.1.2. Validity of the Alex7 in resisted and assisted conditions.

All split times in the resisted sprints and all split times except the first (0–10 m) in the assisted sprint had excellent Pearson's correlation coefficient values ($r = 0.90$–0.98, $p < 0.001$; Table 3.2) between the Alex7 and Witty equipment. The first 10-m assisted running time had a slightly lower but still a good value ($r = 0.88$, $p < 0.001$). However, the Alex7 consistently recorded longer running times compared to the Witty device (up to a 0.16 s difference, CV, 1.00–3.79 %, $p < 0.001$). Furthermore, there was a negative bias between both pieces of equipment for both conditions ($p < 0.001$; Figure 3.2), except for the 0-10 m split time in the resisted run. Still, sprint time remains within a narrow range of limits of agreement on the Bland-Altman plot, and repeatability for most measures was within the 95 % CI. These data suggest that the Alex7 system is consistent but is not as accurate for measuring sprint time. The time differences between the two types of equipment were slightly smaller for assisted (range, 0.03–0.11 s) than for resisted (range, - 0.01 to 0.16 s) sprinting.

Table 3.2 Within-session criterion-referenced validity for the Alex7

Conditions	**Distance**	**Sprint time (Mean ± SD)**		**p**	**ES**	**Criterion-referenced validity**		
		Witty (s)	Alex7 (s)		Cohen's d	t(diff) (s)	CV (%)	Cor. (r)
Resisted	0–10 m	2.13 ± 0.09	2.13 ± 0.10	0.373	0.178	–0.01	1.00	0.92*
	10–20 m	1.57 ± 0.08	1.65 ± 0.09	<0.001	-2.655	0.09	3.79	0.93*
	20–30 m	1.54 ± 0.09	1.62 ± 0.10	<0.001	-2.609	0.08	3.73	0.94*
	0–30 m	5.23 ± 0.25	5.40 ± 0.28	<0.001	-2.678	0.16	2.14	0.98*
Assisted	0–10 m	1.73 ± 0.08	1.78 ± 0.08	<0.001	-1.122	0.05	1.93	0.88*
	10–20 m	1.22 ± 0.05	1.26 ± 0.06	<0.001	-1.307	0.03	1.84	0.90*
	20–30 m	1.14 ± 0.06	1.18 ± 0.06	<0.001	-1.643	0.04	2.25	0.93*
	0–30 m	4.09 ± 0.18	4.21 ± 0.19	<0.001	-2.223	0.11	1.93	0.97*

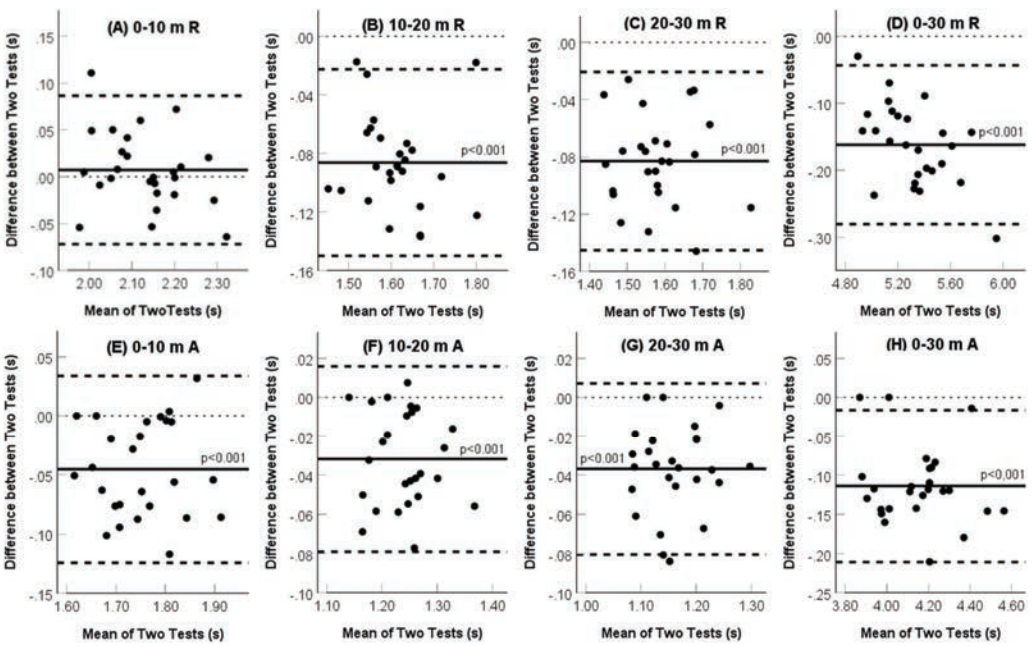


Figure 3.2 Bland–Altman analysis of sprint time differences between Alex7 and Witty

Notes: The plot differences were obtained by subtracting the Alex7 test value from the Witty test value. Thick black solid line – mean difference between the two tests; thick black dashed lines – 95 % limits of agreement; thin black dashed line – zero value.

3.1.3. Performance and Kinematic Differences Between Sprint Conditions

The mean running speed differed between three sprint conditions: 8.17 ± 0.39 m/s in the regular run, 6.59 ± 0.35 m/s in the resisted run ($p < 0.001$), and 8.65 ± 0.44 m/s ($p < 0.05$) in the assisted run. All kinematic variables investigated (Figure 3.3 A–D) differed between the sprint conditions. The largest differences were observed for stride length and ground contact time ($p < 0.001$ for each). The smallest differences were for flight time and running pace. The running flight time and pace did not differ between the regular and assisted runs but differed significantly between the regular and resisted sprints, and between the resisted and assisted sprints ($p < 0.001$ for each). All variables showed a greater absolute difference between the resisted and regular sprints than between the assisted and regular sprints.

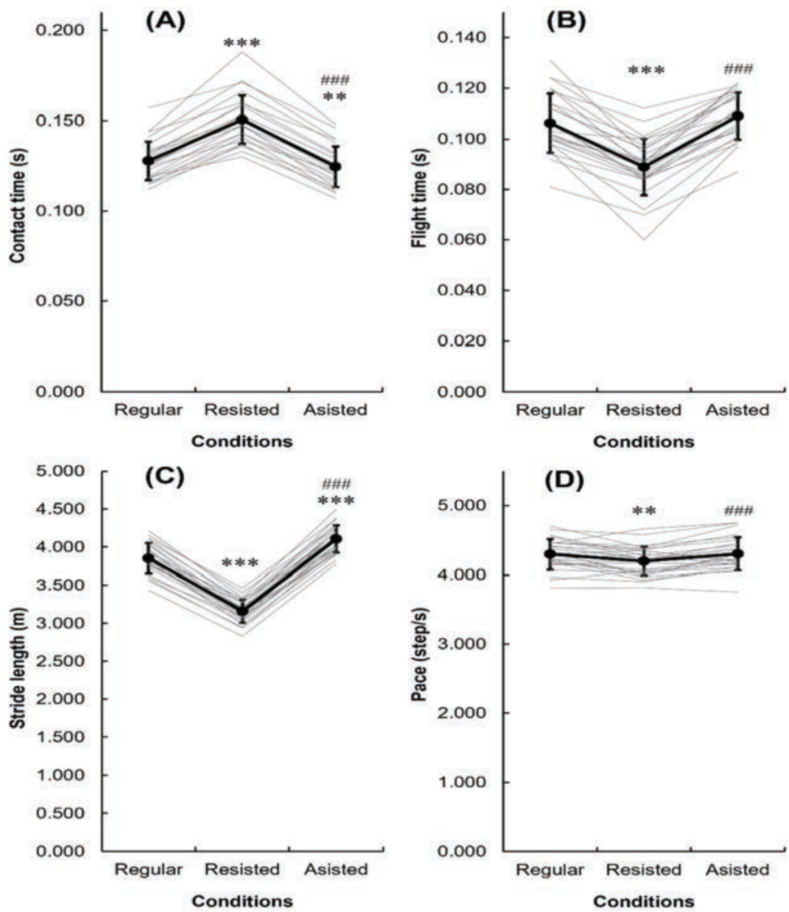


Figure 3.3 The (A) contact time, (B) flight time, (C) stride length, and (D) pace for the regular, resisted, and assisted sprints (mean ± SD and individual data)

Notes: Significantly different from regular sprints (** $p < 0.01$, *** $p < 0.001$). Significantly different from resisted sprints (### $p < 0.001$).

3.1.4. Discussion of the 1st study

The reliability and validity of measurements obtained using the new Alex7 motorized sprint device were investigated to determine whether and how speed and kinematic characteristics differ between assisted and resisted sprints. The primary finding is that the Alex7 device offers reliable measures of sprint performance in both resisted and assisted conditions. However, it is important to note that the Alex7 consistently overestimated running times compared to the Witty device. This overestimation may result from various factors, including differences in measurement methodologies or the specific mechanics of the Alex7 device. Despite this limitation, the Alex7's ability to deliver consistent results highlights its utility for manipulating the load during athlete training. Future research should aim to better understand the causes of the Alex7's running time overestimation and explore methods to mitigate this issue.

In the context of load management, the use of incline, decline, sleds, bungees, and pulleys serves helps to induce the acute effects of overload- or unloaded-assisted stimulation (20), whereas motorized devices such as Alex7 are designed specifically to offer a higher degree of accuracy in load management compared with other devices. The reliability values of the 30-m sprint run time and the split times for each 10 m (ICC, 0.83–0.90) obtained during the resisted running mode with the Alex7 were found to be similar to the within-session reliability values reported by Rakovic et al. (Rakovic et al., 2022) for the 1080 Sprint device (ICC, 0.81–0.95). Rakovic et al. (2022) showed that the split time for the initial 5 m was the least reliable measurement (ICC, 0.81), indicating less reliability for use with short accelerations. In the present study, this finding was partially replicated using a running distance of 10 m instead of 5 m, yielding an ICC of 0.83. Assisted running was also examined and compared with resisted running, showing a similar trend. That is, the lowest reliability value (ICC, 0.83) was obtained for distances of 10 m, whereas medium reliability values were recorded for the 10-m and 20-m split times and total distance of 30 m (ICC = 0.86 and 0.88, respectively). Notably, the highest reliability value was achieved for the 20–30-m split time (ICC = 0.94), all of which had acceptable reliability when used with the new device for facilitating speed training with assisted running.

The Alex7 can provide both contrasting loads and a high variety in magnitude as well as the opportunity to monitor performance and progress. Compared with the Witty timing gates, which were used as the gold standard in this study, the Alex7 device showed strong associations (r = 0.88) for the 10-m split time in the assisted run, and the other correlations for the assisted runs and all correlation values for the resisted runs were nearly perfect (r = 0.90–0.98). Different results were observed for the 1080 Sprint device in the resisted running mode (Rakovic et al., 2022). Nearly perfect validity was found for the 20–30-m split time and the overall 30-m time, but the other correlation values ranged from r = 0.57 to r = 0.83. These differences in validity between the Alex7 and 1080 Sprint devices may reflect differences in the data collection. For example, unstable results were observed for the first 0.7 m due to the participants' inconsistent starting patterns. After being told to prepare for the run, some participants were unable to remain in the static starting position, and their in-place movement started timing before the actual run began. Removing the results of the first 0.7 m eliminated this inaccuracy and produced higher validity values for the first 10 m.

Real-time values from the Alex7 device should be used cautiously because they were significantly longer than those obtained from the Witty timing gates. A consistent discrepancy was observed across all distances, except for the initial split during resistive runs, where no such disparity was noted. This disparity may be attributed to limitations imposed by the Alex7 device in terms of time recording. The controller calculates the distance travelled in meters by multiplying the current number of revolutions (encoder pulses) by circumference. A random error in the calculated length may occur because of differences in the tightness with which the rope was wound on the spool between the assisted and resisted runs and the rope elasticity (although < 1 %). After completion of the resisted run, the rope was recoiled freely back to its starting position, and during the assisted run, the athlete created a resistance for the servomotor and the rope was wrapped tensely around the spool.

It is important that the new Alex7 device may produce meaningful differences in the kinetics and kinematics parameters between assisted and resisted running conditions. The effects on running speed and kinematics depend on the magnitude of the resistance or assistance. The 6-kg (~ 60 N) assistance in the present study caused significant changes in stride length (6.75 %), ground contact time (- 7.69 %), and running speed (6.74 %). The running pace and flight time did not differ significantly between the regular and assisted runs. Similar findings have been reported by Cecilia-Gallego et al. (Cecilia-Gallego et al., 2022). In the study by Van Den Tillaar et al. (Van Den Tillaar, 2018), the 5-kg assistance provided by the motorized DynaSpeed device produces a 5.1 % increase in speed, but the running pace did not differ between the assisted and unloaded sprints. In another study that used a load of 4.7 % of body weight, running speed increased by 6.1 %, but the running flight time did not differ significantly (Clark et al., 2009). In another study, use of a pulling device decreased the contact time by 7.69 % (Sedláček et al., 2004). The data for the current study suggested that the 6-kg force used for assistance was sufficient to achieve the required effects of overspeed running without interfering with the running technique.

The resistance of 10 % of body mass was enough to meaningfully reduce all the running parameters. Compared with the regular sprint, resisted sprinting caused larger changes in running parameters than assisted running. A previous study showed that a resistance of 5 % of body mass elicits significant changes in running speed and stride length but that 15 % of body mass resistance is needed to change stride frequency (Martínez-Valencia et al., 2014). Given that the motorized device provides greater resistance (by eliminating the inertia) than a sled of the same weight and that 10–20 % of body mass resistance provided by the motorized device can induced greater decreases in speed (13–28%) compared with a weighted sled with the same weight (7.5–20 %) (Van den Tillaar, 2020), it was not surprising that the resistance of 10 % body weight sufficient enough to significantly decrease (by 2.33 %; $p < 0.01$) running pace and running speed (by 19.98 %; $p < 0.001$). We note that the participants were non-elite and young (16–17-year-old) football players with no experience in resisted or assisted running. They completed one familiarization session, and this was sufficient to produce high reliability while not altering the running technique. An exception was observed with the split time for 10–20 m in the resisted condition, which improved consistently from the first to the second testing session, indicating a possible need for additional familiarization. Overall, it appears that the Alex7 technology is simple to learn and use in both resisted and assisted training settings, which is important for practitioners.

This study includes several limitations, mainly due to logistical reasons. There is no direct comparison of the Alex7 with well-established systems such as 1080 Sprint or Dynaspeed, which means we lack confirmation that the resistance or assistance is comparable to other similar systems. It would be better to compare timing data with laser systems, which are more accurate than Witty timing gates as they do not rely on cutting light beams with the upper body, making them better suited as gold standards. Finally, only young males were tested, making it unclear whether age, gender, or sport could influence the results. It is reasonable to expect that greater maturity and sprint experience might have positively affected the results.

3.2. Lower limb muscle activity under full and partial towing assistance in sprint running

3.2.1. Spatiotemporal Parameters

Firstly, finish times in the 30 m run were significantly faster in the two assisted running conditions than in the unassisted running condition (fully assisted vs. unassisted - 2.8 %, $p < 0.01$; partially assisted vs. unassisted - 3.4 %, $p < 0.001$) (Figure 3.4). For spatiotemporal parameters, significant differences were found between unassisted running and both assisted running conditions, but not between the fully and partially assisted conditions.

In the stride retained for analysis, faster running speed in both assisted running conditions resulted from significantly higher stride length and flight time compared with the unassisted running condition (fully assisted vs. unassisted: stride length + 8.6 %, $p < 0.001$, flight time + 7.7 %, $p < 0.05$; partially assisted vs. unassisted: stride length + 8.9 %, $p < 0.001$, flight time + 7.8 %, $p < 0.01$) (Figure 3.4). and significantly shorter contact time (fully assisted vs. unassisted: contact time - 4.9 %, $p < 0.05$; partially assisted vs. unassisted: contact time - 6.9 %, $p < 0.01$) (Figure 3.4) By contrast, no differences between any conditions were found for stride frequency. The duty factor was significantly higher in the unassisted running condition than in both assisted running conditions (fully assisted vs. unassisted - 5.5 %, $p < 0.05$; partially assisted vs. unassisted - 6.4 %, $p < 0.01$).

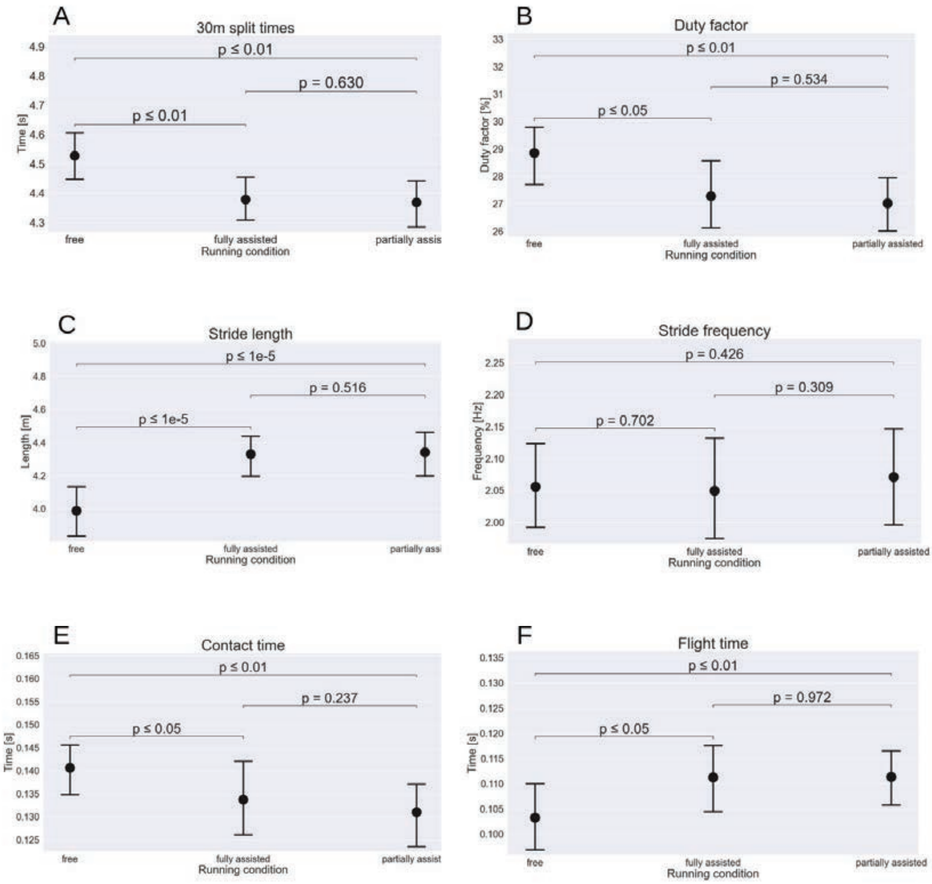


Figure 3.4 (A) thirty-meter split times, (B) duty factor, (C) stride length, (D) stride frequency, (E) contact time and (F) flight time for the unassisted, fully assisted, and partially assisted conditions. Data are presented as mean ± SD

3.2.2. Kinematics

The joint angle of the ankle was discarded from further analysis because of insufficient data quality. For the knee and hip joint angles, no significant differences were found between any conditions (p > 0.05) (Figure 3.5).

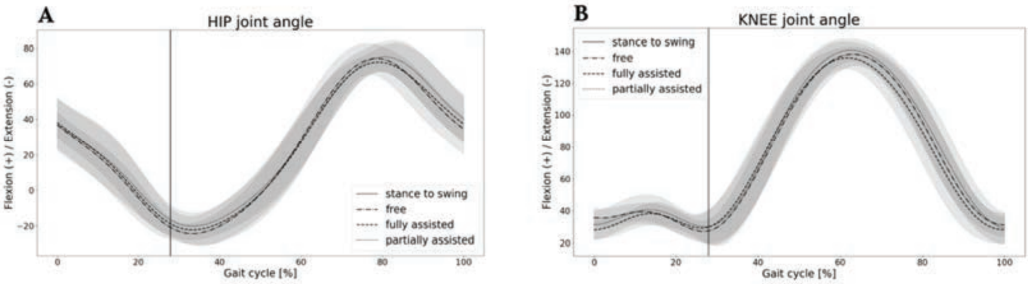


Figure 3.5 (A) hip joint and (B) knee joint angles during the gait cycle. No significant differences were found between any conditions. 0 % = initial contact, 100 % = next ipsilateral initial contact

3.2.3 Electromyography Results

For all measured muscles (biceps femoris, semitendinosus, vastus lateralis, rectus femoris, gluteus maximus), there were no statistically significant differences in mean activation between the unassisted, partially assisted, and fully assisted sprinting conditions (p > 0.05, Figure 3.6). However, given the high inter-individual variability, complementary effect size analysis revealed muscle-dependent differences at discrete points of the gait cycle.

Across conditions, both biceps femoris and semitendinosus peaked during late swing, consistent with their role in limb deceleration prior to foot contact; correspondingly, large effect sizes were observed for biceps femoris during swing (40–44 % of the gait cycle; d > 0.8; assisted < unassisted), while semitendinosus showed a large effect at 88 % (d = 0.8; fully assisted > unassisted) and a near-large effect at 98 % (d = 0.77; partially assisted > unassisted). In parallel, rectus femoris exhibited the most pronounced and temporally extended differences, with large effects from mid-stance to toe-off (20–28 %; d > 0.8, max = 1.35; fully assisted > unassisted) that continued into mid-swing, peaking between 49 % and 57 % (d > 0.8, max = 1.25; unassisted > fully assisted). By contrast, although rectus femoris and gluteus maximus displayed relatively flat activation profiles across the gait cycle, vastus lateralis peaked early in stance and showed a moderate-to-large effect prior to initial contact (91–92 %; d = 0.75; fully assisted > unassisted), while gluteus maximus demonstrated moderate-to-large effects at mid-swing (70 %; d = 0.7; fully assisted > unassisted) and moderate effects at initial contact (10 %; d > 0.6; partially assisted > fully assisted). Taken together, these results indicate muscle-specific, brief, and phase-dependent differences concentrated around late swing and stance transitions, despite no significant differences in mean activation across conditions.

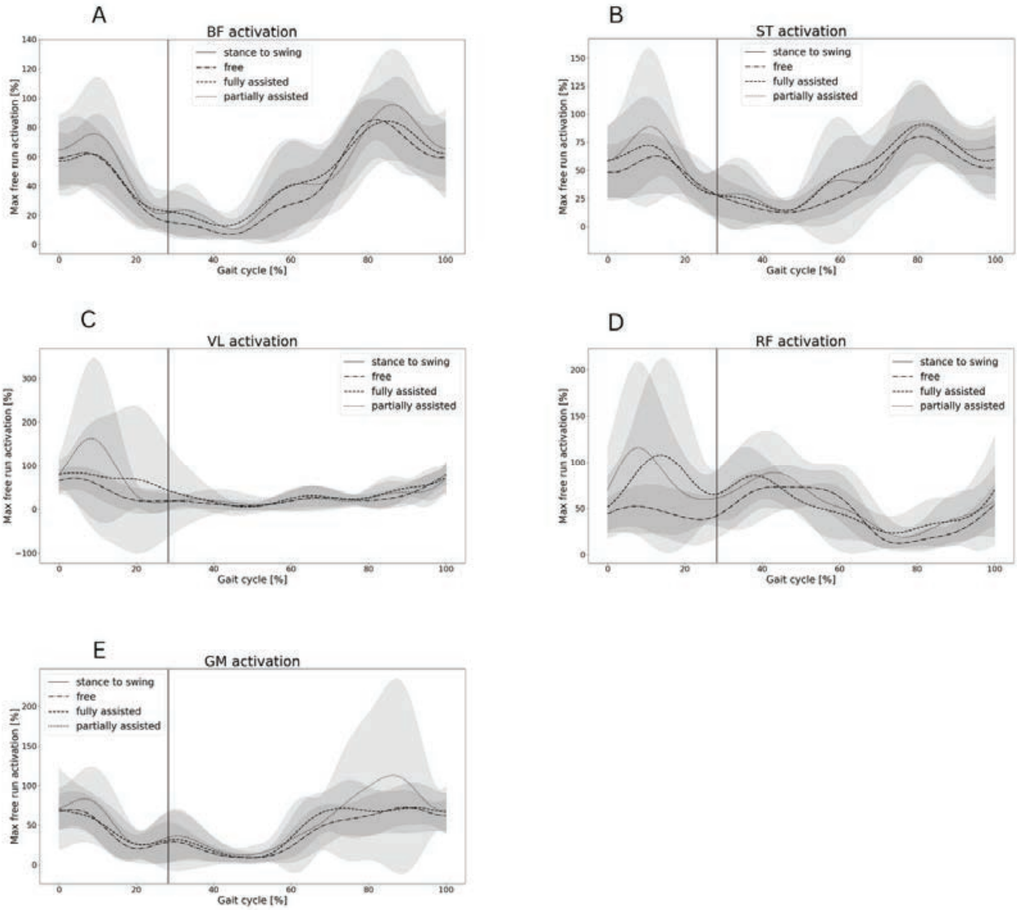


Figure 3.6 EMG activity of (A) biceps femoris, (B) semitendinosus, (C) vastus lateralis, (D) rectus femoris and € gluteus maximus during the gait cycle. Data are presented as mean ± SD across participants. 0 % = initial contact, 100 % = next ipsilateral initial contact

3.2.4. Discussion of the 2nd study

The main aim of this study was to compare lower-limb muscle activation, spatiotemporal parameters, and kinematics across unassisted, partially assisted, and fully assisted sprinting conditions. Contrary to our initial hypothesis, no statistically significant differences were found in muscle activation between the fully and partially assisted conditions. Furthermore, muscle activity in the assisted conditions did not differ significantly from unassisted sprinting across the measured muscles despite changes in running speed, stride length, and contact and flight time. At the same time, effect size analysis identified muscle-specific differences at distinct phases of the gait cycle in both assisted and unassisted conditions, highlighting meaningful patterns that were not apparent from group averages alone. These findings suggest that neuromuscular responses increase with speed up to maximal levels and then plateau at maximal speeds, with phase-specific momentary differences emerging, particularly during swing and stance transitions, and indicate that assisted sprinting was not associated with a reduction in active propulsion despite the potential contribution of passive assistance.

Previous studies have consistently shown increases in muscle activity from submaximal to maximal sprinting speeds (Higashihara et al., 2010; Kyröläinen et al., 2005). However, our protocol included only maximal and supramaximal sprints, omitting submaximal conditions. This may explain why, in general, further increases in muscle activity were not observed, although momentary increases were recorded at some phases and were muscle-dependent. Our results align with earlier findings by Mero and Komi (Mero & Komi, 1987), who also reported that EMG activity plateaus at supramaximal speeds. These results suggest that while neuromuscular demand increases with speed up to a point, it does not necessarily continue to rise under external towing once maximal velocities are exceeded. However, it is also possible that the lack of prior experience with assisted sprinting limited participants' ability to fully engage their neuromuscular system under these novel conditions.

Assisted sprinting may reduce the need for active propulsion by altering the external force demands placed on the athlete. As described by Eston et al. (Eston et al., 1995) in the context of downhill running, eccentric muscle loading can occur without proportional increases in EMG activity due to enhanced contributions from passive and elastic tissues. Similarly, in the present study, the external towing force may have allowed athletes to reach supramaximal speeds without requiring greater neuromuscular output, particularly during the propulsive phase. In this context, it is no surprise that only momentary differences were observed between partially and fully assisted conditions, as these are more similar to each other than to the unassisted condition. Rather than substantial changes in overall activation levels, the muscle activity observed during late swing and early stance likely reflects the need to prepare for ground contact and manage impact forces, particularly the hamstrings, which are critical for stability and control during high-speed running (Chumanov et al., 2007; Mero & Komi, 1986). The finding that muscle activity did not significantly increase during assisted sprinting may be important from a safety standpoint; however, actual mechanical stress on muscles or joints, and the associated injury risk, cannot be inferred from EMG alone, as it reflects muscle activation but not the forces acting on bones, joints, or tissues.

From a spatiotemporal perspective, both assisted conditions led to significantly improved 30 m sprint times compared with the unassisted running condition. This improvement was driven primarily by increases in stride length, with no changes in stride frequency. These findings are consistent with prior research showing that assistance augments horizontal displacement more than step turnover (Clark et al., 2009). Flight time was significantly longer in both assisted conditions, while contact time was significantly shorter. The longer flight time and shorter contact time suggest higher vertical impulses and potentially increased leg stiffness during assisted sprinting. Despite these spatiotemporal changes, joint kinematics in the hip and knee remained unchanged between conditions, suggesting that athletes maintained similar segmental coordination patterns. The stability of joint angles across conditions implies that the observed performance enhancements occurred without major alterations to overall running technique.

High inter-individual variability should be considered when interpreting the findings of this study, as meaningful group-level effects may have been obscured, thereby reducing the statistical power to detect moderate changes in muscle activation. The large standard deviations within each condition indicate that athletes responded differently to the assisted sprinting stimulus, likely due to variations in individual technique or familiarity with towing. Although all participants were familiar with sprinting, they had not previously been exposed to assisted sprinting; thus, the present results likely reflect responses to an initial exposure rather than a well-learned technique. Furthermore, only a single stride per condition (the last complete stride before the 30 m mark) was analyzed at (supra)maximal speed, which may limit the generalizability of the EMG and kinematic findings to the entire maximal-speed phase. Additionally, the study focused on a 30 m sprint for practical feasibility in sports settings, whereas a longer distance could have enabled a more extended period of independent supramaximal running, allowing analysis of multiple strides and more robust EMG assessment. Finally, the inclusion of force plate analysis would provide valuable insight into ground reaction forces and their relationship with muscle activity patterns. Future studies involving athletes well adapted to assisted sprinting are warranted to determine whether specific individuals or muscle groups exhibit consistent neuromuscular adaptations to this type of training.

3.3. Assisted sprint training: individual adaptations linked to force-velocity profiles and spatiotemporal variables

3.3.1. Fully vs. Partially Assisted Sprint Performance

At baseline, there were no significant differences between the control group, fully assisted and partially assisted groups for any sprint time or spatiotemporal variable (all $p > .05$) (Table 3.3). When running with assistance, 30-meter sprint times were reduced by 5.02 % in the control group, 5.8 % in the fully assisted group, and 3.83 % in the partially assisted group. These improvements were significant when comparing assisted to regular sprinting within each group ($p < .05$), but no significant differences were found between the groups ($p > .05$).

The faster assisted sprint times were primarily driven by changes in spatiotemporal mechanics. All groups demonstrated increased step length during assisted running, while flight time increased in both the control and fully assisted groups. Additionally, the control group exhibited a significant reduction in ground contact time during assisted sprints ($p < .05$).

For the assisted sprint, a two-way ANOVA (Group × Time) with repeated measures on Time revealed a significant interaction, $F(2, 21) = 6.07$, $p = .01$, $\eta^2p = .37$ (Table 3.3). Post-hoc tests showed that sprint times remained stable in the control group (pre: 4.16 ± 0.21 s; post: 4.15 ± 0.21 s), whereas the fully assisted group and partially assisted group improved significantly (pre: 4.22 ± 0.16 s; post: 4.13 ± 0.21 s for fully and pre: 4.26 ± 0.14 s; post 4.08 ± 0.17 s for partially). A main effect of Time was observed, $F(1, 21) = 23.40$, $p = .01$, $\eta^2p = .53$, while the main effect of Group was not significant, $F(2, 22) = 0.03$, $p = .98$, $\eta^2p = .00$. There were no significant differences between the fully and partially assisted conditions.

For regular sprint times, a two-way ANOVA (Group × Time) revealed a significant interaction, $F(2, 21) = 6.26$, $p = .01$, $\eta^2p = .37$ (Table 3.3). The control group showed a trend toward slower times from pre- (4.38 ± 0.20 s) to post-test (4.48 ± 0.18 s, $p > .05$), whereas the fully assisted group and a partially assisted group showed a trend toward improvement (pre: 4.48 ± 0.21 s; post: 4.43 ± 0.20 s ($p > .05$) for fully and pre: 4.43 ± 0.17 s; post: 4.38 ± 0.20 s ($p > .05$) for partially). No significant main effects were found for Time, $F(1, 21) = 0.01$, $p = .92$, $\eta^2p = .00$, or Group, $F(2, 21) = 0.15$, $p = 0.86$, $\eta^2p = .01$. There were no significant differences between the fully and partially assisted conditions.

Table 3.3 Two-way repeated measures ANOVA results for sprint performance, spatiotemporal, and device-derived variables in the control, fully assisted and partially assisted training intervention groups

Dependent Variable	Post-Hoc			Factor	df	F	p	η^2p
	Control	Fully assisted	Partially assisted					
Ass 30m (s)	Pre: 4.16 ± 0.21### Post: 4.15 ± 0.21	Pre: 4.22 ± 0.16### Post: 4.13 ± 0.21*	Pre: 4.26 ± 0.14### Post: 4.08 ± 0.17***	Group	2, 21	0.03	0.98	0.00
				Time	1, 21	23.40	0.00	0.53
				Group X Time	2, 21	6.07	0.01	0.37
Reg 30m (s)	Pre: 4.38 ± 0.20 Post: 4.48 ± 0.18*	Pre: 4.48 ± 0.21 Post: 4.43 ± 0.20	Pre: 4.43 ± 0.17 Post: 4.38 ± 0.20	Group	2, 21	0.15	0.86	0.01
				Time	1, 21	0.01	0.92	0.00
				Group X Time	2, 21	6.26	0.01	0.37
Step Length Ass (cm)	Pre: 213.1 ± 9.11### Post: 209.2 ± 12.33	Pre: 207.7 ± 7.18### Post: 205.9 ± 6.64	Pre: 213.9 ± 12.41## Post: 214.3 ± 10.03	Group	2, 21	1.62	0.22	0.13
				Time	1, 21	0.78	0.39	0.04
				Group X Time	2, 21	0.36	0.70	0.03
Step Frequency Ass (step/s)	Pre: 4.36 ± 0.14 Post: 4.40 ± 0.32	Pre: 4.43 ± 0.24 Post: 4.48 ± 0.22	Pre: 4.29 ± 0.29 Post: 4.36 ± 0.26	Group	2, 21	0.67	0.52	0.06
				Time	1, 21	1.84	0.19	0.08
				Group X Time	2, 21	0.02	0.98	0.00
Contact Time Ass (s)	Pre: 0.120 ± 0.00### Post: 0.120 ± 0.01	Pre: 0.126 ± 0.01 Post: 0.120 ± 0.01	Pre: 0.123 ± 0.01 Post: 0.120 ± 0.01	Group	2, 21	0.21	0.81	0.02
				Time	1, 21	2.94	0.10	0.12
				Group X Time	2, 21	1.04	0.37	0.09
Flight Time Ass (s)	Pre: 0.110 ± 0.009## Post: 0.109 ± 0.013	Pre: 0.101 ± 0.006## Post: 0.104 ± 0.007	Pre: 0.112 ± 0.008 Post: 0.111 ± 0.007	Group	2, 21	3.24	0.06	0.24
				Time	1, 21	0.00	0.99	0.00
				Group X Time	2, 21	0.75	0.49	0.07

Dependent Variable	Post-Hoc			Factor	df	F	p	η^2p
	Control	Fully assisted	Partially assisted					
Step Length Reg (cm)	Pre: 194.7 ± 9.27 Post: 194.9 ± 9.81	Pre: 188.6 ± 7.55 Post: 186.8 ± 7.86	Pre: 195.2 ± 11.77 Post: 197.0 ± 11.40	Group	2, 21	2.00	0.16	0.16
				Time	1, 21	0.01	0.94	0.00
				Group X Time	2, 21	1.05	0.37	0.09
Step Frequency Reg (step/s)	Pre: 4.40 ± 0.16 Post: 4.36 ± 0.28	Pre: 4.48 ± 0.23 Post: 4.53 ± 0.21	Pre: 4.35 ± 0.23 Post: 4.35 ± 0.30	Group	2, 21	1.06	0.36	0.09
				Time	1, 21	0.03	0.86	0.00
				Group X Time	2, 21	0.50	0.61	0.05
Contact Time Reg (s)	Pre: 0.127 ± 0.005 Post: 0.129 ± 0.008	Pre: 0.128 ± 0.013 Post: 0.123 ± 0.010**	Pre: 0.126 ± 0.011 Post: 0.124 ± 0.009	Group	2, 21	0.20	0.82	0.02
				Time	1, 21	1.25	0.28	0.06
				Group X Time	2, 21	3.89	0.04	0.27
Flight Time Reg (s)	Pre: 0.101 ± 0.008 Post: 0.102 ± 0.012	Pre: 0.096 ± 0.007 Post: 0.099 ± 0.008	Pre: 0.105 ± 0.012 Post: 0.107 ± 0.012	Group	2, 21	1.73	0.20	0.14
				Time	1, 21	1.25	0.28	0.06
				Group X Time	2, 21	0.12	0.89	0.01

Notes: Data are presented as mean ± SD. Spatiotemporal variables were measured at maximal speed. * Indicates a significant pre-to-post difference within a group ($p < .05$). # Indicates a significant difference when the comparison is between same variables in regular and assisted run ($p < .05$). F-values, p-values, and partial eta squared (η^2p) are provided for the main effects (Group, Time) and their interaction (Group × Time).

Two-way repeated-measures ANOVA revealed significant Group × Time interactions for regular-sprint contact time ($F(1, 21) = 3.89$, $p = .04$, $\eta^2p = .27$), indicating different pre–post trajectories between groups (Table 3.3). No significant main effects were found for Time, $F(1, 21) = 1.25$, $p = .28$, $\eta^2p = .06$, or Group, $F(2, 21) = .20$, $p = .82$, $\eta^2p = .02$. However, only fully assisted group had a significant decrease in contact time from pre: 0.128 ± 0.01 and post: 0.123 ± 0.01, $p < 0.01$. No interaction, time or group effects were observed between the fully and partially assisted conditions at post-training in any other time or spatiotemporal variable (Table 3.3).

3.3.2. Combined intervention and control group comparison

At baseline, there were no significant differences between the intervention and the control groups at any time or spatiotemporal variable (all $p > 0.05$) (Table 3.4).

For the assisted sprint, a two-way ANOVA (Group × Time) with repeated measures on the Time Factor revealed a significant interaction, $F(1, 22) = 7.55$, $p = .01$, $\eta^2p = .26$ (Table 3.4). Post-hoc tests showed that sprint times remained stable in the control group (pre: 4.16 ± 0.21 s; post: 4.15 ± 0.21 s), whereas the training group improved significantly (pre: 4.24 ± 0.15 s; post: 4.10 ± 0.19 s). A main effect of Time was observed, $F(1, 22) = 10.12$, $p < .01$, $\eta^2p = .32$, while the main effect of Group was not significant, $F(1, 22) = 0.05$, $p = .83$, $\eta^2p = .00$.

Table 3.4 Two-way repeated measures ANOVA results for assisted and regular sprint performance and spatiotemporal variables in the control and intervention groups

Dependent Variable	Post-Hoc		Factor	df	F	p	η^2_p
	Control:	Intervention:					
Ass 30m (s)	Pre: 4.16 ± 0.21	Pre: 4.24 ± 0.15	Group	1, 22	0.05	0.83	0.00
	Post: 4.15 ± 0.21	Post: 4.10 ± 0.19***	Time	1, 22	10.12	0.01	0.32
			Group X Time	1, 22	7.55	0.01	0.26
Reg 30m (s)	Pre: 4.38 ± 0.20	Pre: 4.46 ± 0.19	Group	1, 22	0.00	0.97	0.00
	Post: 4.48 ± 0.18*	Post: 4.41 ± 0.20*	Time	1, 22	1.71	0.21	0.07
			Group X Time	1, 22	13.08	0.00	0.37
Step Length Ass (cm)	Pre: 213.1 ± 9.11	Pre: 210.6 ± 10.17	Group	1, 22	0.05	0.82	0.00
	Post: 209.2 ± 12.33	Post: 209.9 ± 9.20	Time	1, 22	1.18	0.29	0.05
			Group X Time	1, 22	0.55	0.47	0.02
Step Frequency Ass (step/s)	Pre: 4.36 ± 0.14	Pre: 4.36 ± 0.27	Group	1, 22	0.02	0.90	0.00
	Post: 4.40 ± 0.32	Post: 4.42 ± 0.24	Time	1, 22	1.46	0.24	0.06
			Group X Time	1, 22	0.03	0.86	0.00
Contact Time Ass (s)	Pre: 0.120 ± 0.004	Pre: 0.124 ± 0.013	Group	1, 22	0.30	0.59	0.01
	Post: 0.120 ± 0.008	Post: 0.120 ± 0.010*	Time	1, 22	1.46	0.24	0.06
			Group X Time	1, 22	1.46	0.24	0.06
Flight Time Ass (s)	Pre: 0.110 ± 0.009	Pre: 0.106 ± 0.009	Group	1, 22	0.66	0.43	0.03
	Post: 0.109 ± 0.013	Post: 0.107 ± 0.008	Time	1, 22	0.04	0.84	0.00
			Group X Time	1, 22	0.51	0.48	0.02
Step Length Reg (cm)	Pre: 194.7 ± 9.27	Pre: 191.7 ± 10.04	Group	1, 22	0.51	0.49	0.02
	Post: 194.9 ± 9.81	Post: 191.6 ± 10.73	Time	1, 22	0.00	0.97	0.00
			Group X Time	1, 22	0.01	0.93	0.00

Dependent Variable	**Post-Hoc**		**Factor**	**df**	**F**	**p**	**η^2_p**
	Control:	**Intervention:**					
Step Frequency Reg (step/s)	Pre: 4.40 ± 0.16 Post: 4.36 ± 0.28	Pre: 4.42 ± 0.23 Post: 4.45 ± 0.27	Group	1, 22	0.24	0.63	0.01
			Time	1, 22	0.01	0.94	0.00
			Group X Time	1, 22	0.66	0.43	0.03
Contact Time Reg (s)	Pre: 0.127 ± 0.005 Post: 0.129 ± 0.008	Pre: 0.127 ± 0.012 Post: 0.124 ± 0.009*	Group	1, 22	0.40	0.53	0.02
			Time	1, 22	0.05	0.83	0.00
			Group X Time	1, 22	6.36	0.02	0.22
Flight Time Reg (s)	Pre: 0.101 ± 0.008 Post: 0.102 ± 0.012	Pre: 0.100 ± 0.010 Post: 0.102 ± 0.011	Group	1, 22	0.00	0.99	0.00
			Time	1, 22	0.81	0.38	0.04
			Group X Time	1, 22	0.21	0.66	0.01

Notes: Data are presented as mean ± SD. Ass = assisted sprint condition; Reg = regular (unassisted) sprint condition. Spatiotemporal variables were measured at maximal speed. * Indicates a significant pre-to-post difference within a group ($p < .05$). F-values, p-values, and partial eta squared ($\eta^2 p$) are provided for the main effects (Group, Time) and their interaction (Group × Time).

For regular sprint times, a two-way ANOVA (Group × Time) revealed a significant interaction, $F(1, 22) = 13.08$, $p < .01$, $\eta^2p = .37$ (Table 3.4). The control group showed significantly slower times from pre- (4.38 ± 0.20 s) to post-test (4.48 ± 0.18 s, $p > 0.05$), whereas the training group showed a trend toward improvement from 4.46 ± 0.19 s to 4.41 ± 0.20 s ($p > .05$). No significant main effects were found for Time, $F(1, 22) = 1.71$, $p = .21$, $\eta^2p = .07$, or Group, $F(1, 22) = 0.00$, $p = .97$, $\eta^2p = .00$.

Two-way repeated-measures ANOVA revealed significant Group × Time interactions for regular-sprint contact time ($F(1,22) = 6.36$, $p = 0.02$, $\eta^2p = 0.22$), indicating different pre–post trajectories between groups. No significant main effects were found for Time, $F(1, 22) = .05$, $p = .83$, $\eta^2p = .00$, or Group, $F(1, 22) = .40$, $p = .53$, $\eta^2p = .02$. No interactions were observed for step length, step frequency, or flight time in the regular condition (all $p > .05$). For the assisted-run spatiotemporal measures, interactions were non-significant (all $p > .05$). However, paired comparisons (asterisks in Table 3.4) showed small but significant within-intervention decreases in regular and assisted contact times ($p < .05$).

3.3.3. High vs. Non-responder Comparison in time and spatiotemporal variables

Athletes in the intervention were retrospectively classified as high responders or non-responders based on the assisted 30-m improvement threshold. Independent-samples tests (Table 3.5) showed that high responders achieved substantially greater gains in the assisted 30-m sprint than non-responders at post-test ($p < .001$; large effect) and for the change score (Δ), also $p < .001$. For the regular 30-m sprint, post-intervention times were significantly faster in high responders ($p < .05$), while pre-test differences were non-significant. None of the spatiotemporal variables differed significantly between groups at pre, post, or for Δ (all $p > .05$).

Table 3.5 Comparison of performance and spatiotemporal variables between high responders and non-responders

Dependent Variable	Mean ± SD		t	df	p	Cohen's d
	Non-Responder:	**High Responder:**				
Ass 30m (s)	Pre: 4.27 ± 0.16$^{\#\#}$	Pre: 4.14 ± 0.09$^{\#\#}$	1.91	12	0.08	1.02
	Post: 4.23 ± 0.12	Post: 3.91 ± 0.09	5.87	12	< .001	3.14
	Δ: -0.04 ± 0.08	Δ: -0.23 ± 0.03	5.74	12	< .001	3.07
Reg 30m (s)	Pre: 4.52 ± 0.22	Pre: 4.33 ± 0.10	1.984	12	0.071	1.06
	Post: 4.48 ± 0.19	Post: 4.27 ± 0.13	2.374	12	0.035	1.269
	Δ: -0.04 ±0.09	Δ: -0.06 ± 0.08	0.63	12	0.54	0.34
Step Length Ass (cm)	Pre: 210. ± 12.57$^{\#\#}$	Pre: 208.7 ± 9.59$^{\#\#}$	0.22	12	0.83	0.12
	Post: 205.7 ± 7.77	Post: 212.1 ± 11.14	-1.25	12	0.23	-0.67
	Δ: -4.29 ± 8.27	Δ: 3.43 ± 6.39	-1.95	12	0.08	-1.04
Step Frequency Ass (step/s)	Pre: 4.32 ± 0.27	Pre: 4.52 ± 0.24	-1.45	12	0.17	-0.77
	Post: 4.42 ± 0.26	Post: 4.56 ± 0.16	-1.24	12	0.24	-0.66
	Δ: 0.09 ± 0.18	Δ: 0.04 ± 0.13	0.65	12	0.53	0.35
Contact Time Ass (s)	Pre: 0.127 ± 0.013	Pre: 0.119 ± 0.013	1.23	12	0.24	0.66
	Post: 0.121 ± 0.009	Post: 0.114 ± 0.010	1.47	12	0.17	0.78
	Δ: -0.006 ± 0.008	Δ: -0.005 ± 0.007	-0.26	12	0.80	-0.14
Flight Time Ass (s)	Pre: 0.106 ± 0.011$^{\#\#}$	Pre: 0.104 ± 0.006$^{\#\#}$	0.46	12	0.65	0.25
	Post: 0.106 ± 0.009	Post: 0.106 ± 0.006	0.03	12	0.97	0.02
	Δ: 0.000 ± 0.006	Δ: 0.002 ± 0.004	-0.82	12	0.43	-0.44
Step Length Reg (cm)	Pre: 188.9 ± 9.11	Pre: 193.9 ± 12.35	-0.86	12	0.41	-0.46
	Post: 187.4 ± 10.82	Post: 193.6 ± 11.99	-1.02	12	0.33	-0.54
	Δ: -1.50 ± 5.90	Δ: -0.29 ± 3.40	-0.45	12	0.66	-0.24

Dependent Variable	Mean ± SD		t	df	p	Cohen's d
	Non-Responder:	High Responder:				
Step Frequency Reg (step/s)	Pre: 4.41 ± 0.23	Pre: 4.49 ± 0.20	-0.63	12	0.54	-0.34
	Post: 4.43 ± 0.28	Post: 4.56 ± 0.25	-0.89	12	0.39	-0.48
	Δ: 0.02 ± 0.20	Δ: 0.07 ± 0.11	-0.62	12	0.55	-0.33
Contact Time Reg (s)	Pre: 0.128 ± 0.013	Pre: 0.123 ± 0.011	0.72	12	0.49	0.38
	Post: 0.123 ± 0.011	Post: 0.121 ± 0.009	0.37	12	0.72	0.20
	Δ: -0.005 ± 0.004	Δ: -0.002 ± 0.005	-1.16	12	0.27	-0.62
Flight Time Reg (s)	Pre: 0.100 ± 0.012	Pre: 0.100 ± 0.007	-0.05	12	0.96	-0.03
	Post: 0.103 ± 0.013	Post: 0.099 ± 0.008	0.75	12	0.47	0.40
	Δ: 0.003 ± 0.007	Δ: -0.002 ± 0.006	1.39	12	0.19	0.74

Notes: Data are presented as mean ± SD. Ass = assisted sprint condition; Reg = regular (unassisted) sprint condition. Spatiotemporal variables were measured at maximal speed. # Indicates a significant difference when the comparison is between same variables in regular and assisted run ($p < .05$).

3.3.4. High vs. Non-responder Comparison in baseline Force-Velocity profile variables

At the baseline, high responders had higher F_0 ($p = 0.01$, $d = 1.65$), Pmax ($p = 0.01$, $d = 1.80$), and RFmax ($p < 0.01$, $d = 1.87$) than nonresponders, which suggested that the responders had superior initial force and power capacities (Figure 3.7). No significant differences were observed for V_0, DRF and slope (all $p > 0.05$). However, DRF ($p = 0.09$, $d = 1.00$) and slope ($p = 0.07$, $d = 1.09$) showed moderate to large effect sizes ($d \geq 1$), indicating a tendency toward steeper F-V profiles in responders.

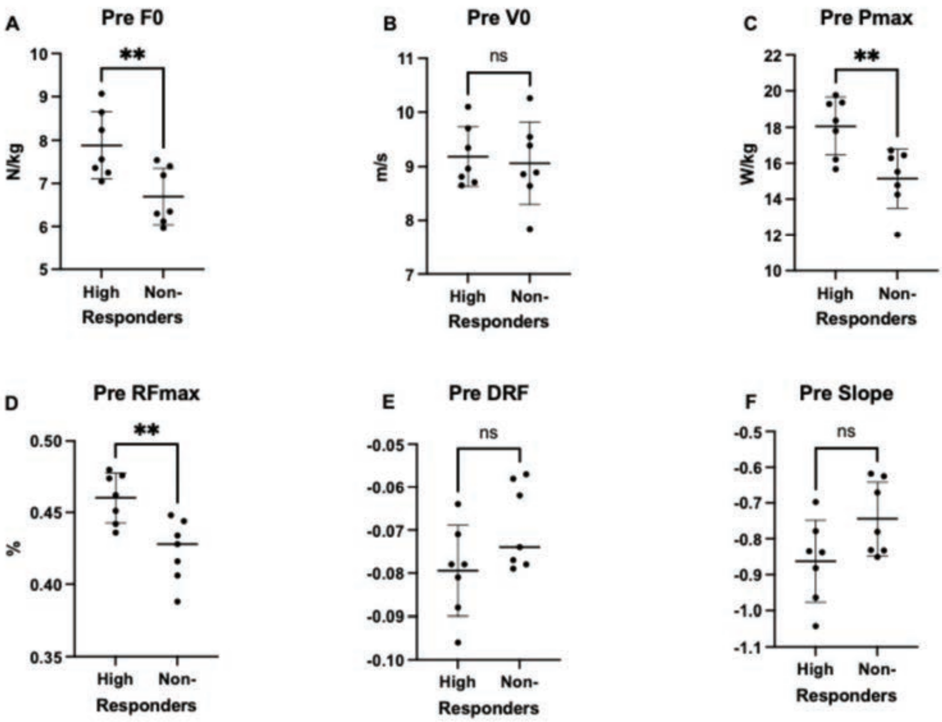


Figure 3.7 Comparison of baseline force-velocity profile variables between high responders and non-responders. Panels show: (A) theoretical maximal horizontal force, (B) theoretical maximal velocity, (C) maximal propulsive power, (D) maximal ratio of force, (E) rate of decrease in RF with increasing speed, and (F) slope of the linear force-velocity relationship.

Notes: Data are presented as mean ± SD with individual values shown. ** Indicates a significant difference between high and non-responders ($p < 0.01$); ns indicates a non-significant difference ($p > 0.05$).

3.3.5. Predictive analyses

To identify predictors of assisted sprint improvement, linear regression analyses were performed using postintervention 30-m assisted time as the dependent variable and baseline F-V parameters as the independent variables (Figure 3.8). For regular sprints, Pmax (adjusted R2 = 0.63) and RFmax (adjusted R2 = 0.54) were the strongest predictors, F_0 showed a moderate association (adjusted R2 = 0.33), whereas V_0 demonstrated only a weak relationship with assisted sprint improvement (adjusted R2 = 0.13).

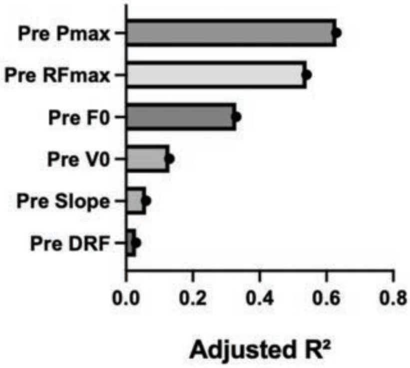


Figure 3.8 Strength (adjusted R2) of regular sprint-derived F-V parameters for predicting assisted sprint improvement

Notes: F_0 = theoretical maximal horizontal force; V_0 = theoretical maximal velocity; Pmax = maximal propulsive power; RFmax = maximal ratio of force; DRF = rate of decrease in RF with increasing velocity; slope = slope of the linear F-V relationship. Higher adjusted R^2 values indicate stronger predictive associations.

3.3.6. Discussion of the 3rd study

The main finding of this study was that incorporating assisted sprinting into soccer-specific training improved assisted sprint velocity in young players. However, these gains did not transfer or transferred minimally to regular sprint velocity and to spatiotemporal variables such as stride length, stride frequency, ground contact time, and flight time at maximal velocity. This pattern aligns with recent meta-analytic findings showing that AST does not consistently produce greater improvements in regular short sprint performance than well-designed conventional sprint training, despite moderate within-group gains in kinematic variables (Myrvang & Van den Tillaar, 2024; Nicholson et al., 2020). The magnitude of improvement observed in this study was strongly associated with the initial power capacities derived from the F-V profile, suggesting that athletes with higher initial force and power levels may derive greater benefits from AST.

The initial aim of this study was to compare continuous towing at supramaximal speed with partial towing limited to slightly below supramaximal speed. However, only negligible differences were observed between the protocols, as reflected by the absence of significant differences in sprint time, stride length, stride frequency, ground contact time, and flight time. This likely reflects the relatively short, assisted distance. That is, assistance was often released late (at ~ 22 m), which left only a brief segment for partial assistance to meaningfully alter the sprint mechanics. Thus, our initial hypothesis that partial towing would yield greater improvements was not confirmed. Combining the data for both assisted modes provided evidence of clear improvements under assisted conditions compared with the control condition. These findings are consistent with prior reports that carefully dosed overspeed exposure can acutely increase step rate and reduce contact times without necessarily changing unassisted top speed in the short term (Haugen, McGhie, et al., 2019; Ross et al., 2001). Recent overspeed studies have also shown that moderate assistance levels and short assisted segments induce primarily adjustments in acute kinematic, such as reduced ground contact and changes in stride frequency, rather than substantial chronic adaptations in regular sprinting, especially in youth and subelite populations(Chang et al., 2024; Frisk et al., 2022).

A key observation was the heterogeneity of response: nearly half of the participants improved by no more than the MDC, whereas a smaller subgroup showed clearly greater gains in assisted run after the intervention. Similar interindividual variability has been reported for sprint training tailored using F-V diagnostics or delivered as generic sprint work (Lahti et al., 2020; Rakovic et al., 2018). Lahti et al. (2020) reported that baseline F-V properties, such as force- or velocity-dominant profiles, can partly identify which athletes adapt and how after resisted or assisted training blocks. The pattern observed in our study aligns with these earlier findings in that assisted towing appears to benefit some athletes considerably, while others show minimal changes after short interventions. The possible reasons for these individual differences include variations in technical proficiency at high limb velocities, differences in neuromuscular readiness to manage the hamstring load during late swing at supramaximal speeds, and the degree to which towing preserves rather than replacing active propulsion (Haugen, McGhie, et al., 2019; Morin & Samozino, 2016; Ross et al., 2001). Indeed, participants had prior experience with elastic overspeed running but not with motorized towing; therefore, differences in familiarity with the specific assistance modality may have influenced the responses. This reinforces the idea that individual mechanical "readiness" and sprint-specific technical competency may be prerequisites for taking full advantage of supramaximal sprint stimuli.

This study also examined whether baseline F-V profiles could help explain these individual differences. The regular sprint-derived variables indicated that baseline Pmax and RFmax were most strongly associated with subsequent assisted sprint performance improvements. These findings are consistent with earlier reports suggesting that F-V characteristics explain part, but not all, of the variability in training adaptations (Lahti et al., 2020; Rakovic et al., 2018). Other studies further support this concept by demonstrating that individualized F-V-oriented training can reduce mechanical imbalances more effectively than generic sprint programs. However, a considerable proportion of the variance in performance outcomes remains unexplained and may be related to neuromechanical, coordinative, and maturational factors (Jiménez-Reyes et al., 2017; Li, Zhi, et al., 2025; Morin & Samozino, 2016). In addition, differences in training history, technical proficiency, and responsiveness to external mechanical stimuli may also contribute to the observed variability. Therefore, while F-V profiling may provide useful information for guiding training strategies, it should likely be considered alongside other individual characteristics when interpreting adaptations to assisted sprint training.

Importantly, the improvements in assisted sprint times transferred only minimally to regular 30-m sprint performance within the timeframe of this study. This finding is consistent with that of earlier reports showing that overspeed exposure can acutely improve velocity-side qualities, such as shorter ground contact times and faster step rates, but may not lead to immediate improvements in regular sprint performance unless there is sufficient volume, progression, and integration applied to high-quality unassisted sprinting (Haugen, McGhie, et al., 2019; Ross et al., 2001). The minor differences observed in regular sprints following improvements in assisted sprinting in this study also support the idea that at least part of the adaptations were sensorimotor, which reflect the ability of the athlete to coordinate movement under external pulling forces, rather than structural or neural changes that transfer to free sprinting. This interpretation is reinforced by acute and short-term overspeed studies demonstrating that assisted training often yields kinematic adaptations without corresponding increases in regular sprint speed unless paired with progressive loading and movement-specific consolidation (Chang et al., 2024; Frisk et al., 2022).

Two practical implications emerge from these findings. First, assistance should be carefully dosed and increased progressively, such as using slightly longer assisted distances, more sessions, or a gradual transition from partial to brief fully assisted exposure. Second, transfer to regular sprinting may be enhanced by integrating assisted and well-executed unassisted sprints within the same training cycle while ensuring that the level of assistance preserves the natural sprint mechanics (Lahti et al., 2020; Petrakos et al., 2016). Recent reliability data for motorized towing systems also support their use for controlled supramaximal exposure when the level of assistance is carefully adjusted to preserve natural sprint mechanics (Eriksrud & Westheim, 2025).

This study has several limitations. First, the sample size was small, which is a common constraint in applied team sport research. Second, we used 30-m assisted efforts; although longer assisted segments might create a stronger mechanical stimulus, these are less practical in soccer settings. Third, the participants continued their usual soccer preparation, and concurrent training effects cannot be ruled out. Forth, the assistance force was applied as an absolute load (6 kg) rather than normalized to body mass. Therefore, the assistance force varied somewhat between individuals, which may have contributed to inter-individual variability in the mechanical stimulus. Finally, part of the observed improvements, possibly reflecting a lack of familiarization, may be due to adaptation to the overspeed stimulus rather than purely training-induced changes. However, responses were heterogeneous, with clear responders and non-responders, suggesting that individual mechanical and neuromuscular characteristics also influenced adaptations to assisted sprinting (Haugen, McGhie, et al., 2019).

CONCLUSIONS

1. The Alex7 motorized device demonstrates high validity and reliability for monitoring resisted and assisted sprinting tasks performed during training. It provides a suitable and controlled training environment for monitoring neuromuscular and biomechanical responses to different sprint loading conditions.
2. Although full towing assistance does not reduce muscle activation compared with partial assistance or unassisted sprinting, both assisted conditions improve sprint performance and alter spatiotemporal characteristics. Differences in muscle activation are observed only during specific phases of the gait cycle, particularly during the transition from swing to stance, however, the interpretation of these differencies is limited by the high variability of the data. Neuromuscular activity increases with running velocity up to maximal levels and remains relatively stable once maximal velocity is reached, regardless of the magnitude of external assistance.
3. Assisted sprint training is effective in improving assisted sprint performance in young football players. However, these improvements show limited transfer to unassisted sprint performance and spatiotemporal characteristics. Training adaptations are closely associated with the athletes' initial force-velocity profile characteristics. Athletes with greater baseline force and power capacities generally demonstrate greater performance improvements following assisted sprint training.

SANTRAUKA

ĮVADAS

Greitumas yra viena svarbiausių fizinių savybių, lemiančių sėkmę daugelyje sporto šakų. Lengvojoje atletikoje gebėjimas pasiekti didelį bėgimo greitį ypač svarbus tokiose rungtyse kaip 100 m bėgimas, barjerinis bėgimas ar šuolis į tolį. Komandinėse sporto šakose, tokiose kaip futbolas, regbis ar krepšinis, gebėjimas per kuo trumpesnį laiką pasiekti maksimalų greitį taip pat turi didelę reikšmę. Vienas greitas prasiveržimas gali nulemti, ar žaidėjas pirmas pasieks kamuolį, prasiverš pro varžovų gynybą ar sukurs progą pelnyti taškus. Todėl gebėjimas išvystyti ir išlaikyti didelį bėgimo greitį trumpose distancijose yra svarbi įvairių sporto šakų atletų savybė (Gualtieri et al., 2023; Lockie et al., 2012). Taip pat svarbu gebėti išlaikyti didelį judėjimo greitį kuo mažiau pavargstant ir išvengiant traumų (Morin & Samozino, 2016; Moura et al., 2023; Pietraszewski et al., 2025; Thompson, 2017).

Vieni atletai pasižymi spartesniu įsibėgėjimu ir didesniu jėgos generavimu sprinto pradžioje, tačiau sunkiau pasiekia maksimalų greitį. Kiti priešingai – geba išvystyti labai didelį maksimalų greitį, tačiau jiems trūksta jėgos pirmuose sprinto metruose. Todėl vis daugiau dėmesio skiriama jėgos ir greičio charakteristikų vertinimui – profilaivimui, leidžiančiam nustatyti individualias sportininko stipriąsias ir silpnąsias savybes bei pagal jas individualizuoti treniravimo krūvį (Buchheit et al., 2014; Morin et al., 2012; Nagahara et al., 2018a; Samozino et al., 2016). Tradiciniai greitumo lavinimo metodai dažniausiai skirti abiem jėgos ir greičio spektro pusėms gerinti. Sprinto treniravimas su pasipriešinimu, pavyzdžiui, tempiant slidę ar bėgant į įkalnę, sudaro didesnį pasipriešinimą, todėl gerina gebėjimą generuoti horizontaliąją jėgą ir didina horizontalųjį jėgos impulsą (Alcaraz et al., 2018; Cahill et al., 2020; Dougan et al., 2025; Stavridis et al., 2023). Sprintas palengvintomis sąlygomis, kai sportininkas bėga į nuokalnę arba pavėjui, ir bėgimas su užtempimu, kai sportininkas yra tempiamas specialiomis gumomis arba sistemomis, leidžia pasiekti didesnį nei įprasta bėgimo greitį ir skatina adaptaciją prie dar labiau padidinto greičio biomechanikos bei greitesnio kojų judesių atlikimo (Cecília-Gallego et al., 2022; Gleadhill et al., 2023; Lahti et al., 2020; Myrvang & Van den Tillaar, 2024; Ross et al., 2001). Taikomi kartu šie metodai gali papildyti vienas kitą ir sudaryti visapusiškesnę greitumo lavinimo sistemą (Lahti et al., 2020; Myrvang & Van den Tillaar, 2024).

Nepaisant šių metodų potencialo, praktikoje išlieka nemažai problemų. Tradicinės slidės ar elastinės gumos leidžia sukurti pasipriešinimą arba asistavimą, tačiau neleidžia tiksliai kontroliuoti apkrovos. Krūvį gali veikti įvairūs aplinkos veiksniai: dangos tipas, trintis ar nuolydis, todėl sudėtinga pakartoti vienodas sąlygas ar tiksliai įvertinti sportininko generuojamus rodiklius (Cross et al., 2019; Cross, Tinwala, et al., 2017; Petrakos et al., 2016; Van den Tillaar, 2020). Dėl šios priežasties treniravimo krūviai dažnai nustatomi tik apytiksliai, o tai apsunkina individualizuotą treniravimą ir pažangos stebėjimą. Siekiant geriau suprasti sportininko greitumo savybes ir individualizuoti treniravimą vis plačiau taikomas jėgos ir greičio (F-V) profiliavimas. Vertinant teorinės maksimalios horizontaliosios jėgos (F_0) ir teorinio maksimalaus greičio (V_0) santykį galima nustatyti, ar sportininkas labiau orientuotas į jėgą, greitį ar pasižymi labiau subalansuotu profiliu. Tai leidžia geriau suprasti, kokias savybes reikėtų lavinti treniruočių metu (Baena-Raya et al., 2021; Fernández-Galván et al., 2022; Haugen, Breitschädel, et al., 2019; Morin et al., 2019; Samozino et al., 2022). Ankstesni tyrimai rodo, kad jėgos ir greičio profiliavimas gali padėti priimti efektyvesnius treniravimo sprendimus. Pavyzdžiui, sportininkams, kuriems trūksta jėgos, gali būti naudingesnis sprinto treniravimas su pasipriešinimu, o atletams, kuriems trūksta greičio, – asistuotas sprintas (Cross et al., 2018; Lahti et al., 2020). Vis dėlto individualus atsakas į sprinto treniruotes gali labai skirtis, todėl ne visi sportininkai progresuoja vienodai ar prognozuojamai (Lahti et al., 2020; Rakovic et al., 2018). Dėl šios priežasties tampa svarbu ieškoti būdų, kaip tiksliau prognozuoti, kuriems sportininkams konkretūs treniravimo metodai bus veiksmingiausi. Manoma, kad šias prognozavimo galimybes galėtų pagerinti papildomi žingsnių charakteristikų rodikliai, tokie kaip žingsnio ilgis, žingsnio dažnis, atramos trukmė ar gebėjimas išlaikyti greitį (Meng et al., 2024; Murata et al., 2018). Ypač bėgimas su užtempimu, leidžiantis pasiekti didesnį nei įprasta greitį, gali atskleisti sportininko savybes, neišryškėjančias atliekant įprastą sprintą.

Technologijų pažanga pastaraisiais metais suteikė naujų galimybių tiek sprintui treniruoti, tiek atliekant mokslinius tyrimus. Šiuolaikiniai motorizuoti įrenginiai, tokie kaip „Sprint 1080“ ar „DynaSpeed“, leidžia tiksliai valdyti pasipriešinimą ar asistavimą, užtempimo jėgą ir realiuoju laiku registruoti jėgos, greičio, atstumo bei galios rodiklius (Chang et al., 2024; Cross et al., 2018; Haugen, McGhie, et al., 2019; Jiménez-Reyes et al., 2024; Lahti et al., 2020; Matusiński et al., 2022). Viena iš tokių inovacijų yra Lietuvoje sukurtas motorizuotas „Alex7“ įrenginys. Nors savo funkcionalumu jis panašus į jau egzistuojančius motorizuotus sprinto įrenginius, „Alex7“ buvo kuriamas ypatingą dėmesį skiriant mobilumui ir prieinamumui, todėl jį galima naudoti tiek aukšto meistriškumo, tiek mėgėjų sporte. Nešiojamų motorizuotų įrenginių validumo tyrimų iki šiol atlikta nedaug, todėl tokių naujesnių įrenginių kaip „Alex7“ tikslumas ir patikimumas turi būti įvertintas prieš juos plačiai taikant treniruojantis ar atliekant mokslinius tyrimus. Be to, nors pilnas užtempimas mokslinėje literatūroje išnagrinėtas gana plačiai, dalinis užtempimas, kai pasiekus tam tikrą greitį tempimas nutraukiamas, iki šiol sistemiškai neištirtas. Manoma, kad toks metodas gali padėti išlaikyti aktyvesnį raumenų darbą ir geresnę judesių kontrolę, esant didesniam nei maksimalus greitis skatindamas efektyvesnes nervų ir raumenų sistemos adaptacijas.

Be to, vis dar nepakankamai aišku, kaip bėgimas su užtempimu veikia nervų ir raumenų sistemos veiklą. Tik nedaugelyje tyrimų nagrinėta, kaip esant skirtingoms užtempimo sąlygoms kinta raumenų aktyvumo modeliai ir judesių koordinacija (Cecília-Gallego et al., 2022; Mero & Komi, 1987). Taip pat, nors jėgos ir greičio profiliavimas plačiai taikomas individualizuojant treniruotes, manoma, kad jo prognostinės galimybės galėtų būti pagerintos papildomai įtraukiant žingsnio charakteristikų ir kinematinius rodiklius. Toks kompleksinis vertinimas galėtų padėti treneriams tiksliau nustatyti individualius sportininkus ribojančius veiksnius ir parinkti tikslingesnes greitumo lavinimo programas. Siekiant mažinti atotrūkį tarp mokslo ir praktikos svarbu užpildyti šias mokslines spragas. Geresnis bėgimo su užtempimu strategijų, nervų ir raumenų sistemos reakcijų bei prognozavimo metodų supratimas suteiktų treneriams ir sporto specialistams moksliškai pagrįstas priemones, padedančias gerinti sprinto rezultatus ir kartu mažinti traumų riziką.

Todėl šios disertacijos **tikslas** – nustatyti, ar galima sukelti didesnio laipsnio sportininko nervų ir raumenų sistemos adaptacijas taikant individualizuotus bėgimo su užtempimu metodus.

Tyrimo uždaviniai:

1. Nustatyti nauju motorizuotu įrenginiu matuojamų sprinto rezultatų tikslumą ir patikimumą bėgimo su pasunkinimu ir bėgimo su užtempimu sąlygomis.
2. Palyginti pilno ir dalinio užtempimo poveikį nervų-raumeninės sistemos aktyvumui ir bėgimo žingsnio biomechanikai.
3. Įvertinti šešių savaičių asistuojamo sprinto treniruotės poveikį jaunųjų futbolininkų sprinto rezultatams, žingsnio charakteristikų rodikliams ir jėgos bei greičio profiliams ir nustatyti, ar pradiniai šių rodiklių duomenys leidžia prognozuoti individualų treniruotes adaptacinį efektą.

Hipotezės:

1. Naujas motorizuotas įrenginys pateiks tikslius ir patikimus sprinto rezultatų matavimus bėgimo su pasunkinimu ir bėgimo su užtempimu sąlygomis.
2. Dalinis užtempimas padidins raumenų aktyvumą ir leis išvystyti didesnį galingumą nei pilnas užtempimas esant panašiam supramaksimaliam bėgimo greičiui.
3. Žingsnio charakteristikų rodiklių derinimas su jėgos ir greičio profiliais leis tiksliau prognozuoti, kurie sportininkai pasieks didžiausią progresą po asistuojamo sprinto treniruočių.

Praktinė tyrimo reikšmė:

Ši disertacija papildo sprinto treniravimo srities mokslines žinias apie asistuojamo sprinto taikymą, jėgos ir greičio profiliavimą bei sprinto biomechaniką. Darbe įvertintas motorizuoto įrenginio tinkamumas sprinto rezultatams matuoti bėgimo su pasunkinimu ir užtempimu sąlygomis, taip pat ištirtas pilno ir dalinio užtempimo poveikis raumenų aktyvumui ir sprinto biomechanikai. Tyrimo rezultatai leidžia geriau suprasti sprinto treniravimo metu vykstančius biomechaninius ir nervų bei raumenų sistemos pokyčius.

Praktiniu požiūriu šio tyrimo rezultatai gali suteikti treneriams ir sporto specialistams daugiau informacijos apie asistuojamo sprinto taikymo galimybes lavinant greitumą. Tyrimo metu nustatyti rodikliai gali padėti tiksliau individualizuoti sprinto treniravimo krūvius, vertinti sportininkų greitumo savybes ir prognozuoti individualų atsaką į treniruotes. Taip pat šio darbo rezultatai gali būti naudingi planuojant greitumo ugdymo programas ir siekiant efektyviau lavinti galingumą įvairiuose greičio diapazonuose.

1. TYRIMO METODIKA IR ORGANIZAVIMAS

1.1. Tiriamieji

Šioje disertacijoje pristatomuose trijuose tyrimuose dalyvavo skirtingos sportininkų grupės, atrinktos atsižvelgiant į konkrečius kiekvieno tyrimo tikslus ir uždavinius. Nepaisant tam tikrų skirtumų tarp tiriamųjų grupių, visus dalyvius siejo bendros charakteristikos – reguliari sprinto treniruotės patirtis ir dalyvavimas varžybinėje sportinėje veikloje. Visi tiriamieji prieš dalyvavimą tyrimuose buvo supažindinti su tyrimų eiga, taikomomis procedūromis bei galimomis rizikomis ir pateikė rašytinį informuotą sutikimą dalyvauti tyrime. Nepilnamečių sportininkų atveju papildomai buvo gautas jų tėvų arba globėjų rašytinis sutikimas. Visi tyrimai buvo vykdomi laikantis Helsinkio deklaracijos principų ir buvo patvirtinti Lietuvos sporto universiteto Bioetikos komiteto (kodai: MNL-TRS(M)-2023-606; BNL-TRS(B)-2025-783).

Pirmajame tyrime dalyvavo 27 jaunieji futbolininkai vaikinai, rungtyniavę Lietuvos aukščiausio lygio U16 ir U18 futbolo lygose. Tiriamųjų amžiaus vidurkis – 16,5 ± 0,8 metų, ūgis – 179,5 ± 6,9 cm, kūno masė –67,7 ± 8,3 kg. Visi sportininkai turėjo reguliarių sprinto treniruočių patirties, tačiau iki tyrimo nebuvo naudoję motorizuotų sistemų, skirtų sprinto bėgimui pasunkinti ir palengvinti.

Antrajame tyrime dalyvavo 14 vyrų sportininkų, aktyviai užsiimančių sporto šakomis, kuriose sprinto gebėjimai yra svarbus sportinį rezultatą lemiantis veiksnys. Vienas tiriamasis tyrimo nebaigė, todėl į galutinę analizę buvo įtraukti 13 sportininkų. Tiriamųjų amžiaus vidurkis – 21,4 ± 1,5 metų, ūgis – 1,86 ± 0,07 m, kūno masė – 81,8 ± 8,5 kg. Visi dalyviai turėjo sprinto treniruočių patirties, tačiau anksčiau treniruotėse nebuvo bėgę sprinto su užtempimu, naudodamiesi motorizuotu įrenginiu. Šiam tyrimui buvo pasirinkta mažesnė, tačiau techniškai pajėgi sportininkų grupė, siekiant užtikrinti aukštos kokybės elektromiografinių ir kinematinių duomenų surinkimą sprinto su užtempimu metu.

Trečiajame tyrime dalyvavo 27 jaunieji futbolininkai vaikinai. Tyrimo metu trys sportininkai nebaigė visos intervencijos programos, todėl galutinėje analizėje buvo vertinami 24 tiriamieji. Vienas sportininkas paliko futbolo akademiją, vienas sportininkas buvo perkeltas į aukštesnio lygio komandą, o vienas pasitraukė dėl nesusijusios su sprinto treniruotėmis traumos. Tiriamųjų amžiaus vidurkis – 16,5 ± 2,1 metų, ūgis –1,80 ± 0,06 m, kūno masė – 69,3 ± 9,7 kg. Sportininkai buvo suskirstyti į sprinto su užtempimu treniruočių grupę (n = 17) ir kontrolinę grupę (n = 7). Sudarant grupes atsižvelgta į pradines jėgos ir greičio profilio charakteristikas. Tyrimas buvo vykdomas pasirengimo kitam sezonui laikotarpiu. Tyrimo metu visi sportininkai per savaitę dalyvavo penkiose savaitinėse treniruotėse: intervencinės grupės sportininkai dalyvavo trijose savaitinėse futbolo treniruotėse ir dviejose savaitinėse sprinto treniruotėse, po kurių buvo taikomi jėgos ugdymo pratimai, o kontrolinė grupė turėjo tris savaitines futbolo treniruotėse ir dvi savaitines jėgos ugdymo treniruotes. Sprinto treniruočių lankomumas buvo aukštas – dalyviai vidutiniškai dalyvavo 11,6 ± 1,5 iš 12 galimų sprinto treniruočių sesijų. Visų tiriamųjų buvo prašoma viso tyrimo metu išlaikyti įprastą treniruočių režimą ir mitybos įpročius.

1.2. Tyrimo procedūros

1.2.1. Standartizuota pramankšta ir pasiruošimas testavimui

Prieš kiekvieną testavimo arba treniruotės sesiją tiriamieji atliko 20 min. trukmės standartizuotą pramankštą, kurią sudarė 5 min. trukmės lengvas bėgimas, dinaminiai šlaunies užpakalinės ir priekinės dalies, sėdmenų bei blauzdų raumenų tempimo pratimai. Po jų buvo atliekami specifiniai bėgimo pratimai, skirti raumenų grupėms, dalyvaujančioms bėgant sprintą, aktyvuoti. Pramankštos pabaigoje tiriamieji atliko keturis progresinius 30 m greitėjimus bėgdami maždaug 70 %, 80 %, 90 % ir 95 % subjektyviai suvokiamų maksimalių pastangų intensyvumu, siekdami aktyvuoti nervų ir raumenų sistemą prieš maksimalų sprinto atlikimą.

Pasiruošimas tyrimui taip pat apėmė tiriamųjų kūno masės matavimą iki 0,1 kg tikslumu naudojant kalibruotas skaitmenines svarstykles („Tanita TBF-300“), visos tyrimuose naudojamos įrangos („Alex7“, „OptoJump“, „Witty“ fotoelementų sistemos ir antrojo tyrimo metu naudotų elektromiografijos (EMG) sensorių) patikrinimą bei kalibravimą pagal gamintojų rekomendacijas ir saugumo instrukcijų pateikimą prieš kiekvieną sesiją. Sprinto su užtempimu atveju tiriamiesiems papildomai paaiškinta, kaip tinkamai reaguoti į užtempimo jėgą ir saugiai sulėtinti bėgimą po užtempimo fazės pabaigos.

Visi testavimai buvo atliekami lengvosios atletikos manieže, ant 60 m ilgio guminės dangos bėgimo takelio, siekiant kontroliuoti aplinkos veiksnius, tokius kaip vėjas ar dangos skirtumai. Poilsio intervalai tarp maksimalių sprintų buvo standartizuoti ir truko nuo 5 iki 6 min. pasyvaus poilsio. Tiriamiesiems taip pat buvo nurodyta iki kiekvienos testavimo sesijos likus 48 val. vengti intensyvios fizinės veiklos.

1.2.2. Pirmasis tyrimas: „Alex7“ tikslumas, patikimumas ir atsikartojamumas

Testavimo procedūra

Pirmąją tyrimo savaitę tiriamieji buvo supažindinti su tyrimo eiga, procedūromis ir naudojama įranga. Išmatuota tiriamųjų kūno masė, reikalinga sprinto su pasunkinimu metu individualizuotam pasipriešinimui nustatyti. Taip pat tiriamieji supažindinti su „Alex7“ įrenginio veikimo principais ir turėjo galimybę po kelis kartus išbandyti sprintą su pasunkinimu ir sprintą su užtempimu, siekiant sumažinti mokymosi efektą vėlesnių testavimų metu.

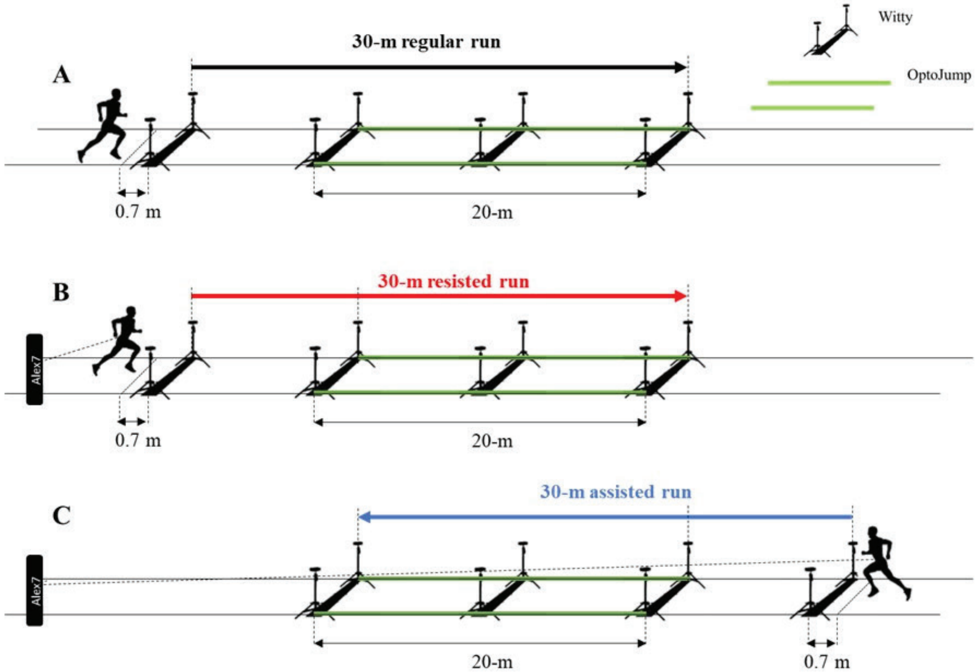
Per kitas dvi savaites buvo atliekami identiški testavimai, skirti „Alex7“ įrenginio tikslumui, patikimumui ir matavimų atsikartojamumui įvertinti, lyginant gautus rezultatus su „Witty“ fotoelementų sistemos duomenimis. Testavimo metu tiriamieji standartizuota tvarka du kartus bėgo 30 m sprintą (1 pav.):

1. Maksimalų sprintą be pasunkinimo ir užtempimo.
2. Sprintą su pasunkinimu, kai „Alex7“ įrenginys taikė 10 % tiriamojo kūno masės pasipriešinimą.
3. Sprintą su užtempimu, kai „Alex7“ įrenginys taikė nuolatinę 6 kg užtempimo jėgą.

Siekiant sumažinti cirkadinių ritmų poveikį, visi kiekvieno tiriamojo testavimai buvo atliekami tuo pačiu paros metu. Analizei pasirinktas greičiausias sprinto bandymas. „Witty“ fotoelementų sistema buvo išdėstyta ties 0, 10, 20 ir 30 m žymomis, siekiant užfiksuoti 10, 20 ir 30 m sprinto laikus. Siekiant išvengti netyčinio laiko fiksavimo starto pozicijoje, sprinto pradžioje tiriamasis stovėjo pirmąją koją pastatęs 70 cm prieš pirmąjį fotoelementą (Kamandulis et al., 2013; Lukonaitienė et al., 2020).

„Alex7“ įrenginys tuo pačiu metu registravo sprinto greitį ir nubėgtą atstumą. Siekiant užtikrinti „Alex7“ ir „Witty“ sistemų matavimų sinchronizaciją, pradinis 0,7 m atstumas iki pirmojo fotoelemento buvo eliminuojamas iš „Alex7“ registruojamų duomenų. Sprinto su užtempimu metu 6 kg užtempimo jėga taikyta iki finišo linijos, po kurios užtempimas buvo automatiškai atjungiamas siekiant užtikrinti saugų greičio mažinimą.

„OptoJump“ sistema 10–30 m bėgimo zonoje registravo žingsnių charakteristikas, įskaitant kontakto su žeme laiką, polėkio trukmę, žingsnio ilgį ir žingsnių dažnį. Analizei iš kiekvieno sprinto bandymo buvo atrinkti keturi iš eilės atlikti žingsniai, kurių metu buvo pasiektas didžiausias bėgimo greitis. Pagrindiniai analizuoti rodikliai buvo bendras 30 m sprinto laikas, 10 ir 20 m tarpiniai laikai, „OptoJump“ sistemos registruoti žingsnių charakteristikų rodikliai ir „Alex7“ registruoti greičio ir atstumo rodikliai.



1 pav. Testavimo schema bėgant maksimalų sprintą (A), sprintą su pasunkinimu (B) ir sprintą su užtempimu (C)

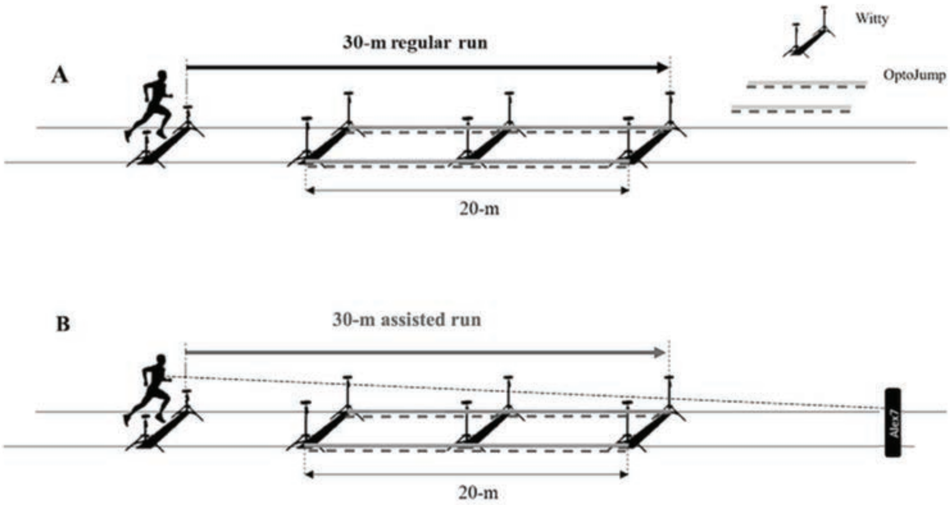
1.2.3. Antrasis tyrimas: elektromiografija, kinematika ir žingsnių charakteristika sprinto su užtempimu metu

Testavimo procedūra

Visi antrojo tyrimo matavimai buvo atlikti per vieną testavimo dieną. Kiekvienas tiriamasis tris kartus bėgo 30 m sprintą (2 pav.): maksimalų sprintą be užtempimo, sprintą su pilnu užtempimu ir sprintą su daliniu užtempimu. Sprinto su pilnu užtempimu metu „Alex7“ įrenginys viso sprinto metu teikė pastovią 6 kg tempimo jėgą. Sprinto su daliniu užtempimu metu 6 kg užtempimo jėga taikyta tol, kol tiriamasis pasiekė greitį, 0,5 m/s mažesnį, nei jo pasiektas maksimalus greitis pilno užtempimo metu. Pasiektas 0,5 m/s mažesnis greitis atitiko maždaug 95 % maksimalaus sprinto bėgimo greičio su pilnu užtempimu.

Sprinto bėgimas buvo standartizuotas – pirmiausia tiriamieji bėgo maksimalų sprintą be užtempimo, tuomet sprintą su pilnu užtempimu ir galiausiai sprintą su daliniu užtempimu. Tiriamieji du kartus bėgo maksimalų 30 m sprintą skirtingomis sąlygomis. Nuovargio poveikiui sumažinti tarp visų bėgimų taikytas 6 min. trukmės pasyvaus poilsio intervalas. Analizei pasirinkti greičiausi bėgimai esant skirtingoms sąlygoms.

„Witty“ fotoelementų sistema buvo išdėstyta ties 0, 10, 20 ir 30 m žymomis, siekiant užfiksuoti bendrą sprinto laiką ir tarpinius laikus. „OptoJump“ sistema



2 pav. Testavimo schema bėgant maksimalų sprintą (A) ir sprintą su užtempimu (B)

10–30 m bėgimo zonoje registravo žingsnių charakteristikas: žingsnio ilgį, žingsnių dažnį, kontakto su žeme laiką, polėkio trukmę ir atramos fazės santykį. Analizei buvo pasirinktas paskutinis visas atramos ir polėkio ciklą apimantis žingsnis iki 30 m finišo linijos, siekiant užtikrinti vienodą analizuojamą sprinto atkarpą visomis sprinto bėgimo sąlygomis.

Apatinių galūnių kinematiniai rodikliai buvo registruoti naudojant inercinius judesio matavimo sensorius (IMU), pritvirtintus prie pėdos, blauzdos, šlaunies ir kryžkaulio srities. Prieš kiekvieną testavimą sensoriai buvo kalibruojami pagal gamintojo rekomendacijas naudojant standartizuotą N-padėtį. Duomenys buvo registruoti 2000 Hz dažniu.

Elektromiografijos metu buvo registruojamas didžiojo sėdmens (*gluteus maximus*), tiesiojo šlaunies (rectus femoris), plataus šoninio šlaunies (*vastus lateralis*), pusgyslinio (*semitendinosus*) ir dvigalvio šlaunies (*biceps femoris*) raumens aktyvumas dominuojančioje kojoje. Elektrodai buvo tvirtinami pagal SENIAM rekomendacijas prieš tai paruošus odą. EMG signalai registruoti 2000 Hz dažniu, filtruojami taikant 20–450 Hz dažnių juostos filtrą. EMG signalai buvo normalizuojami pagal didžiausią reikšmę, užregistruotą sprinto be užtempimo metu analizuojamo žingsnio metu. Analizuojamas žingsnis nustatytas naudojant bėgimo. žingsnio fazės identifikavimo algoritmą, leidusį tiksliai sinchronizuoti „OptoJump“, IMU ir EMG duomenis

Pagrindiniai analizuoti rodikliai buvo bendras bėgimo laikas ir tarpiniai laikai, žingsnių charakteristikos, apatinių galūnių sąnarių kampai ir raumenų aktyvumas bėgant visomis trimis sprinto sąlygomis. Toks tyrimo dizainas leido tiesiogiai palyginti pilną bei dalinį užtempimą ir įvertinti, kaip skirtingos užtempimo strategijos veikia sprinto mechaniką ir raumenų aktyvumą, taip pat palyginti nervų ir raumenų sistemos atsaką sprinto be užtempimo, dalinio užtempimo ir pilno užtempimo metu.

1.2.4. Trečiasis tyrimas: sprinto su užtempimu treniruočių intervencija

Testavimo procedūra

Trečiajame tyrime sportininkai buvo testuojami prieš šešių savaičių sprinto su užtempimu treniruočių intervenciją ir po jos. Siekiant sumažinti cirkadinių ritmų poveikį, visi kiekvieno tiriamojo testavimai standartizuotomis sąlygomis buvo atliekami tuo pačiu paros metu. Kiekviena testavimo sesija prasidėjo standartizuota pramankšta. Visi tiriamieji turėjo ankstesnės sprinto su užtempimu patirties naudojant elastinį užtempimą (gumas), tačiau nė vienas anksčiau nenaudojo motorizuoto sprinto su užtempimu įrenginio.

Sprinto rezultatams įvertinti tiriamieji du kartus bėgo 30 m sprintą: maksimalų sprintą iš aukšto starto ir sprintą su užtempimu, kai „Alex7“ motorizuotas įrenginys viso sprinto metu taikė nuolatinę 6 kg užtempimo jėgą. Kiekvienas sprintas buvo bėgamas po du kartus, tarp bandymų taikant 5 min. trukmės pasyvaus poilsio intervalą. Analizei pasirinktas greičiausias kiekvienos sąlygos sprinto bandymas.

Sprinto laikai buvo registruojami naudojant „Witty“ fotoelementų sistemą („Microgate“, Italija), kurios fotoelementai išdėstyti ties 0, 5, 10, 15, 20, 25 ir 30 m žymomis. Žingsnių charakteristikos registruotos naudojant „OptoJump Next“ sistemą („Microgate“) 10–30 m bėgimo atkarpoje. Buvo analizuojamas žingsnio ilgis, žingsnių dažnis, kontakto su žeme laikas ir polėkio trukmė. Analizei buvo atrinkti du nuoseklūs žingsniai, atlikti didžiausiu greičiu greičiausio sprinto bandymo metu tiek maksimalaus sprinto, tiek sprinto su užtempimu sąlygomis.

Jėgos ir greičio profilio rodikliai buvo apskaičiuojami remiantis maksimalaus sprinto rezultatais taikant Samozino ir kt. (2016) aprašytą metodiką (Morin & Samozino, 2016; Samozino et al., 2016). Naudojant tarpinius sprinto laikus ir tiriamųjų antropometrinius duomenis apskaičiuoti teorinės maksimalios horizontaliosios jėgos, teorinio maksimalaus greičio, maksimalios galios (Pmax), maksimalaus jėgos santykio (RFmax), jėgos santykio mažėjimo greičio (DRF) bei jėgos ir greičio kreivės nuolydžio rodikliai.

Kadangi pirmasis fotoelementas įrengtas ties starto linija, tačiau 20 cm aukštyje nuo žemės paviršiaus, sportininkui pradėjus judėti laikas būdavo fiksuojamas ne iš karto. Siekiant sumažinti šią paklaidą ir tiksliau apskaičiuoti jėgos ir greičio profilio rodiklius, visiems tarpiniams sprinto laikams taikyta laiko korekcija (Δt), paremta Stenroth ir kt. (2023) aprašytu metodu (Stenroth et al., 2023). Gavus koreguotus tarpinius laikus, apskaičiuoti momentiniai greičio, horizontaliosios jėgos ir stūmimo galios rodikliai.

Treniruočių procedūra

Po pradinio testavimo sportininkai buvo suskirstyti į intervencinę ir kontrolinę grupes. Intervencinės grupės sportininkai papildomai atliko sprinto su užtempimu treniruočių programą, o kontrolinė grupė tęsė įprastą treniruočių procesą be sprinto su užtempimu intervencijos.

Intervencinės grupės sportininkai buvo suskirstyti į dar dvi grupes pagal treniruočių metu taikomą užtempimo tipą. Pilno užtempimo grupė 30 m sprintą bėgo naudodami nuolatinę 6 kg užtempimo jėgą, kuri atitiko 8,7 ± 1,2 % sportininkų kūno masės. Dalinio užtempimo grupė sprintą bėgo užtempimą taikant iki iš anksto nustatyto greičio, atitinkančio 95 % individualaus maksimalaus sprinto greičio su pilnu užtempimu, po kurio užtempimas buvo automatiškai atjungiamas ir sportininkas tęsdavo sprintą be pagalbos.

Grupės buvo sudarytos taip, kad jų vidutinės teorinio maksimalaus greičio, teorinės maksimalios horizontaliosios jėgos bei jėgos ir greičio kreivės nuolydžio reikšmės, apskaičiuotos pagal maksimalaus sprinto rezultatus, būtų panašios ir atspindėtų panašius pradinius mechaninius profilius.

Treniruočių intervenciją sudarė 12 treniruočių, vykusių per šešias savaites – po dvi treniruotes per savaitę. Kiekviena treniruotė prasidėdavo standartizuota pramankšta, identiška naudotai testavimo metu. Po pramankštos sportininkai keturis kartus bėgdavo maksimalaus intensyvumo 30 m sprintą su užtempimu, priklausomai nuo grupės taikant pilną arba dalinį užtempimą. Tarp sprinto bėgimų taikytas 5 min. trukmės pasyvaus poilsio intervalas, siekiant užtikrinti visišką nervų ir raumenų sistemos atsigavimą.

Laikyta, kad sportininkas sėkmingai baigė treniruočių intervenciją, jei dalyvavo ne mažiau kaip 10 iš 12 numatytų treniruočių sesijų. Pasibaigus intervencijai visi sportininkai pakartotinai atliko testavimus taikant identiškas procedūras kaip ir pradinio testavimo metu.

Duomenų analizė

Pirmiausia buvo palygintos visos trys tiriamųjų grupės. Kadangi abiejų sprinto su užtempimu treniruočių metodų – pilno ir dalinio užtempimo – nervų ir raumenų sistemos atsakas bei sprinto rezultatų pokyčiai buvo panašūs, abi intervencinės grupės tolesnei analizei buvo sujungtos į vieną bendrą intervencinę grupę. Tai leido tiksliau įvertinti sprinto su užtempimu treniruočių intervencijos poveikį lyginant ją su kontroline grupe.

Siekiant įvertinti individualų sportininkų atsaką į treniruočių intervenciją tiriamieji retrospektyviai suskirstyti į didelį progresą padariusius (angl. *high responders*) ir nepadariusius (angl. *non-responders*) sportininkus pagal 30 m sprinto su užtempimu rezultatų pagerėjimą. Mažiausias aptinkamas pokytis (MDC) apskaičiuotas pagal formulę:

$$MDC = 1{,}96 \times \sqrt{2} \times SEM,$$

kur SEM – standartinė matavimo paklaida, apskaičiuota remiantis dviem pakartotiniais sprinto su užtempimu pirmo testo, įvykusio prieš intervenciją, bandymais (Furlan & Sterr, 2018; Intaruk et al., 2024).

Šiame tyrime apskaičiuota MDC reikšmė buvo 0,13 s ir atspindėjo mažiausią pokytį, viršijantį įprastą matavimo paklaidą. Didelį progresą padariusiaisiais laikyti tie tiriamieji, kurių sprinto rezultatas pagerėjo ≥ 0,19 s, t. y. maždaug 50 % daugiau nei MDC reikšmė (n = 7). Nepadariusiaisiais progreso laikyti tie tiriamieji, kurių rezultato pagerėjimas buvo ≤ 0,13 s (n = 7). Sportininkai, kurių rezultato pagerėjimas pateko tarp 0,13 ir 0,19 s, į šią analizę buvo neįtraukti. Toks dviejų ribinių reikšmių metodas buvo taikomas siekiant atskirti matavimo paklaidą nuo reikšmingų sprinto rezultatų pokyčių.

1.3. Statistinė analizė

Apskaičiuoti visų sprinto laikų ir kinematinių rodiklių aritmetiniai vidurkiai ir standartiniai nuokrypiai (SD). Duomenų normalumas tikrintas taikant Shapiro-Wilk kriterijų. Sferiškumo prielaida vertinta naudojant Mauchly testą, o šiai prielaidai nesant tenkinamai taikyta Greenhouse-Geisser korekcija.

Pirmasis tyrimas: „Alex7“ tikslumas, patikimumas ir atsikartojamumas

Santykinis matavimų patikimumas vertintas apskaičiuojant intraklasinį koreliacijos koeficientą (ICC), taikant dviejų krypčių mišrų modelį pavieniams matavimams. ICC reikšmės interpretuotos kaip vidutinės (0,50–0,74), geros (0,75–0,89) ir puikios (≥ 0,90) (Koo & Li, 2016). Absoliutus patikimumas vertintas apskaičiuojant standartinę matavimo paklaidą (SEM), kuri apskaičiuota pagal formulę SD/√2. Taip pat buvo apskaičiuotas variacijos koeficientas (CV): SD/mean × 100 %.

Ryšiui tarp „Alex7“ ir „Witty“ sistemų rezultatų nustatyti naudotas Pirsono koreliacijos koeficientas (r). Koreliacijos stiprumas interpretuotas kaip didelis (0,50–0,69), labai didelis (0,70–0,89), beveik tobulas (0,90–0,99) ir tobulas (1,00) (Hopkins, 2000). Kriteriniam validumui vertinti apskaičiuotas vidutinis skirtumas ir variacijos koeficientas, o vidutinių skirtumų statistinis reikšmingumas vertintas taikant porinių imčių Stjudento t kriterijų. Efekto dydžiui nustatyti naudotas Cohen d koeficientas, interpretuojant reikšmes kaip dideles (≥ 0,80), vidutines (0,50–0,79), mažas (0,20–0,49) arba trivialias (< 0,20) (Fritz et al., 2012). Matavimų suderinamumui tarp pakartotinių „Alex7“ matavimų ir tarp „Alex7“ bei „Witty“ sistemų nustatyti taikyta Bland-Altman analizė (Bland & Altman, 1999). Sisteminei paklaidai nustatyti naudotas 95 % pasikliautinasis intervalas.

Antras tyrimas: EMG, kinematika ir žingsnių charakteristika sprinto su užtempimu metu

Kadangi visų žingsnių charakteristikų rodiklių duomenys atitiko parametrinių testų taikymo prielaidas, skirtumams tarp sprinto bėgimo sąlygų nustatyti taikyta pakartotinių matų dispersinė analizė (ANOVA). Nustačius statistiškai reikšmingą poveikį poriniai palyginimai atlikti taikant daugkartinius priklausomų imčių t kriterijus su Benjamini-Hochberg korekcija.

Kinematinių rodiklių ir raumenų aktyvumo duomenys analizuoti taikant pakartotinių matų dispersinę analizę visai duomenų sekai naudojant statistinį parametrinį modeliavimą (angl. *statistical parametric mapping,* SPM) – taip siekta nustatyti reikšmingus skirtumus tarp sąlygų skirtingose judesio fazėse. Nustačius statistiškai reikšmingą poveikį poriniai palyginimai atlikti naudojant daugkartinius priklausomų imčių t kriterijus su koreguotu reikšmingumo lygmeniu.

Efekto dydis (Cohen d) apskaičiuotas kaip skirtumas tarp grupių vidurkių, normalizuotas pagal sprinto be užtempimo sąlygos standartinį nuokrypį (Pataky, 2012). Efekto dydžiai apskaičiuoti kiekvienai sąlygų porai ir kiekvienam analizuojamam raumeniui. Cohen d interpretuotos pagal įprastai taikomas ribas: apie 0,20 – mažas efektas, apie 0,50 – vidutinis efektas, apie 0,80 – didelis efektas (Cohen, 1988). Šios ribos plačiai taikomos sporto mokslo tyrimuose (Hopkins, 2002).

Statistinė analizė buvo atlikta naudojant SPSS v25.0 programinę įrangą Windows operacinei sistemai (IBM, Armonk, NY, JAV) bei JASP programą (0.11.1 versija). Statistinio reikšmingumo lygmuo nustatytas esant $\alpha = 0,05$.

Trečiasis tyrimas: sprinto su užtempimu treniruočių intervencija

Išskirtys nustatytos vizualiai, analizuojant QQ grafikus ir liekanų sklaidą, taip pat pagal standartizuotas liekanas ($|z| > 3$). Reikšmės, galinčios daryti reikšmingą įtaką regresijos modeliui, vertintos taikant Cook atstumą (Cook‘s distance; > 4/n) Taip pat tikrintos tiesinės regresijos prielaidos, įskaitant liekanų normalųjį pasiskirstymą ir reikšmingą įtaką analizei galinčių turėti išskirčių nebuvimą (Ghasemi & Zahediasl, 2012; Zhu et al., 2012). Statistinio reikšmingumo lygmuo nustatytas esant $\alpha = 0,05$.

Priklausomų kintamųjų skirtumams įvertinti taikyta dviejų veiksnių dispersinė analizė (ANOVA, Grupė × Laikas), kartotinius matavimus taikant laiko veiksniui. Nustačius statistiškai reikšmingą sąveiką poriniai palyginimai atlikti taikant Holm korekciją daugkartiniams palyginimams. Efekto dydis vertintas naudojant dalinį eta kvadratą (η^2p).

Pirmiausia analizė atlikta atskirai vertinant tris grupes: kontrolinę, pilno užtempimo ir dalinio užtempimo. Vėliau abi sprinto su užtempimu grupės sujungtos į vieną intervencinę grupę ir lygintos su kontroline grupe. Analizuoti rodikliai apėmė sprinto rezultatus (30 m maksimalaus sprinto ir 30 m sprinto su užtempimu laikus) ir žingsnių charakteristikas esant abiem sprinto sąlygoms: žingsnio ilgį, žingsnių dažnį, kontakto su žeme laiką ir polėkio trukmę.

Grupių vidiniams pokyčiams įvertinti taikytas porinių imčių Stjudento t kriterijus, siekiant nustatyti reikšmingus pokyčius tarp testavimų, atliktų prieš treniruočių intervenciją ir po, bei palyginti sprinto be užtempimo ir sprinto su užtempimu rodiklius tuo pačiu bėgimo momentu. Šie t kriterijai naudoti kaip papildoma analizė greta dviejų veiksnių kartotinių matų ANOVA, siekiant aiškiau atskleisti konkrečius porinius skirtumus.

Nepriklausomų imčių Stjudento t kriterijus taikytas lyginant didelį progresą padariusių tiriamųjų ir progreso nepadariusių tiriamųjų testus prieš intervenciją, testus po intervencijos ir pokytį (Δ = po – prieš). Analizuojami 30 m maksimalaus sprinto ir sprinto su užtempimu rezultatai bei žingsnių charakteristikos: žingsnio ilgis, žingsnių dažnis, kontakto su žeme laikas ir polėkio trukmė tiek sprinto be užtempimo, tiek sprinto su užtempimu sąlygomis. Taip pat palyginti sprinto be užtempimo ir sprinto su užtempimu rodikliai grupių viduje. Efekto dydžiui įvertinti naudotas Cohen d, o kai buvo tikslinga, apskaičiuoti 95 % pasikliautinieji intervalai. Esant nevienodoms dispersijoms taikyta Welch korekcija.

Nepriklausomų imčių Stjudento t kriterijus taip pat naudotas pradiniams jėgos ir greičio profilio rodikliams palyginti tarp progresą padariusių ir progreso nepadariusių tiriamųjų. Analizė apėmė teorinės maksimalios horizontaliosios jėgos, teorinio maksimalaus greičio, maksimalios galios, maksimalaus jėgos santykio, jėgos santykio mažėjimo greičio ir jėgos ir greičio kreivės nuolydžio rodiklius, apskaičiuotus pagal maksimalaus sprinto rezultatus. Efekto dydžiui įvertinti naudotas Cohen d, o nesant dispersijų homogeniškumo taikyta Welch korekcija.

Visi statistiniai skaičiavimai atlikti naudojant „IBM SPSS Statistics“ programinę įrangą (28.0 versija, Armonkas, Niujorkas, JAV). Statistinio reikšmingumo lygmuo nustatytas esant = 0,05.

2. REZULTATAI

2.1. Pirmas tyrimas: „Alex7” įrenginio tikslumo, patikimumo ir atsikartojamumo vertinimas

2.1.1. „Alex7” įrenginio matavimų patikimumas sprinto su pasunkinimu ir sprinto su užtempimu sąlygomis

1 lentelėje pateikiami su „Alex7“ įrenginiu registruotų 30 m sprinto su pasunkinimu ir 30 m sprinto su užtempimu bendro laiko ir tarpinių laikų pirmojo testavimo ir pakartoto testavimo rezultatai (1 lentelė) „Alex7“ užfiksuoti sprinto laikai pasižymėjo puikiu matavimų patikimumu (ICC = 0,83–0,94) tiek sprinto su pasunkinimu, tiek sprinto su užtempimu metu. Mažiausias patikimumas nustatytas pirmojoje sprinto atkarpoje (0–10 m), kur ICC reikšmės esant abiem sprinto sąlygoms svyravo nuo 0,83 iki 0,86. Variacijos koeficientas svyravo nuo 0,80 iki 1,43 %, o standartinė matavimo paklaida nuo 0,01 iki 0,05 s, visomis sprinto sąlygomis.

Sprinto su pasunkinimu bėgime 10–20 m atkarpos laikas pakartotinio testavimo metu reikšmingai pagerėjo, palyginti su pirmuoju testavimu ($p < 0,001$), nors šio rodiklio patikimumas išliko panašus į kitų analizuotų rodiklių. Kitose pasunkinto bėgimo atkarpose ir visose bėgimo su užtempimu atkarpose pakartoto testavimo laikai nepasikeitė.

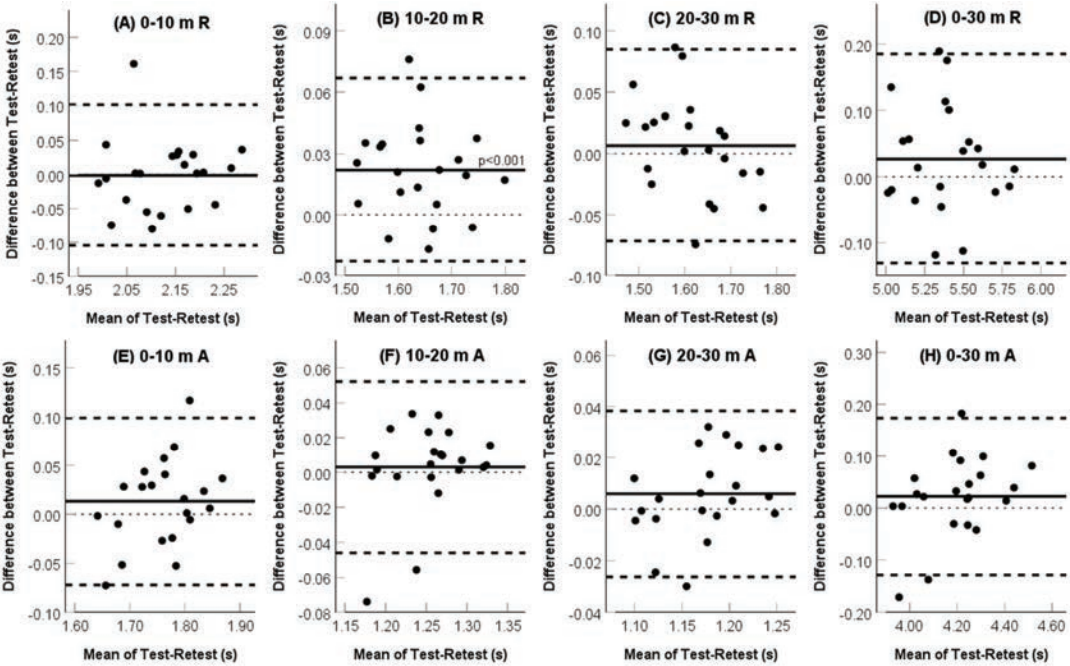
Bland-Altman analizė neatskleidė reikšmingo sisteminio nuokrypio tarp pakartotinių matavimų, išskyrus 10–20 m atkarpos laiką sprinto su pasunkinimu sąlygomis ($p < 0,001$; 3 pav.). Siauros suderinamumo ribos parodė nedidelį rezultatų išsibarstymą tarp pakartotinių testavimų ir gerą matavimų stabilumą. Daugumos rodiklių pakartotinių matavimų rezultatai pateko į 95 % pasikliautinąjį intervalą.

Žingsnio ilgis tarp dviejų testavimo sesijų reikšmingai skyrėsi tiek sprinto su pasunkinimu, tiek sprinto su užtempimu metu ($p < 0,05$; 1 lentelė), tačiau kitų kinematinių rodiklių rezultatuose reikšmingų skirtumų nenustatyta. Beveik visi žingsnio charakteristikos rodikliai pasižymėjo geru pakartotinių matavimų patikimumu (ICC = 0,79–0,88), išskyrus vidutinį žingsnio ilgio patikimumą, gautą sprinto su pasunkinimu metu (ICC = 0,74), ir puikų bėgimo greičio patikimumą, gautą sprinto su užtempimu metu (ICC = 0,94). Apskritai beveik visų rodiklių sprinto su užtempimu metu gautos ICC reikšmės buvo šiek tiek didesnės, palyginti su sprinto su pasunkinimu metu gautomis reikšmėmis.

1 lentelė. „Alex7" fiksuojamų bendrų ir tarpinių bėgimo laikų, bei „OptoJump" fiksuojamos žingsnių charakteristikos atsikartojamumas

Rodikliai	**Testas (vidurkis ± SD)**	**Pakartotas testas (vidurkis ± SD)**	**Vidurkio skirtumas ± SD**	**p reikšmė**	**ICC**	**ICC (95% CI)**	**CV (%)**	**SEM (s)**
Bėgimo su pasunkinimu laikai								
0 – 10 m atkarpa	2.13 ± 0.09	2.13 ± 0.09	-0.002 ± 0.053	0.890	0.83*	[0.64 to 0.93]	1.24	0.03
10 – 20 m atkarpa	1.65 ± 0.07	1.63 ± 0.07	0.022 ± 0.023	< 0.001	0.92*	[0.53 to 0.98]	1.12	0.02
20 – 30 m atkarpa	1.62 ± 0.08	1.61 ± 0.10	0.007 ± 0.040	0.444	0.90*	[0.77 to 0.96]	1.40	0.02
0 – 30 m atkarpa	5.39 ± 0.24	5.37 ± 0.25	0.027 ± 0.081	0.131	0.94*	[0.86 to 0.98]	0.85	0.05
Bėgimo su užtempimu laikai								
0 – 10 m atkarpa	1.77 ± 0.08	1.76 ± 0.07	0.013 ± 0.044	0.167	0.83*	[0.63 to 0.92]	1.43	0.03
10 – 20 m atkarpa	1.25 ± 0.05	1.25 ± 0.04	0.003 ± 0.025	0.573	0.86*	[0.70 to 0.94]	0.95	0.01
20 – 30 m atkarpa	1.18 ± 0.05	1.17 ± 0.04	0.006 ± 0.016	0.105	0.94*	[0.85 to 0.97]	0.80	0.01
0 – 30 m atkarpa	4.21 ± 0.18	4.18 ± 0.15	0.022 ± 0.077	0.188	0.88*	[0.74 to 0.95]	1.01	0.04
Bėgimo su pasunkinimu žingsnių charakteristika								
Atremties trukmė (s)	0.15 ± 0.01	0.15 ± 0.01	-0.002 ± 0.005	0.066	0.88*	[0.73 to 0.95]	2.16	0.00
Polėkio trukmė (s)	0.09 ± 0.01	0.09 ± 0.01	0.001 ±0.007	0.596	0.79*	[0.56 to 0.91]	3.93	0.00
Žingsnio ciklo trukmė (m)	3.18 ± 0.14	3.25 ± 0.16	0.069 ± 0.094	0.003	0.74*	[0.31 to 0.90]	1.74	0.06
Žingsnių dažnis (žingsniai/s)	4.17 ± 0.20	4.13 ± 0.23	0.044 ±0.127	0.116	0.82*	[0.61 to 0.92]	1.72	0.07
Bėgimo su užtempimu žingsnių charakteristika								
Atremties trukmė (s)	0.12 ± 0.01	0.12 ± 0.01	0.000 ± 0.006	0.951	0.85*	[0.66 to 0.93]	2.82	0.00
Polėkio trukmė (s)	0.11 ± 0.01	0.11 ± 0.01	0.003 ± 0.006	0.079	0.79*	[0.55 to 0.91]	3.41	0.00
Žingsnio ciklo trukmė (m)	4.13 ± 0.18	4.19 ± 0.20	0.059 ±0.090	0.005	0.85*	[0.57 to 0.94]	1.40	0.06
Žingsnių dažnis (žingsniai/s)	4.28 ± 0.23	4.23 ± 0.22	0.044 ± 0.128	0.124	0.83*	[0.63 to 0.93]	1.70	0.07

Santrumpos: ICC – intraklasinis koreliacijos koeficientas (* $p < 0{,}001$); CI – pasikliautinasis intervalas; CV – variacijos koeficientas; SEM – standartinė matavimo paklaida.



3 pav. Bland-Altman analizė, vertinant „Alex7” užfiksuotų sprinto laikų pakartotinių matavimų suderinamumą

Pastaba. Skirtumai diagramoje buvo apskaičiuoti iš pirmojo testavimo rezultato atimant pakartotinio testavimo rezultatą. Stora juoda ištisinė linija – vidutinis skirtumas tarp dviejų testavimų; storos juodos punktyrinės linijos – 95 % suderinamumo ribos; plona juoda punktyrinė linija – nulinė reikšmė.

Santrumpos: R – sprintas su pasunkinimu; A – sprintas su užtempimu.

2.1.2. „Alex7“ įrenginio informatyvumas sprinto su pasunkinimu ir sprinto su užtempimu sąlygomis

Visų sprinto su pasunkinimu tarpinių laikų ir visų sprinto su užtempimu tarpinių laikų, išskyrus pirmąją 0–10 m atkarpą, Pirsono koreliacijos koeficiento reikšmės tarp „Alex7“ ir „Witty“ sistemų buvo puikios ($r = 0{,}90$–$0{,}98$; $p < 0{,}001$; 2 lentelė). Sprinto su užtempimu pirmosios 0–10 m atkarpos koreliacija buvo šiek tiek mažesnė, tačiau vis tiek išliko didelė ($r = 0{,}88$; $p < 0{,}001$).

Vis dėlto „Alex7“ sistema nuosekliai registravo ilgesnius sprinto laikus nei „Witty“ fotoelementų sistema. Skirtumai tarp sistemų siekė iki 0,16 s, o variacijos koeficientas svyravo nuo 1,00 iki 3,79 % ($p < 0{,}001$). Bland-Altman analizė parodė neigiamą sisteminę paklaidą tarp „Alex7“ ir „Witty“ sistemų tiek sprinto su pasunkinimu, tiek sprinto su užtempimu sąlygomis ($p < 0{,}001$; 4 pav.), išskyrus sprinto su pasunkinimu 0–10 m atkarpą.

Nepaisant nustatytų skirtumų, sprinto laikų reikšmės Bland-Altman diagramose pateko į siauras suderinamumo ribas, o daugumos rodiklių pakartojamumas išliko 95 % pasikliautinojo intervalo ribose. Šie rezultatai rodo, kad „Alex7“ sistema pasižymi nuosekliais matavimais, tačiau sprinto laikų registravimo tikslumas buvo mažesnis nei „Witty“ fotoelementų sistemos.

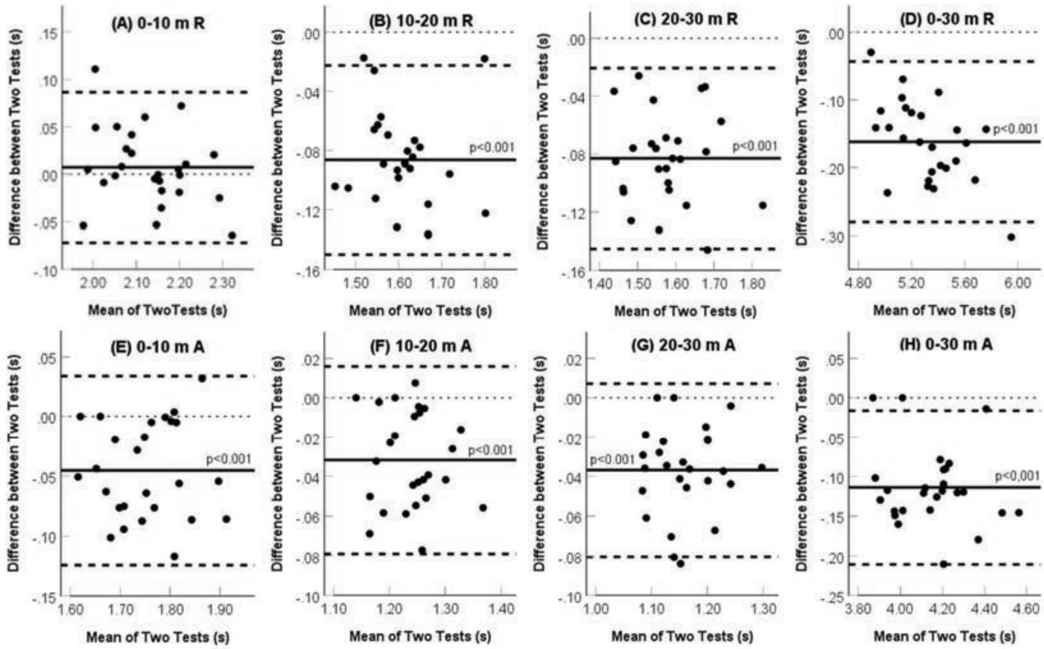
Skirtumai tarp abiejų sistemų buvo šiek tiek mažesni sprinto su užtempimu sąlygomis (0,03–0,11 s) nei sprinto su pasunkinimu sąlygomis (-0,01–0,16 s).

2 lentelė. „Alex7“ įrenginio kriterinis validumas vienos testavimo sesijos metu

Sprintas	**Atkarpa**	**Sprinto bėgimo laikas (Vidurkis ± SD)**		**P reikšmė**	**ES**	**Criterion-referenced validity**		
		Witty (s)	Alex7 (s)		Cohen‘s d	t(diff) (s)	CV (%)	Cor. (r)
Su pasunkinimu	0–10 m	2.13 ± 0.09	2.13 ± 0.10	0.373	0.178	-0.01	1.00	0.92*
	10–20 m	1.57 ± 0.08	1.65 ± 0.09	<0.001	-2.655	0.09	3.79	0.93*
	20–30 m	1.54 ± 0.09	1.62 ± 0.10	<0.001	-2.609	0.08	3.73	0.94*
	0–30 m	5.23 ± 0.25	5.40 ± 0.28	<0.001	-2.678	0.16	2.14	0.98*
Su užtempimu	0–10 m	1.73 ± 0.08	1.78 ± 0.08	<0.001	-1.122	0.05	1.93	0.88*
	10–20 m	1.22 ± 0.05	1.26 ± 0.06	<0.001	-1.307	0.03	1.84	0.90*
	20–30 m	1.14 ± 0.06	1.18 ± 0.06	<0.001	-1.643	0.04	2.25	0.93*
	0–30 m	4.09 ± 0.18	4.21 ± 0.19	<0.001	-2.223	0.11	1.93	0.97*

Pastaba. Duomenys pateikiami kaip vidurkis ± standartinis nuokrypis (SD).

Santrumpos: ES – efekto dydis; t(diff) – vidutinis skirtumas tarp matavimo sistemų; CV – variacijos koeficientas; Cor. (r) – Pirsono koreliacijos koeficientas; * – statistiškai reikšminga koreliacija (p < 0,001). Witty – „Witty“ fotoelementų sistema; Alex7 – motorizuotas sprinto įrenginys „Alex7“.



4 pav. Bland-Altman analizė, vertinant sprinto laikų skirtumus tarp „Alex7” ir „Witty” sistemų

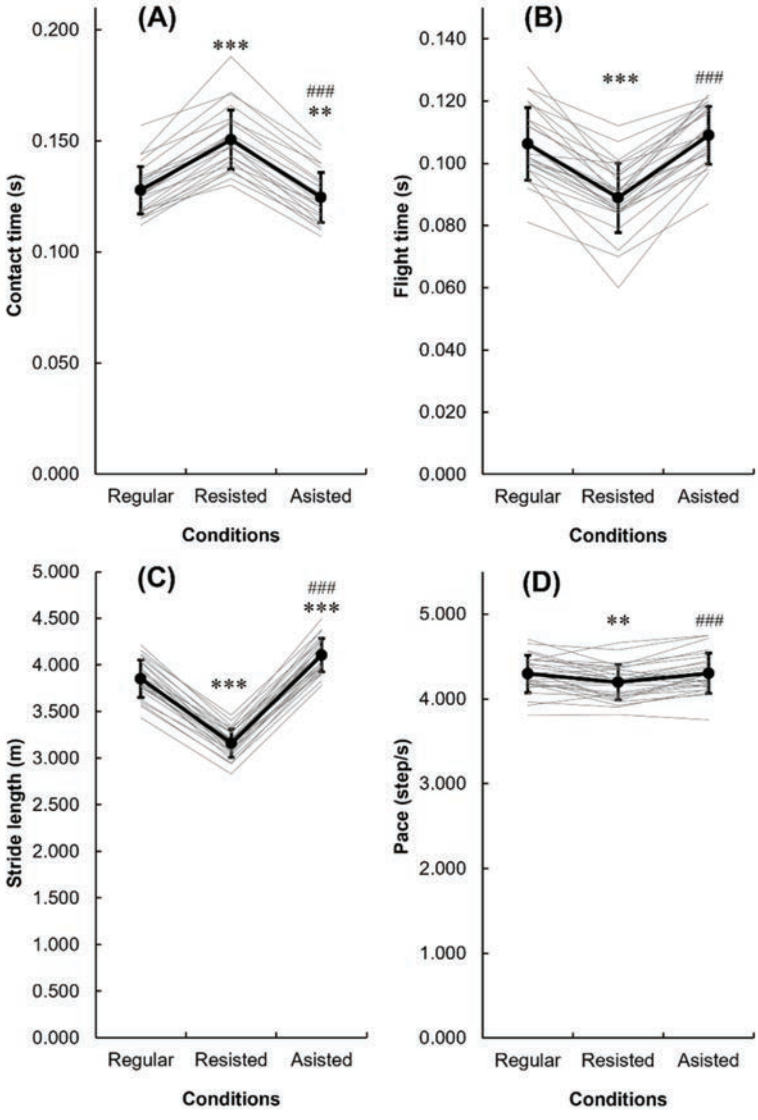
Pastaba. Skirtumai diagramoje buvo apskaičiuoti iš „Witty“ sistemos rezultato atimant „Alex7“ sistemos rezultatą. Stora juoda ištisinė linija – vidutinis skirtumas tarp dviejų sistemų; storos juodos punktyrinės linijos – 95 % suderinamumo ribos; plona juoda punktyrinė linija – nulinė reikšmė.

Santrumpos: R – sprintas su pasunkinimu; A – sprintas su užtempimu.

2.1.3. Sprinto rezultatų ir žingsnių charakteristikos parametrų skirtumai esant skirtingoms sprinto sąlygoms

Vidutinis bėgimo greitis reikšmingai skyrėsi esant visoms trims sprinto sąlygoms: maksimalaus sprinto metu jis siekė 8,17 ± 0,39 m/s, sprinto su pasunkinimu metu – 6,59 ± 0,35 m/s ($p < 0,001$), o sprinto su užtempimu metu – 8,65 ± 0,44 m/s ($p < 0,05$).

Visi analizuoti žingsnių charakteristikos parametrai (5 pav. A–D) reikšmingai skyrėsi esant skirtingoms sprinto sąlygoms. Didžiausi žingsnio ilgio ir kontakto su žeme trukmės rodiklių skirtumai ($p < 0,001$). Mažiausi polėkio trukmės ir žingsnių dažnio rodiklių skirtumai. Polėkio trukmė ir žingsnių dažnis nesiskyrė esant maksimalaus sprinto ir sprinto su užtempimu sąlygoms, tačiau reikšmingai skyrėsi esant maksimalaus sprinto ir sprinto su pasunkinimu bei sprinto su pasunkinimu ir sprinto su užtempimu sąlygoms ($p < 0,001$). Visų analizuotų rodiklių absoliutūs skirtumai buvo didesni esant sprinto su pasunkinimu ir maksimalaus sprinto nei esant sprinto su užtempimu ir maksimalaus sprinto sąlygoms.



5 pav. Atremties trukmė (A), polėkio trukmė (B), žingsnio ilgis (C) ir žingsnių dažnis (D) maksimalaus sprinto, sprinto su pasunkinimu ir sprinto su užtempimu metu (vidurkis ± SD ir individualūs duomenys)

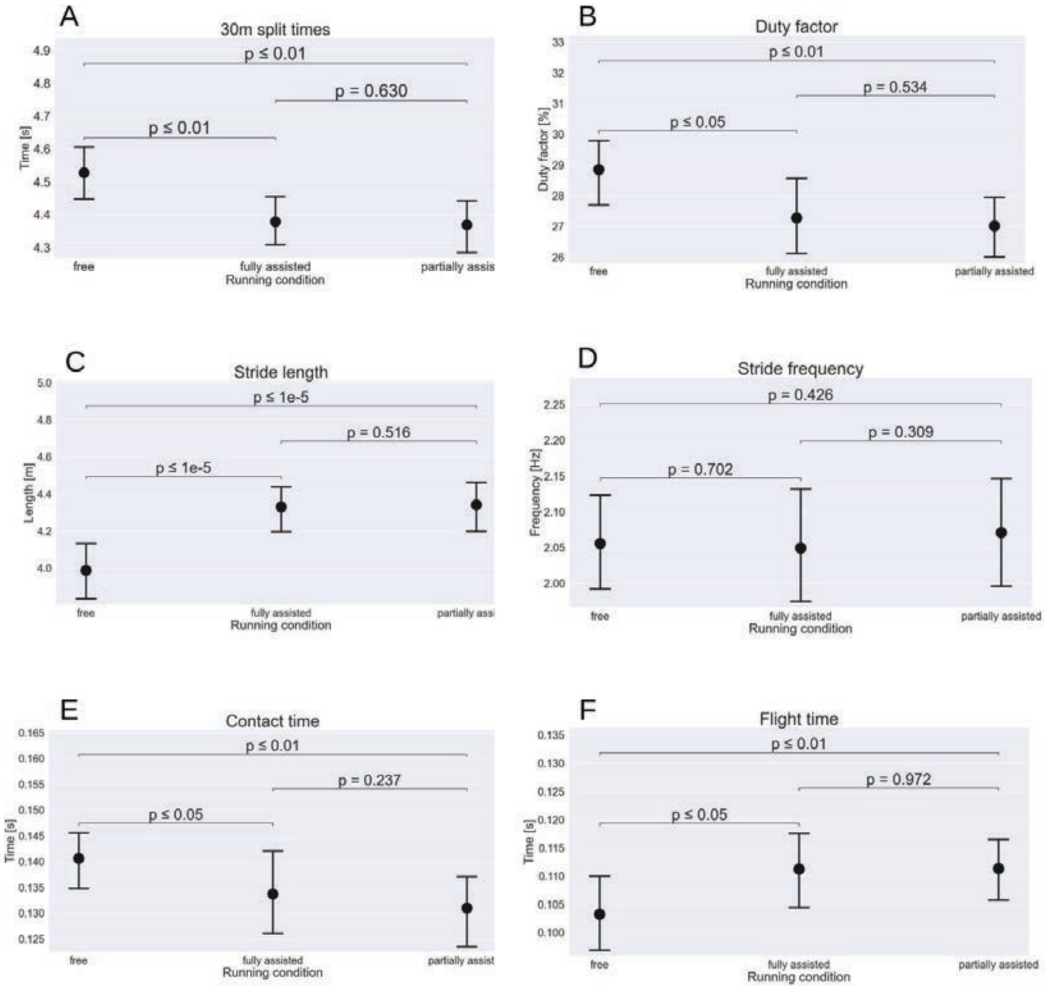
Pastaba. Reikšmingai skiriasi nuo maksimalaus sprinto (** p < 0,01; *** p < 0,001); reikšmingai skiriasi nuo sprinto su pasunkinimu (### p < 0,001). *Regula*r – sprinto bėgimas, *resisted* – sprinto bėgimas su pasunkinimu, *assisted* – sprinto bėgimas su užtempimu.

2.2. Antrasis tyrimas: apatinių galūnių raumenų aktyvumas sprinto bėgimo metu taikant pilną ir dalinį užtempimą.

2.2.1. Žingsnių charakteristika

Pirmiausia nustatyta, kad 30 m sprinto bėgimo rezultatai, gauti bėgant tiek su pilnu, tiek su daliniu užtempimu buvo reikšmingai geresni nei sprinto rezultatai bėgant be užtempimo. Lyginant pilno užtempimo bėgimą su sprintu be užtempimo skirtumas 2,8 %, ($p < 0,01$); lyginant dalinio užtempimo bėgimą su bėgimu be užtempimo – 3,4 %, ($p < 0,001$) (6 pav.). Vertinant žingsnių charakteristikų rodiklius, reikšmingi skirtumai nustatyti tarp sprinto be užtempimo ir abiejų sprinto bėgimų su skirtingais užtempimo būdais, tačiau skirtumų tarp bėgimo su pilnu ir bėgimo su daliniu užtempimu žingsnių charakteristikoje nenustatyta.

Analizuojamo žingsnio metu didesnis bėgimo greitis abiejuose sprinto su užtempimu bėgimuose buvo susijęs su reikšmingai didesniu žingsnio ilgiu ir ilgesne polėkio trukme. Pilno užtempimo bėgimo metu žingsnio ilgis padidėjo 8,6 %, ($p < 0,001$), polėkio trukmė – 7,7 %, ($p < 0,05$); dalinio užtempimo bėgimo metu žingsnio ilgis padidėjo 8,9 %, ($p < 0,001$), polėkio trukmė – 7,8 %, ($p < 0,01$) (6 pav.). Taip pat skirtingi užtempimo būdai reikšmingai sumažino atremties trukmės laiką. Pilno užtempimo metu atremties trukmė sumažėjo 4,9 %, $p < 0,05$; dalinio užtempimo metu – 6,9 %, $p < 0,01$) (6 pav.). Žingsnių dažnis visų skirtingų sprinto bėgimų metu išliko toks pats. Atramos fazės santykis (DF) sprinto be užtempimo bėgimo metu buvo reikšmingai didesnis nei abiejuose skirtinguose sprinto su užtempimu bėgimuose. Pilno užtempimo bėgimo metu sumažėjo 5,5 %, ($p < 0,05$); dalinio užtempimo bėgimo metu – 6,4 %, ($p < 0,01$).

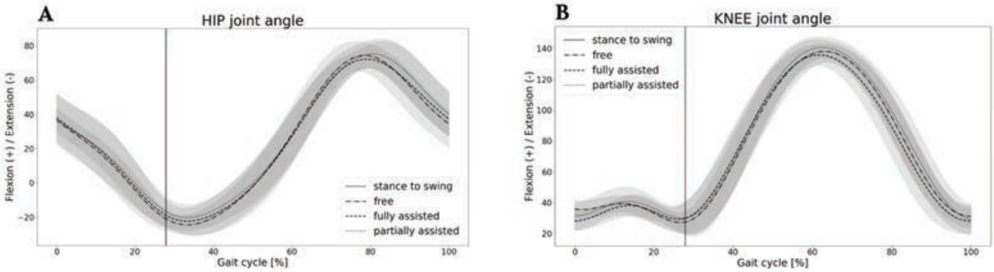


6 pav. 30 m sprinto bėgimo laikas (A), atramos fazės santykis (B), žingsnio ciklo ilgis (C), žingsnių dažnis (D), atramos trukmės laikas (E) ir polėkio trukmė (F) sprinto be užtempimo, sprinto su pilnu užtempimu ir sprinto su daliniu užtempimu bėgimo metu

Duomenys pateikiami kaip vidurkis ± standartinis nuokrypis.

2.2.2. Kinematiniai rodikliai

Čiurnos sąnario kampo duomenys į tolesnę analizę nebuvo įtraukti dėl nepakankamos duomenų kokybės. Vertinant kelio ir klubo sąnarių kampus, statistiškai reikšmingų skirtumų tarp visų skirtingų sprinto bėgimų nenustatyta ($p > 0{,}05$) (7 pav.).



7 pav. Klubo sąnario (A) ir kelio sąnario (B) kampai žingsnio ciklo metu

0 % – pirmasis kontaktas su žeme, 100 % – kitas tos pačios kojos kontaktas su žeme

2.2.3. Elektromiografijos rezultatai

Vertinant visų analizuotų raumenų (dvigalvio šlaunies – *biceps femoris,* pusgyslinio – *semitendinosus,* plataus šoninio šlaunies – *vastus lateralis,* tiesiojo šlaunies – *rectus femoris* ir didžiojo sėdmens – *gluteus maximus*) vidutinį aktyvumą, statistiškai reikšmingų skirtumų tarp sprinto be užtempimo, sprinto su daliniu užtempimu ir sprinto su pilnu užtempimu nenustatyta (8 pav.).

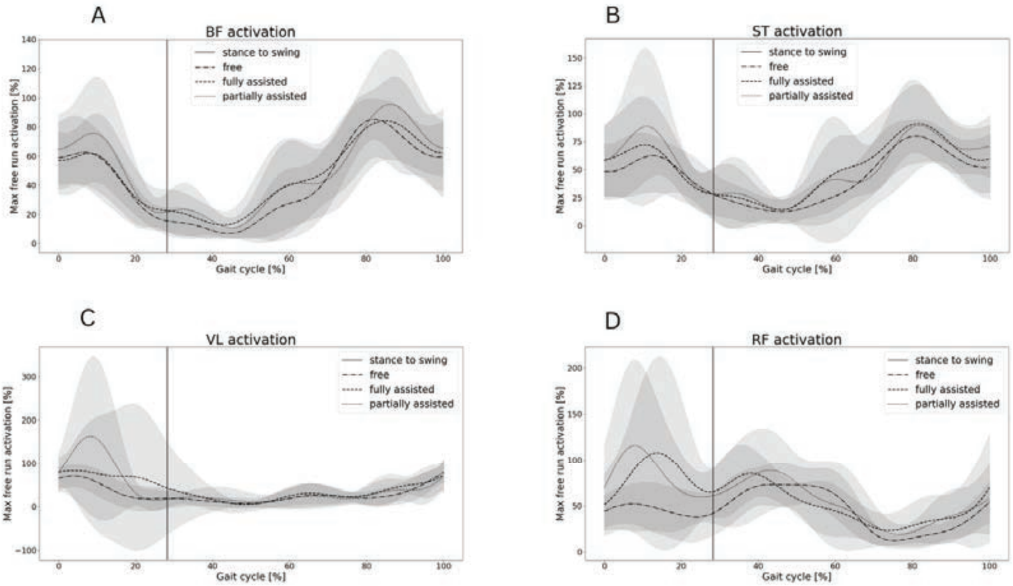
Vis dėlto, dėl didelio individualių rodiklių variabilumo papildoma efekto dydžio analizė atskleidė raumens aktyvumo skirtumų tikimybę atskirose žingsnio ciklo fazėse.

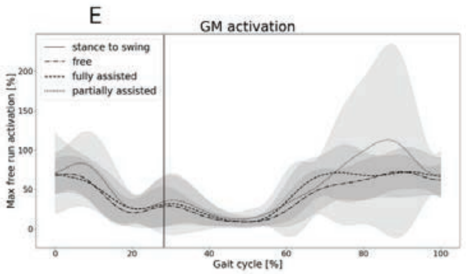
Esant skirtingoms sprinto sąlygoms didžiausias dvigalvio šlaunies (*biceps femoris*) ir pusgyslinio (*semitendinosus*) raumens aktyvumas nustatytas mosto vėlyvosios fazės metu. Didelis efekto dydis (d = 0,8) pagrindžia galimybę, kad ties 88 % žingsnio ciklo pusgyslinio raumens aktyvumas buvo didesnis pilno užtempimo bėgimo metu, palyginti su bėgimu be užtempimo. Taip pat gauta artima dideliam efekto dydžiui reikšmė (d = 0.77) ties 98 % patvirtina didesnio aktyvumo galimybę dalinio užtempimo bėgimo metu, palyginti su bėgimu be užtempimo. Dvigalvio šlaunies raumens atveju mosto fazėje, ties 40 – 44 % žingsnio ciklo, nustatyti dideli efekto dydžiai (d > 0,8), rodantys mažesnį aktyvumą abiejų sprinto su užtempimu bėgimų metu, palyginti su sprinto bėgimu be užtempimo.

Ryškiausi ir ilgiausiai trunkantys skirtumai nustatyti tiesiojo šlaunies (*rectus femoris*) raumens elektromiografijoje. Dideli efekto dydžiai buvo stebimi nuo vidurinės atramos fazės iki atsispyrimo nuo žemės, ties 20 – 28 % žingsnio ciklo (d > 0,8; d_{max} = 1,35), kai tiesiojo šlaunies raumens aktyvumo rodiklių reikšmės bėgant su pilnu užtempimu buvo didesnės už reikšmes, gautas sprinto bėgimo be užtempimo metu. Šie skirtumai tęsėsi ir vidurinėje mosto fazėje, kur didžiausi efekto dydžiai nustatyti tarp 49–57 % žingsnio ciklo (d > 0,8; d_{max} = 1,25), tačiau šiuo atveju raumens aktyvumo rodiklių reikšmės, gautos sprinto bėgimo be užtempimo metu, buvo didesnės už reikšmes, gautas sprinto bėgimo su pilnu užtempimu metu.

Platusis šoninis šlaunies (*vastus lateralis*) raumuo didžiausią aktyvumą pasiekė ankstyvosios atramos fazės metu, o prieš kontaktą su žeme, ties 91–92 % žingsnio ciklo, buvo nustatytas vidutinis efekto dydis (d = 0,75). Tuo momentu raumens aktyvacija bėgant su pilnu užtempimu buvo didesnė, palyginti su aktyvacija bėgant be užtempimo. Didžiojo sėdmens (*gluteus maximus*) raumens atveju vidutinio efekto dydžiai buvo nustatyti vidurinėje mosto fazėje ties 70 % žingsnio ciklo; (d = 0,7), aktyvacija pilno užtempimo metu buvo didesnė už aktyvaciją bėgant be užtempimo ir ankstyvojoje atremties fazėje, ties 10 % žingsnio ciklo; (d > 0,6), kur raumens aktyvacija dalinio užtempimo metu buvo didesnė už raumens aktyvaciją, registruotą pilno užtempimo metu.

Apibendrinant galima teigti, kad, nors statistiškai reikšmingų skirtumų nėra, vertinant vidutinį raumenų aktyvumą esant skirtingoms sprinto sąlygoms, efekto dydžio analizė atskleidė trumpalaikius, nuo raumens priklausančius ir skirtingose žingsnio ciklo fazėse pasireiškiančius skirtumus.





8 pav. Dvigalvio šlaunies (A), pusgyslinio (B), plataus šoninio šlaunies (C), tiesiojo šlaunies (D) ir didžiojo sėdmens (E) raumens EMG aktyvumas žingsnio ciklo metu esant skirtingoms bėgimo sąlygoms

Duomenys pateikiami kaip vidurkis ± standartinis nuokrypis. 0 % – pirmasis kontaktas su žeme, 100 % – kitas tos pačios kojos kontaktas su žeme

2.3. Trečiasis tyrimas: sprinto su užtempimu treniruočių intervencija: individualios adaptacijos, susijusios su jėgos ir greičio profiliais ir žingsnių charakteristikomis

2.3.1. Sprinto rezultatų skirtumai taikant pilną ir dalinį užtempimą

Prieš treniruočių intervenciją statistiškai reikšmingų skirtumų tarp kontrolinės, pilno užtempimo ir dalinio užtempimo grupių nenustatyta nei sprinto rezultatų, nei žingsnių charakteristikų rodikliuose (visi $p > 0,05$) (3 lentelė). Palyginus sprintą be užtempimo ir sprintą su užtempimu, 30 m sprinto su užtempimu metu bėgimo laikas kontrolinėje grupėje sumažėjo 5,02 %, pilno užtempimo grupėje – 5,8 %, o dalinio užtempimo grupėje – 3,83 %. Šie pagerėjimai statistiškai reikšmingi kiekvienos grupės viduje ($p < 0,05$), tačiau tarp grupių reikšmingų skirtumų nenustatyta ($p > 0,05$).

Geresni sprinto su užtempimu rezultatai daugiausia buvo susiję su žingsnių charakteristikų pokyčiais. Visose grupėse sprinto su užtempimu metu padidėjo žingsnio ilgis, o kontrolinėje ir pilno užtempimo grupėse padidėjo ir polėkio trukmė. Be to, kontrolinėje grupėje sprinto su užtempimu metu nustatytas reikšmingai trumpesnis kontakto su žeme laikas (visi $p < 0,05$) (3 lentelė).

Vertinant sprinto su užtempimu rezultatus, dviejų veiksnių dispersinė analizė (Grupė × Laikas), taikant kartotinius matavimus laiko veiksniui, parodė reikšmingą sąveiką: $F(2,21) = 6,07$, $p = 0,01$, $\eta^2p = 0,37$ (3 lentelė). Post hoc analizė parodė, kad kontrolinėje grupėje sprinto rezultatai išliko stabilūs (prieš 4,16 ± 0,21 s; po 4,15 ± 0,21 s), o pilno užtempimo ir dalinio užtempimo grupėse sprinto rezultatai reikšmingai pagerėjo (pilno užtempimo grupėje: prieš – 4,22 ± 0,16 s; po – 4,13 ± 0,21 s; dalinio užtempimo grupėje: prieš – 4,26 ± 0,14 s; po – 4,08 ± 0,17 s). Taip pat nustatytas reikšmingas laiko veiksnio poveikis: $F(1,21) = 23,40$, $p = 0,01$, $\eta^2p = 0,53$, tačiau grupės veiksnio poveikis nebuvo statistiškai reikšmingas: $F(2,22) = 0,03$, $p = 0,98$, $\eta^2p = 0,00$. Reikšmingų skirtumų tarp pilno ir dalinio užtempimo grupių nenustatyta.

Vertinant sprinto be užtempimo rezultatus, dviejų veiksnių dispersinė analizė (Grupė × Laikas) taip pat parodė reikšmingą sąveiką: $F(2,21) = 6,26$, $p = 0,01$, $\eta^2p = 0,37$ (3 lentelė). Kontrolinėje grupėje nustatytas sprinto rezultatų pablogėjimas: prieš – 4,38 ± 0,20 s; po – 4,48 ± 0,18 s; ($p > 0,05$), o pilno ir dalinio užtempimo grupėse rezultatai gerėjo (pilno užtempimo grupėje: prieš – 4,48 ± 0,21 s; po – 4,43 ± 0,20 s; $p > 0,05$; dalinio užtempimo grupėje: prieš – 4,43 ± 0,17 s; po – 4,38 ± 0,20 s; $p > 0,05$). Vis dėlto nei laiko veiksnio poveikis ($F(1,21) = 0,01$, $p = 0,92$, $\eta^2p = 0,00$), nei grupės veiksnio poveikis: ($F(2,21) = 0,15$, $p = 0,86$, $\eta^2p = 0,01$) nebuvo statistiškai reikšmingi. Reikšmingų skirtumų tarp pilno ir dalinio užtempimo grupių taip pat nenustatyta.

3 lentelė. Dviejų veiksnių kartotinių matavimų dispersinės analizės (ANOVA) rezultatai, vertinant sprinto rezultatus, žingsnių charakteristikas ir įrenginio registruotus rodiklius kontrolinėje, pilno užtempimo ir dalinio užtempimo treniruočių intervencijos grupėse

Rodiklis	Post-Hoc			Factorius	df	F	p	η^2p
	Kontrolinė gr.	Pilno užtemp. gr.	Dalinio užtemp. gr.					
30m laikas su užtempimu (s)	Prieš: 4.16 ± 0.21###	Prieš: 4.22 ± 0.16###	Prieš: 4.26 ± 0.14###	Groupė	2, 21	0.03	0.98	0.00
	Po: 4.15 ± 0.21	Po: 4.13 ± 0.21*	Po: 4.08 ± 0.17***	Laikas	1, 21	23.40	0.00	0.53
				Groupė X Laikas	2, 21	6.07	0.01	0.37
30m laikas be užtempimo (s)	Prieš: 4.38 ± 0.20	Prieš: 4.48 ± 0.21	Prieš: 4.43 ± 0.17	Groupė	2, 21	0.15	0.86	0.01
	Po: 4.48 ± 0.18*	Po: 4.43 ± 0.20	Po: 4.38 ± 0.20	Laikas	1, 21	0.01	0.92	0.00
				Groupė X Laikas	2, 21	6.26	0.01	0.37
Žingsnio ilgis su užtempimu (cm)	Prieš: 213.1 ± 9.11###	Prieš: 207.7 ± 7.18###	Prieš: 213.9 ± 12.41##	Groupė	2, 21	1.62	0.22	0.13
	Po: 209.2 ± 12.33	Po: 205.9 ± 6.64	Po: 214.3 ± 10.03	Laikas	1, 21	0.78	0.39	0.04
				Groupė X Laikas	2, 21	0.36	0.70	0.03
Žingsnio dažnis su užtempimu (žingsniai/s)	Prieš: 4.36 ± 0.14	Prieš: 4.43 ± 0.24	Prieš: 4.29 ± 0.29	Groupė	2, 21	0.67	0.52	0.06
	Po: 4.40 ± 0.32	Po: 4.48 ± 0.22	Po: 4.36 ± 0.26	Laikas	1, 21	1.84	0.19	0.08
				Groupė X Laikas	2, 21	0.02	0.98	0.00
Atremties trukmė su užtempimu (s)	Prieš: 0.120 ± 0.00###	Prieš: 0.126 ± 0.01	Prieš: 0.123 ± 0.01	Groupė	2, 21	0.21	0.81	0.02
	Po: 0.120 ± 0.01	Po: 0.120 ± 0.01	Po: 0.120 ± 0.01	Laikas	1, 21	2.94	0.10	0.12
				Groupė X Laikas	2, 21	1.04	0.37	0.09
Polėkio trukmė su užtempimu (s)	Prieš: 0.110 ± 0.009##	Prieš: 0.101 ± 0.006##	Prieš: 0.112 ± 0.008	Groupė	2, 21	3.24	0.06	0.24
	Po: 0.109 ± 0.013	Po: 0.104 ± 0.007	Po: 0.111 ± 0.007	Laikas	1, 21	0.00	0.99	0.00
				Groupė X Laikas	2, 21	0.75	0.49	0.07

Rodiklis	**Post-Hoc**			**Factorius**	**df**	**F**	**p**	**$\eta^2 p$**
	Kontrolinė gr.	**Pilno užtemp. gr.**	**Dalinio užtemp. gr.**					
Žingsnio ilgis be užtempimo (cm)	Prieš: 194.7 ± 9.27 Po: 194.9 ± 9.81	Prieš: 188.6 ± 7.55 Po: 186.8 ± 7.86	Prieš: 195.2 ± 11.77 Po: 197.0 ± 11.40	Groupė	2, 21	2.00	0.16	0.16
				Laikas	1, 21	0.01	0.94	0.00
				Groupė X Laikas	2, 21	1.05	0.37	0.09
Žingsnio dažnis be užtempimo (žingsniai/s)	Prieš: 4.40 ± 0.16 Po: 4.36 ± 0.28	Prieš: 4.48 ± 0.23 Po: 4.53 ± 0.21	Prieš: 4.35 ± 0.23 Po: 4.35 ± 0.30	Groupė	2, 21	1.06	0.36	0.09
				Laikas	1, 21	0.03	0.86	0.00
				Groupė X Laikas	2, 21	0.50	0.61	0.05
Atremties trukmė be užtempimo (s)	Prieš: 0.127 ± 0.005 Po: 0.129 ± 0.008	Prieš: 0.128 ± 0.013 Po: 0.123 ± 0.010**	Prieš: 0.126 ± 0.011 Po: 0.124 ± 0.009	Groupė	2, 21	0.20	0.82	0.02
				Laikas	1, 21	1.25	0.28	0.06
				Groupė X Laikas	2, 21	3.89	0.04	0.27
Polėkio trukmė be užtempimo (s)	Prieš: 0.101 ± 0.008 Po: 0.102 ± 0.012	Prieš: 0.096 ± 0.007 Po: 0.099 ± 0.008	Prieš: 0.105 ± 0.012 Po: 0.107 ± 0.012	Groupė	2, 21	1.73	0.20	0.14
				Laikas	1, 21	1.25	0.28	0.06
				Groupė X Laikas	2, 21	0.12	0.89	0.01

Pastaba. Duomenys pateikiami kaip vidurkis ± standartinis nuokrypis. Žingsnių charakteristikų rodikliai vertinti maksimalaus bėgimo greičio metu. * – statistiškai reikšmingas skirtumas tarp prieš ir po treniruočių intervencijos gautų testų rezultatų, vertinamų grupės viduje ($p < 0,05$); # – statistiškai reikšmingas skirtumas lyginant tuos pačius rodiklius sprinto be užtempimo ir sprinto su užtempimu sąlygomis ($p < 0,05$). Pateikiamos F, p ir dalinio eta kvadrato ($\eta^2 p$) reikšmės grupės, laiko bei grupės ir laiko sąveikos poveikiui įvertinti.

Dviejų veiksnių kartotinių matų dispersinė analizė parodė reikšmingą grupės ir laiko sąveiką sprinto be užtempimo atremties trukmės laiko rodiklyje ($F(1,21) = 3,89$, $p = 0,04$, $\eta^2p = 0,27$), rodančią skirtingą rodiklio kitimą prieš ir po intervencijos tarp grupių (3 lentelė). Tačiau nei laiko veiksnio poveikis ($F(1,21) = 1,25$, $p = 0,28$, $\eta^2p = 0,06$), nei grupės veiksnio poveikis ($F(2,21) = 0,20$, $p = 0,82$, $\eta^2p = 0,02$) nebuvo statistiškai reikšmingi.

Vis dėlto tik pilno užtempimo grupėje nustatytas reikšmingas atremties trukmės laiko sumažėjimas prieš intervenciją ($0,128 \pm 0,01$ s) ir po ($0,123 \pm 0,01$ s), ($p < 0,01$). Kitų sprinto rezultatų ar žingsnių charakteristikų rodiklių statistiškai reikšmingų grupės, laiko ar jų sąveikos efektų tarp pilno ir dalinio užtempimo grupių po intervencijos nenustatyta (3 lentelė).

2.3.2. Intervencinės ir kontrolinės grupės palyginimas sujungus pilno ir dalinio užtempimo grupes

Prieš treniruočių intervenciją statistiškai reikšmingų skirtumų tarp intervencinės ir kontrolinės grupės nenustatyta nei sprinto rezultatų, nei žingsnių charakteristikų rodikliuose (visi $p > 0,05$) (4 lentelė).

Vertinant sprinto su užtempimu rezultatus, dviejų veiksnių dispersinė analizė (Grupė × Laikas), taikant kartotinius matavimus laiko veiksniui, parodė reikšmingą grupės ir laiko sąveiką: $F(1,22) = 7,55$, $p = 0,01$, $\eta^2p = 0,26$ (4 lentelė). Post hoc analizė parodė, kad kontrolinėje grupėje sprinto rezultatai išliko stabilūs (prieš $4,16 \pm 0,21$ s; po $4,15 \pm 0,21$ s), o intervencinėje grupėje sprinto rezultatai reikšmingai pagerėjo (prieš $4,24 \pm 0,15$ s; po $4,10 \pm 0,19$ s). Taip pat nustatytas reikšmingas laiko veiksnio poveikis: $F(1,22) = 10,12$, $p < 0,01$, $\eta^2p = 0,32$, tačiau grupės veiksnio poveikis nebuvo statistiškai reikšmingas: $F(1,22) = 0,05$, $p = 0,83$, $\eta^2p = 0,00$.

Vertinant sprinto be užtempimo rezultatus, dviejų veiksnių dispersinė analizė (Grupė × Laikas) taip pat parodė reikšmingą grupės ir laiko sąveiką: $F(1,22) = 13,08$, $p < 0,01$, $\eta^2p = 0,37$ (4 lentelė). Kontrolinėje grupėje nustatytas sprinto rezultatų pablogėjimas (prieš $4,38 \pm 0,20$ s; po $4,48 \pm 0,18$ s; $p > 0,05$), tuo tarpu intervencinėje grupėje rezultatai gerėjo (prieš: $4,46 \pm 0,19$ s; po: $4,41 \pm 0,20$ s; $p > 0,05$). Vis dėlto nei laiko veiksnio poveikis ($F(1,22) = 1,71$, $p = 0,21$, $\eta^2p = 0,07$), nei grupės veiksnio poveikis ($F(1,22) = 0,00$, $p = 0,97$, $\eta^2p = 0,00$) nebuvo statistiškai reikšmingi.

Dviejų veiksnių kartotinių matų dispersinė analizė parodė reikšmingą grupės ir laiko sąveiką sprinto be užtempimo atremties trukmės rodiklyje ($F(1,22) = 6,36$, $p = 0,02$, $\eta^2p = 0,22$), rodančią skirtingą rodiklio kitimą prieš ir po intervencijos tarp grupių. Tačiau nei laiko veiksnio poveikis ($F(1,22) = 0,05$, $p = 0,83$, $\eta^2p = 0,00$), nei grupės veiksnio poveikis ($F(1,22) = 0,40$, $p = 0,53$, $\eta^2p = 0,02$) nebuvo statistiškai reikšmingi. Vertinant sprinto be užtempimo žingsnio ilgį, žingsnių dažnį ir polėkio trukmę, reikšmingų grupės ir laiko sąveikos efektų nenustatyta (visi $p > 0,05$).

Sprinto su užtempimu žingsnių charakteristikų rodikliuose reikšmingų sąveikos efektų taip pat nenustatyta (visi $p > 0,05$).

Vis dėlto porinių palyginimų analizė (žvaigždutėmis pažymėti rodikliai; 4 lentelė) parodė nedidelį, tačiau statistiškai reikšmingą atremties trukmės sumažėjimą intervencinėje grupėje tiek sprinto be užtempimo, tiek sprinto su užtempimu sąlygomis ($p < 0,05$).

4 lentelė. Dviejų veiksnių kartotinių matų dispersinės analizės (ANOVA) rezultatai, vertinant sprinto rezultatus ir žingsnių charakteristikas kontrolinėje ir intervencinėje grupėje

Rodiklis	Post-Hoc		Factorius	df	F	p	η^2_p
	Kontrolinė grupė:	Intervencinė grupė:					
30m laikas su užtempimu (s)	Prieš: 4.16 ± 0.21	Prieš: 4.24 ± 0.15	Groupė	1, 22	0.05	0.83	0.00
	Po: 4.15 ± 0.21	Po: 4.10 ± 0.19***	Laikas	1, 22	10.12	0.01	0.32
			Groupė X Laikas	1, 22	7.55	0.01	0.26
30m laikas be užtempimo (s)	Prieš: 4.38 ± 0.20	Prieš: 4.46 ± 0.19	Groupė	1, 22	0.00	0.97	0.00
	Po: 4.48 ± 0.18*	Po: 4.41 ± 0.20*	Laikas	1, 22	1.71	0.21	0.07
			Groupė X Laikas	1, 22	13.08	0.00	0.37
Žingsnio ilgis su užtempimu (cm)	Prieš: 213.1 ± 9.11	Prieš: 210.6 ± 10.17	Groupė	1, 22	0.05	0.82	0.00
	Po: 209.2 ± 12.33	Po: 209.9 ± 9.20	Laikas	1, 22	1.18	0.29	0.05
			Groupė X Laikas	1, 22	0.55	0.47	0.02
Žingsnio dažnis su užtempimu (žingsniai/s)	Prieš: 4.36 ± 0.14	Prieš: 4.36 ± 0.27	Groupė	1, 22	0.02	0.90	0.00
	Po: 4.40 ± 0.32	Po: 4.42 ± 0.24	Laikas	1, 22	1.46	0.24	0.06
			Groupė X Laikas	1, 22	0.03	0.86	0.00
Atremties trukmė su užtempimu (s)	Prieš: 0.120 ± 0.004	Prieš: 0.124 ± 0.013	Groupė	1, 22	0.30	0.59	0.01
	Po: 0.120 ± 0.008	Po: 0.120 ± 0.010*	Laikas	1, 22	1.46	0.24	0.06
			Groupė X Laikas	1, 22	1.46	0.24	0.06
Polėkio trukmė su užtempimu (s)	Prieš: 0.110 ± 0.009	Prieš: 0.106 ± 0.009	Groupė	1, 22	0.66	0.43	0.03
	Po: 0.109 ± 0.013	Po: 0.107 ± 0.008	Laikas	1, 22	0.04	0.84	0.00
			Groupė X Laikas	1, 22	0.51	0.48	0.02
Žingsnio ilgis be užtempimo (cm)	Prieš: 194.7 ± 9.27	Prieš: 191.7 ± 10.04	Groupė	1, 22	0.51	0.49	0.02
	Po: 194.9 ± 9.81	Po: 191.6 ± 10.73	Laikas	1, 22	0.00	0.97	0.00
			Groupė X Laikas	1, 22	0.01	0.93	0.00

Rodiklis	Post-Hoc		Factorius	df	F	p	η^2_p
	Kontrolinė grupė:	**Intervencinė grupė:**					
Žingsnio dažnis be užtempimo (žingsniai/s)	Prieš: 4.40 ± 0.16 Po: 4.36 ± 0.28	Prieš: 4.42 ± 0.23 Po: 4.45 ± 0.27	Groupė	1, 22	0.24	0.63	0.01
			Laikas	1, 22	0.01	0.94	0.00
			Groupė X Laikas	1, 22	0.66	0.43	0.03
Atremties trukmė be užtempimo (s)	Prieš: 0.127 ± 0.005 Po: 0.129 ± 0.008	Prieš: 0.127 ± 0.012 Po: 0.124 ± 0.009*	Groupė	1, 22	0.40	0.53	0.02
			Laikas	1, 22	0.05	0.83	0.00
			Groupė X Laikas	1, 22	6.36	0.02	0.22
Polėkio trukmė be užtempimo (s)	Prieš: 0.101 ± 0.008 Po: 0.102 ± 0.012	Prieš: 0.100 ± 0.010 Po: 0.102 ± 0.011	Groupė	1, 22	0.00	0.99	0.00
			Laikas	1, 22	0.81	0.38	0.04
			Groupė X Laikas	1, 22	0.21	0.66	0.01

Pastaba. Duomenys pateikiami kaip vidurkis ± standartinis nuokrypis. Žingsnių charakteristikų rodikliai vertinti maksimalaus bėgimo greičio metu. * – statistiškai reikšmingas skirtumas tarp prieš ir po treniruočių intervencijos gautų testų rezultatų, vertinamų grupės viduje ($p < 0,05$). Pateikiamos F, p ir dalinio eta kvadrato ($\eta^2 p$) reikšmės grupės, laiko bei grupės ir laiko sąveikos poveikiui įvertinti.

2.3.3. Didelį progresą padariusiųjų grupės ir labai mažą progresą padariusiųjų grupės palyginimas pagal bėgimo rezultatus ir žingsnių charakteristikas

Intervencinėje grupėje sportininkai retrospektyviai buvo suskirstyti į didelį progresą padariusiųjų ir labai mažą progresą padariusiųjų grupes pagal 30 m sprinto su užtempimu bėgimo rezultatų kaitą. Nepriklausomų imčių analizė (5 lentelė) parodė, kad didelį progresą padariusiųjų grupė po intervencijos pasiekė reikšmingai geresnius 30 m sprinto su užtempimu rezultatus nei labai mažą progresą padariusiųjų grupė ($p < 0{,}001$; didelis efekto dydis). Reikšmingi skirtumai tarp grupių taip pat buvo nustatyti vertinant rezultatų pokytį (Δ) ($p < 0{,}001$).

Vertinant 30 m sprinto be užtempimo rezultatus, po intervencijos didelį progresą padariusiųjų grupės sportininkų laikai buvo reikšmingai geresni nei labai mažą progresą padariusiųjų grupės ($p < 0{,}05$), tačiau prieš intervenciją statistiškai reikšmingų skirtumų tarp grupių nenustatyta.

Žingsnių charakteristikų rodikliai tarp grupių statistiškai reikšmingai nesiskyrė nei prieš intervenciją, nei po jos, nei vertinant rodiklių pokytį (Δ) (visi $p > 0{,}05$).

5 lentelė. Bėgimo rezultatų ir žingsnių charakteristikų palyginimas tarp didelį progresą padariusiųjų ir labai mažą progresą padariusiųjų grupių

Rodiklis	Vidutinė reikšmė ± standartinis nuokrypis		t	df	p	Cohen's d
	Progreso nepadariusieji:	Didelį progresą padariusieji:				
30m laikas su užtempimu (s)	Prieš: 4.27 ± 0.16##	Prieš: 4.14 ± 0.09##	1.91	12	0.08	1.02
	Po: 4.23 ± 0.12	Po: 3.91 ± 0.09	5.87	12	< .001	3.14
	Δ: -0.04 ± 0.08	Δ: -0.23 ± 0.03	5.74	12	< .001	3.07
30m laikas be užtempimo (s)	Prieš: 4.52 ± 0.22	Prieš: 4.33 ± 0.10	1.984	12	0.071	1.06
	Po: 4.48 ± 0.19	Po: 4.27 ± 0.13	2.374	12	0.035	1.269
	Δ: -0.04 ±0.09	Δ: -0.06 ± 0.08	0.63	12	0.54	0.34
Žingsnio ilgis su užtempimu (cm)	Prieš: 210. ± 12.57##	Prieš: 208.7 ± 9.59##	0.22	12	0.83	0.12
	Po: 205.7 ± 7.77	Po: 212.1 ± 11.14	-1.25	12	0.23	-0.67
	Δ: -4.29 ± 8.27	Δ: 3.43 ± 6.39	-1.95	12	0.08	-1.04
Žingsnio dažnis su užtempimu (žingsniai/s)	Prieš: 4.32 ± 0.27	Prieš: 4.52 ± 0.24	-1.45	12	0.17	-0.77
	Po: 4.42 ± 0.26	Po: 4.56 ± 0.16	-1.24	12	0.24	-0.66
	Δ: 0.09 ± 0.18	Δ: 0.04 ± 0.13	0.65	12	0.53	0.35
Atremties trukmė su užtempimu (s)	Prieš: 0.127 ± 0.013	Prieš: 0.119 ± 0.013	1.23	12	0.24	0.66
	Po: 0.121 ± 0.009	Po: 0.114 ± 0.010	1.47	12	0.17	0.78
	Δ: -0.006 ± 0.008	Δ: -0.005 ± 0.007	-0.26	12	0.80	-0.14
Polėkio trukmė su užtempimu (s)	Prieš: 0.106 ± 0.011##	Prieš: 0.104 ± 0.006##	0.46	12	0.65	0.25
	Po: 0.106 ± 0.009	Po: 0.106 ± 0.006	0.03	12	0.97	0.02
	Δ: 0.000 ± 0.006	Δ: 0.002 ± 0.004	-0.82	12	0.43	-0.44
Žingsnio ilgis be užtempimo (cm)	Prieš: 188.9 ± 9.11	Prieš: 193.9 ± 12.35	-0.86	12	0.41	-0.46
	Po: 187.4 ± 10.82	Po: 193.6 ± 11.99	-1.02	12	0.33	-0.54
	Δ: -1.50 ± 5.90	Δ: -0.29 ± 3.40	-0.45	12	0.66	-0.24

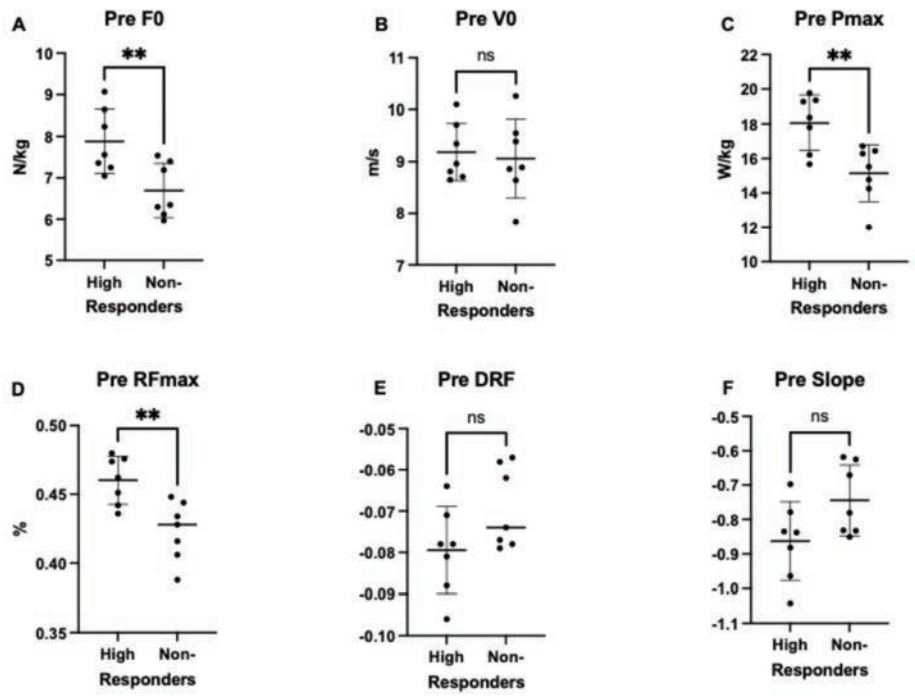
Žingsnio dažnis be užtempimo (žingsniai/s)	Prieš: 4.41 ± 0.23	Prieš: 4.49 ± 0.20	-0.63	12	0.54	-0.34
	Po: 4.43 ± 0.28	Po: 4.56 ± 0.25	-0.89	12	0.39	-0.48
	Δ: 0.02 ± 0.20	Δ: 0.07 ± 0.11	-0.62	12	0.55	-0.33
Atremties trukmė be užtempimo (s)	Prieš: 0.128 ± 0.013	Prieš: 0.123 ± 0.011	0.72	12	0.49	0.38
	Po: 0.123 ± 0.011	Po: 0.121 ± 0.009	0.37	12	0.72	0.20
	Δ: -0.005 ± 0.004	Δ: -0.002 ± 0.005	-1.16	12	0.27	-0.62
Polėkio trukmė be užtempimo (s)	Prieš: 0.100 ± 0.012	Prieš: 0.100 ± 0.007	-0.05	12	0.96	-0.03
	Po: 0.103 ± 0.013	Po: 0.099 ± 0.008	0.75	12	0.47	0.40
	Δ: 0.003 ± 0.007	Δ: -0.002 ± 0.006	1.39	12	0.19	0.74

Pastaba. Duomenys pateikiami kaip vidurkis ± standartinis nuokrypis. Žingsnių charakteristikų rodikliai vertinti maksimalaus bėgimo greičio metu. # – statistiškai reikšmingas skirtumas lyginant tuos pačius rodiklius sprinto be užtempimo ir sprinto su užtempimu sąlygomis ($p < 0,05$).

2.3.4. Didelį progresą padariusiųjų grupės ir labai mažą progresą padariusiųjų grupės palyginimas pagal pradinius jėgos ir greičio profilio rodiklius

Prieš treniruočių intervenciją didelį progresą padariusiųjų grupė pasižymėjo didesnėmis F_0 ($p = 0,01$, $d = 1,65$), Pmax ($p = 0,01$, $d = 1,80$) ir RFmax ($p < 0,01$, $d = 1,87$) reikšmėmis nei labai mažą progresą padariusiųjų grupė (9 pav.). Šie rezultatai rodo, kad didelį progresą padariusiųjų grupės sportininkai jau prieš intervenciją pasižymėjo geresnėmis jėgos ir galios generavimo savybėmis.

Statistiškai reikšmingų skirtumų tarp grupių V_0, DRF ir jėgos ir greičio santykio nuolydžio rodikliuose nenustatyta (visi $p > 0,05$). Vis dėlto DRF ($p = 0,09$, $d = 1,00$) ir jėgos ir greičio santykio nuolydžio ($p = 0,07$, $d = 1,09$) rodikliuose buvo nustatyti dideli efekto dydžiai ($d \geq 1$), rodantys tendenciją, kad didelį progresą padariusiųjų grupės sportininkų jėgos ir greičio profiliai turėjo statesnį jėgos ir greičio santykio nuolydį.



9 pav. Pradinių jėgos ir greičio profilio rodiklių palyginimas tarp didelį progresą padariusiųjų ir labai mažą progresą padariusiųjų grupių

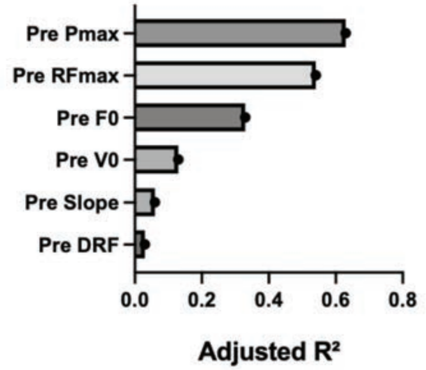
Teorinė maksimali horizontalioji jėga (A); teorinis maksimalus greitis (B); maksimali galia (C); maksimalus horizontaliosios jėgos santykis (D); horizontaliosios jėgos mažėjimo greitėjant rodiklis (E); tiesinės jėgos ir greičio priklausomybės nuolydis (F)

Pastaba. Duomenys pateikiami kaip vidurkis ± standartinis nuokrypis kartu pateikiant individualias reikšmes. ** – statistiškai reikšmingas skirtumas tarp didelį progresą padariusiųjų ir labai mažą progresą padariusiųjų grupių ($p < 0,01$); ns – statistiškai nereikšmingas skirtumas ($p > 0,05$).

2.3.5. Prognozuojamų ryšių analizė

Siekiant nustatyti rodiklius, galinčius prognozuoti sprinto su užtempimu rezultatų pagerėjimą, atlikta tiesinė regresinė analizė, kurioje priklausomas kintamasis buvo 30 m sprinto su užtempimu rezultatas, pasiektas treniruočių intervencijos metu, o nepriklausomi kintamieji – pradiniai jėgos ir greičio profilio rodikliai (10 pav.).

Analizė parodė, kad stipriausi prognostiniai ryšiai nustatyti Pmax (pakoreguotas $R^2 = 0{,}63$) ir RFmax (pakoreguotas $R^2 = 0{,}54$) rodikliams. F_0 rodiklis pasižymėjo vidutinio stiprumo sąsaja su sprinto su užtempimu rezultatų pagerėjimu (pakoreguotas $R^2 = 0{,}33$), o V_0 rodiklio ryšys buvo silpnas (pakoreguotas $R^2 = 0{,}13$).



10 pav. Sprinto be užtempimo metu nustatytų jėgos ir greičio profilio rodiklių prognostinė vertė prognozuojant sprinto su užtempimu rezultatų pagerėjimą (pakoreguotas R^2)

Santrumpos: F_0 – teorinė maksimali horizontalioji jėga; V_0 – teorinis maksimalus greitis; Pmax – maksimali propulsinė galia; RFmax – maksimalus horizontaliosios jėgos santykis; DRF – horizontaliosios jėgos mažėjimo greitėjant rodiklis; slope – tiesinės jėgos ir greičio priklausomybės nuolydis.

Pastaba. Didesnės pakoreguoto R^2 reikšmės rodo stipresnes prognostines sąsajas.

IŠVADOS

1. Motorizuotas įrenginys „Alex7“ pasižymi dideliu informatyvumu ir patikimumu diferencijuojant sprinto užduotis su pasunkinimu ir užtempimu. Tai tinkama priemonė kurti kontroliuojamą treniruočių aplinką, leidžiančią vertinti nervų ir raumenų sistemos bei biomechaninius pokyčius esant skirtingoms sprinto apkrovos sąlygoms.
2. Nors pilnas užtempimas nesumažina raumenų aktyvumo, palyginti su daliniu užtempimu ar įprastu bėgimu, abiem užtempimo sąlygomis gerėja sprinto rezultatai, atitinkamai kinta bėgimo žingsnio charakteristikos. Atskirų raumenų aktyvumo skirtumai pasireiškia tik tam tikrose žingsnio ciklo fazėse, ypač pereinant iš mosto į atramos fazę, tačiau šių skirtumų interpretaciją riboja didelis duomenų variabilumas. Nervų ir raumenų sistemos aktyvumas didėja augant bėgimo greičiui iki maksimalių reikšmių, o jas pasiekus išlieka santykinai stabilus, nepriklausomai nuo išorinės pagalbos dydžio.
3. Sprinto treniruotės su užtempimu yra veiksminga priemonė gerinant jaunųjų futbolininkų bėgimo greitį su užtempimu. Tačiau šie pokyčiai turi mažai įtakos įprasto sprinto rezultatams ir žingsnio charakteristikų rodikliams. Treniruočių poveikis glaudžiai susijęs su pradinėmis sportininkų jėgos ir greičio profilio charakteristikomis – sportininkai, pasižymėję didesnėmis pradinėmis jėgos ir galios reikšmėmis, po sprinto treniruočių su užtempimu programos demonstruoja didesnį progresą.

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SCIENTIFIC PUBLICATIONS

The thesis based on the following articles:

156. Skujytė, A., Lukonaitienė, I., Stanislovaitienė, J., **Šilinskas**, V., Bradauskienė, K., Mamkus, G., & Kamandulis, S. (2024). Reliability and validity of sprint performance using the Alex7 motorized device. *Frontiers in Sports and Active Living*, 6, 1412861, doi: 10.3389/fspor.2024.1412861.
157. Skujytė, A., Kamandulis, S., Genitrini, M., Satkunskienė D., Šilinskas, V., Lukonaitienė, I., Bradauskienė, K., Mickevičius, M., Stanislovaitienė, J., Samozino, P. (2026). Lower limb muscle activity under full and partial towing assistance in sprint running. *Sports Biomechanics*, 2026 Jul 2:1-14. doi: 10.1080/14763141.2026.2693711. Online ahead of print.
158. Skujytė, A., Šilinskas, V., Trinkūnas, E., Lukonaitienė, I., Samozino, P., Kamandulis, S. (2026). Assisted Sprint Training: Individual Adaptations Linked to Force-Velocity Profiles and Spatiotemporal Variables. *Journal of Strength and Conditioning Research* (accepted for publication). Ahead of print.

The thesis data presented in conferences:

159. Skujytė, A.; Lukonaitienė, I.; Stanislovaitienė, J.; **Šilinskas**, V.; Trimailovas, A.; Bradauskienė, K.; Mamkus, G.; Kamandulis, S. Test-retest reliability of motorized Alex7 device for resisted and assisted sprints in youth basketball players // Current trends in sports sciences and physical education : 16th conference of Baltic Society of Sport Sciences : May 24–25th, 2023, Biała Podlaska, Poland: programme and abstracts. Biała Podlaska. 2023, p. 67.
160. Trimailovas, A.; Skujytė, A.; Stnislovaitienė, J.; **Šilinskas**, V.; Bradauskienė, K.; Mamkus, G.; Conte, D.; Kamandulis, S.; Lukonaitienė, I. Comparison between soccer and basketball players kinematic sprinting characteristics of regular and resisted run // Sportininkų rengimo valdymas ir sportininkų darbingumą lemiantys veiksniai: tarptautinė mokslinė-praktinė konferencija, 2023 m.gruod. 14 d. Kaunas, Lietuva : programa ir pranešimų tezės. Kaunas: Lietuvos sporto universitetas. ISSN 2538-7952. 2023, p. 80.
161. Kamandulis, S.; Skujyte, A.; Genitrini, M.; Satkunskiene, D.; Silinskas, V.; Lukonaitiene, I,. Bradauskiene, K.; Samozino, P. Leg muscle activation under full and partial towing assistance in sprint running : oral presentation // 30th annual congress of the European college of sport science, 1–4 July 2025, Rimini, Italy : book of abstracts / edited by: Marcora, S., Narici, M., Paoli, A., De Vito, G., Tsolakidis, E., Thompson, J.L., Ferrauti, A., Piacentini, M.F. Cologne : European College of Sport Science, 2025. ISBN 9783981841480. p. 1009.
162. Skujyte, A.; Genitrini, M.; Silinskas, V.; Lukonaitiene, I.; Bradauskiene, K.; Trinkunas, E.; Samozino, P.; Kamandulis, S. Comparison of different sprint training sessions with assisted running: effects on performance and kinematics in 30-meter sprints : conventional print poster presentation // 30th annual congress of the European college of sport science, 1–4 July 2025, Rimini, Italy : book of abstracts / edited by: Marcora, S., Narici, M., Paoli, A., De Vito, G., Tsolakidis, E., Thompson, J.L., Ferrauti, A., Piacentini, M.F. Cologne : European College of Sport Science, 2025. ISBN 9783981841480. p. 594-595.

PUBLICATIONS

First publication „Reliability and validity of sprint performance using the Alex7 motorized device":

frontiers | Frontiers in Sports and Active Living

TYPE Original Research
PUBLISHED 25 July 2024
DOI 10.3389/fspor.2024.1412861

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RECEIVED 05 April 2024
ACCEPTED 16 July 2024
PUBLISHED 25 July 2024

CITATION
Skujyte A, Lukonaitiene I, Stanislovaitiene J, Šilinskas V, Bradauskiene K, Mamkus G and Kamandulis S (2024) Reliability and validity of sprint performance using the Alex7 motorized device.
Front. Sports Act. Living 6:1412861.
doi: 10.3389/fspor.2024.1412861

Reliability and validity of sprint performance using the Alex7 motorized device

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Introduction: Advancements in technology have recently made it possible to implement effective training solutions across different environmental conditions. This study evaluated the reliability and validity of measures obtained from the innovative motorized device, Alex7 (Inosportas, Lithuania), and differences in speed and kinematic characteristics between resisted and assisted sprinting in young football players.
Methods: Twenty-seven male athletes (mean age: 16.5 ± 0.8 years; height: 179.5 ± 6.9 cm; body weight: 67.7 ± 8.3 kg) each performed 30-m sprints twice under three different conditions: regular, resisted, and assisted sprinting. The Alex7 device provided the assistance and resistance during sprints. Results were compared with those from Witty timing gates. Ground contact time, flight time, stride length, and pace were measured using the OptoJump system. Reliability was assessed using two-way mixed intraclass correlation coefficients (ICCs) for single measures, the standard error of the mean (SEM), and the coefficient of variation (CV). Pearson's correlation coefficient determined the associations between Alex7 and Witty timing systems. Criterion-referenced validity was based on the mean difference and CV. Systematic bias was determined by limits of agreement using Bland–Altman analysis.
Results: Running times obtained using the Alex7 equipment exhibited good to excellent test-retest reliability between sessions (ICC, 0.83–0.94) and good to excellent correlation (Pearson's r = 0.88–0.98) between the Alex7 and Witty systems in both assisted and resisted running conditions. However, the Alex7 device consistently produced longer running times than the Witty device (up to 0.16 s difference, $p < 0.001$). The different running conditions produced substantial variations in kinematic variables, such as stride length, ground contact time, and running speed ($p < 0.001$ for all), but the effects on flight time and running pace were smaller.
Discussion: The Alex7 device shows high reliability for creating resisted and assisted running conditions for young football players. However, it tends to overestimate running time, necessitating caution when assessing the time parameters.

KEYWORDS
test-retest, kinematic parameters, assisted sprinting, resisted sprinting, youth, football

1 Introduction

To enhance sprint performance, methods range from high-magnitude resisted overload at low velocity to unloaded assisted sprinting using elastic cords, bungees, or pulleys (1–4). These two opposite training modalities induce specific neural and

 10.3389/fspor.2024.1412861

muscular adaptations (5), which can be measured and expressed in the force–velocity relationship (6, 7). The maximum performance of the neuromuscular system is determined by the intercepts in this relationship, although controlling resisted and assisted testing and training is difficult and requires skill. This becomes more challenging in team sports such as football because of the training complexity and limited time available to develop both speed and power.

Recent technological advances have enabled practical solutions for training under varying environmental conditions (8, 9). Several robotic devices are used to provide resisted or assisted motorized towing for sprint assessment and training (DynaSpeed, 1080 Sprint). These motorized devices allow for greater accuracy in setting the resisted and assisted load magnitude. A new device, Alex7 (Inosportas, Lithuania), has been developed recently. Similar to other systems, the Alex7 provides resistance (up to 30 kg) with a cable to prevent full speed running or assists at a speed (up to 14 m/s) that is faster than the maximum achieved during regular sprinting. It also offers assessments of velocity and displacement for real-world data collection, facilitating individualized sprint training. High performers can especially benefit from actual training data (10), but this information is useful only if the new equipment provides accurate and consistent results.

Given the novelty of the Alex7, this study primarily aimed to establish its reliability and validity. The secondary aim was to compare the differences in speed and kinematic characteristics between resisted and assisted sprints to identify individual variability between young athletes in a football squad. It was expected that the Alex7 would prove reliable and useful for measuring and developing young football players' sprint capacity.

2 Materials and methods

2.1 Participants

Twenty-seven young male football players competing in top-tier U16 and U18 leagues (age, 16.5 ± 0.8 years; stature, 179.5 ± 6.9 cm; body weight, 67.7 ± 8.3 kg) were recruited. *a priori* power analysis (G*Power version 3.1.9.7, University of Düsseldorf, Germany) indicated that a minimum sample size of 23 participants was required, with an alpha level (α) of 0.05 and a statistical power of 0.80. This calculation was based on a pilot study in which 14 young basketball players performed a 30-meter sprint twice, resulting in an effect size of 0.82 for the time difference between trials. The participants had no recent injuries or medical conditions that could interfere with maximal exertion in each sprint trial. All participants regularly performed sprinting during their training sessions, but none had prior experience in completing motorized resisted or assisted sprinting. After verbal and written explanation of the experimental design and its potential risks and benefits, written informed consent was obtained from all players and their respective parents/guardians. The study adhered to the high ethical guidelines in sports sciences (11). Ethical approval was received by the local Institutional Review Board (code: MNL-TRS (M)-2023-606).

2.2 Design

The kinematic running parameters and their changes during a 30-m sprint were measured using three types of equipment (Witty, OptoJump, and Alex7) under the following conditions: regular (no resistance or assistance), with resistance, and with assistance created by the motorized Alex7 device (Figure 1). The testing sessions were conducted in a repeated manner on a weekly basis. The initial week was designated for regular running and familiarization with the resisted and assisted sprinting conditions. In the following 2 weeks, the testing was conducted identically and incorporated both resisted and assisted sprinting, and the results were used to assess the reliability and validity of the Alex7 device. All testing sessions for each participant occurred at about the same time of day on the same weekday. The primary outcome variables were sprint time and velocity, ground contact time, flight time, stride length, and pace.

2.3 Procedures

All testing occurred on a rubberized indoor track with a 60-m straightway. During the first testing day, height (to the nearest 0.1 cm, Martin-type anthropometer, GPM instrument, Siber-Hegner, Switzerland) and body mass (to the nearest 0.1 kg, TBF-300 Body Composition Analyzer, Tanita, Philpots Close, UK) were recorded. Before each testing session, a standardized 20-min warm-up that included jogging, dynamic stretches, specific running exercises, and submaximal sprints was performed (8, 12).

Running times for the entire 30 m, with 10-m and 20-m splits, were recorded for each condition (regular, resisted, and assisted) using Witty photocells (Microgate, Bolzano, Italy). The participant began each sprint trial with his lead foot placed 70 cm behind the first photocell to prevent inadvertent triggering of timing in the start position (13, 14). Two sprint trials were conducted with a minimum of 6 min of passive recovery between each trial in each condition (8). The fastest sprint time was used in the analysis of each condition and each testing session (13).

During each sprint trial, the kinematic parameters of velocity, ground contact time, flight time, stride length, and pace were measured over 10–30 m using the OptoJump modular system (Microgate, Bolzano, Italy), an optical data acquisition system comprising two parallel bars containing light-emitting diodes that detect any interruption in communication between the bars (Figure 1). The kinematic parameters were computed based on the data obtained from the four fastest steps performed by each participant. Calculations of kinematic parameters during running measured using the OptoJump have been reported to have high validity [intraclass correlation coefficient (ICC), 0.96–0.99; mean bias, 0.4%–2.7%] (15).

During the resisted and assisted trials, the participants sprinted while wearing a waist harness connected to the Alex7 composite fibre cable (High Tenacity Polyester and Dyneema®12 strand braid), which was wrapped around a 90-mm diameter spool and extendable up to 31 m in length. The cable load was controlled using a servomotor (Mitsubishi HG-SR152) and the

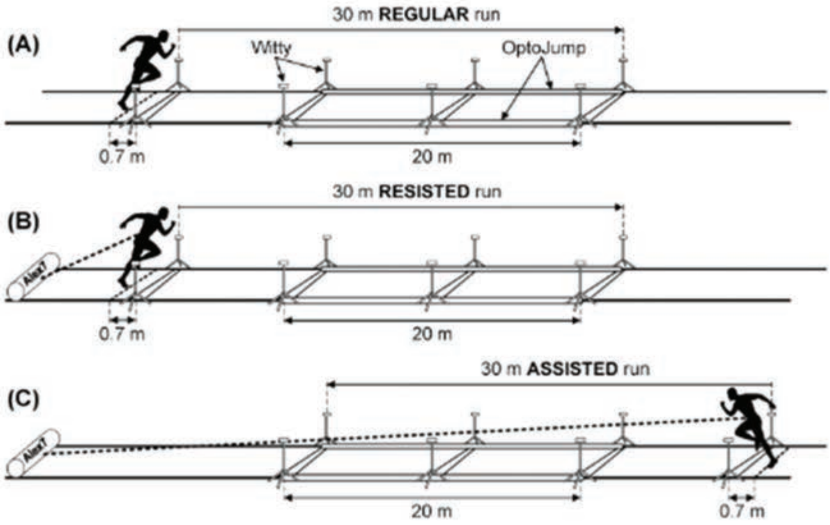

FIGURE 1
Schematic diagram of the experimental testing setup for regular (A), resisted (B), and assisted (C) sprint testing. Three different devices (OptoJump, Witty, and Alex7) were used during each trial.

accompanying programmable controller. During the resisted run, the participant ran with the resistance attached to the cable set at 10% of body weight. In the assisted trial, the participant was pulled with an assisted load of 6 kg. This load was selected based on a previous investigation that reported a substantial increase in maximal velocity using a 7-kg load in sprinters (8) but less of an effect using a 6-kg load in football players lacking experience of being pulled with a motorized device.

The Alex7 device applied resistance or assistance, and the timing was initiated immediately at the start of the sprint, that is, 0.7 m before the athlete reached the first photocell of the Witty timing gate. The time interval corresponding to the initial 0.7 m was extracted from the Alex7 device and was used to measure the 30-m sprint time and to calculate the 10-m and 20-m split times in each experimental condition. Per the manufacturer's recommendations, all trials using the Alex7 were completed in the Isotonic mode. The controller measures the distance travelled by the sprinter and was programmed to terminate the assisted load at the finish line to allow the participant to decelerate safely after completing the maximum-velocity portion of the sprint.

2.4 Statistical analysis

Mean and standard deviation (SD) were presented for all sprint times and kinematic parameters. The Shapiro–Wilk test confirmed normal data distribution. Relative reliability was assessed using two-way mixed ICCs for single measures, interpreted as moderate (0.50–0.74), good (0.75–0.89), and excellent (≥0.90) (16). Absolute reliability was assessed with the standard error of the mean (SEM), calculated as $SD/\sqrt{2}$, and coefficient of variation (CV), computed as $SD/mean \times 100\%$. Pearson's correlation coefficient (r) determined the associations between Alex7 and Witty timing systems, interpreted as large (0.50–0.69), very large (0.70–0.89), nearly perfect (0.90–0.99), and perfect (1.00) (17). For criterion-referenced validity, mean difference (tdiff) and CV were calculated, with paired sample t-tests testing the significance of mean differences. Cohen's d was used for effect sizes, interpreted as large (≥0.80), medium (0.50–0.79), small (0.20–0.49), or trivial (<0.20) (18). Bland-Altman analyses illustrated agreement between repeated measures for Alex7 and between Alex7 and Witty timing systems (19). The 95% CI of the mean difference determined systematic bias. All statistical analyses were performed using IBM SPSS Statistics (version 28.0, Armonk, NY, USA), with significance set at $\alpha = 0.05$.

3 Results

The descriptive statistics for the between-session comparison during the resisted and assisted running split times using the Alex7 are presented in Table 1. Running times measured with the Alex7 demonstrated good to excellent test-retest reliability (ICC, 0.83–0.94) in both assisted and resisted conditions. The reliability of the split time tended to be lower in the first part of the course (ICCs of 0.83–0.86 for 0–10 m) in both assisted and

TABLE 1 Between-session reliability of the Alex7 outcome time and optoJump kinematic variables.

	Test (mean ± SD)	Retest (mean ± SD)	Mean difference ± SD	p =	ICC	ICC (95% CI)	CV (%)	SEM (s)
Running splits								
R 0–10 m	2.13 ± 0.09	2.13 ± 0.09	−0.002 ± 0.053	0.890	0.83*	[0.64 to 0.93]	1.24	0.03
R 10–20 m	1.65 ± 0.07	1.63 ± 0.07	0.022 ± 0.023	<0.001	0.92*	[0.53 to 0.98]	1.12	0.02
R 20–30 m	1.62 ± 0.08	1.61 ± 0.10	0.007 ± 0.040	0.444	0.90*	[0.77 to 0.96]	1.40	0.02
R 0–30 m	5.39 ± 0.24	5.37 ± 0.25	0.027 ± 0.081	0.131	0.94*	[0.86 to 0.98]	0.85	0.05
A 0–10 m	1.77 ± 0.08	1.76 ± 0.07	0.013 ± 0.044	0.167	0.83*	[0.63 to 0.92]	1.43	0.03
A 10–20 m	1.25 ± 0.05	1.25 ± 0.04	0.003 ± 0.025	0.573	0.86*	[0.70 to 0.94]	0.95	0.01
A 20–30 m	1.18 ± 0.05	1.17 ± 0.04	0.006 ± 0.016	0.105	0.94*	[0.85 to 0.97]	0.80	0.01
A 0–30 m	4.21 ± 0.18	4.18 ± 0.15	0.022 ± 0.077	0.188	0.88*	[0.74 to 0.95]	1.01	0.04
Kinematic variables								
R Contact time (s)	0.15 ± 0.01	0.15 ± 0.01	−0.002 ± 0.005	0.066	0.88*	[0.73 to 0.95]	2.16	0.00
R Flight time (s)	0.09 ± 0.01	0.09 ± 0.01	0.001 ± 0.007	0.596	0.79*	[0.56 to 0.91]	3.93	0.00
R Stride length (m)	3.18 ± 0.14	3.25 ± 0.16	0.069 ± 0.094	0.003	0.74*	[0.31 to 0.90]	1.74	0.06
R Pace (step/s)	4.17 ± 0.20	4.13 ± 0.23	0.044 ± 0.127	0.116	0.82*	[0.61 to 0.92]	1.72	0.07
A Contact time (s)	0.12 ± 0.01	0.12 ± 0.01	0.000 ± 0.006	0.951	0.85*	[0.66 to 0.93]	2.82	0.00
A Flight time (s)	0.11 ± 0.01	0.11 ± 0.01	0.003 ± 0.006	0.079	0.79*	[0.55 to 0.91]	3.41	0.00
A Stride length (m)	4.13 ± 0.18	4.19 ± 0.20	0.059 ± 0.090	0.005	0.85*	[0.57 to 0.94]	1.40	0.06
A Pace (step/s)	4.28 ± 0.23	4.23 ± 0.22	0.044 ± 0.128	0.124	0.83*	[0.63 to 0.93]	1.70	0.07

ICC, interclass correlation coefficient (*$p < 0.001$); CI, confidence interval; CV, coefficient of variation; SEM, standard error of the mean; R, running with resistance; A, running with assistance.

resisted conditions. The CV was 0.80%–1.43%, and the SEM was 0.01–0.05 s for the time intervals independent of the running condition. In contrast to the other variables, the split time for 10–20 m in the resisted condition improved significantly and consistently from the first testing session to the retest ($p < 0.001$). Notably, this improvement was accompanied by a similar level of reliability as that for the other markers assessed. In addition, Bland-Altman analyses showed no significant systematic bias between repeated measurements except for the 10–20 m split time in the resisted condition ($p < 0.001$, Figure 2). The narrow range of limits of agreement on the Bland-Altman plot indicates high stability and low variation between test occasions. Repeatability for most measures was within the 95% CI.

Stride length differed between the two testing sessions for both the resisted and assisted sprints ($p < 0.05$, Table 1) but not for other kinematic variables. Almost all kinematic variables showed good test-retest reliability (ICC, 0.79–0.88), except for a moderate value for stride length (ICC, 0.74) in the resisted sprint and an excellent value for running speed in the assisted sprint (ICC, 0.94). In general, the ICCs for almost all variables were slightly higher in the assisted than the resisted sprints.

All split times in the resisted sprints and all split times except the first (0–10 m) in the assisted sprint had excellent Pearson's correlation coefficient values (r = 0.90–0.98, $p < 0.001$; Table 2) between the Alex7 and Witty equipment. The first 10-m assisted running time had a slightly lower but still a good value (r = 0.88, $p < 0.001$). However, the Alex7 consistently recorded longer running times compared to the Witty device (up to a 0.16 s difference, CV, 1.00%–3.79%, $p < 0.001$). Furthermore, there was a negative bias between both pieces of equipment for both conditions ($p < 0.001$, Figure 3), except for the 0–10 m split time in the resisted run. Still, sprint time remains within a narrow range of limits of agreement on the Bland-Altman plot, and repeatability for most measures was within the 95% CI. These data suggest that the Alex7 system is consistent but is not as accurate for measuring sprint time. The time differences between the two types of equipment were slightly smaller for assisted (range, 0.03–0.11 s) than for resisted (range, −0.01 to 0.16 s) sprinting.

The mean running speed differed between three sprint conditions: 8.17 ± 0.39 m/s in the regular run, 6.59 ± 0.35 m/s in the resisted run ($p < 0.001$), and 8.65 ± 0.44 m/s ($p < 0.05$) in the assisted run. All kinematic variables investigated (Figures 4A–D) differed between the sprint conditions. The largest differences were observed for stride length and ground contact time ($p < 0.001$ for each). The smallest differences were for flight time and running pace. The running flight time and pace did not differ between the regular and assisted runs but differed significantly between the regular and resisted sprints, and between the resisted and assisted sprints ($p < 0.001$ for each). All variables showed a greater absolute difference between the resisted and regular sprints than between the assisted and regular sprints.

4 Discussion

The reliability and validity of measurements obtained using the new Alex7 motorized sprint device were investigated to determine whether and how speed and kinematic characteristics differ between assisted and resisted sprints. The primary finding is that the Alex7 device offers reliable measures of sprint performance in both resisted and assisted conditions. However, it is important to note that the Alex7 consistently overestimated running times compared to the Witty device. This overestimation may result from various factors, including differences in measurement methodologies or the specific mechanics of the Alex7 device. Despite this limitation, the Alex7's ability to deliver consistent results highlights its utility for manipulating the load during

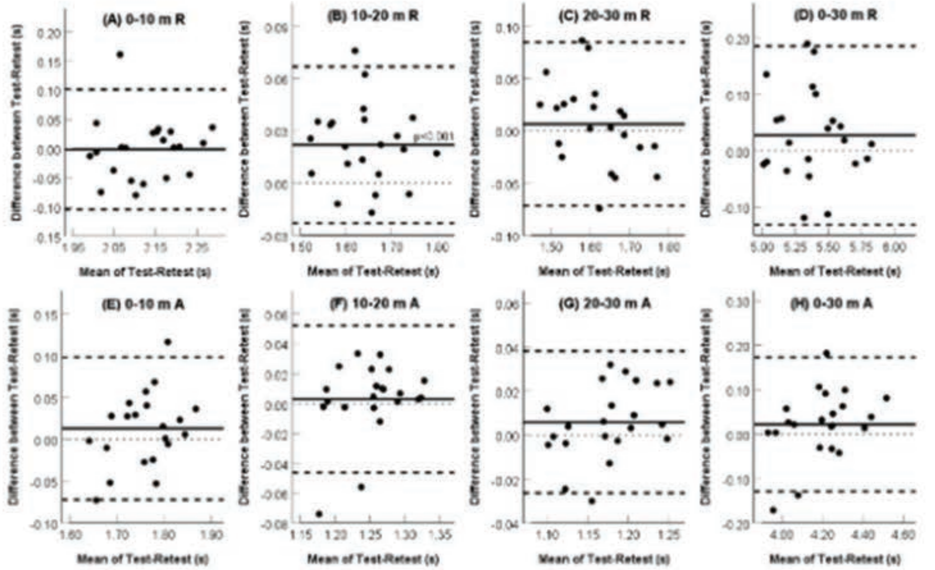

FIGURE 2
Bland-Altman analysis of test-retest sprint times derived from Alex7. The plot differences were obtained by subtracting the retest value from the test value. Thick black solid line – mean difference between the two tests; thick black dashed lines – 95% limits of agreement; thin black dashed line – zero value.

TABLE 2 Within-session criterion-referenced validity for the Alex7.

Conditions	Distance	Sprint time (Mean ± SD)		p	ES	Criterion-referenced validity		
		Witty (s)	Alex7 (s)		Cohen's d	t(diff) (s)	CV (%)	Cor. (r)
Resisted	0–10 m	2.13 ± 0.09	2.13 ± 0.10	0.373	0.178	-0.01	1.00	0.92*
	10–20 m	1.57 ± 0.08	1.65 ± 0.09	<0.001	−2.655	0.09	3.79	0.93*
	20–30 m	1.54 ± 0.09	1.62 ± 0.10	<0.001	−2.609	0.08	3.73	0.94*
	0–30 m	5.23 ± 0.25	5.40 ± 0.28	<0.001	−2.678	0.16	2.14	0.98*
Assisted	0–10 m	1.73 ± 0.08	1.78 ± 0.08	<0.001	−1.122	0.05	1.93	0.88*
	10–20 m	1.22 ± 0.05	1.26 ± 0.06	<0.001	−1.307	0.03	1.84	0.90*
	20–30 m	1.14 ± 0.06	1.18 ± 0.06	<0.001	−1.643	0.04	2.25	0.93*
	0–30 m	4.09 ± 0.18	4.21 ± 0.19	<0.001	−2.223	0.11	1.93	0.97*

t_{diff}, time difference between the systems; CV, coefficient of variation; p, p-value of the paired samples t-test for the difference between Witty and Alex7; ES, effect size; Cor., Pearson's correlation coefficient (*$p < 0.001$).

athlete training. Future research should aim to better understand the causes of the Alex7's running time overestimation and explore methods to mitigate this issue.

In the context of load management, the use of incline, decline, sleds, bungees, and pulleys serves helps to induce the acute effects of overload- or unloaded-assisted stimulation (20), whereas motorized devices such as Alex7 are designed specifically to offer a higher degree of accuracy in load management compared with other devices. The reliability values of the 30-m sprint run time and the split times for each 10 m (ICC, 0.83–0.90) obtained during the resisted running mode with the Alex7 were found to be similar to the within-session reliability values reported by Rakovic et al. (9) for the 1080 Sprint device (ICC, 0.81–0.95). Rakovic et al. (9) showed that the split time for the initial 5 m was the least reliable measurement (ICC, 0.81), indicating less reliability for use with short accelerations. In the present study, this finding was partially replicated using a running distance of 10 m instead of 5 m, yielding an ICC of 0.83. Assisted running was also examined and compared with resisted running, showing a similar trend. That is, the lowest reliability value (ICC, 0.83) was obtained for distances of 10 m, whereas medium reliability values were recorded for the 10-m and 20-m split times and total distance of 30 m (ICC = 0.86

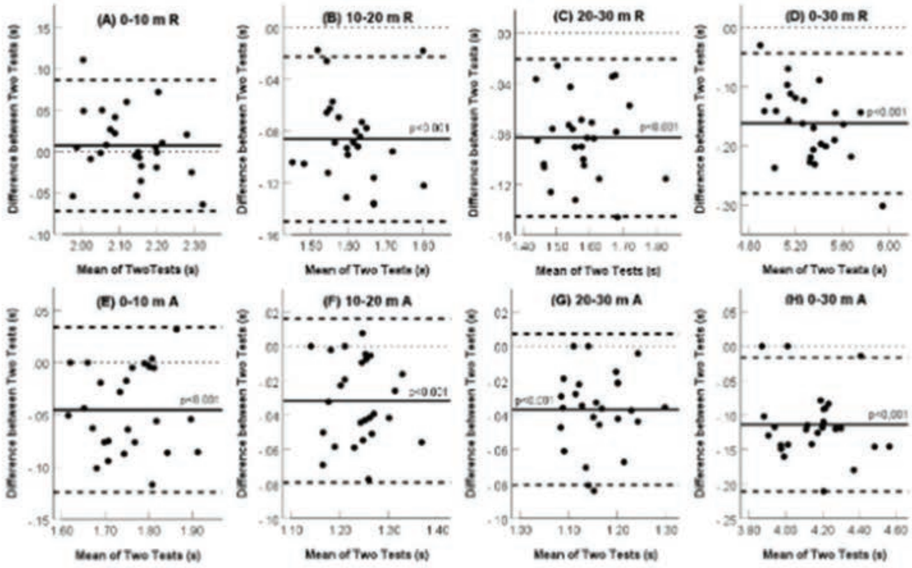

FIGURE 3
Bland-Altman analysis of sprint time differences between witty and Alex7 equipment. The plot differences were obtained by subtracting the Alex7 test value from the Witty test value. Thick black solid line – mean difference between the two tests; thick black dashed lines – 95% limits of agreement; thin black dashed line – zero value.

and 0.88, respectively). Notably, the highest reliability value was achieved for the 20–30-m split time (ICC = 0.94), all of which had acceptable reliability when used with the new device for facilitating speed training with assisted running.

The Alex7 can provide both contrasting loads and a high variety in magnitude as well as the opportunity to monitor performance and progress. Compared with the Witty timing gates, which were used as the gold standard in this study, the Alex7 device showed strong associations (r = 0.88) for the 10-m split time in the assisted run, and the other correlations for the assisted runs and all correlation values for the resisted runs were nearly perfect (r = 0.90–0.98). Different results were observed for the 1080 Sprint device in the resisted running mode (9). Nearly perfect validity was found for the 20–30-m split time and the overall 30-m time, but the other correlation values ranged from r = 0.57 to r = 0.83. These differences in validity between the Alex7 and 1080 Sprint devices may reflect differences in the data collection. For example, unstable results were observed for the first 0.7 m due to the participants' inconsistent starting patterns. After being told to prepare for the run, some participants were unable to remain in the static starting position, and their in-place movement started timing before the actual run began. Removing the results of the first 0.7 m eliminated this inaccuracy and produced higher validity values for the first 10 m.

Real-time values from the Alex7 device should be used cautiously because they were significantly longer than those obtained from the Witty timing gates. A consistent discrepancy was observed across all distances, except for the initial split during resistive runs, where no such disparity was noted. This disparity may be attributed to limitations imposed by the Alex7 device in terms of time recording. The controller calculates the distance travelled in meters by multiplying the current number of revolutions (encoder pulses) by circumference. A random error in the calculated length may occur because of differences in the tightness with which the rope was wound on the spool between the assisted and resisted runs and the rope elasticity (although <1%). After completion of the resisted run, the rope was recoiled freely back to its starting position, and during the assisted run, the athlete created a resistance for the servomotor and the rope was wrapped tensely around the spool.

It is important that the new Alex7 device may produce meaningful differences in the kinetics and kinematics parameters between assisted and resisted running conditions. The effects on running speed and kinematics depend on the magnitude of the resistance or assistance. The 6-kg (~60 N) assistance in the present study caused significant changes in stride length (6.75%), ground contact time (−7.69%), and running speed (6.74%). The running pace and flight time did not differ significantly between the regular and assisted runs. Similar findings have been reported by Cecilia-Gallego et al. (21). In the study by Van Den Tillaar et al. (22), the 5-kg assistance provided by the motorized DynaSpeed device

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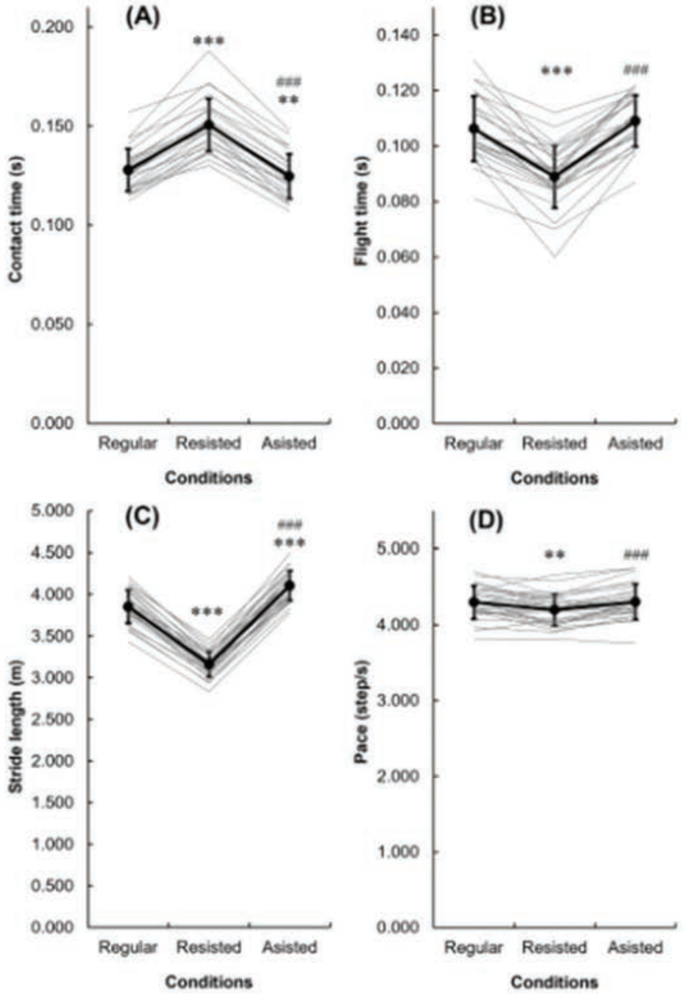

FIGURE 4
The contact time (A), flight time (B), stride length (C), and pace (D) for the regular, resisted, and assisted sprints (mean ± SD and individual data). Significantly different from regular sprints (** $p < 0.01$, *** $p < 0.001$). Significantly different from resisted sprints (### $p < 0.001$).

produces a 5.1% increase in speed, but the running pace did not differ between the assisted and unloaded sprints. In another study that used a load of 4.7% of body weight, running speed increased by 6.1%, but the running flight time did not differ significantly (23). In another study, use of a pulling device decreased the contact time by 7.69% (24). The data for the current study suggested that the 6-kg force used for assistance was sufficient to achieve the required effects of overspeed running without interfering with the running technique.

The resistance of 10% of body mass was enough to meaningfully reduce all the running parameters. Compared with the regular sprint, resisted sprinting caused larger changes in running parameters than assisted running. A previous study showed that a resistance of 5% of body mass elicits significant changes in running speed and stride length but that ≥15% of body mass resistance is needed to change stride frequency (25). Given that the motorized device provides greater resistance (by eliminating the inertia) than a sled of the same weight and that 10%–20% of body mass resistance provided by the motorized device can induced greater decreases in speed (13%–28%) compared with a weighted sled with the same weight (7.5%–20%) (26), it was not surprising that the resistance of 10% body weight sufficient enough to significantly decrease (by 2.33%; $p < 0.01$) running pace and running speed (by 19.98%; $p < 0.001$). We note that the participants were non-elite and young (16–17-year-old) football players with no experience in resisted or assisted running. They completed one familiarization session, and this was sufficient to produce high reliability while not altering the running technique. An exception was observed with the split time for 10–20 m in the resisted condition, which improved consistently from the first to the second testing session, indicating a possible need for additional familiarization. Overall, it appears that the Alex7 technology is simple to learn and use in both resisted and assisted training settings, which is important for practitioners.

This study includes several limitations, mainly due to logistical reasons. There is no direct comparison of the Alex7 with well-established systems such as 1080 Sprint or Dynaspeed, which means we lack confirmation that the resistance or assistance is comparable to other similar systems. It would be better to compare timing data with laser systems, which are more accurate than Witty timing gates as they do not rely on cutting light beams with the upper body, making them better suited as gold standards. Finally, only young males were tested, making it unclear whether age, gender, or sport could influence the results. It is reasonable to expect that greater maturity and sprint experience might have positively affected the results.

5 Conclusions

The Alex7 device demonstrates high reliability for creating resisted and assisted running conditions for young football players. However, its tendency to overestimate running times necessitates caution when interpreting time parameters. Future research should aim to refine the Alex7's measurement accuracy and explore its applications across various sports, gender and age groups. Additionally, investigating the underlying factors contributing to the observed overestimation of running times could enhance the device's accuracy.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Ethical approval was received by the local Institutional Review Board (code: MNL-TRS (M)-2023-606). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

AS: Conceptualization, Data curation, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. IL: Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. JS: Conceptualization, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. VŠ: Data curation, Formal Analysis, Investigation, Writing – review & editing. KB: Investigation, Writing – original draft, Writing – review & editing. GM: Formal Analysis, Writing – review & editing. SK: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Acknowledgments

We thank the coaches and players for their participation and express our gratitude to the participating clubs' administration.

Conflict of interest

One of the authors (AS) spouse works in a company that created the motorized device Alex7.

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

Publisher's note

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Second publication „Lower limb muscle activity under full and partial towing assistance in sprint running" has been accepted.

Lower limb muscle activity under full and partial towing assistance in sprint running

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Abstract
This study investigated how different levels of sprint assistance influence neuromuscular activity and performance. Concerns exist that full assistance may reduce active muscle engagement due to passive contributions. Thirteen male athletes from various sports performed 30-m sprints under three conditions: unassisted, partially assisted, and fully assisted, using a motorized towing device. Surface electromyography recorded activity of five lower limb muscles (rectus femoris, vastus lateralis, semitendinosus, biceps femoris, and gluteus maximus), while spatiotemporal parameters were measured over the final 10 m using Optojump. Sprint times were significantly improved in both assisted conditions compared to unassisted sprints (partial: −3.4%, full: −2.8%; $p < 0.01$), primarily due to increased stride length ($p < 0.001$), longer flight time, and shorter contact time ($p < 0.05$ for both), while stride frequency remained unchanged. Contrary to hypothesis, EMG analyses revealed no statistically significant differences in muscle activity between conditions, despite improved performance and the potential contribution of passive propulsion. Large effect sizes ($d > 0.8$) were briefly observed, in a muscle-dependent manner, at discrete points of the gait cycle. These findings suggest that assisted sprinting enhances performance without reducing neuromuscular demands, although the results should be interpreted in light of the athletes' inexperience with assisted running.

Key words
Electromyography, Running kinematics, Spatiotemporal parameters, Supramaximal speed, Alex7 run.

Introduction

Sprint speed is a critical attribute in many sports, particularly in disciplines in which athletes must reach and sustain maximal running velocity. In track and field, this includes sprint and hurdle events, and long jump. In American football, sprint speed is especially important for wide receivers and cornerbacks, and in soccer, sprinting is frequently required by wingers, fullbacks, strikers, and other players in various game situations (Gualtieri et al., 2023).

In recent decades, scientific research has explored adaptations to sprinting, with a strong focus on using different training methods to optimize performance. Researchers have investigated various sprint training approaches by analyzing the kinetic and kinematic running parameters, muscle activity patterns using electromyography (EMG), and the short-term and long-term responses to sprint training (Howard et al., 2018; Kyröläinen, 2005; Matusiński et al., 2022; Van Den Tillaar & Gamble, 2017; Yu et al., 2008). Among these methods, assisted sprinting has been studied for its potential to increase speed through neuromuscular adaptations (Mero & Komi, 1987). Scientists have examined different assisted sprinting techniques, including running with a tailwind, downhill running, elastic cord towing, and sprinting using mechanical towing devices (Corn & Knudson, 2003; Ebben et al., 2008; Sedláček et al., 2004). Assisted sprint training can improve maximal running speed, stride length, and stride frequency by increasing muscle power and neuromuscular efficiency (Cecilia-Gallego et al., 2022).

With the advances and widespread availability of assisted sprint training devices, researchers can now explore different towing techniques in greater detail. One approach, known as full towing, involves applying varying levels of force to assist the athlete during sprinting. For example, Van den Tillaar (2021) studied assisted running using towing forces of 3, 4, and 5 kg, and Clark et al. (2021) used a force of 7 kg (Clark et al., 2021; van den Tillaar, 2021). One potential limitation of this fully assisted method is that the assistance reduces the active propulsion because the pulling force propels the athlete forward, which limits the stress applied to the involved muscles and the expected training adaptations. Another method is partially assisted running, which involves applying a towing force until the athlete reaches a predetermined running speed and then automatically releasing the towing force. Although never studied, this approach might reduce the stress caused by excessive pulling and allow the athlete to remain in control and to actively propel forward. Understanding how these different towing strategies influence sprint mechanics and muscle activity would help to optimize assisted sprint training methods. In game sports such as football and rugby, athletes typically reach maximal sprinting speeds within 30 m, and this distance is commonly used in performance testing protocols to assess acceleration and top-speed capabilities (Nicholson et al., 2020; Figueira et al., 2021).

The present study evaluated leg muscle activity and spatiotemporal and kinematic parameters under two assisted sprint conditions: the first in which the athlete reached his supramaximal running speed with full towing assistance, and the second that used partial towing assistance (limited) to cap the speed to 0.5 m/s less than the supramaximal speed. We hypothesized that the muscle activity would be lower during fully assisted running than partially assisted running and that fully assisted running would elicit higher speed, shorter contact time, longer flight time, and greater step length.

Materials and methods

Participants

Fourteen male athletes who were actively engaged in sports requiring sprinting were recruited for this study. One participant was excluded from all analyses due to missing data, resulting in a final analytical sample of thirteen participants (age: 21.4 ± 1.5 years; body mass: 81.8 ± 8.5 kg; height: 1.86 ± 0.07 m). The participants had no recent injuries or medical conditions that could interfere with maximal exertion in each sprint trial. All participants regularly performed sprinting during their training sessions, but none had prior experience in completing motorized assisted sprinting. After verbal and written explanation of the experimental design and its potential risks and benefits, written informed consent was obtained from all players and their respective parents/guardians. The study adhered to the ethical guidelines in sports sciences (Guelmemi et al., 2024). Ethical approval was received by the local institutional review board (code: BNL-TRS (B)-2025-783).

Protocol

At the beginning of the session, body mass was measured using a TBF-300 Body Composition Analyzer (Tanita, Yiewsley, UK), and participants completed a standardized 20 min warm-up consisting of jogging, dynamic stretching, sprint-specific drills, and submaximal sprints to ensure optimal preparation (Clark et al., 2021; Taylor et al., 2009).

The experimental setup is shown in Figure 1, which details the different sprinting conditions and the role of the motorized device Alex7 run (Inosportas, Kaunas, Lithuania) in providing assistance. Each participant performed six 30 m sprints from a standing start under three conditions: unassisted sprinting, fully assisted sprinting, and partially assisted sprinting. Two trials were performed per condition, and the participants were asked to exercise at maximal effort for each run. A minimum of 6 min of passive recovery was provided between trials to prevent fatigue accumulation. The fully assisted condition provided continuous external towing of 6 kg throughout the sprint, and the partially assisted condition applied the same assistance but only until the runner reached a velocity 0.5 m/s below their supramaximal speed, which corresponded to 95.02% (± 0.14) of the maximal speed achieved under full towing. This threshold was pre-programmed in the Alex7 motorized towing system, which allows users to set a specific speed-based release point. The system continuously monitored running speed using an internal encoder, and the towing force was disengaged as soon as the target velocity was reached, with minimal delay. This release point was chosen to maintain a small safety margin, allowing the athlete to remain in control and reducing the likelihood of neuromuscular inhibition caused by perceived loss of control at maximal speeds.

All sprints were conducted on a regular indoor track with a 60 m straightway. Sprint times were recorded using Witty photocells (Microgate, Bolzano, Italy), which captured the total 30 m sprint times and 10 m and 20 m split times. Spatiotemporal parameters were assessed using an OptoJump photocell lane measuring 20 m (Microgate). Lower-body kinematics were recorded using MyoMotion inertial measurement units (IMU) sensors (Noraxon, Scottsdale, USA). EMG activity was recorded with wireless EMG sensors (Noraxon) for all conditions.

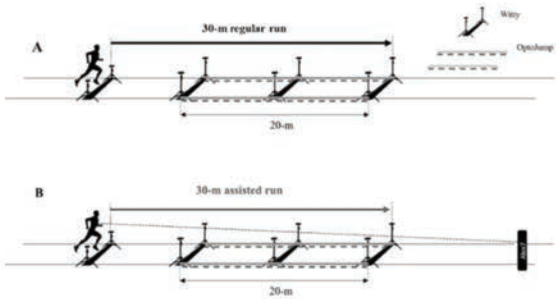

FIG. 1. Schematic diagram of the experimental testing setup for unassisted (A) and assisted (B) sprint testing. Three different devices (OptoJump, Witty, and Alex7 run) were used during each trial. Adapted with permission from Skujytė et al., (2024).

Data collection

Spatiotemporal parameters

In the present study, stride length, stride frequency, contact time, flight time, and duty factor (i.e., the ratio of contact time to stride duration, expressed as a percentage) were assessed. Spatiotemporal parameters were recorded using an array of OptoJump photocells spanning from the 10 m to the 30 m mark of the running lane. Sprint time was registered for the entire 30 m distance.

Kinematics

Lower-body joint angles were recorded using four MyoMotion IMU sensors (Noraxon), which were placed on the foot dorsum, shank, thigh, and sacrum (Zeng et al., 2022) Sensors were fixed using a Velcro elastic band. The sensor size was 37.6 mm length × 52 mm width × 18.1 mm thickness, and the weight was 34 g. Data were recorded with a sample rate of 200 Hz. Before each single trial, the system was calibrated according to the manufacturer's instructions. Calibration required participants to stand still in a standardized N-pose for a few seconds. After a positive outcome was obtained for the calibration, the participant was instructed to begin the running trial. The reliability of this specific setup has been previously demonstrated (Berner et al., 2020; Cottam et al., 2022) and adopted in previous investigations focusing on sprint kinematics (Donaldson et al., 2023).

EMG

The electrodes were placed on each muscle after skin preparation according to the SENIAM recommendations (http://www.seniam.org/). The skin was carefully shaved and rinsed with alcohol before placement of the electrodes on the following muscles: gluteus maximus, rectus femoris, vastus lateralis, semitendinosus, and biceps femoris. Electrodes were placed only on one leg, and the correct placement was verified by muscle palpation and observation of the EMG signal during voluntary contraction. Wireless silver/silver chloride electrodes were used, with an interelectrode distance of 20 mm, and the signal was collected using wireless EMG sensors (Noraxon). The sensor size was 37 mm × 24.5 mm × 16.5 mm, and the weight was 14 g. The analog-to digital (A/D) converter was 24 bit, common mode rejection ratio was >100 dB, input impedance was >100 MΩ, and sampling rate was 2000 Hz. Before each single run, the baseline EMG signal was reset.

Data analysis

Gait phase detection

Gait phases, such as initial contact and toe-off, were identified using a previously validated algorithm (Bergamini et al., 2012). In brief, the angular velocity of the pelvis-mounted IMU sensor was wavelet-transformed twice. This operation allows for simultaneous derivation and smoothing by removing the high-frequency noise components in the derived time series (Jianwen et al., 2006). Peaks and valleys in the second derivative of pelvis angular velocity represent the initial contacts and toe-offs of each step, respectively. For subsequent analysis, the last full stride with the sensor-equipped leg before the 30 m mark was considered in all three conditions. In the partially assisted condition, this stride consistently occurred after the towing force had been released and the athlete had reached predetermined speed of the supramaximal velocity (mean: 21.90 ± 2.02 m). The initial contacts and toe-offs of both legs were identified using the algorithm (i.e., for each step), but one leg only was equipped with the IMU and EMG sensors to identify the correct stride knee and hip joint angles. If either angle presented as > 45° of flexion at the initial contact, it was deduced that the sensor-equipped leg was in the swing phase in that instant. Therefore, the subsequent initial contact was identified as the beginning of the stride of interest. The end of this stride was identified as the second initial contact after the beginning of the stride (i.e., the next ipsilateral initial contact).

Spatiotemporal parameters

Likewise, spatiotemporal parameters from OptoJump were extracted from the last complete stride before the 30-m finish line, ensuring consistency across measurement systems. This methodological choice was intended to minimize the inclusion of strides occurring during the immediate post-release transitional phase. Given that towing release occurred at approximately 22 m and that athletes had several meters to re-stabilize their running pattern before the analyzed stride, the selected stride likely reflected stabilized sprinting mechanics, thereby allowing valid comparisons across conditions.

Kinematics

For the stride of interest, the ankle, knee, and hip joint angles were extracted, and the data were smoothed upon computation using Noraxon proprietary software (MyoResearch, version 3.14).

Analysis of EMG

After visual inspection of the data quality using the proprietary software, the data for one subject were discarded. All subsequent analysis was performed in a Python environment after exporting data to comma-separated value format. For each muscle, data for the full run were bandpass filtered (20–450 Hz) for denoising and full-wave rectification. Root mean square was computed. Subsequently, the envelope was calculated by lowpass filtering the rectified data at 10 Hz, and the data of the stride of interest were extracted. For the three running conditions, the EMG envelope was normalized to and expressed as a percentage of the maximum value recorded in the unassisted running (control) condition for the stride of interest. To verify the robustness of the EMG normalization procedure, the analysis was repeated with EMG envelopes normalized to the maximal value observed across all three conditions. This alternative normalization did not alter the direction or statistical significance of the main findings. Subsequently and for each muscle, the EMG normalized data were resampled to 1001 data points, thus obtaining a data point per each 0.1% of the stride of interest.

Statistics

Descriptive statistics (mean ± SD) were calculated for each variable. The Shapiro–Wilk test was used to confirm normal distribution of the data. Sphericity was evaluated with Mauchly's test, and the Greenhouse–Geisser correction was applied when this assumption was violated. As the assumptions for parametric tests were met for all spatiotemporal variables, a repeated-measures analysis of variance (ANOVA) was performed for the first stance to identify statistically significant differences between conditions. When significant effects were found, post hoc pairwise comparisons were conducted using multiple t tests for dependent samples with the Benjamini–Hochberg correction.

For analysis of kinematics and muscle activity, a repeated-measures ANOVA was performed on the whole time series using statistical parametric mapping to identify significant differences between conditions. In cases of significant effects, pairwise comparisons were performed using multiple t tests for dependent samples with adjusted significance thresholds. The effect size (Cohen's d) was computed as the difference between group means normalized to the standard deviation of the unassisted running condition (Pataky, 2012). Effect sizes were calculated for each pair of conditions and for each muscle, and interpreted using conventional benchmarks, where values of approximately 0.20, 0.50, and 0.80 represent small, moderate, and large effects, respectively (Cohen, 1988). These benchmarks are widely used in sports science contexts (Hopkins, 2002).

Statistical analyses were performed using SPSS v25.0 for Windows (IBM, Armonk, NY, USA) and JASP (Version 0.11.1). The level of significance was set at 0.05.

Results

Spatiotemporal parameters

Firstly, finish times in the 30 m run were significantly faster in the two assisted running conditions than in the unassisted running condition (fully assisted vs. unassisted -2.8%, $p < 0.01$; partially assisted vs. unassisted -3.4%, $p < 0.01$) (Figure 2). For spatiotemporal parameters, significant differences were found between unassisted running and both assisted running conditions, but not between the fully and partially assisted conditions (Figure 2).

In the stride retained for analysis, faster running speed in both assisted running conditions resulted from significantly higher stride length and flight time compared with the unassisted running condition (fully assisted vs. unassisted: stride length +8.6 %, $p < 0.001$, flight time +7.7 %, $p < 0.05$; partially assisted vs. unassisted: stride length +8.9 %, $p < 0.001$, flight time +7.8 %, $p < 0.01$) (Figure 2), and significantly shorter contact time (fully assisted vs. unassisted: contact time -4.9 %, $p < 0.05$; partially assisted vs. unassisted: contact time -6.9 %, $p < 0.01$) (Figure 2). By contrast, no differences between any conditions were found for stride frequency. The duty factor was significantly higher in the unassisted running condition than in both assisted running conditions (fully assisted vs. unassisted -5.5 %, $p < 0.05$; partially assisted vs. unassisted -6.4 %, $p < 0.01$).

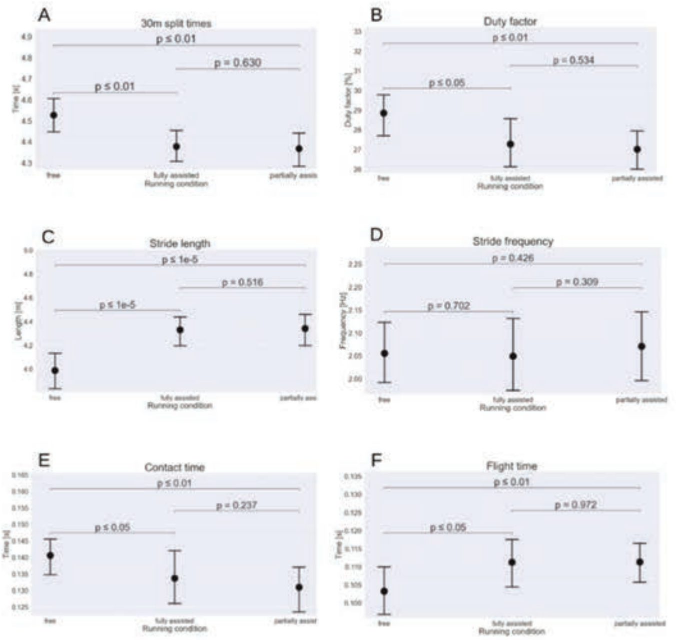

FIG. 2. Thirty-meter split times (A), duty factor (B), stride length (C), stride frequency (D), contact time (E) and flight time (F) for the unassisted, fully assisted, and partially assisted conditions. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, ns = not significant. Data are presented as mean ± SD.

Kinematics

The joint angle of the ankle was discarded from further analysis because of insufficient data quality. For the knee and hip joint angles, no significant differences were found between any conditions ($p > 0.05$) (Figure 3).

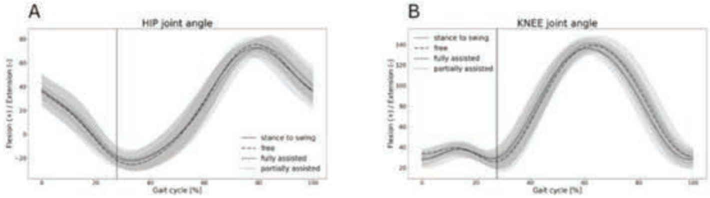

FIG. 3. Hip joint (A) and knee joint (B) angles during the gait cycle. No significant differences were found between any conditions. 0% = initial contact, 100% = next ipsilateral initial contact.

EMG results

For all measured muscles (biceps femoris, semitendinosus, vastus lateralis, rectus femoris, gluteus maximus), there were no statistically significant differences in mean activation between the unassisted, partially assisted, and fully assisted sprinting conditions ($p > 0.05$, Figure 4). However, given the high inter-individual variability, complementary effect size analysis revealed muscle-dependent differences at discrete points of the gait cycle.

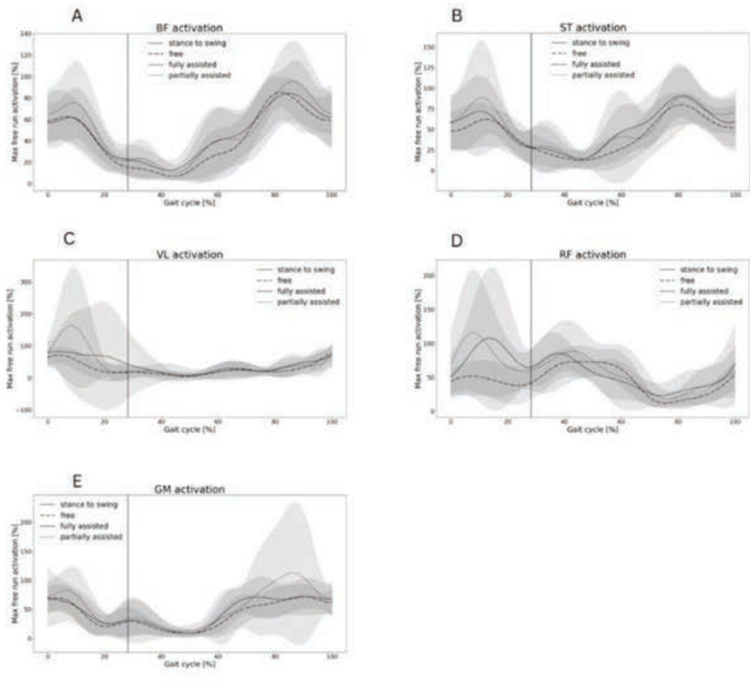

FIG. 4. EMG activity of biceps femoris (BF), semitendinosus (ST), vastus lateralis (VL), rectus femoris (RF) and gluteus maximus (GM) during the gait cycle. Data are presented as mean ± SD across participants. 0% = initial contact, 100% = next ipsilateral initial contact.

Across conditions, both biceps femoris and semitendinosus peaked during late swing, consistent with their role in limb deceleration prior to foot contact; correspondingly, large effect sizes were observed for biceps femoris during swing (40–44% of the gait cycle; $d > 0.8$; assisted < unassisted), while semitendinosus showed a large effect at 88% ($d = 0.8$; fully assisted > unassisted) and a near-large effect at 98% ($d = 0.77$; partially assisted > unassisted). In parallel, rectus femoris exhibited the most pronounced and temporally extended differences, with large effects from mid-stance to toe-off (20–28%; $d > 0.8$, max = 1.35; fully assisted > unassisted) that continued into mid-swing, peaking between 49% and 57% ($d > 0.8$, max = 1.25; unassisted > fully assisted). By contrast, although rectus femoris and gluteus maximus displayed relatively flat activation profiles across the gait cycle, vastus lateralis peaked early in stance and showed a moderate-to-large effect prior to initial contact (91–92%; $d = 0.75$; fully assisted > unassisted), while gluteus maximus demonstrated moderate-to-large effects at mid-swing (70%; $d = 0.7$; fully assisted > unassisted) and moderate effects at initial contact (10%; $d > 0.6$; partially assisted > fully assisted). Taken together, these results indicate muscle-specific, brief, and phase-dependent differences concentrated around late swing and stance transitions, despite no significant differences in mean activation across conditions.

Discussion and implications

The main aim of this study was to compare lower-limb muscle activation, spatiotemporal parameters, and kinematics across unassisted, partially assisted, and fully assisted sprinting conditions. Contrary to our initial hypothesis, no statistically significant differences were found in muscle activation between the fully and partially assisted conditions. Furthermore, muscle activity in the assisted conditions did not differ significantly from unassisted sprinting across the measured muscles despite changes in running speed, stride length, and contact and flight time. At the same time, effect size analysis identified muscle-specific differences at distinct phases of the gait cycle in both assisted and unassisted conditions, highlighting meaningful patterns that were not apparent from group averages alone. These findings suggest that neuromuscular responses increase with speed up to maximal levels and then plateau at maximal speeds, with phase-specific momentary differences emerging, particularly during swing and stance transitions, and indicate that assisted sprinting was not associated with a reduction in active propulsion despite the potential contribution of passive assistance.

Previous studies have consistently shown increases in muscle activity from submaximal to maximal sprinting speeds (Higashihara et al., 2010; Kyröläinen, 2005). However, our protocol included only maximal and supramaximal sprints, omitting submaximal conditions. This may explain why, in general, further increases in muscle activity were not observed, although momentary increases were recorded at some phases and were muscle-dependent. Our results align with earlier findings by (Mero & Komi, 1987), who also reported that EMG activity plateaus at supramaximal speeds. These results suggest that while neuromuscular demand increases with speed up to a point, it does not necessarily continue to rise under external towing once maximal velocities are exceeded. However, it is also possible that the lack of prior experience with assisted sprinting limited participants' ability to fully engage their neuromuscular system under these novel conditions.

Assisted sprinting may reduce the need for active propulsion by altering the external force demands placed on the athlete. As described by Eston et al. (1995) in the context of downhill running, eccentric muscle loading can occur without proportional increases in EMG activity due to enhanced contributions from passive and elastic tissues. Similarly, in the present study, the external towing force may have allowed athletes to reach supramaximal speeds without requiring greater neuromuscular output, particularly during the propulsive phase. In this context, it is no surprise that only momentary differences were observed between partially and fully assisted conditions, as these are more similar to each other than to the unassisted condition. Rather than substantial changes in overall activation levels, the muscle activity observed during late swing and early stance likely reflects the need to prepare for ground contact and manage impact forces, particularly the hamstrings, which are critical for stability and control during high-speed running (Chumanov et al., 2007; Mero & Komi, 1986). The finding that muscle activity did not significantly increase during assisted sprinting may be important from a safety standpoint; however, actual mechanical stress on muscles or joints, and the associated injury risk, cannot be inferred from EMG alone, as it reflects muscle activation but not the forces acting on bones, joints, or tissues.

From a spatiotemporal perspective, both assisted conditions led to significantly improved 30 m sprint times compared with the unassisted running condition. This improvement was driven primarily by increases in stride length, with no changes in stride frequency. These findings are consistent with prior research showing that assistance augments horizontal displacement more than step turnover (Clark et al., 2009). Flight time was significantly longer in both assisted conditions, while contact time was significantly shorter. The longer flight time and shorter contact time suggest higher vertical impulses and potentially increased leg stiffness during assisted sprinting. Despite these spatiotemporal changes, joint kinematics in the hip and knee remained unchanged between conditions, suggesting that athletes maintained similar segmental coordination patterns. The stability of joint angles across conditions implies that the observed performance enhancements occurred without major alterations to overall running technique.

High inter-individual variability should be considered when interpreting the findings of this study, as meaningful group-level effects may have been obscured, thereby reducing the statistical power to detect moderate changes in muscle activation. The large standard deviations within each condition indicate that athletes responded differently to the assisted sprinting stimulus, likely due to variations in individual technique or familiarity with towing. Although all participants were familiar with sprinting, they had not previously been exposed to assisted sprinting; thus, the present results likely reflect responses to an initial exposure rather than a well-learned technique. Furthermore, only a single stride per condition (the last complete stride before the 30 m mark) was analyzed at (supra)maximal speed, which may limit the generalizability of the EMG and kinematic findings to the entire maximal-speed phase. Additionally, the study focused on a 30 m sprint for practical feasibility in sports settings, whereas a longer distance could have enabled a more extended period of independent supramaximal running, allowing analysis of multiple strides and more robust EMG assessment. Finally, the inclusion of force plate analysis would provide valuable insight into ground reaction forces and their relationship with muscle activity patterns. Future studies involving athletes well adapted to assisted sprinting are warranted to determine whether specific individuals or muscle groups exhibit consistent neuromuscular adaptations to this type of training.

Conclusions

This study found no significant differences in lower-limb muscle activation between unassisted, partially assisted, and fully assisted sprinting conditions, despite improved sprint times and changes in spatiotemporal parameters under both assisted conditions. Contrary to our initial hypothesis, fully assisted sprinting was not associated with a decrease in muscle activity compared with partially assisted or unassisted running, despite the potential contribution of passive propulsion. Indeed, muscle-specific, phase-dependent differences emerged at discrete points of the gait cycle, indicating that neuromuscular responses increase with speed up to maximal levels and then plateau at maximal speeds, with only brief variations occurring during key phases, particularly during swing and stance transitions. The observed inter-individual variability and lack of familiarization with assisted running highlight the need for further research into personalized responses to assisted sprinting across different athlete populations.

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Third publication „Assisted Sprint Training: Individual Adaptations Linked to Force-Velocity Profiles and Spatiotemporal Variables" has been accepted.

Assisted Sprint Training: Individual Adaptations Linked to Force–Velocity Profiles and Spatiotemporal Variables

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Abstract

This study investigated the effects of a 6-week assisted sprint training (AST) program on sprint performance, spatiotemporal variables, and force–velocity (F-V) profiles in youth soccer players and explored whether baseline regular sprint characteristics were associated with individual adaptations. Twenty-four players aged 16.5 ± 2.1 years were allocated to a fully AST, partially AST, or control group. Both assisted groups completed 12 sessions of 30-m towed sprints using a motorized device. Sprint performance was assessed under regular and assisted conditions before and after training, while the F–V profile was derived from regular conditions before training. Assisted sprint times improved significantly in the intervention groups (4.24 s [95% CI 4.16–4.33] to 4.10 s [95% CI 4.01–4.20]; $\eta^2p = 0.26$); but regular 30-m sprint times and spatiotemporal variables did not change significantly. High responders displayed greater initial force and power capacities (theoretical maximal horizontal force [F_0], maximal propulsive power [P_{max}], maximal ratio of force [RF_{max}]) than nonresponders. Regression analysis indicated that Pmax and RFmax were the strongest predictors of improvement (adjusted $R^2 > 0.53$ for both), whereas a theoretical maximal velocity showed a weak association (adjusted $R^2 = 0.13$). Overall, AST improved performance only under assisted conditions, with the observed adaptations likely driven in part by sensorimotor adjustments. However, there was great interindividual variability. These findings highlight the relevance of F-V profiling for identifying potential responders and suggest that AST provides limited short-term transfer to regular sprint performance.

Key Words: overspeed training, Alex7 run, soccer, individual responsiveness

Introduction

Sprint performance is a critical factor in many sports, particularly soccer, in which short accelerations and maximal speed often determine the game outcomes. Resisted and assisted sprint training (AST) are commonly used to improve sprint mechanics and neuromuscular performance (4,15). Recent systematic reviews of research involving soccer code athletes indicate that various sprint training methods, including resisted, assisted, and combined approaches, can improve short sprint performance, although the effect sizes are typically small to moderate and the responses are strongly influenced by age, competitive level, and the training period within the competition season (18). Assisted sprinting, in which athletes are towed to supramaximal speeds, emphasizes the production of propulsive force at high velocities at the velocity end of the force–velocity (F-V) spectrum and may allow athletes to run beyond their typical unassisted F-V profile, unlike heavy resisted sprinting, which shifts loading toward the force-oriented end. By acutely reducing ground contact time and increasing stride frequency, assisted sprinting may improve the neuromuscular qualities needed to produce force at high velocities (21). However, overspeed or assisted sprinting remains less studied than resisted methods, and the available findings suggest heterogeneous acute responses in young athletes, such as changes in step length, contact time, and stride frequency, according to the magnitude of the assistance applied (1–3,6).

The effectiveness of sprint training may depend on the individual's initial propulsive force capacity, which can be characterized according to their F-V profile. That is, athletes with a lower maximal propulsive force may benefit more from resisted training, and those with lower maximal velocity capabilities may respond better to assisted training (16). Research on F-V profiling suggests that individual tailoring of sprint training can induce different adaptations. Within this framework, it is thought that power–force–velocity profiling can help to maximize sprint performance by improving the athlete's propulsive power capacity (PH_{max}), which is described as the power associated with the step-averaged anteroposterior external force. It is also thought that the force- or velocity-oriented profile can be used to guide individualized loading strategies to increase PH_{max} (10,12,16). According to Samozino et al. (2021), sprint acceleration performance depends on both the maximal propulsive power (P_{max}) and the slope of the linear F-V relationship, which determines the mean propulsive power an athlete can produce over a given sprint distance.

For each sprint distance and PH_{max}, knowing the optimal F-V profile might allow an athlete to maximize the average propulsive power and thus performance (22). Rakovic et al. (2018) reported that individualized training based on horizontal F-V profiling produced improvements in sprint performance and mechanical variables similar to those induced by general sprint training, although the individual responses varied. Lahti et al. (2020) found that theoretical maximal velocity (V_0) improved in both heavy resisted and assisted sprint groups but that the theoretical maximal horizontal force (F_0) and the slope of the linear F-V relationship showed group-dependent changes. Importantly, Lahti et al. (2020) also showed that the direction of training-induced adaptations depends on the athlete's initial F-V profile; that is, athletes who began with a more force-oriented profile tended to improve velocity-related qualities, whereas those with a more velocity-oriented profile showed greater gains in force-related capacities. These results raise key questions such as: (i) How well can the initial F-V profile predict V_0 improvement? (ii) Does incorporating pretraining characteristics, such as stride length, stride frequency, contact and flight times, speed maintenance, and the time to reach top speed, improve the predictive accuracy?

In real training settings, assisted sprinting can be applied in different ways. During full towing, the athlete is pulled forward continuously with a fixed force (e.g., 3–7 kg), which may reduce active propulsion and limit adaptations. By contrast, partial towing involves releasing the assistance once a target speed is reached, which may preserve muscle engagement and movement control, although this approach has not been tested experimentally. Evidence from overspeed and towing studies suggests that the degree of assistance and the length of the assisted segment critically influence the kinematic and kinetic adaptations, and that moderate loads often produce subtle or highly individual responses (1,2,6,26). An important question remains whether the velocity gains acutely achieved through assisted sprinting transfer to regular sprint performance.

In this study, we compared two AST methods in youth soccer players: continuous towing to supramaximal speed and partial towing limited to 0.5 $m \cdot s^{-1}$ below supramaximal speed. We hypothesized the following: i) partial towing would yield greater improvements in assisted und regular sprint times because it may induce greater active propulsion, ii) both assisted training methods would transfer effectively to regular sprint performance, and iii) F-V profiles and spatiotemporal variables could help predict changes in V_0.

Methods

Experimental Approach to the Problem

A pre–post intervention design was implemented. All athletes completed baseline testing, a 6-week training period, and postintervention testing under identical conditions. Two experimental groups performed AST in addition to their regular soccer activities, and the control group continued their regular soccer training only. The dependent variables were the test outcomes of sprint performance and spatiotemporal parameters (i.e., 30-m sprint time, stride length, stride frequency, ground contact time, and flight time) in regular and assisted conditions. The independent variables were time and intervention mode (fully assisted vs. partially assisted vs. control). Baseline F-V profiles and spatiotemporal variables were analyzed to identify the predictors of the training response.

Participants

Twenty-seven male youth soccer players were recruited from the same soccer school. The inclusion criteria required players to be free from injuries or medical conditions affecting maximal sprinting. Participants had previous experience with overspeed sprinting using elastic towing (bungee), but none had prior experience with motorized assisted sprinting. Participants were initially allocated into two intervention groups (fully assisted sprinting and partially assisted sprinting) and one control group, each comprising nine players. Stratified randomization was applied to ensure a balanced allocation according to playing position and baseline sprint performance. Players were assigned to a group based on their individual F-V profile characteristics derived from regular sprint trials, primarily the theoretical maximal velocity, with additional consideration of theoretical maximal horizontal force and the slope of the linear F-V relationship to ensure balanced mechanical sprint capacities across groups. Three players did not complete the intervention: one was released from his soccer academy, one was promoted to a higher league, and one withdrew because of an injury not related to sprints. The final sample comprised 24 participants (age: 16.5 ± 2.1 years, range: 14-20 years; body mass: 69.3 ± 9.7 kg; height: 1.80 ± 0.06 m). The study was conducted during the preparation phase for the next season. In this study, all players completed five training sessions during the week comprising three soccer training sessions and two sprint training sessions for the intervention groups followed by strength conditioning for both the intervention and control groups. Adherence to the sprint training program was high, and participants attended an average of 11.6 ± 1.5 sessions out of 12 total sprint sessions available during the intervention period. Participants were instructed to maintain their usual training routine and regular diet throughout the study period.

Written informed consent was obtained from all athletes and their legal guardians after providing verbal and written information about the study procedures, risks, and benefits. The study complied with the 2024 Declaration of Helsinki and was approved by the local institutional ethics committee (code: BNL-TRS(B)-2025-783, Lithuanian Sport University).

Procedures

The intervention consisted of four 30-m assisted sprints performed twice weekly for a total of 12 sessions. Each session began with a standardized 20-min warm-up comprising jogging, dynamic stretching, sprint drills, and progressive accelerations. Fully assisted sprinting involved 30-m sprints with a constant towing force of 6 kg applied by a motorized device (Alex7 run, Inosportas, Kaunas, Lithuania) which corresponded to 8.7 ± 1.2 % of the athletes' body mass. Supramaximal speed was defined as the highest velocity achieved during preliminary fully assisted sprint trials. The reliability and validity of sprint performance measurements using the Alex7 device have previously been demonstrated (24). Partially assisted sprinting used the same initial towing force (6 kg), which was automatically released once the athlete reached 0.5 $m \cdot s^{-1}$ below his individual supramaximal speed, allowing him to self-propel through the final portion of the sprint. A 5-min passive rest interval was provided between each sprint to minimize fatigue.

Data Collection and Variables

Testing was conducted indoors under standardized environmental conditions. Each athlete was tested at the same time of day before and after the intervention to minimize circadian variability. The athletes completed the same standardized warm-up used for training sessions. Each testing session comprised two sprint conditions performed from a standing start: a 30-m regular sprint and a 30-m assisted sprint with a constant towing force of 6 kg. Both sprint conditions were performed twice, with 5 min of passive rest between trials. The fastest trial for each condition was recorded for analysis. Sprint times were recorded using a photocell timing system (Witty Gate, Microgate, Bolzano, Italy), with gates positioned at 0, 5, 10, 15, 20, 25, and 30 m. The first gate was set at a height of 20 cm to ensure that the timing began at the initiation of forward movement rather than the foot placement at the line. Performance outcomes were expressed as both absolute sprint times and pre–post differences.

Spatiotemporal variables were collected using the OptoJump Next modular system (Microgate) over the 10–30-m segment. Stride length, stride frequency, ground contact time, and flight time were extracted, and the two fastest consecutive strides within this segment of the fastest trial were analyzed for both the regular and assisted sprint conditions.

F-V profile parameters were calculated from regular sprint trials, using the validated field method described by Samozino et al. (2016), which estimates step-averaged horizontal anteroposterior force, velocity, and propulsive power from split time and anthropometric data through exponential modeling of the velocity–time curve. From this modeling, F_0, V_0, P_{max}, *slope*, maximal ratio of force (RF_{max}), and the rate of decrease in RF with increasing speed (*DRF*) were derived.

Because the first photocell was positioned directly at the start line and 20 cm above the ground, the timing beam was typically broken only after the athlete had already initiated forward movement. This produced a systematic delay in the recorded start time and consequently an underestimation of early acceleration velocity and force values. To address this misalignment between the true onset of movement and photocell triggering, a time-shift optimization procedure was applied, based on the approach validated by Stenroth et al., (2023), who demonstrated that adjusting split times by an optimized temporal offset substantially improves the reliability and validity of F-V variables when the start instant cannot be captured precisely. Accordingly, a constant time correction (Δt) was added to all raw split times. Δt was determined by minimizing the discrepancy between the modeled and observed positions during the exponential fitting. This correction ensured that the reconstructed velocity–time curve originated from true zero velocity conditions and that all F-V variables (F_0, V_0, P_{max}, RF_{max}, DRF, *slope)* were calculated with the correct temporal alignment. After the corrected split times were obtained, instantaneous step-averaged velocity, horizontal force, and propulsive power were computed according to the procedures outlined in Samozino et al. (2016).

Data Analysis

All three groups were first compared. The two assisted sprint modes showed similar neuromuscular and performance responses; therefore, they were combined into a single intervention group for comparison with the control group, which allowed a more robust estimate of the intervention effect. Individual responses were examined by classifying athletes as high responders or nonresponders based on the changes in assisted 30-m sprint times. The minimal detectable change (MDC) was calculated from the standard error of measurement (SEM) of two pretest trials using the formula $MDC = 1.96 \times \sqrt{2} \times SEM$. The MDC was 0.13 s and represented the smallest change exceeding the typical measurement error (7,11). A stricter threshold of ≥0.19 s, which was ~50% above the MDC, was used to define high responders ($n = 7$). Athletes who improved by ≤0.13 s were defined as nonresponders ($n = 7$), and those whose MDC was >0.13 and <0.19 s were excluded from this analysis. This dual-threshold approach was used to distinguish measurement variability from meaningful performance adaptations.

Statistical Analysis

All data are reported as mean ± standard deviation (SD). Outliers were screened visually using QQ plots and residuals, and standardized residuals ($|z|>3$). Influential points in the regression analysis were checked using Cook's distance (>4/n). Assumptions of linear regression, including normality of residuals and absence of influential observations, were verified using these diagnostic procedures. Alpha was set at 0.05 (8,27). Analyses were conducted in JASP (version 0.95.1, Intel, Santa Clara, CA, USA).

Group Comparisons and Intervention Effects

A two-way analysis of variance (ANOVA, group × time) with repeated measures on the time factor was conducted to identify differences in dependent variables. When significant interaction effects were observed, post hoc pairwise comparisons were performed using Holm-adjusted multiple comparisons. Effect sizes for ANOVA were reported as partial eta squared (η^2p). This analysis was first performed with three separate groups: control, fully assisted, and partially assisted. A second analysis was then conducted after merging the two assisted groups into a single intervention group to compare them directly with the control group. The variables included were sprint performance outcomes (regular and assisted 30-m sprint times) and spatiotemporal variables in both sprint conditions (step length, step frequency, contact time, and flight time). Within-group comparisons were evaluated using the paired-samples *t* test to identify significant pre-to-post changes within each group and to compare assisted vs. regular sprint conditions at the same time.

Comparison of Responders and Nonresponders

The independent-samples *t* test was used to compare the pretest, posttest, and change scores between responders and nonresponders (Δ = post – pre) for both performance and spatiotemporal variables. The performance comparisons included regular and assisted 30-m sprint times, and the spatiotemporal comparisons included step length, step frequency, ground contact time, and flight time during both regular and assisted sprinting. Within-group comparisons between regular and assisted sprinting for the same variables were conducted. A p value < 0.05 was considered to be significant. Effect sizes are reported using Cohen's d, and 95% confidence intervals (CI) were calculated where appropriate. Welch's correction was applied when the variances were unequal.

The independent-samples *t* test was used to compare baseline F-V variables between responders and nonresponders. The analysis included F_0, V_0, P_{max}, RF_{max}, DRF and the slope of the F-V relationship, which were calculated for the regular sprint runs. Effect sizes are reported using Cohen's d, and Welch's correction was applied when the assumptions of equal variances were violated.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

ChatGPT (Version 5.1, Open AI, San Francisco, CA, USA) was used to assist in optimizing English language clarity and readability. The authors critically reviewed and edited the manuscript and take full responsibility for the final published content.

Results

Fully vs. Partially Assisted Sprint Performance

At the baseline, there were no significant differences between the control, fully assisted, and partially assisted groups for any sprint time or spatiotemporal variable (all $p > 0.05$). A two-way ANOVA (group × time) for assisted sprints revealed a significant interaction effect on sprint performance ($F(2, 21) = 6.07$, $p = 0.01$, $\eta^2p = 0.37$). Post hoc analysis showed significant improvements in the fully assisted (pre: 4.22 ± 0.16; post: 4.13 ± 0.21 s) and partially assisted (pre: 4.26 ± 0.14; post: 4.08 ± 0.17 s) groups; the value in the control group remained unchanged. For regular sprint times, the group × time interaction was also significant ($F(2, 21) = 6.26$, $p = 0.01$, $\eta^2p = 0.37$), but only the assisted groups showed a trend toward improvement ($p > 0.05$).

Combined Intervention vs. Control Groups

No baseline differences were found between groups ($p > 0.05$; Table 1). In the assisted condition, the 30-m sprint time was reduced within each group ($p < 0.05$), but no significant differences were found between the groups ($p > 0.05$). Both groups exhibited increased step length during assisted running ($p < 0.05$).

For assisted sprint times, a significant group × time interaction was observed ($F(1, 22) = 7.55$, $p = 0.01$, $\eta^2p = 0.26$); the sprint time improved in the intervention group (pre: 4.24 ± 0.15; post: 4.10 ± 0.19 s) but remained unchanged in the control group. For the regular sprint times, a significant interaction was also observed ($F(1, 22) = 13.08$, $p < 0.01$, $\eta^2p = 0.37$); that is, the times slowed slightly in the control group and improved slightly in the intervention group. Contact time decreased significantly in the intervention group in both the assisted and regular sprints. No other significant spatiotemporal interactions were found.

Table 1. Two-way repeated-measures ANOVA results for assisted and regular sprint performance and spatiotemporal variables in the control and intervention groups.
Note: Data are presented as mean ± SD. Spatiotemporal variables were measured at maximal speed. *Indicates a significant pre-to-post difference within a group ($p < 0.05$); # Indicates a significant difference between the same variable in the regular and assisted run ($p < 0.05$). F, p, and partial eta squared (η^2p) values are provided for the main effects (group, time) and their interaction (group × time). Ass = assisted sprint condition; Reg = regular (unassisted) sprint condition.

Comparison of High Responders vs. Nonresponders in Time and Spatiotemporal Variables
No significant between-group differences were observed at the baseline, although a nonsignificant trend indicated faster times among the high responders in both the assisted (0.13 s difference, $p = 0.08$) and regular (0.19 s difference, $p = 0.07$) sprint conditions. The independent-samples t test revealed that high responders had significantly greater improvement in performance compared with nonresponders for the assisted 30-m sprint ($p < 0.001$, Table 2). In the regular 30-m sprint, postintervention times were also significantly faster in the high responder group ($p < 0.05$).

Table 2. Comparison of performance, spatiotemporal, and device-derived variables between high responders and non-responders.
Note: Data are presented as mean ± SD. Ass = assisted sprint condition; Reg = regular (unassisted) sprint condition. Spatiotemporal variables were measured at maximal speed.

Comparison of Responders vs. Nonresponders in Baseline F-V Profile Variables
At the baseline, high responders had higher F_0 ($p = 0.01$, d = 1.65), P_{max} ($p = 0.01$, d = 1.80), and RF_{max} ($p < 0.01$, d = 1.87) than nonresponders, which suggested that the responders had superior initial force and power capacities (Figure 1). No significant differences were observed for V_0, DRF and slope (all $p > 0.05$). However, DRF ($p = 0.09$, d = 1.00) and slope ($p = 0.07$, d = 1.09) showed moderate to large effect sizes (d ≥ 1), indicating a tendency toward steeper F–V profiles in responders.

Figure 1. Comparison of baseline force–velocity profile variables between high responders and non-responders. Panels show: (A) theoretical maximal horizontal force (F_0), (B) theoretical maximal velocity (V_0), (C) maximal propulsive power (Pmax), (D) maximal ratio of force (RFmax), (E) rate of decrease in RF with increasing speed (DRF), and (F) slope of the linear force–velocity relationship.
Note: Data are presented as mean ± SD with individual values shown. **Indicates a significant difference between high and non-responders ($p < 0.01$); ns indicates a non-significant difference ($p > 0.05$).

Predictive Analyses
To identify predictors of assisted sprint improvement, linear regression analyses were performed using postintervention 30-m assisted time as the dependent variable and baseline F-V parameters as the independent variables (Figure 2). For regular sprints, P_{max} (adjusted $R^2 = 0.63$) and RF_{max} (adjusted $R^2 = 0.54$) were the strongest predictors, F_0 showed a moderate association (adjusted $R^2 = 0.33$), whereas V_0 demonstrated only a weak relationship with assisted sprint improvement (adjusted $R^2 = 0.13$)

Figure 2. Strength (adjusted R^2) of regular sprint-derived F-V parameters for predicting assisted sprint improvement.
Note: F_0 = theoretical maximal horizontal force; V_0 = theoretical maximal velocity; Pmax = maximal propulsive power; RFmax = maximal ratio of force; DRF = rate of decrease in RF with increasing velocity; slope = slope of the linear F–V relationship. Higher adjusted R^2 values indicate stronger predictive associations.

Discussion
The main finding of this study was that incorporating assisted sprinting into soccer-specific training improved assisted sprint velocity in young players. However, these gains did not transfer or transferred minimally to regular sprint velocity and to spatiotemporal variables such as stride length, stride frequency, ground contact time, and flight time at maximal velocity. This pattern aligns with recent meta-analytic findings showing that AST does not consistently produce greater improvements in regular short sprint performance than well-designed conventional sprint training, despite moderate within-group gains in kinematic variables (17,18). The magnitude of improvement observed in this study was strongly associated with the initial

power capacities derived from the F–V profile, suggesting that athletes with higher initial force and power levels may derive greater benefits from AST.

The initial aim of this study was to compare continuous towing at supramaximal speed with partial towing limited to slightly below supramaximal speed. However, only negligible differences were observed between the protocols, as reflected by the absence of significant differences in sprint time, stride length, stride frequency, ground contact time, and flight time. This likely reflects the relatively short, assisted distance. That is, assistance was often released late (at ~22 m), which left only a brief segment for partial assistance to meaningfully alter the sprint mechanics. Thus, our initial hypothesis that partial towing would yield greater improvements was not confirmed. Combining the data for both assisted modes provided evidence of clear improvements under assisted conditions compared with the control condition. These findings are consistent with prior reports that carefully dosed overspeed exposure can acutely increase step rate and reduce contact times without necessarily changing unassisted top speed in the short term (9,21). Recent overspeed studies have also shown that moderate assistance levels and short assisted segments induce primarily adjustments in acute kinematic, such as reduced ground contact and changes in stride frequency, rather than substantial chronic adaptations in regular sprinting, especially in youth and subelite populations (1,2,6).

A key observation was the heterogeneity of response: nearly half of the participants improved by no more than the MDC, whereas a smaller subgroup showed clearly greater gains in assisted run after the intervention. Similar interindividual variability has been reported for sprint training tailored using F-V diagnostics or delivered as generic sprint work (13,20). Lahti et al. (2020) reported that baseline F-V properties, such as force- or velocity-dominant profiles, can partly identify which athletes adapt and how after resisted or assisted training blocks. The pattern observed in our study aligns with these earlier findings in that assisted towing appears to benefit some athletes considerably, while others show minimal changes after short interventions. The possible reasons for these individual differences include variations in technical proficiency at high limb velocities, differences in neuromuscular readiness to manage the hamstring load during late swing at supramaximal speeds, and the degree to which towing preserves rather than replacing active propulsion (9,16,21). Indeed, participants had prior experience with elastic overspeed running but not with motorized towing; therefore, differences in familiarity with the specific assistance modality may have influenced the responses. This reinforces the idea that individual mechanical "readiness" and sprint-specific technical competency may be prerequisites for taking full advantage of supramaximal sprint stimuli.

This study also examined whether baseline F–V profiles could help explain these individual differences. The regular sprint-derived variables indicated that baseline P_{max} and RF_{max} were most strongly associated with subsequent assisted sprint performance improvements. These findings are consistent with earlier reports suggesting that F–V characteristics explain part, but not all, of the variability in training adaptations (13,20). Other studies further support this concept by demonstrating that individualized F–V–oriented training can reduce mechanical imbalances more effectively than generic sprint programs. However, a considerable proportion of the variance in performance outcomes remains unexplained and may be related to neuromechanical, coordinative, and maturational factors (12,14,16). In addition, differences in training history, technical proficiency, and responsiveness to external mechanical stimuli may also contribute to the observed variability. Therefore, while F–V profiling may provide useful information for guiding training strategies, it should likely be considered alongside other individual characteristics when interpreting adaptations to assisted sprint training.

Importantly, the improvements in assisted sprint times transferred only minimally to regular 30-m sprint performance within the timeframe of this study. This finding is consistent with that of earlier reports showing that overspeed exposure can acutely improve velocity-side qualities, such as shorter ground contact times and faster step rates, but may not lead to immediate improvements in regular sprint performance unless there is sufficient volume, progression, and integration applied to high-quality unassisted sprinting (9,21). The minor differences observed in regular sprints following improvements in assisted sprinting in this study also support the idea that at least part of the adaptations were sensorimotor, which reflect the ability of the athlete to coordinate movement under external pulling forces, rather than structural or neural changes that transfer to free sprinting. This interpretation is reinforced by acute and short-term overspeed studies demonstrating that assisted training often yields kinematic adaptations without corresponding increases in regular sprint speed unless paired with progressive loading and movement-specific consolidation (1,2,6).

Two practical implications emerge from these findings. First, assistance should be carefully dosed and increased progressively, such as using slightly longer assisted distances, more sessions, or a gradual transition from partial to brief fully assisted exposure. Second, transfer to regular sprinting may be enhanced by integrating assisted and well-executed unassisted sprints within the same training cycle while ensuring that the level of assistance preserves the natural sprint mechanics (13,19). Recent reliability data for motorized towing systems also support their use for controlled supramaximal exposure when the level of assistance is carefully adjusted to preserve natural sprint mechanics (5).

This study has several limitations. First, the sample size was small, which is a common constraint in applied team sport research. Second, we used 30-m assisted efforts; although longer assisted segments might create a stronger mechanical stimulus, these are less practical in soccer settings. Third, the participants continued their usual soccer preparation, and concurrent training effects cannot be ruled out. Forth, the assistance force was applied as an absolute load (6 kg) rather than normalized to body mass. Therefore, the assistance force varied somewhat between individuals, which may have contributed to inter-individual variability in the mechanical stimulus. Finally, part of the observed improvements, possibly reflecting a lack of familiarization, may be due to adaptation to the overspeed stimulus rather than purely training-induced changes. However, responses were heterogeneous, with clear responders and non-responders, suggesting that individual mechanical and neuromuscular characteristics also influenced adaptations to assisted sprinting (9).

In conclusion incorporating assisted sprinting into soccer-specific training effectively improves assisted sprint velocity in young soccer players, although these gains transferred minimally to regular sprint performance and spatiotemporal variables. Improvements were strongly associated with the athletes' initial power capacities derived from the F–V profile. Overall, the results suggest a trend toward greater benefits for athletes with higher baseline force and power characteristics, which appear to influence their responses to AST.

Practical Applications

Motorized assisted sprinting offers an effective method for controlled supramaximal exposure and detailed profiling of the athlete's capacity. Although short-term improvements were limited to the assisted condition, F-V profiling may help identify athletes more likely to benefit from such training. Integrating assisted and unassisted sprinting within the same training cycle, with progressive adjustment of assistance levels, may enhance transfer and support individualized sprint development.

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Table 1. Two-way repeated-measures ANOVA results for assisted and regular sprint performance and spatiotemporal variables in the control and intervention groups.

	Post-Hoc		Factor	df	F	p	η^2_p
	Control:	Intervention:					
Ass 30m (s)	Pre: 4.16 ± 0.21##	Pre: 4.24 ± 0.15##	Group	1, 22	0.05	0.83	0.00
	Post: 4.15 ± 0.21	Post: 4.10 ± 0.19***	Time	1, 22	10.12	0.01	0.32
			Group X Time	1, 22	7.55	0.01	0.26
Reg 30m (s)	Pre: 4.38 ± 0.20	Pre: 4.46 ± 0.19	Group	1, 22	0.00	0.97	0.00
	Post: 4.48 ± 0.18*	Post: 4.41 ± 0.20*	Time	1, 22	1.71	0.21	0.07
			Group X Time	1, 22	13.08	0.00	0.37
Step Length Ass (cm)	Pre: 213.1 ± 9.11##	Pre: 210.6 ± 10.17##	Group	1, 22	0.05	0.82	0.00
	Post: 209.2 ± 12.33	Post: 209.9 ± 9.20	Time	1, 22	1.18	0.29	0.05
			Group X Time	1, 22	0.55	0.47	0.02
Step Frequency Ass (step/s)	Pre: 4.36 ± 0.14	Pre: 4.36 ± 0.27	Group	1, 22	0.02	0.90	0.00
	Post: 4.40 ± 0.32	Post: 4.42 ± 0.24	Time	1, 22	1.46	0.24	0.06
			Group X Time	1, 22	0.03	0.86	0.00
Contact Time Ass (s)	Pre: 0.120 ± 0.004	Pre: 0.124 ± 0.013	Group	1, 22	0.30	0.59	0.01
	Post: 0.120 ± 0.008	Post: 0.120 ± 0.010*	Time	1, 22	1.46	0.24	0.06
			Group X Time	1, 22	1.46	0.24	0.06
Flight Time Ass (s)	Pre: 0.110 ± 0.009	Pre: 0.106 ± 0.009	Group	1, 22	0.66	0.43	0.03
	Post: 0.109 ± 0.013	Post: 0.107 ± 0.008	Time	1, 22	0.04	0.84	0.00
			Group X Time	1, 22	0.51	0.48	0.02
Step Length Reg (cm)	Pre: 194.7 ± 9.27	Pre: 191.7 ± 10.04	Group	1, 22	0.51	0.49	0.02
	Post: 194.9 ± 9.81	Post: 191.6 ± 10.73	Time	1, 22	0.00	0.97	0.00
			Group X Time	1, 22	0.01	0.93	0.00
Step Frequency Reg (step/s)	Pre: 4.40 ± 0.16	Pre: 4.42 ± 0.23	Group	1, 22	0.24	0.63	0.01
	Post: 4.36 ± 0.28	Post: 4.45 ± 0.27	Time	1, 22	0.01	0.94	0.00
			Group X Time	1, 22	0.66	0.43	0.03
Contact Time Reg (s)	Pre: 0.127 ± 0.005	Pre: 0.127 ± 0.012	Group	1, 22	0.40	0.53	0.02
	Post: 0.129 ± 0.008	Post: 0.124 ± 0.009*	Time	1, 22	0.05	0.83	0.00
			Group X Time	1, 22	6.36	0.02	0.22
Flight Time Reg (s)	Pre: 0.101 ± 0.008	Pre: 0.100 ± 0.010	Group	1, 22	0.00	0.99	0.00
	Post: 0.102 ± 0.012	Post: 0.102 ± 0.011	Time	1, 22	0.81	0.38	0.04
			Group X Time	1, 22	0.21	0.66	0.01

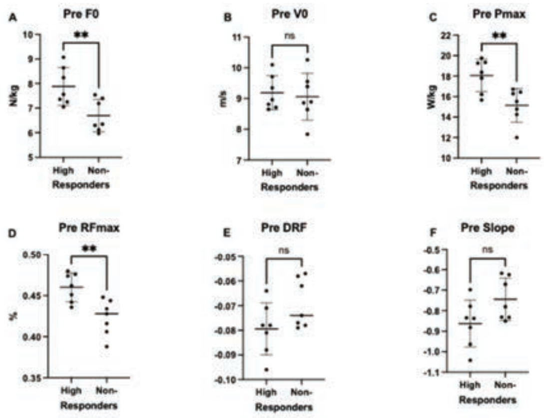

Figure 1. Comparison of baseline force–velocity profile variables between high responders and non-responders. Panels show: (A) theoretical maximal horizontal force (F_0), (B) theoretical maximal velocity (V_0), (C) maximal propulsive power (Pmax), (D) maximal ratio of force (RFmax), (E) rate of decrease in RF with increasing speed (DRF), and (F) slope of the linear force–velocity relationship.

Table 2. Comparison of performance, spatiotemporal, and device-derived variables between high responders and non-responders.

Dependent Variable	Mean ± SD		t	df	p	Cohen's d
	Non-Responder:	High Responder:				
Ass 30m (s)	Pre: 4.27 ± 0.16	Pre: 4.14 ± 0.09	1.91	12	0.08	1.02
	Post: 4.23 ± 0.12	Post: 3.91 ± 0.09	5.87	12	< .001	3.14
	Δ: -0.04 ± 0.08	Δ: -0.23 ± 0.03	5.74	12	< .001	3.07
Reg 30m (s)	Pre: 4.52 ± 0.22	Pre: 4.33 ± 0.10	1.98	12	0.07	1.06
	Post: 4.48 ± 0.19	Post: 4.27 ± 0.13	2.37	12	0.04	1.27
	Δ: -0.04 ±0.09	Δ: -0.06 ± 0.08	0.63	12	0.54	0.34
Step Length Ass (cm)	Pre: 210. ± 12.57	Pre: 208.7 ± 9.59	0.22	12	0.83	0.12
	Post: 205.7 ± 7.77	Post: 212.1 ± 11.14	-1.25	12	0.23	-0.67
	Δ: -4.29 ± 8.27	Δ: 3.43 ± 6.39	-1.95	12	0.08	-1.04
Step Frequency Ass (step/s)	Pre: 4.32 ± 0.27	Pre: 4.52 ± 0.24	-1.45	12	0.17	-0.77
	Post: 4.42 ± 0.26	Post: 4.56 ± 0.16	-1.24	12	0.24	-0.66
	Δ: 0.09 ± 0.18	Δ: 0.04 ± 0.13	0.65	12	0.53	0.35
Contact Time Ass (s)	Pre: 0.127 ± 0.013	Pre: 0.119 ± 0.013	1.23	12	0.24	0.66
	Post: 0.121 ± 0.009	Post: 0.114 ± 0.010	1.47	12	0.17	0.78
	Δ: -0.006 ± 0.008	Δ: -0.005 ± 0.007	-0.26	12	0.80	-0.14
Flight Time Ass (s)	Pre: 0.106 ± 0.011	Pre: 0.104 ± 0.006	0.46	12	0.65	0.25
	Post: 0.106 ± 0.009	Post: 0.106 ± 0.006	0.03	12	0.97	0.02
	Δ: 0.000 ± 0.006	Δ: 0.002 ± 0.004	-0.82	12	0.43	-0.44
Step Length Reg (cm)	Pre: 188.9 ± 9.11	Pre: 193.9 ± 12.35	-0.86	12	0.41	-0.46
	Post: 187.4 ± 10.82	Post: 193.6 ± 11.99	-1.02	12	0.33	-0.54
	Δ: -1.50 ± 5.90	Δ: -0.29 ± 3.40	-0.45	12	0.66	-0.24
Step Frequency Reg (step/s)	Pre: 4.41 ± 0.23	Pre: 4.49 ± 0.20	-0.63	12	0.54	-0.34
	Post: 4.43 ± 0.28	Post: 4.56 ± 0.25	-0.89	12	0.39	-0.48
	Δ: 0.02 ± 0.20	Δ: 0.07 ± 0.11	-0.62	12	0.55	-0.33
Contact Time Reg (s)	Pre: 0.128 ± 0.013	Pre: 0.123 ± 0.011	0.72	12	0.49	0.38
	Post: 0.123 ± 0.011	Post: 0.121 ± 0.009	0.37	12	0.72	0.20
	Δ: -0.005 ± 0.004	Δ: -0.002 ± 0.005	-1.16	12	0.27	-0.62
Flight Time Reg (s)	Pre: 0.100 ± 0.012	Pre: 0.100 ± 0.007	-0.05	12	0.96	-0.03
	Post: 0.103 ± 0.013	Post: 0.099 ± 0.008	0.75	12	0.47	0.40
	Δ: 0.003 ± 0.007	Δ: -0.002 ± 0.006	1.39	12	0.19	0.74

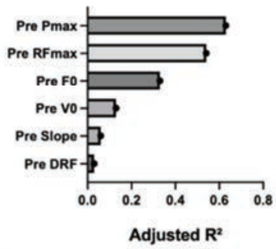

Figure 2. Strength (adjusted R^2) of regular sprint-derived F-V parameters for predicting assisted sprint improvement.

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