CHANGES IN SPRINTING KINEMATICS AFTER AN EIGHT WEEK MOBILITY PROGRAM AND ITS RELATIONSHIP WITH MAXIMAL SPEED AND ACCELERATION IN PROFESSIONAL FOOTBALL PLAYERS

Luca Fleres

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University of Jyväskylä
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Supervisors: Juha Ahtiainen & Johan Lahti

ABSTRACT

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Sprinting is an essential skill in football, and it has been widely researched with special attention to linear trajectories. The mechanics of sprinting and the running technique are unique to each player, but there are anatomical and postural features that can have an impact on how a player runs, as is the case of lumbo-pelvic control and its positioning during sprinting. This study investigates whether pelvis positioning affects running mechanics and what changes might occur in the sprinting kinematics after an 8-week mobility intervention program aimed at optimizing lumbo-pelvic control.

Ninety-five active professional football players playing in the highest league in Finland were included in this study. They performed 2 maximal 30m sprints as a baseline, and the measurements were repeated after 8 weeks. The players were given a mobility program and a series of progressive running drills after the first data collection point with the aim of increasing lumbo-pelvic control and improving running technique. The variables measured were top speed, horizontal force production, and kinematic analysis of the hip angles at touch down and toe-off. These two angles were then summed to create one single score, which will be referred to as the kickback score. This score represents the quality of the running technique. Top speed and acceleration were measured with Musclelab laser gun using split times at the 5m, 10m, 15m, 20m, 25m, and 30m marks. Kinematic analysis was performed using Kinovea motion analysis software.

No statistically significant change (-0.98% +/- 5.14%, $p = 0.06$) was observed in the kickback score following the intervention. No statistically significant change was observed in top speed (0.06% +/- 2.84%, $p = 0.97$). There was a statistically significant change in horizontal force (F0), which increased by 2,20% +/- 6.64% ($p = 0.01$). No correlation was found between the three variables.

This study demonstrated that 8 weeks of mobility and running technique protocols caused an increase in F0 even though no changes in running kinematics of professional footballers occurred. It also appears that changes in F0, top speed, and kickback mechanics are not associated with each other. Pelvis anterior rotation causes a decrease in hip flexion of up to 10 degrees, which has the kinematic consequence of creating a shorter path for vertical force production during sprinting. To the best of our knowledge, this study was the first to aim to induce changes in anatomical positioning and control of the pelvis and to investigate its impact on force production during full speed running. As a result of this study, some of the methods used for the kinematic analysis can be easily adopted by football coaches without requiring much expertise and used as a tool for individualized programs that aim at increasing running performance as well as injury prevention.

Keywords: Running anatomy, sprinting kinetics, lumbo-pelvic control

USED ABBREVIATIONS

APT	anterior pelvic tilt
CT	contact time
DL	dominant leg
F0	horizontal force
FCT	foot contact time
FT	flight time
GCT	ground contact time
GRF	ground reaction force
MVP	maximal vertical projection
NDL	non dominant leg
SL	step length

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1 INTRODUCTION

Sprinting is an essential skill required in field sports such as football (soccer). The ability to produce high speed in the shortest amount of time is perhaps the most valuable feature in sprinting (Robert et al. 2011). Time-motion analyses of football matches report professional players to regularly run distances from 10 to13 km of which only about 10% is run at very high speed (up to 25.2 km · h^{-1}) and about 3% can be defined as sprinting (speed ≥ 25.2 km · h^{-1}) (Mohr et al. 2005, Sveinsson et al. 2005). In field sports like football, where the maximal speed is rarely achieved due to the relatively short duration of the sprints (about 2 seconds on average), acceleration becomes a key factor (Duthie et al. 2006). Thus, training specificity to improve acceleration has a major role in field sports, and it must include both neuromuscular type of training as well as optimal technique (Behm, 1995). Observational studies in the last 10 years have shown a great increase in high-speed running and sprinting by 24-35 % and 36–63 %, respectively (Bradley et al. 2016. Bush et al. 2015), demonstrating the increasing demands of the game in relation to sprinting and high-speed running. For the athlete to be able to cover the necessary distance in the shortest time possible, efficient power production is required. More efficient power production leads to an increase in the velocity at which the athlete is able to move their body in space (Gaspere et al. 2019).

The efficiency of sprinting comes from a combination of factors such as sprinting mechanics, technique, and the ability of the athlete to produce force and with high level athletes it might become difficult to change well established running patterns. Kinematic analysis can be an effective tool to help coaches identify the alignment and position of the body segments and how they move in space during sprinting (Ralph, 2015).

A combination of kinematic and kinetic analysis is involved in the process of analyzing running technique in order to optimize sprinting efficiency. Research has not fully answered whether it is necessary for field athletes to train linear speed and maximal speed (Duthie, 2003). To do so may be contrary to the requirements of their sport, which often involve sudden change of direction and rarely require maximal speed to be achieved (Duthie, 2003). Optimizing kinematics is a complex task, particularly in adults with well-established kinematic patters (Lahti et al. 2020).

Speed and acceleration are paramount in football and sprinting mechanics as well as kinematics can be evaluated through motion analysis. Being able to have a reliable protocol that can be used effectively to identify individual characteristics of each athlete's technique would certainly contribute to the sport and enrich the literature.

2 REVIEW OF LITERATURE

2.1 Sprinting performance in field sport

2.1.1 Field vs track sprinting

Sprinting in field sports differs from sprinting on a track. Sprinting on a track is a skill that has a specific goal: achieving maximal speed in the shortest time possible while running in a given lane in a known environment. The running surface is almost identical in every sprinting competition, and there is therefore smaller need for sensory adaptation when translating from training to a competition setting (Sayers, 2020).

In contrast, athletes running and sprinting on a pitch can have different starting positions (e.g., standing on one leg; perform a sharp chance of direction) which are based on the specific context of the action (Sayers, 2020). They must scan a broader area and use different postures, changes in speed (acceleration and sudden deceleration) and process sensory information as they are running. The pitch itself might also present some differences and imperfections such as holes in the grass, different friction, wet spots which require further information processing when sprinting. Ultimately, they must implement changes of direction, which are probably the main component of sprinting in a field sport (Sayers, 2020).

Due to these differences, it could be argued that athletes in field sports should not train sprinting technique in the same manner as track sprinters do. While this may be true to some extent, running on a pitch or on a track does share several common features and goals as well as some fundamental principles such as the need for effective acceleration and having to overcome inertia. In addition they both rely on ground reaction forces (GRF) (Caldback, 2019).

2.1.2 Sprinting demands in field sports

To fully understand sprinting performance in field sports, it must be considered that linear sprinting is not the only sprinting technique required. Curvilinear sprinting is in fact a fundamental skill which differs from linear sprinting in terms of kinematics and kinetics of the movements (Alberto et al. 2020). Curvilinear sprinting accounts for approximately 85% of the actions performed at maximal velocity in football (Caldback, 2019). This has very important implications for coaches and athletes, and it underlines the importance of further research into curvilinear sprinting within the field of sport sciences.

Linear sprinting kinetic analysis of individual steps has been conducted using a 50-meter-long force plate placed under the running surface (Nagahara et al. 2018., Akifumi et al. 2019). This enabled calculation of force production of every step during acceleration and at maximum velocity. A recent study by Alberto et al. (2020) compared the kinematics of linear sprinting with curvilinear sprinting to both the right and left sides. They found that curvilinear sprinting with the dominant leg (DL) on the inner side was faster than linear sprinting for most players, and that curvilinear sprinting with non-dominant leg (NDL) on the inner side resulted in a slower 17m sprint time. Notably, ground contact time of the inner leg was longer than the outer leg in all curvilinear sprints (Alberto et al. 2020).

Force profiles differ between linear and curvilinear sprints, not just because centripetal forces are acting during curvilinear sprint but also because foot contact time (FCT) differs between linear and curvilinear sprinting, and the ground reaction force (GRF) must also be different. Alberto F. et al. (2020) did not consider kinetic variables or made use of force plates in their curvilinear sprinting study. Thus, it is difficult to ascertain the source of decreased performance in curvilinear sprinting with NDL on the inner side. It is possible that decreased GRF production may occur in both legs, or only in the NDL. It is also impossible to relate force production changes to FCT in curvilinear sprinting both within one and between legs. Sprints in this study were conducted over 17m to assess acceleration in sprinting performance. Propulsive forces play a major role during the acceleration phase in sprinting as demonstrated by Morin et al.

(2015), as opposed to vertical forces which have been shown to be a critical factor during steady maximal speed (Weiyand et al. 2000).

2.1.3 Metabolic and morphological adaptation to sprinting

Physiological changes occur in skeletal muscle with sprint training (Ross & Leveritt, 2001). The muscle metabolic adaptation to sprinting has shown trained sprinters to have undergone enzyme changes in all three energy systems which tend to disappear with detraining (Ross & Leveritt, 2001). Ross & Leveritt (2001) have shown increases in myokinase and creatine phosphokinase resulting from short distance sprinting training and that elite sprinters are able to breakdown phosphocreatine (PCr) more rapidly compared to sub elite sprinters. The same study also showed changes have also been reported concerning glycogen enzymes, which were increased after both long and short sprint types of training. These results have been shown to return to baseline after a period ranging from 7 weeks to 6 months of detraining (Ross & Leveritt, 2001). The importance of glycogen becomes obvious when we consider that it contributes to about 75% of the energy needed during the first 10 seconds of sprinting (Bogdanis et al. 1998). Some considerations also should be made concerning aerobic metabolism. When sprinting activity starts to exceed 10 seconds, the presence of aerobic metabolism enzymes also increases proportionally (Bogdanis et al. 1998).

The muscles also undergo morphological changes due to repeated sprinting training (Bret et al. 2002). Specifically, the orientation of the muscle fibers, the cross-sectional area, the sarcoplasmic reticulum, and the actual muscle fiber type are impacted by exposure to sprint training (Bret et al. 2002). Muscle fibers are expected to shift towards type IIa, increased cross-sectional area and increased sarcoplasmic reticulum to improve the release of calcium. (Bret et al. 2002).

There have been several studies looking at different strategies to explicitly target sprinting features, and it appears that training sprinting every day does not actually improve peak and mean power in sprinting (Parra et al. 2000). However, training sprinting every third day has shown improvements in as little as three weeks of training (Parra et al. 2000). Sprint training alone does not significantly increase muscle cross sectional area (CSA) in the short term (6-7 weeks) (Linossier et al. 1993). Conversely, a prolonged sprint training cycle ranging from 8 weeks to 8 months could increase muscle CSA up to 16% (Cadefau et al. 1990).

2.2 Biomechanical components of sprinting

2.2.1 Kinetics of sprinting

Optimal running technique should aim at maximizing the contribution in force production of different components of the body (muscles, tendon stiffness, elastic force) (Sayers, 2020). It is important to have clear understanding of the sprinting phases and how the variables change from starting position up to steady high speed running and sprinting.

Phases in sprinting. Sprinting can be broken down into three phases: starting position, acceleration phase and max velocity phase (Blazevich, 2019). At the starting position we first must overcome inertia. The athlete needs to produce a good concentric force without a counter movement. This force should be applied in a horizontal and vertical line, towards the ground. The contact time in this phase is at its greatest because of the starting position, but as the athlete gains momentum the contact time will be reduced. As the athlete moves from this starting phase to the acceleration phase, ground contact is reduced from the initial phase with force being applied to the ground primarily in the horizontal direction. As the athlete enters the max velocity phase (>25.2 km/h), ground contact time is at its shortest. Force must therefore be produced rapidly. At this stage, vertical forces have a bigger role than horizontal forces, with the goal of producing the maximal amount of force in the shortest amount of time (Blazevich, 2019).

Ground reaction forces during sprinting. According to Weyand et al. (2000), the main factor for achieving top speed other than running technique, is related to GRF. Their study hypothesized that the main factor contributing to maximal speed is GRF, rather than the positioning of the limbs. The study showed a correlation between GRF and top speed. Swing time was very similar between the groups and the mechanics of the movement was also similar, with an increase in stride frequency towards top speed. That also implies a reduced ground contact as well and swing time. Based on their findings, the authors suggested that the mechanism that allows runners to reach higher speeds is not by decreasing swing times but by increasing the maximum rates at which force can be applied to the ground (Weyand et al., 2000).

2.2.2 Sprinting Kinematics

Sprinting is an attempt to reach maximal or close to maximal velocity, and to project the body forward following specific kinematic patterns (Weyand et al., 2000). Efficient running mechanics translates into greater force production and thus improved speed (Weyand et al. 2000). According to ALTIS coaches (McMillan, 2019), the gait cycle can be divided into 5 stages (Figure 1), as follows:

Touch-down: Indicated the moment in which the front foot touches the ground.

Full support: The moment in which the leg is bearing all the body weight. Particularly relevant in this phase is the position of the body in relation to the foot, as that would determine the impact of breaking forces

Toe-off: The moment in which the supporting leg leaves the ground. The front leg in this phase focuses on the knee drive, which is the height of the knee in relation to the ground

Strike: The phase where the foot is no longer in contact with the ground and the leg is approaching the ground for a new touch-down

Maximal vertical projection: The flying phase of running, defined as maximal vertical projection.

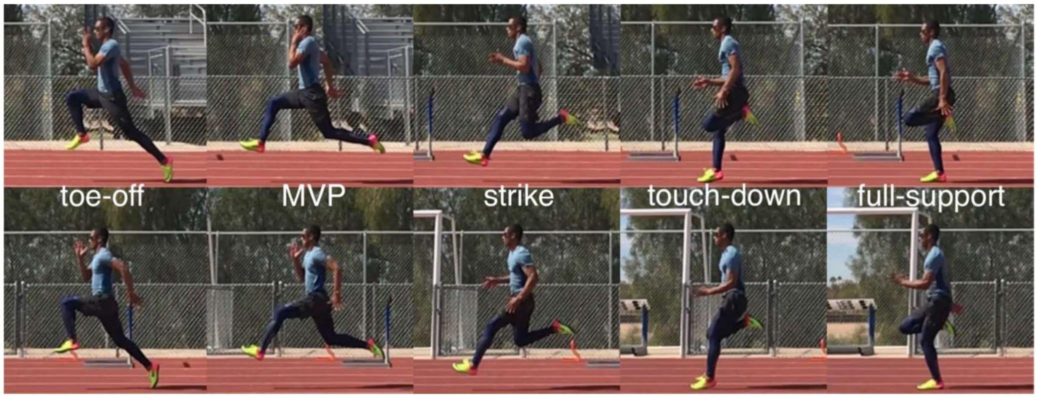


Figure 1. The Kinogram method was developed from ALTIS coaches and has been widely used among Olympic level athletes. It breaks down sprinting Kinematics in 5 different stages. Each phase is represented in both sagittal planes.

Besides the kinematic phases of running, the National Strength and Conditioning Association (NSCA) considers differences between the contexts in which sprinting can be performed (Hoffeman, 2012). Starting position for instance can be static in track and field sprinting, but it is almost always dynamic in field sports like football and therefore the kinematics and kinetics involved in the different contexts require different techniques. When starting a sprint from a two point-stance the athlete's body weight should be equally distributed between both feet, with elbows flexed at a 90 degree angle and the athlete's centre of mass should be above the front leg. Two-thirds of the body weight should be shifted to the front leg when initiating the sprint. Following the starting phase, the body will gradually straighten, and the strides will increase their length. This is defined as the acceleration phase, which would gradually be leading to maximal velocity. While this can be true for a track sprinter, it does not directly apply to sprinting in football, where the athletes are often starting their sprint from a single leg stance or in a dynamic context requiring higher sensory adaptation and shorter processing time (Barlett, 2007).

2.2.3 Ground contact time

One of the main requirements in field sports is the ability to accelerate quickly. Robert et al. (2011) investigated the factors that differentiate faster and slower athletes in field sports. The main finding was that ground contact time is the major factor determining acceleration performance. Specifically, the contact times (CT) in the faster group were significantly shorter in 0-5m and 0-10m sprints (figure 2). Weyand et al. (2000) also found that ground contact time used to generate force was the biggest determinant in faster athletes.

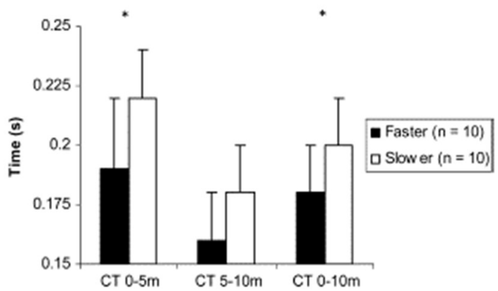


Figure 2. Comparison of contact times (CTs) for faster and slower groups in the 0-5m, 5-10m and 0-10m sprint performance. Significance set at p = 0.05. Robert G. et al., 2011

These findings indicate that by minimizing ground contact time, field sport athletes are able to increase their acceleration (Weyand et al. 2000). These findings were also confirmed by Murphy et al. (2003) who showed that faster athletes had a significantly lower contact time in a 15m sprint than slower athletes. While there were no differences in peak force produced between slower and faster groups in the 0-5m sprints, time to achieve peak force was shorter in the faster group (Robert et al. 2011). This indicates that the faster athletes were able to produce peak force faster (figure 3) and more efficiently.

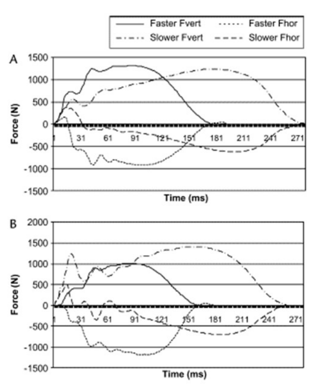


Figure 3. Sample force trace from a typical subject from the faster and slower groups for the first contact (A) and second contact (B) in a 5m sprint. (Robert et al., 2011) Fvert = vertical force. Fhor = horizontal force

The results showed in figure 3 show the greater ability of the faster group to produce force efficiently. One of the findings for this study was also that there was no significant difference in leg stiffness between groups, which might not be as important in short accelerations as it would be in 100m sprint (Bret et al. 2002).

2.3 Sprint mechanics

2.3.1 Defining the components

To fully understand what defines the fastest sprinters in the world, Rabita et al. (2015) studied the mechanics of maximal running sprint acceleration in high-level athletes. The authors analyzed the sprints of elite and sub-elite athletes, with the hypothesis that a linear force-velocity relationship would characterize faster sprinters as well as higher maximal power and better orientation of the force onto the ground. The results showed that elite sprinters can reach about 90% of their maximal step frequency already after the third step (Rabita et al. 2015). The study also showed that horizontal net GRF is paramount to accelerate the body forward. These results also confirm that the vertical component of GRF is not the determining biomechanical component during the acceleration phase, but it is vital during top speed. The importance of vertical GRF production in top-speed performance has been confirmed by Morin et al. (2011, 2012). Having knowledge of the kinetics and kinematics of sprinting in field sports can help coaches to better understand how changes in technique in one parameter (e.g., increased vertical or horizontal force) can affect another (e.g., increased step length SL). This allows practitioners to adjust training individually for each athlete or specific sport requirement (Robert et al., 2013).

The need for acceleration-specific force development has been underlined in a correlation study between velocity, step length (SL), contact time (CT) and flight time (FT) among 22 healthy men to determine the influence of stance kinetics on sprint velocity and step kinematics during a maximal 10m sprint (Robert et al. 2013). The results showed a correlation between sprint velocity, SL, CT and FT (figure 4), with greater SL, shorter CT and longer FT in faster subjects. There was only reduced correlation between step kinematics and stance kinetics, however, the subjects who generated greater vertical force (VF) and relative force (RF) did have lower CT and greater SL within the acceleration phase (0-5m).

		0–5 m Velocity	5–10 m Velocity	0–10 m Velocity
SL				
0–5 m	*r*	0.502	0.092	0.397
	p	0.011†	0.662	0.049†
5–10 m	*r*	0.497	0.342	0.475
	p	0.011†	0.094	0.016†
0–10 m	*r*	0.535	0.219	0.462
	p	0.006†	0.292	0.020†
Step frequency				
0–5 m	*r*	−0.192	0.155	−0.091
	p	0.359	0.460	0.664
5–10 m	*r*	−0.170	0.181	−0.070
	p	0.416	0.388	0.741
0–10 m	*r*	−0.191	0.168	−0.088
	p	0.361	0.421	0.677
CT				
0–5 m	*r*	−0.216	−0.506	−0.308
	p	0.300	0.010†	0.135
5–10 m	*r*	−0.099	−0.390	−0.170
	p	0.639	0.054	0.415
0–10 m	*r*	−0.201	−0.477	−0.282
	p	0.334	0.016†	0.172
Flight time				
0–5 m	*r*	0.522	0.278	0.453
	p	0.007†	0.178	0.023†
5–10 m	*r*	0.335	0.172	0.288
	p	0.102	0.412	0.163
0–10 m	*r*	0.470	0.198	0.398
	p	0.018†	0.343	0.049†

**n* = 25.
†Significant ($p \leq 0.05$) relationship between the 2 variables.

Figure 4. Correlations between mean velocity and step length, step frequency, contact time, and flight time, in the 0-5, 5-10, and 0-10 intervals in a 10m sprint (Robert et al. 2013) SL = Step length CT = Contact time

The authors concluded that longer SLs are indicative of higher force production coming from the muscles involved in the sprint steps. Flight time is naturally longer because of a longer SL, and CT becomes shorter within faster subjects. These results would suggest that faster field sport athletes are capable of generating greater SL while efficiently reducing the CT to generate greater forces. In field sports, where acceleration is a key factor, these findings would suggest that the ability to accelerate efficiently is related to reducing CT in the early phase of the sprint. During running at full speed, a higher hip flexion and thus higher knee drive, will have the biomechanical advantage of providing a longer path for the front foot back to the ground. This has the benefit of generating more power and greater propulsive force and reducing ground contact time (figure 5) (Blazevich, 2019).

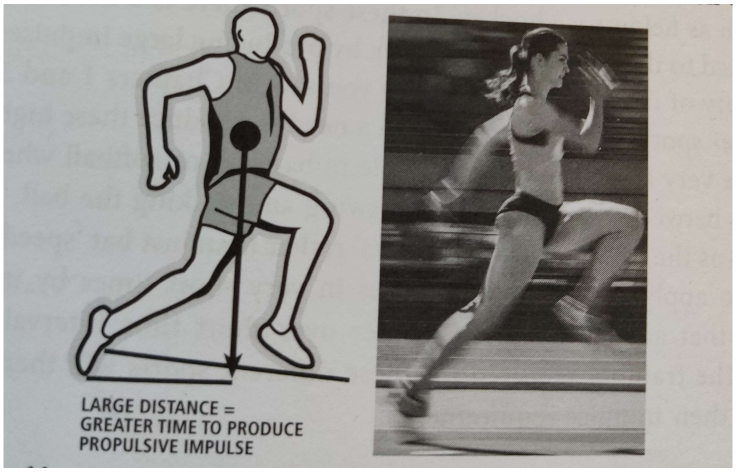


Figure 5. Knee drive representation (Blazevich, 2019). The picture on the right shows ideal hip flexion during high speed running. Closer or above parallel thigh will have greater distance thus more time to produce force

To minimize breaking forces during max speed phase, the landing (front) leg should be as vertical as possible towards the ground, creating shorter contact time and higher force production and maximizing the elastic force stored in the tendon (Blazevich, 2019). Figure 6 shows a representation of the vector acting in response to the angle at which the front foot is landing and how an angle closer to 90 degrees would generate less breaking forces in favor of greater vertical force (Blazevich, 2019).

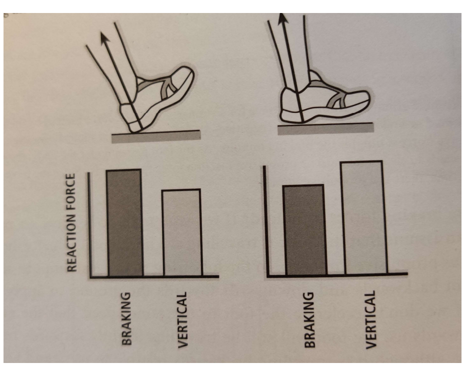


Figure 6. Representation of breaking forces acting during the touch-down phase before full support (Blazevich, 2019).

2.3.2 Individual running properties

Research has explored possible differences in the mechanical properties of sprinting among different roles covered in the field, as well as performance differences between genders (Haugen et al. 2020). The aim was to provide practitioners with data that can be used to develop individualized programs that target those athletes specific needs (Morin et al. 2016).

For the aforementioned purpose, a 40m sprints database collected at the Norwegian Olympic Center since 1995 was used as the foundation to highlight the mechanical components of sprinting in football players, and to define differences related to player standard which (level of competition), player position, age and gender (Haugen et al. 2020). The characteristics that were observed are reported in figure 7.

Category (sex)	n =	Age (y)	BM (kg)	10 m time (s)	40 m time (s)	F0 (N)	V0 ($m \cdot s^{-1}$)	P_{max} ($W \cdot kg^{-1}$)	S_{FV} ($N \cdot s^{-1} \cdot m^{-1} \cdot kg^{-1}$)	RF_{max} (%)	D_{RF} (%)
National team (W)	93	24 ± 4	64 ± 5	2.17 ± 0.06	6.12 ± 0.22	7.6 ± 0.5	8.1 ± 0.4	15.5 ± 1.3	−0.94 ± 0.07	43.2 ± 1.5	−8.9 ± 0.7
Top Division (W)	65	21 ± 3	63 ± 6	2.21 ± 0.07	6.28 ± 0.24	7.5 ± 0.4	7.8 ± 0.4	14.7 ± 1.3	−0.97 ± 0.06	42.4 ± 1.5	−9.2 ± 0.6
Junior academy (W)	49	18 ± 2	62 ± 6	2.20 ± 0.09	6.28 ± 0.29	7.6 ± 0.7	7.8 ± 0.4	14.8 ± 1.8	−0.97 ± 0.08	42.4 ± 2.2	−9.2 ± 0.8
Forwards (W)	42	22 ± 3	65 ± 6	2.16 ± 0.07	6.10 ± 0.25	7.6 ± 0.5	8.1 ± 0.5	15.5 ± 1.4	−0.94 ± 0.07	43.2 ± 1.6	−8.8 ± 0.7
Defenders (W)	53	23 ± 4	62 ± 5	2.19 ± 0.06	6.19 ± 0.23	7.6 ± 0.4	8.0 ± 0.4	15.1 ± 1.3	−0.95 ± 0.07	42.8 ± 1.4	−9.0 ± 0.7
Midfielders (W)	47	23 ± 4	63 ± 5	2.19 ± 0.07	6.22 ± 0.24	7.6 ± 0.4	7.9 ± 0.4	15.1 ± 1.4	−0.96 ± 0.06	42.7 ± 1.6	−9.1 ± 0.6
Goalkeepers (W)	16	21 ± 4	67 ± 5	2.22 ± 0.06	6.33 ± 0.20	7.5 ± 0.4	7.7 ± 0.3	14.5 ± 1.2	−0.97 ± 0.05	42.1 ± 1.4	−9.2 ± 0.5
<20 y (W)	38	18 ± 1	64 ± 6	2.20 ± 0.08	6.24 ± 0.27	7.6 ± 0.6	7.9 ± 0.5	15.0 ± 1.6	−0.96 ± 0.07	42.6 ± 1.8	−9.1 ± 0.7
20–24 y (W)	72	22 ± 1	63 ± 5	2.19 ± 0.06	6.18 ± 0.23	7.6 ± 0.4	8.0 ± 0.5	15.2 ± 1.3	−0.95 ± 0.07	42.9 ± 1.4	−9.0 ± 0.7
>24 y (W)	48	27 ± 3	64 ± 6	2.18 ± 0.06	6.16 ± 0.24	7.6 ± 0.4	8.0 ± 0.4	15.3 ± 1.3	−0.95 ± 0.06	43.0 ± 1.5	−9.0 ± 0.6
National team (M)	57	25 ± 4	79 ± 6	2.01 ± 0.05	5.51 ± 0.16	8.5 ± 0.5	9.2 ± 0.4	19.5 ± 1.4	−0.92 ± 0.07	47.0 ± 1.4	−8.5 ± 0.7
Top Division (M)	282	24 ± 4	78 ± 7	2.02 ± 0.06	5.53 ± 0.18	8.4 ± 0.5	9.2 ± 0.4	19.4 ± 1.6	−0.91 ± 0.07	47.2 ± 1.6	−8.4 ± 0.6
2nd division (M)	69	23 ± 4	80 ± 8	2.03 ± 0.06	5.58 ± 0.17	8.2 ± 0.5	9.2 ± 0.4	18.8 ± 1.6	−0.90 ± 0.06	46.6 ± 1.6	−8.3 ± 0.6
3rd-5th division (M)	59	23 ± 4	77 ± 8	2.09 ± 0.05	5.74 ± 0.15	7.9 ± 0.4	8.9 ± 0.4	17.6 ± 1.1	−0.90 ± 0.07	45.4 ± 1.2	−8.4 ± 0.6
Forwards (M)	90	23 ± 4	78 ± 6	1.99 ± 0.06	5.45 ± 0.18	8.6 ± 0.6	9.3 ± 0.4	20.1 ± 1.6	−0.92 ± 0.07	47.9 ± 1.5	−8.5 ± 0.6
Defenders (M)	110	25 ± 4	79 ± 6	2.02 ± 0.06	5.53 ± 0.16	8.4 ± 0.6	9.3 ± 0.4	19.4 ± 1.6	−0.91 ± 0.07	47.2 ± 1.5	−8.4 ± 0.6
Midfielders (M)	102	23 ± 4	75 ± 5	2.03 ± 0.05	5.56 ± 0.17	8.3 ± 0.5	9.2 ± 0.4	19.1 ± 1.5	−0.91 ± 0.06	47.0 ± 1.4	−8.5 ± 0.6
Goalkeepers (M)	37	25 ± 4	84 ± 6	2.04 ± 0.05	5.62 ± 0.16	8.3 ± 0.5	9.0 ± 0.4	18.6 ± 1.3	−0.92 ± 0.07	46.5 ± 1.3	−8.5 ± 0.6
<20 y (M)	66	18 ± 1	75 ± 6	2.00 ± 0.06	5.51 ± 0.17	8.5 ± 0.6	9.3 ± 0.4	19.7 ± 1.7	−0.92 ± 0.07	47.5 ± 1.6	−8.5 ± 0.6
20–24 y (M)	99	22 ± 1	78 ± 6	2.01 ± 0.05	5.50 ± 0.15	8.5 ± 0.5	9.3 ± 0.4	19.7 ± 1.5	−0.91 ± 0.07	47.5 ± 1.5	−8.5 ± 0.6
24–28 y (M)	97	26 ± 1	79 ± 7	2.02 ± 0.05	5.51 ± 0.17	8.4 ± 0.5	9.3 ± 0.4	19.4 ± 1.5	−0.90 ± 0.07	47.2 ± 1.5	−8.4 ± 0.6
>28 y (M)	77	30 ± 2	81 ± 7	2.04 ± 0.06	5.62 ± 0.16	8.3 ± 0.6	9.0 ± 0.4	18.7 ± 1.5	−0.92 ± 0.07	46.6 ± 1.6	−8.6 ± 0.6

W = women, M = men, BM = body mass. Time zero corresponds to the first rise of the horizontal force production. F_0 = maximal horizontal force, v_0 = theoretical maximal velocity, P_{max} = maximal horizontal power, S_{FV} = force-velocity slope, RF_{max} = ratio of force, D_{RF} = index of force application technique.

Figure 7. Player characteristics and mechanical components divided by playing standards, gender, age and playing position (Haugen et al. 2020).

The mechanical output of sprinting performance showed a decline past the age of 28 in male athletes, and conversely, female athletes aged >24 showed better output than those aged <20. The study found that strikers have superior mechanical properties compared to defenders, midfielders, and goalkeepers respectively. That is explained by the demands of the position, which sees the strikers involved in on-field situations and challenges which require longer sprint distances (Andrzejewski et al. 2018). One interesting finding of this study was that female athletes were more orientated towards force production over velocity compared to their male counterparts. Morin and Samozino (2016) suggested that players should specifically focus training to address measure deficits. Players with horizontal force deficit should train to improve horizontal force and players with velocity deficit, should instead focused on speed training. the results of these studies appear to show that female athletes may benefit from doing more velocity training than male athletes. However, this recommendation should be taken with caution as it does not account for individual characteristics.

2.4 Lumbo-pelvic control

The position of the pelvis in running can have an impact in the way the body segments are displaced in the air and thus their positioning at the moment of impact with the ground (Blazevich, 2019). Figure 8 showes both a neutral and a non neutral pelvis position. Anterior pelvic tilt (APT) is a condition in which the pelvis is anteriorly rotated, with a consequential increased lumbar lordosis and stretched hamstrings (figure 8).

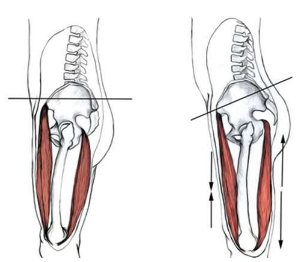


Figure 8. Anterior pelvic tilt representation. The combination of tight erector spinae, shorter psoas creates unnatural stretch of the hamstrings, increasing risk for injuries and hindering hip flexion during running.

As a consequence of APT, limited hip extension has been observed due to tight hip flexor musculature, as well as stretched hamstrings and tight erector spinae. In fact, APT has been correlated with limited hip extension range of motion (ROM) during running in elite runners (Schache et al. 2000). The reduced hip extension in the back leg will cause a reduced hip flexion of up to 10 degrees in the front leg (Alizadeh, 2019) and thus a shorter trajectory with potential reduction in vertical force production and increased breaking forces at the touch down phase (Blazevich, 2019).

For such reasons, anterior pelvic tilt may not be a desirable characteristic in football players due to the impact it has on sprinting performance. To tackle this limitation, a combination of active exercises and manual therapy as shown significant results in reducing APT angle over a period of 6 weeks in comparison to control group (Mendiguchia et al. 2020). It is important to understand that a multimodal approach is needed when wanting to change APT, and that muscle imbalance plays a key role in pelvic stability. A combination of active mobility exercises, control exercises, manual therapy, foam rolling, neuromuscular control and strength exercises are the elements that were successfully combined in this study to bring pelvic position in a more neutral state (Mendiguchia et al. 2020). Thus, screening for APT in football players could provide the coaches with valuable information about running technique and potentially provide a margin for improvement which could lead to an increase in top speed.

3 AIMS OF THE STUDY

The main purpose of this research was to investigate sprinting kinematics during maximal speed in a 30-meter sprint among professional football players and their relationship with lumbo-pelvic control before and after an individualized mobility program. The second aim of this research was to investigate a possible correlation between maximal speed, acceleration and running technique.

3.1 Research questions

1) Will an 8-week mobility and running drills program cause any changes in the lumbo-pelvic control and running kinematics of professional footballers?

Hypotheses: A 6-week intervention program has been shown to reduce anterior pelvic tilt (APT) and increase lumbo-pelvic control significantly compared to a control group (Mendiguchia et al. 2020). It could be assumed that an 8-week intervention will cause some changes in the degree of pelvic tilt, although it is unknown whether those changes will have an impact on running kinematics.

2) Will changes in pelvis position translate into faster sprinting performance overall, including acceleration and maximal speed?

Hypotheses: Improved lumbo-pelvic control and running technique will translate into greater ground reaction force production overall and thus faster sprinting (Weyand et al., 2000). Specifically, the portion of sprinting for analysis is at 22.5m, when the athletes are approaching maximal speed. Vertical forces are an important factor during this phase and increasing hip flexion should translate in greater vertical force production and thus higher top speed (Blazevich, 2019).

4 METHODS

4.1 Subjects

Participants were recruited from the professional football league in Finland, Veikkausliiga. Five football teams were included in the study and a total of 95 players aged between 17-36 years old took part in the study. Inclusion and exclusion criteria are presented in Table 1.

Table 1. Inclusion and exclusion criteria based on the protocol published by Lahti et al. (2020).

Inclusion and exclusion criteria	
Inclusion criteria	• The player accepts that their medical data can be collected • The players are involved in training sessions though the start of the 2020 and 2021 preseason (January) to the end of the season (October)
Exclusion criteria	• Goalkeepers (only field players included due to a higher hamstring injury risk and lack of actual sprinting during games)

Of the 95 players that took part in the study, only 67 were included in the final analysis. The reason for excluding some of the subjects was due to reliability issues. The third round of measurements was delayed significantly due to unpredictable changes in the season that were imposed by the football federation, and some teams had much longer intervention period, which would have altered the reliability of the changes in comparison to other teams. Consequently, only the first and second data point were included in the analysis. Each team had exactly 8 weeks between the first and second measurements and that ensured ethical handling of the data as well as reliability. All players included had performed all the tests in both sessions as well as two maximal sprints per session.

The study was conducted in accordance with the declaration of Helsinki. The subjects signed a written consent which was sent via email prior to the first testing date, and they were allowed to refuse any test at any time and without a specific reason. Participation was completely voluntary and players under 18 years of age required parental consent. The study protocol for the intervention was approved by the Central Finland healthcare District (U6/2019).

4.2 Study design and procedures

This study is part of a larger study on hamstring injury prevention and the study design followed the protocol previously published by Lahti et al. (2020). For that study, a cohort study was conducted in 2019 over two professional football seasons to collect normative data to be used as a control. The 2020 season was planned as the intervention season but due to the COVID-19 pandemic the intervention was postponed to the 2021 season.

4.2.1 Study Design

The study design was experimental, and it can be seen in Figure 9. All subjects completed three measurement sessions. The first measurements took place in the pre-season and the remaining were in-season measurements. All screenings were conducted by the author of this thesis. Measurements/Screenings included a preliminary interview followed by measurement of ROM, strength, lumbo-pelvic control, and sprinting technique using kinematic (video) analysis. All tests are published in the original study (Lahti et al. 2020). After the screening, individualized mobility and lumbo-pelvic control program was implemented for the players who were found “positive” in the assessment tests.

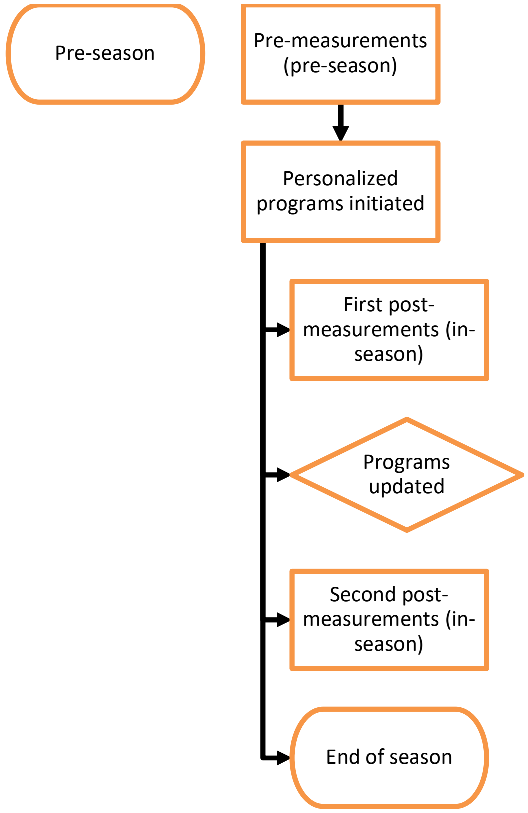


Figure 9. The original study design included 3 data points. For this study Pre and First post-measurements were used

4.2.2 Kickback

For the lumbo-pelvic control evaluation, the subjects were assessed based two maximal 30m sprints. Sagittal plane two-dimensional (2D) sprinting kinematics were assessed in the 30m sprints using a high-speed camera (Samsung S21, 240 fps) at the 22.5 m point, and placed 11m perpendicular to the line of sprinting (Figure 10). Sprinting took place during the warm-up phase of regular training. The warmup was not standardized, and strength and conditioning coaches of each team were in charge of conducting them. During the set up the field was inspected to avoid holes and imperfections which could have led to inconveniences or affect the performance.

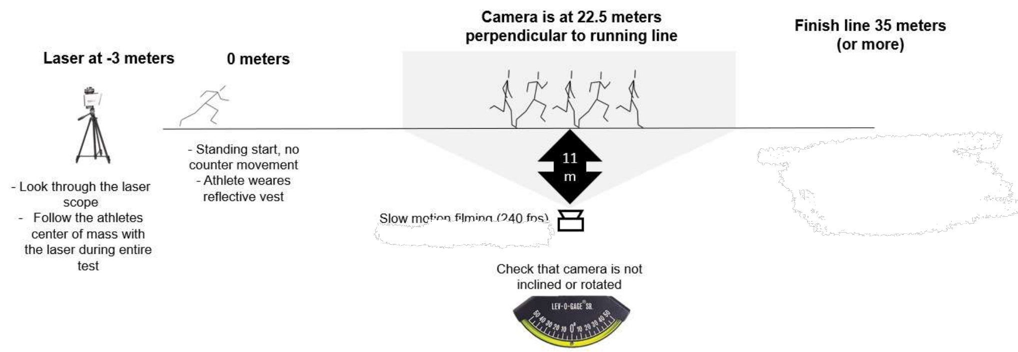


Figure 10. Visual representation of the sprinting test protocol.

Sagittal plane running kinematics, focusing on the touch-down and toe-off phases of the sprinting were measured. The angles were tracked from the greater trochanter to the lateral or medial epicondyle of the knee joint. The combination of the angles at touch down and toe off was used to define the kickback mechanism. Angles are calculated based on the mean value of two strides (touchdown and toe-off) within two maximal sprints using Kinovea video analysis software (v.0.8.15), and an example of the calculation method is provided in figure 11 (Lahti et al. 2020).

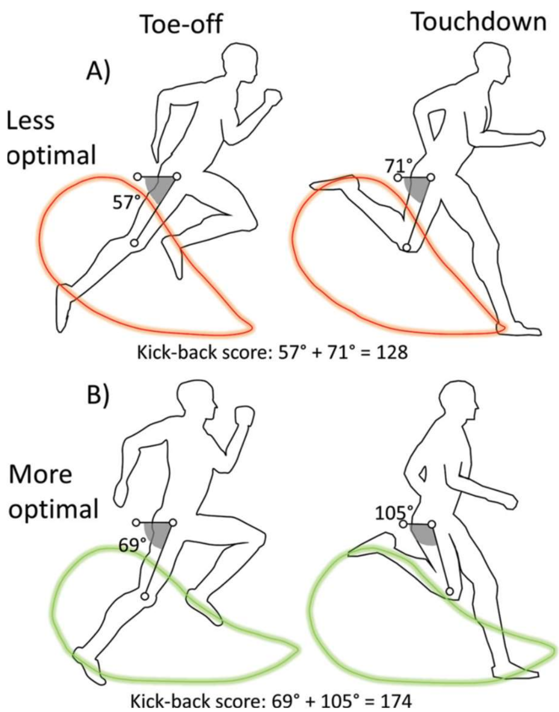


Figure 11. The kickback mechanism from the protocol published by Lahti et al. (2020). This visual representation shows the angles that were analyzed during kinematic analysis. A greater score would equal to more optimal kinematic

Maximal speed, acceleration (0m-5m, 5m-10m, 10m-15m, 15m-20m, 25m-30m) and horizontal force production (F0) were also estimated through a laser speed device (MuscleLab LaserSpeed, Stathelle, Norway) and analyzed through the software provided from the same company. The laser gun was calibrated beforehand and trial sprints were conducted to ensure the correct functioning of the laser and software before proceeding with data collection.

4.2.3 Intervention

Once the players were evaluated, intervention programs were assigned. The programs were integrated as part of the normal training routine and adherence was supervised by the team's strength and conditioning coaches and physiotherapists, who had undergone familiarization sessions and were provided with instructions and videos for all the exercises included in the intervention program. Allocation to groups was defined on the base of the kickback score. Ideally, the study would have used an algorithm and machine learning such as Ayala et al. (2019). However, that would have required years of data to create a reliable database and, unfortunately, we did not have enough data to create a strong model from the previous seasons. It was for this reason that the team's percentile was chosen as classification method for "positives" and "negatives". However, this system presents some limitations in the form of potentially create false negatives and not address true positives.

As stated, each team's positives and negatives were assigned through the use of percentiles. For the lumbo-pelvic control, a positive result would equal to a kickback score equal of smaller than the team's 33^{rd} percentile and it would imply 4 training interventions per week. For the horizontal force production (F0) of the sprinting, a percentile equal or lower than the team's 66^{th} would qualify the player for heavier resistance to improve early acceleration and force production, as well as a sprinting drills program (figure 14). The programs for lumbo-pelvic control and F0 can be observed respectively in figures 12-13.

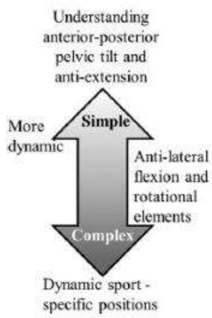
Structure of exercises within both A and B sessions	Exercise category	Weekly session volume (2–4 sessions)	Exercises	Sets and reps
	A	Negative test results: once per week (A) Positive test results: twice per week (A+A)	1. Stir the pot 2. Plank to bridge 3. Hip hinge 4. Anti-side flexion split squat jumps 5. Overhead A-skips	2×6 rotations per side 2×3 s holds per position 2×8 2×8 2×6–8 skips per side
	B	Negative test results: once per week (B) Positive test results: twice per week (B+ B)	1. Dead bug scissor kicks 2. Side plank roll to dead bug 3. Rotations with bar 4. Hip hinge into wall kick 5. Lateral overhead step-ups	2×8 kicks per side 2×3 s per position 2×5 m (forward and backward) 2×4 per side 2×4–6 per side

Figure 12. Lumbo-pelvic control exercises (Lahti et al. 2020). These exercises were prescribed to players based on the sprinting test. Positive players would perform 4 sessions per week, whereas negative players would only perform 2 sessions per week

Phase	Weeks	Day 1 Early acceleration(15–20 min)	Day 2 High-speed sprinting (12.5–17.5 min)	Day 3 (20–25 min) High-speed sprinting Early acceleration	Total sprint volume Early acceleration	 High-speed sprinting
Preseason: initiation	Week 1–3	A. Sprint drills 5 min B. Light/heavy sled work ×5 to 10–15m C. 5 m sprints×4, last two are races	A. Sprint drills 5 min B. Wicket sprints×3 to 45 m, 10 m rolling start before wickets, 20 m wickets, 15 m run through. Intensity: 80%, 90%, 100%. Wicket distance: progressive	A. Sprint drills 5 min B. Wicket sprints×3 to 45 m, full acceleration start 10 m, 20 m wickets, 15 m run through. Intensity: 80%, 90%, 100%. Wicket distance: progressive. Contrast first two wicket runs with sled sprints, total sled distance 2×15 m	130 +20=150 m (130 m sled work, 20 m first steps work)	135 +135=270 m (70 m is 100% sprinting)
Preseason: increase upright sprintingvolume, add curved sprinting	Week 4	A. Sprint drills 5 min B. Light/heavy sled work ×5 to 10–15 m C. 5 m sprints×4, last two are races	A. Sprint drills 5 min B. Wicket sprints×4 to 45, 10 m rolling start before wickets, 20 m wickets, 15 m run through. Intensity: 80%, 90%, 90%, 100%. Wicket distance: progressive. 90% runs are curved (1×left, 1×right).	A. Sprint drills 5 min B. Wicket sprints×4 to 45 m, full acceleration start 10 m, 20 m wickets, 15 m run through. Intensity: 80%, 90%, 90%, 100%. Wicket distance: progressive 90% runs are curved (1×left, 1×right). Contrast first two wicket runs with sled sprints, total sled distance 2×15 m	130 +20=150 m (130 m sled work, 20 m first steps work)	180 +180=360 m (70 m is 100% sprinting)
Pre-season: Increase early acceleration sprinting volume	Week 5–7	A. Sprint drills 5 min B. Light/heavy sled work ×6 to 10–15m C. 5 m sprints ×4, last two are races	A. Sprint drills 5 min B. Wicket sprints ×4 to 45 m, 10 m rolling start before wickets, 20 m wickets, 15 m run through. Intensity: 80%, 90%, 90%, 100%. Wicket distance, progressive from 1.5 to >1.8 m. 90% runs are curved (1×left, 1×right).	A. Sprint drills 5 min B. Wicket sprints ×4 to 45 m, full acceleration start 10 m, 20 m wickets, 15 m run through. Intensity: 80%, 90%, 90%, 100%. Wicket distance: progressive. 90% runs are curved (1×left, 1×right). Contrast first wicket run with sled sprints, total sled distance 1×15 m	135 +20=155 m (160m sled work, 30m first steps work)	180 +180=360 m (70 m is 100% sprinting)
Taper: used before post-testing or double match weeks in-season	Week 8	A. Sprint drills 5 min B. Light/heavy sled work ×3 to 20 m C. 5-m sprints ×4, last two are races	A. Sprint drills 5 min B. Wicket sprints ×3 to 45 m,10 m rolling start before wickets, 20 m wickets, 15 m run through. Intensity: 80%, 90%, 100%. Wicket distance: progressive	REST	80 m (60m sled work, 20 m first steps work)	135 m (45 m is 100% sprinting)
Phase	Weeks	Day 1 Early acceleration(15–20 min)	Day 2 High-speed sprinting (12.5–17.5 min)	Day 3 (20–25 min) High-speed sprinting Early acceleration	Total sprint volume Early acceleration	 High-speed sprinting
In-season: one match week structure	Same as week 5–7 structure	A. Sprint drills 5 min B. Light/heavy sled work ×6 to 10–15 -m C. 5 m sprints×4, last wo are races	A. Sprint drills 5 min B. Wicket sprints ×4 to 45 m, 10 m rolling start before wickets, 20 m wickets, 15 m run through. Intensity: 80%, 90%, 90%, 100%. Wicket distance, progressive from 1.5 to >1.8 m. 90% runs are curved (1×left, 1×right).	A. Sprint drills 5 min B. Wicket sprints ×4 to 45 m, full acceleration start 10 m, 20 m wickets, 15 m run through. Intensity: 80%, 90%, 90%, 100%. Wicket distance: progressive. 90% runs are curved (1×left, 1×right). Contrast first wicket run with sled sprints, total sled distance 1×15 m	135 +20=155 m (160 m sled work, 30 m first steps work)	180 +180=360 m (70 m is 100% sprinting)

Figure 13. Sprinting and acceleration programming (Lahti et al. 2020). The sprinting and acceleration drills were structured to be progressively overloaded.

Week	Day	Exercises
Week 1–2	All 3 days	A-skip progressions, Pogo jumps (sagittal and lateral), dribble bleeds
Week 3–4	1	A-skip progressions, unilateral pogo jumps, dribble bleeds
	2	A-skip progressions, lateral A-skips
	3	Same as day 1
Week 5–6	1	A-skip progressions, lateral A-skips, scissors (high frequency)
	2	A-skip progressions, skip jumps, dribble bleeds
	3	Same as day 1
Week 7–8	1	A-skip progressions, lateral A-skips, scissors (progressive: high frequency to power)
	2	A-skip progressions, skip jumps, dribble bleeds, pogo jumps
	3	Same as day 1
In-season	1	A-skip progressions, lateral A-skips, scissors (progressive: high frequency to power to dribble bleeds)
	2	A-skip progressions, pogo jumps, skip jumps
	3	Same as day 1

Figure 14. Sprint drills programming (Lahti et al. 2020). Players with a deficit in the F0, were also given a series of sprinting drills.

4.2.4 Statistical analysis

Mean values and standard deviations are presented in this report for all measurements. Potential differences at baseline between groups were assessed using one way analysis of variance (ANOVA) with multiple comparisons, and post hoc Bonferroni were completed when applicable. Levene's homogeneity of variance test was conducted. Confidence interval was set at 95% and *p*-value at 0.05. Pre- and post-analysis were conducted using paired samples T-test with a confidence interval of 95%. Bivariate correlation tests were performed using Pearson's correlation coefficient and significance was set at $p = 0.05$. Statistical analysis was performed with SPSS software (IBM Corporation, Armonk, NY, USA). The data was also analyzed at the group level for each team, group 1 to 5, with a series of paired sample T-tests for pre and post measurements of kickback, top speed and F0 and bivariate correlation tests to assess if there was any correlation between the changes.

5 RESULTS

No statistically significant differences were observed from pre and post intervention for the kickback variable, or top speed in all subjects. A statistically significant difference was observed in F0 between all subjects, which increased by 2.20% (-0.16 +/- 0.52, p = 0.01)

Table 2 reports mean values for all variables in all subjects. Figures 15-16-17 shows a visual representation of pre and post intervention as well as significance of the changes. Results showed not significant correlation between the changes in F0, kickback and top speed (table 3).

Table 2. Paired samples T-test comparing baseline with post intervention. Mean values, standard deviation (SD) and standard error (SE) are reported for all variables. A statistically significant difference was found in F0 between pre and post intervention.

	Paired Differences							
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Kickback before - after	1.89	8.36	1.02	-0.14	3.93	1.85	66	0.06
Top speed (km/h) before -after	-0.002	0.88	0.10	-0.21	0.21	-0.02	66	0.97
F0 (N/kg) before - after	-0.16	0.52	0.06	-0.29	-0.03	-2.57	66	0.01

F0 = horizontal force production

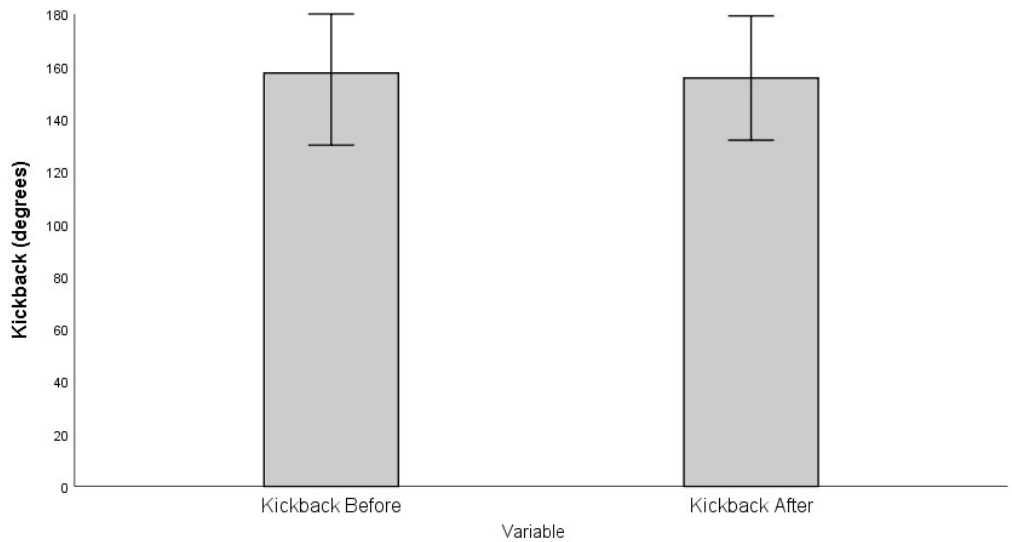


Figure 15. No difference in kickback pre and post lumbo-pelvic mobility intervention was observed between all subjects (1.89 ± 8.36 degrees, $p = 0.06$).

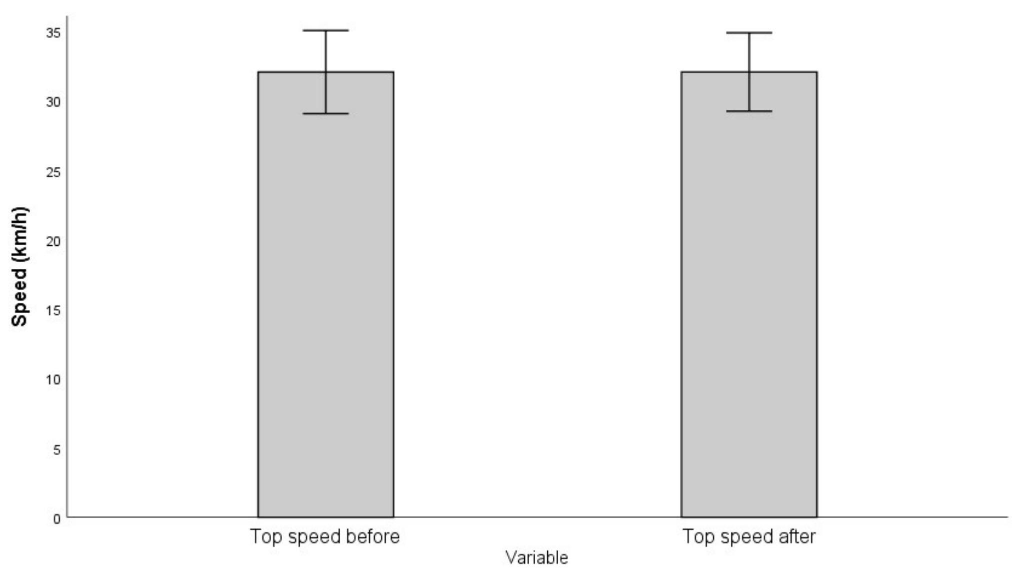


Figure 16. No change in top speed before and after the lumbo-pelvic mobility intervention was observed between all subjects (-0.002 ± 0.88 $km \cdot h^{-1}$, $p = 0.97$)

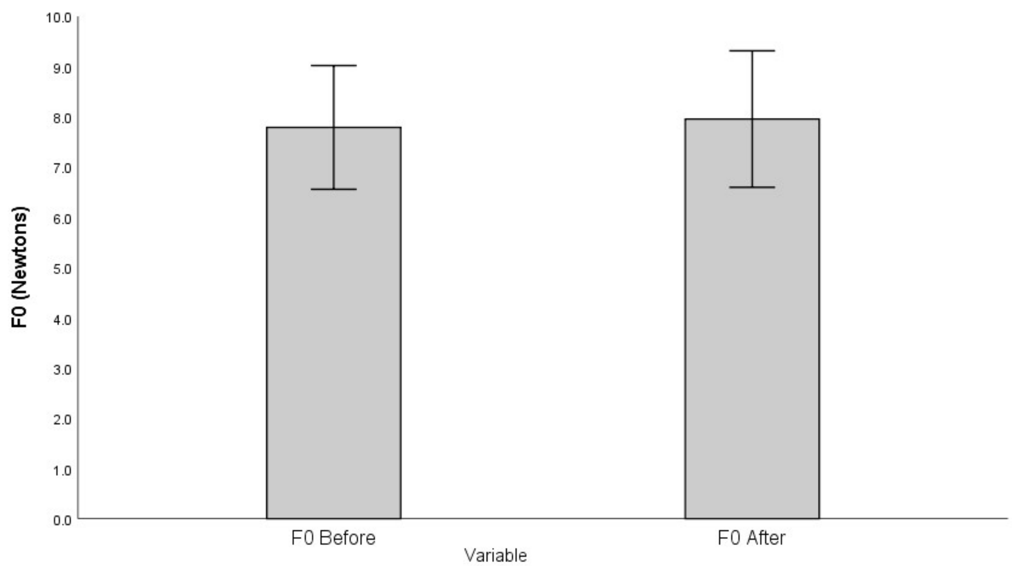


Figure 17. Before and after intervention shows horizontal force (F0) improved by 2,20% (mean percentage) and the improvement were statistically significant (-0.16 +/- 0.52, p = 0.01)

Table 3. Correlations between the changes in all the variables. No correlation was found between the pre and post intervention changes, thus chances in F0 do not appear to be correlated to changes in kickback or top speed.

		Kickback	Top Speed	F0
Kickback changes	Pearson Correlation	1	-0.02	-0.15
	Sig. (2-tailed)		0.83	0.20
	N	67	67	67
Speed changes	Pearson Correlation	-0.02	1	0.06
	Sig. (2-tailed)	0.83		0.63
	N	67	67	67
F0 changes	Pearson Correlation	-0.15	0.06	1
	Sig. (2-tailed)	0.20	0.63	
	N	67	67	67

Statistically significant changes were found from pre- to post intervention for kickback and F0 for group 2 (Table 4). Group 2 showed statistically significant changes in both kickback and force production, the changes are reported in table 5. No correlations were observed between the changes.

Table 4. Group 2 in kickback and force production

	t	df	Sig. (2-tailed)
Kickback before - after	5.69	9	0.001
Top speed (Km/h) before - after	-0.50	9	0.62
F0 (N/Kg) before - after	-3.45	9	0.007

F0 = horizontal force

Table 5. Changes after intervention in group 2

	N	Mean	Std. Deviation
Kickback change	10	-6.26%	3.32%
Speed (Km/h) change	10	1.05%	5.37%
F0 (N/Kg) change	10	8.00%	7.11%

F0 = horizontal force

6 DISCUSSION

This study has demonstrated that an 8-week mobility intervention program among professional football players did not cause statistically significant changes in running kinematics and top speed. A statistically significant difference in F0 after the intervention was observed but the changes in F0 were not correlated with top speed and kickback.

The intervention program in this study did not cause changes in the running kinematics of professional football players. Maas (2022) also failed to demonstrate changes in running kinematics after a 12-week intervention in novice runners. However, he demonstrated a reduction in peak vertical GRF after the intervention. This may indicate a redistribution of the forces in the body, despite no changes in kinematics (Maas, 2022). Changes in running kinematics, even when drastically small, may still have an effect on GRF. This could Imply that the changes in F0 in this study, might still be linked to small changes in running kinematics.

When analyzing the groups separately, only group 2 showed statistically significant changes after intervention in both kickback and F0. The kickback changes were negative, meaning that the scores had significantly decreased after intervention. Group 2 showed the highest mean for the kickback during the first round of data collection and during the second round the mean score was much closer to all the other groups. The reasons for such change could be due to fatigue, as the second round of measurements was conducted in-season and professional players undergo very high physiological and psychological pressure that can hinder performance. Additionally, each group was performing the required physical conditioning imposed by training and their own strength and conditioning coaches, which are obviously different for each team. It might be the case that some subjects were working more on some aspects rather than others. Due to the nature of the sample group, independent work could not be controlled and thus we can only speculate that group 2 was consistently working on horizontal force production.

Anterior pelvic tilt has been studied in football as a potential risk factor for hamstring injuries (Wodecki, 2002). The hamstrings are attached to the pelvis and when excessive anterior rotation is present, they are stretched more than their natural resting length. Hamstrings also dictate how much the knee can extend during the swing phase of running and thus that has an impact on kinematics itself (Shahab & Klaus, 2019). A change in angle of a joint will have an impact and cause a change in the adjacent joint as a consequence (Svoboda, 2016). Shahab and Klaus (2019) have demonstrated that there is a correlation between standing APT angle and hip flexion, and that changes in pelvis orientation are correlated with the amount of hip flexion. APT reduces hip flexion by about 10 degrees during sprinting, consequently lowering the knee drive. This creats a shorter trajectory for the landing foot and reduces the amount of force being produced during foot contact time (FCT) (Alizadeh, 2019). High-speed running demands have drastically increased over the past few years (Bradley et al. 2016. Bush et al. 2015), and training specificity for sprinting in field sports has grown exponentially (Lahti et al. 2020).

Mendiguchia et al. (2020) successfully achieved a reduction in APT but did not look at running kinematics in his study. This experiment tried to affect the sprinting kinematics of professional footballers with a mobility program intervention. However, we did not directly measure APT in static position, which would have been beneficial. We know that when there is APT in sprinting, compensatory movements occur, causing extra strain to the hamstrings and affecting running kinematics (Shahab & Klaus, 2019).

The kinematic analysis was conducted with Kinovea motion analysis software, and it looked at the thigh angles during touch down and toe off. Concerning the kinematics of running and the aforementioned elongation of the hamstrings, those two angles were certainly addressing excessive stretch of the hamstrings during the swing phase however, the front thigh hip flexion was not measured, and the analysis did not use markers and it was conducted manually. Testing took place during regular football practices as part of the preparation/activation at the end of the team warm-up. It was therefore impractical to use motion analysis with reflective markers for the whole team.

In terms of reliability of the methods selected, several studies have compared 2D and 3D kinematic analysis and the results were sometimes conflicting, with the 2D kinematic analysis being reliable with rotational movements while lateral movements being consistently different from the results obtained with the 3D methods during complex actions such as a golf swing (Castle et al. 2020). Two-dimensional kinematic analysis has shown excellent intra-rater reliability when analyzing frontal plane running kinematics, looking at contralateral pelvis drop, peak hip abduction angle and peak knee abduction angle (Maykut et al. 2015). In this study the kinematic analysis was looking at sagittal plane and the sequences were analyzed following the same exact routine and methodology for each of the sprints and the lack of rotational movements made it possible to keep high accuracy.

The segment of sprinting analyzed in this study was at the 22,5m mark and when the players are approaching maximal speed, vertical forces play a major role (Blazevich, 2019). Future studies that want to identify a kinematic correlation with maximal force production should measure the knee drive angle (hip flexion) and the full support stance in relation to center of gravity, as this would indirectly give an estimation vertical force production and breaking forces during maximal speed sprinting.

6.1 Study Limitations

This study has some limitations. The most relevant limitation was that APT was not measured in static position. That would have connected the theoretical correlation between APT and sprinting kinematics and would have strengthened the assessment. This study did not look at the front chain kinematics of the sprinting (knee drive and full support phases), and since APT reduces hip flexion and knee drive (Alizadeh, 2019), it would have been relevant to observe that correlation and the changes before and after intervention. Compliance to the program was not directly supervised and adherence was ensured from team's strength and conditioning coaches and physiotherapists. Dealing with professional and competitive athletes brings some restrictions, such as limited time for testing. The COVID pandemic also played a significant role and resulted in the need to postpone data collection, consequently impacting the duration of the intervention. An entire measurement time point was excluded from the study due to disparity in the intervention length between teams.

6.2 Strengths of the study

The study sample was relatively large (n = 95), considering the participants were all professional athletes playing in the highest football league in Finland. The study protocol had been piloted in 2019 for a whole year in a cohort study (Lahti et al. 2020) and it was part of a multifactorial intervention study for hamstring injury prevention, the first of its kind. All measurements were conducted by the same researcher to ensure consistency. The novelty of the study is a strength itself since this was, to the author knowledge, the first study looking at changes in sprinting kinematics after a mobility and lumbo-pelvic control intervention.

7 CONCLUSIONS

This study demonstrated that the kickback mechanism in sprinting is not affected by mobility and lumbo-pelvic control exercised over an 8-week time span. However, more effective power production would certainly be related to efficient kinematics (Gaspere et al. 2019) and changing the running kinematics in professional athletes is a task that requires well planned strategies. Some of the limitations in the sprinting kinematics arise from anatomical and postural deficiencies, such as APT and limited hip flexion/extension (Alizadeh, 2019). Also, the coaching component comes into play, particularly in football where perhaps acceleration is thought to be separate from top speed when in fact, the connection between top speed and acceleration is linear (Samozino et al. 2016). However, Morin et al. (2020) have also emphasized that two players with the same top speed time might have a very different mechanical output, and that would require the coaches to focus on specific characteristic to improve performance. Individualized programs should aim at correcting players deficiencies and the approach should be multifactorial, incorporating strengthening of weaker muscles, reducing imbalances, optimizing ROM & mobility, and improving technique through coaching cueing, specific drills and manual therapy. Progression and periodization should go accordingly with seasonal commitments and general load.

7.1 Practical applications

Research is moving towards more individualized approaches to player specific characteristics both in injury prevention (Lahti et al. 2020) and performance (Morin at al. 2020). However, there are general aspects of sprinting kinematics that can be observed at a group level, and coaches could benefit greatly from simple 2D kinematic analysis. The methods used in this study can be successfully utilized for identifying pelvis position and unwanted hamstring elongation during sprinting. The drills and exercises provided were successfully integrated withing team’s warm up routines, avoiding extra load upon the players.

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