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Acceleration versus maximum speed sprinting: A pilot study assessing sprint performance, eccentric knee flexor strength, and muscle architecture

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ABSTRACT

The objective of this study was to implement a pilot protocol to investigate the effects of acceleration and maximum speed sprint training on sprint performance, eccentric knee flexor strength, and knee flexor muscle architecture. A pre- and post-intervention study including a control group was employed. Twelve male field sport athletes (age = 23.1 ± 3.2 years, height = 180.1 ± 8.3 cm, body mass = 80.1 ± 6.4 kg) were recruited to participate in this study. Participants were allocated to either an acceleration, maximum speed, or a control group. Participants completed pre- and post-testing consisting of a 40-metre sprint, eccentric knee flexor strength assessment, and an ultrasound of the Biceps Femoris Long Head (BF_{LH}). Training interventions were completed over 6 weeks with 2 sessions per week. Knee flexor muscle soreness data was collected using a 10-point scale. BF_{LH} fascicle length increased by 1.95 cm in the acceleration group and 1.67cm in the maximum speed group. Trivial changes were reported in eccentric knee flexor strength for all three groups. Both acceleration and maximum speed training improved sprint performance. Both forms of sprint training were effective for increasing BF_{LH} fascicle length. Maximum speed sprinting may offer a prophylactic benefit for modifiable hamstring injury risk factors. These findings should be confirmed with studies on a larger scale.

1. Introduction

Hamstring strain injury (HSI) is consistently one of the most common injuries experienced by athletes competing in field sports with a high-speed running (HSR) component (AFL, 2021; Ekstrand et al., 2021). This incurs a significant time away from competition (AFL, 2021), and substantial financial cost (Hickey et al., 2014; Specialty, 2017). Previous work has identified modifiable risk factors for HSI, such as the combination of low eccentric knee flexor strength, and short Bicep Femoris Long Head (BF_{LH}) fascicles (Bourne et al., 2017; Timmins et al., 2015b). Whilst Timmins et al. (2015b) demonstrated thresholds of less than 337 N and 10.56 cm place professional soccer athletes at increased risk, Dow et al. (2021) found that that thresholds should be sport specific. Therefore, the context of eccentric strength and architectural adaptations are still highly relevant for HSI prevention purposes. Eccentric hamstring exercises have previously been shown to effectively mediate these risk factors. Exercises such as the Nordic Hamstring Exercise (NHE) increase strength and fascicle length with relatively low volume (Presland et al., 2018), however, some of the criticism stems from the non-specific movement of the NHE (Freeman et al., 2021). This is

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echoed by researchers who found that compliance was poor amongst professional soccer teams (Bahr et al., 2015), and a recent review has questioned the preventative effect of the exercise for HSI, suggesting it should only be conditionally prescribed (Impellizzeri et al., 2021).

Shorter fascicle lengths in the BF_{LH} have been shown to be associated with increased risk of future HSI (Timmins et al., 2015b). This is best explained by a presumed greater number of sarcomeres in series, increasing the ability of the fascicle to tolerate high loads (Morgan, 1990). Previous work has identified that adaptations to the fascicles of the BF_{LH} occur over relatively short periods of time (7 – 10 days**;** Presland et al., 2018). Therefore, the ability to measure fascicle length accurately and reliably is important, as it provides valuable insight as to whether adaptation or maladaptation's have occurred. Of the available methods to assess BF_{LH} fascicle length, two dimensional (2D) β-mode ultrasound is the most cost effective and easily accessible method (Franchi et al., 2020; Sarto et al., 2021). A current issue with using 2D ultrasound to measure fascicle length is that the entire fascicle is not captured in a single image. Therefore, an estimation must be made using points digitised from the image. A body of research has demonstrated that this method of ultrasound to be valid and reliable measure to assess fascicle length at rest for several different muscles (Blazevich et al., 2006; Kellis et al., 2009; Timmins et al., 2015a).

Sprinting, either through acceleration or maximum speed instances, is the most common activity associated with HSI in Australian Football (Freeman et al., 2021). It is postulated that the late-swing phase, where the hamstring works maximally to decelerate the lower leg, is the most likely point in the gait cycle where injury occurs. Currently, five key studies (Freeman et al., 2019; Ishøi et al., 2017; Krommes et al., 2017; Mendiguchia et al., 2020; Timmins et al., 2021) have examined the effect of eccentric knee flexor strengthening on sprint performance in field sport athletes. Of these studies, four reported increases in eccentric knee flexor strength (Freeman et al., 2019; Ishøi et al., 2017; Mendiguchia et al., 2020; Timmins et al., 2021), one reported small to moderate increases in fascicle length (Mendiguchia et al., 2020), and three reported increases in acceleration sprint performance (Ishøi et al., 2017; Krommes et al., 2017; Timmins et al., 2021). Two of the studies investigated sprint training, showing a significant increase in eccentric knee flexor strength (Freeman et al., 2019), and a significant increase in BF_{LH} fascicle length (Mendiguchia et al., 2020). These two interventions have both utilised a combination of acceleration, maximum speed, and resisted sprinting as a part of the training program.

Furthermore, sprinting has been proposed as a potential "vaccine" for HSI (Edouard et al., 2019). In a field sport setting, both acceleration and maximum speed are important components of sprinting. Higashihara et al. **(**2017**)** reported significant differences in acceleration and maximum speed sprinting. This is reflected by a change in the orientation of force, whereby acceleration requires more horizontal force production and maximum speed transitions to more vertical force production. The acceleration gait displays significantly higher Biceps Femoris (BF) activation when compared to the medial hamstrings (Higashihara et al., 2017). This is supported by findings suggesting the BF is key component of acceleration sprinting (Morin et al., 2015). Interestingly, HSI are more frequent in the BF opposed to the medial hamstrings (Askling et al., 2012), yet hamstring injuries occur during both accelerations and maximum speed sprints. Conversely, the medial hamstrings are significantly more activated during the swing phase of the maximum speed sprint (Higashihara et al., 2017), potentially as they are required to decelerate the lower leg from high-speed in preparation for ground contact. These findings are further consolidated by significant increases in force production and negative work completed by the hamstrings as running speeds exceed 80% V_{max} (Chumanov et al., 2007; Dorn et al., 2012; Fiorentino et al., 2014). It should also be considered that Higashihara et al. (2017) measured acceleration at the 15-metre mark. As ~74% V_{max} is achieved by the 10-metre mark of a sprint (Healy et al., 2019), the 15-metre mark may not be a true reflection of acceleration.

As previously established, maximum speed sprinting is a risk for HSI. However, if carefully administered with progressive overload, maximum speed training can be expected to produce adaptations that will make the hamstrings more robust. This strategy is likely to be effective when you consider that conventional hamstring exercises (including the NHE) do not mirror the stress placed upon the hamstrings that sprinting at 100% V_{max} does (Prince et al., 2021; van den Tillaar et al., 2017). Sprint training also provides the additional benefit of improving sprint performance. Therefore, given the significantly higher activation, force production and work completed, maximum speed sprinting may provide a better prophylactic effect on HSI opposed to acceleration sprinting. Findings from previous studies (Edouard et al., 2019; Freeman et al., 2021; Freeman et al., 2019; Mendiguchia et al., 2020) point towards the need for further investigation of sprint training for HSI risk mitigation. Furthermore, the clear differences between acceleration and maximum speed sprinting (Higashihara et al., 2017) suggest that different training adaptations, specifically on modifiable risk factors such as muscle architecture and eccentric knee flexor strength are possible. This study's primary aim is to outline the training responses of two separate sprint training methods: acceleration and maximum speed on modifiable risk factors such as eccentric knee flexor strength and BF_{LH} fascicle length, whilst concurrently assessing changes in sprint performance.

2. Methods

2.1. Participants

Twelve amateur male Australian Rules football athletes (age = 23.1 ± 3.2 years, height = 180.1 ± 8.3 cm, body mass = 80.1 ± 6.4 kg, training experience = 6 ± 2.6 years) were recruited to participate in this study. No participant reported any prior HSI. This project received ethical approval from the University Human Research Ethics Committee (Approval Number – A19-135). All participants were injury free for six months prior to the study. Participants were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study.

2.2. Study design

Participants in the pilot study completed a series of tests before they were allocated into one of two interventions, or a control group. Following the completion of a standardised warm up, testing consisted of a 40-metre sprint, an eccentric knee flexor strength assessment, and an ultrasound of the BF_{LH}. Once testing was complete, participants were allocated into the three groups based upon their eccentric knee flexor strength (the strongest participant was allocated to acceleration training, the second strongest to maximum speed training, and the third strongest to the control group. This process was repeated until all participants were allocated, leaving four participants for each condition. This was completed to create equality of pre-training eccentric strength across the three groups before training interventions were completed. Following six weeks of training and a weekly ultrasound scan of the BF_{LH}, participants repeated the same testing procedure. Throughout the training intervention, participants were instructed to maintain their normal training load, and not to add any additional hamstring specific exercises.

2.3. Testing procedures

Prior to completing sprint testing, participants completed a standardised warm up of a 4-minute jog, 20 metres of walking lunges, 20 metres of lateral lunges, 20 metres of arabesques, and 20 metres of hamstring sweeps. Following this general component of the warm up, 20 metres of high knees, butt kicks, A-Skips, and A-Skips for maximal height were performed. Participants then completed four run-throughs over 40 metres, commencing at approximately 60% of perceived maximal effort and progressing to approximately 95% to 100% of perceived maximal effort.

2.3.1. Sprint performance

A 40-metre sprint was measured using timing gates (Speedlight; Swift Performance, QLD, AUS) to assess the acceleration and maximum speed capabilities of participants. As outlined in Figure 1, a 0 – 10-metre split was incorporated to assess acceleration qualities and a 30 – 40-metre split was incorporated to estimate maximum speed qualities (Freeman et al., 2019; Young et al., 2008). Participants completed two 40-metre trials with a full recovery between trials (i.e., longer than 5 minutes). A third trial was completed if the second trial was more than 0.2 s quicker than the first. Participants were instructed to start with their preferred foot forward, with the opposing arm raised in the air to avoid the premature start of the timing system. Participants were required to be in a stationary position with their torso as close as possible to the light beam. All participants were instructed they were unable to rock to gain any momentum prior to starting. Participants used a self-selected distance from the front toe to the start line to allow for various body dimensions, providing the torso was as close to the beam as possible. Participants were allowed to trial these starting positions during their run-throughs in the warm up, however, the pre-testing distance was recorded for post-testing, with the range being 0 cm from the timing gate to 40 cm from the timing gate. This testing was completed in a temperature-controlled (21 °C) basketball stadium, on a wooden springboard surface with all participants wearing the same footwear for pre and post testing. The best (fastest) time between the 0 – 10-metre split and 30 – 40-metre split was retained for analysis.

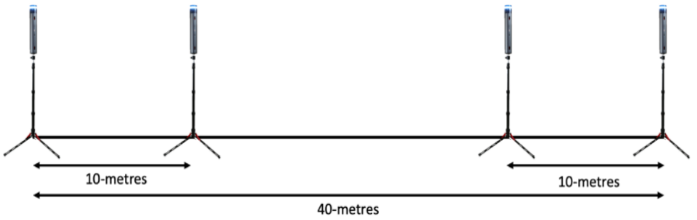

Figure 1: Diagram of sprint testing protocol used for acceleration (0 – 10-metre) and estimated maximum speed (30 – 40-metre).

2.3.2. Eccentric knee flexor strength

Participants involved in this project had all previously completed the testing procedure for eccentric knee flexor strength (NordBord; VALD Performance, QLD) through prior individual training or testing sessions. This device has been previously shown to be a valid and reliable measure of eccentric knee flexor strength (Opar et al., 2013). Following a 5-minute break after the sprint testing, participants performed a warm up set of three repetitions at approximately 60%, 70%, and 80% of perceived maximum effort. Following a 3-minute rest, participants were instructed to perform three maximal contractions. Participants were instructed to maintain a straight line from the shoulder, through the hip to the knee, whilst keeping hands at chest level to brace for the point of failure (Freeman et al., 2019). Whilst performing each repetition, participants were instructed to control the contraction for as long as possible (Opar et al., 2013). If the participant was able to complete a full repetition, external resistance was available to ensure a maximal effort. The corresponding knee position was recorded so that the participant set up was repeatable in the post-testing (Opar et al., 2013). The best trial for left leg, right leg, and peak bilateral force was retained for analysis.

2.3.3. BF_{LH} architecture

Intra-rater reliability of muscle imaging was completed prior to the commencement of the pilot intervention. The timeframe between the first test and the second test was three days. Participants were well-rested for 24 hours before both imaging sessions and were instructed to complete no sprinting or resistance training between visits. Ultrasound images of the left BF_{LH} muscle belly was captured using 2D β-mode ultrasound (frequency = 12 MHz, depth = 6.5 cm, field of view = 14 × 47 mm; Mindray DP-20; Shenzhen, ROC).

To ensure consistency of the scanning site, the distance between the ischial tuberosity and knee joint fold was marked at the halfway point along the line of the BF_{LH}. This distance corresponds closely with the belly of the BF_{LH}. This is important for two key reasons (Blazevich et al., 2006). Firstly, estimates assume that there is no curvature of fascicles or aponeurosis, which is only true at the midpoint of the muscle belly. Secondly, the common assumption is that the structure of the BF_{LH} is isotropic, which is not accurate because as the muscle moves closer to the origin or insertion point, the muscle changes shape to fit in with the respective anatomical structures. Once this site was marked, the distance of this site was recorded from various anatomical landmarks, such as the head of the fibula to ensure a reproducible scanning area. Participants lay prone with a pillow placed under the left ankle, before a layer of conductive gel was placed over the scanning site. The linear probe was placed longitudinally and perpendicular to the posterior thigh (Blazevich et al., 2006; Timmins et al., 2015a). The sonographer ensured minimal pressure was applied to the skin, as this has previously been shown to influence image quality (Blazevich et al., 2006; Timmins et al., 2015a). To obtain adequate images, the probe was slightly manipulated to ensure the superficial and intermediate aponeurosis were parallel. To ensure a quality image was captured, the sonographer completed several hours of training, and was mentored by a researcher experienced in $\mathrm{BF_{LH}}$ sonography.

Following the image collection, analysis was performed offline (MicroDicom, V.2.7.9, Bulgaria). Following previously established methods six markers were digitally created for each of the images (Timmins et al., 2015a). The gap between superficial and intermediate aponeurosis was used to establish muscle thickness. A clear fascicle of interest with no curvature or distortion was then marked on the image (Supplementary Figure 1). For both aponeuroses, the aponeurosis angle was defined as the angle created by a horizontal line across the image and the intersecting line marked as the aponeurosis (Timmins et al., 2015a). To estimate fascicle length, a previously validated equation (Timmins et al., 2015a) was used:

$$\mathrm{FL} = \sin(\mathrm{AA} + 90^\circ) \times \frac{\mathrm{MT}}{\sin[180^\circ - (\mathrm{AA} + 180^\circ - \mathrm{PA})]}$$

in which FL = Fascicle Length, AA = Aponeurosis Angle, MT = Muscle Thickness, and PA = Pennation Angle. Fascicle Length was reported in absolute terms (cm). All analysis was performed by the same sonographer, who was blinded to participant identifiers when completing the analysis. This process was then repeated for the weekly ultrasound scans to track $\mathrm{BF_{LH}}$ fascicle length changes in acceleration and maximum speed participants. These images were collected at a standardised time; 24 hours after the second training session of the week. This frequency of measurement allows for accurate recording of time course changes in fascicle length, which is of particular interest given the short adaptation window observed in prior resistance training study (Presland et al., 2018).

2.4. Training interventions

Participants completed training sessions individually under the supervision of a qualified strength and conditioning coach during the restrictions of the Victorian Government COVID-19 restrictions in 2020. All sessions were completed with a minimum of 48 hours of recovery between sprint exposures. Prior to each training session, participants completed a standardised warm up procedure like that used for testing sessions. A full description of both the acceleration and maximum speed training programs can be seen in Table 1 and Table 2, respectively.

Table 1: Acceleration training program.

Session	Start	Reps	Distance (m)	Intensity (%ME)	Rest (min)	Volume (m)
1	Standing	8	5	100%	1	90
	Standing	5	10	100%	1	
2	Standing	8	5	100%	1	100
	Standing	6	10	100%	1	
3	Falling	6	5	100%	1	110
	3-point	8	10	100%	2	
4	3-point	6	5	100%	1	110
	Falling	8	10	100%	2	
5	Standing	12	10*	100%	2	120
6	Falling	12	10	100%	2	120
7	3-point	4	10	100%	2	130
	Standing	6	15	100%	2	
8	3-point	4	10*	100%	2	130
	Standing	6	15*	100%	2	
9	Falling	5	5	100%	1	140
	Falling	4	10	100%	2	
	Falling	5	15	100%	2	
10	Standing	5	5*	100%	1	150
	Falling	5	10*	100%	2	
	Standing	5	15*	100%	2	
11	Falling	3	10	100%	1	140
	Standing	8	15	100%	2	
12	Standing	4	5	100%	1	140
	Standing	4	10	100%	2	
	Standing	4	15	100%	2	

Note: *denotes racing against timing gates, Reps = Repetitions, %ME = percentage of perceived maximum effort.

Table 2: Maximum speed training program.

Session	Session description	Reps	Distance (m)	Intensity (%ME)	Rest (min)	Max. velocity volume (m)
1	30-metre build with 10-metre hold	2	20	95–100%	3	80
	30-metre build – 10-metre hold – 20-metre float – 10-metre hold	2	20	95–100%	3 – 5	
2	30-metre build with 10-metre hold	5	10	100%	3 – 5	50
3	30-metre build with 15-metre hold	5	15	100%	3 – 5	75
4	30-metre build – 10-metre hold – 20-metre float – 10-metre hold	4	20	100%	3 – 5	80
5	30-metre build – 10-metre hold – 20-metre float – 10-metre hold	5	20	100%	3 – 5	80
6	30-metre build – 10-metre hold – 20-metre float – 10-metre hold	4	20*	100%	3 – 5	80
7	30-metre build with 15-metre hold	6	15	100%	3 – 5	90
8	30-metre build with 15-metre hold	6	15*	100%	3 – 5	90
9	30-metre build with 15-metre hold	4	10	100%	3 – 5	80
	30-metre build – 10-metre hold – 20-metre float – 10-metre hold	2	20	100%	3 – 5	
10	30-metre build with 15-metre hold	3	20	100%	3 – 5	80
	30-metre build – 10-metre hold – 20-metre float – 10-metre hold	1	20	100%	3 – 5	
11	30-metre build – 10-metre hold – 20-metre float – 10-metre hold	6	20	100%	3 – 5	120
12	30-metre build with 15-metre hold	3	10	100%	3 – 5	90
	30-metre build with 15-metre hold	3	20	100%	3 – 5	

Note: *denotes racing against timing gates, Reps = Repetitions, %ME = percentage of perceived maximum effort.

Both training programs were designed following considerations outlined by Haugen and colleagues (Haugen et al., 2019). The mismatch in volume between the acceleration and maximum speed interventions is explained by Haugen et al. (2019) guidelines that suggest better adaptations for acceleration occur with slightly higher volumes, whereas maximum speed training volumes are typically lower. Additionally, maximum speed sessions must also account for the gradual build up to achieve maximum speed (Haugen et al., 2019). A gradual build up was favoured over an all-out acceleration for two reasons. Firstly, it would avoid hard accelerations and secondly, a gradual acceleration produces higher maximum velocities in field sport athletes (Young et al., 2018). Hamstring muscle soreness was collected as a point of interest in this study. To collect hamstring muscle soreness information, athletes were asked at the start of the following session to rate their soreness on a scale of 0 – 10, where 0 was equal to no soreness, and 10 was to extreme hamstring soreness (Freeman et al., 2019).

2.5. Statistical analyses

The statistical analyses for this study were performed using SPSS Version 25.0 (IBM, Armonk New York, NY, USA). To determine intra-rater reliability for muscle architecture measures, a Shapiro-Wilk test was used to assess the data for normal distribution. To assess test-retest reliability between the first and second scan, intra-class correlation coefficients (ICC) were calculated. This was supported by further calculations of the typical error (TE), and the coefficient of variation (CV). The minimal detectable change at a 95% confidence interval was calculated in accordance with Timmins et al. (2015a) as $TE \times 1.96 \times \sqrt{2}$. Previous research suggests the following ICC values are suitable for use in this analysis; less than or equal to 0.79 as poor, 0.80 to 0.89 as moderate, and greater than or equal to 0.90 as high (Timmins et al., 2015a; Watsford et al., 2010). Due to the COVID-19 restrictions enforced in Victoria, Australia during participant recruitment, the sample size was not high enough to achieve statistical power. A key focus of this analysis was to closely examine the individual responses to the training interventions. Individual results are often undervalued when interpreting group data. This descriptive method is also a useful application for practitioners seeking to assess changes in their athletes. Presentation of individual changes alongside the trends of a group (or in a sporting example, a team) provides context around the information.

3. Results

3.1. Compliance

Seven of the eight participants allocated to training interventions completed all 12 training sessions. The eighth participant completed 11 of a possible 12 sessions. Typically, sessions were completed on a Monday to Thursday or Tuesday to Friday schedule.

3.2. Sprint performance

All athletes that completed a sprint training intervention improved split times, whereby the acceleration group increased fascicle length by 1.95 ± 0.68 cm and the maximum speed group increased by 1.67 ± 0.50 cm (Figure 2). Both the acceleration training group and the maximum speed training group displayed larger improvements in maximum speed than acceleration. Two of the three control participants were slower in the post-testing.

3.3. Eccentric knee flexor strength

Eleven of the 12 participants completed this study, however, one member of the control group dropped out due to work commitments. In general, acceleration and maximum speed training elicited a 5% and 4% increase in eccentric strength, respectively. The control participants improved eccentric strength to a slightly greater degree (9%). A full outline of the individual eccentric strength results can be seen in Table 3.

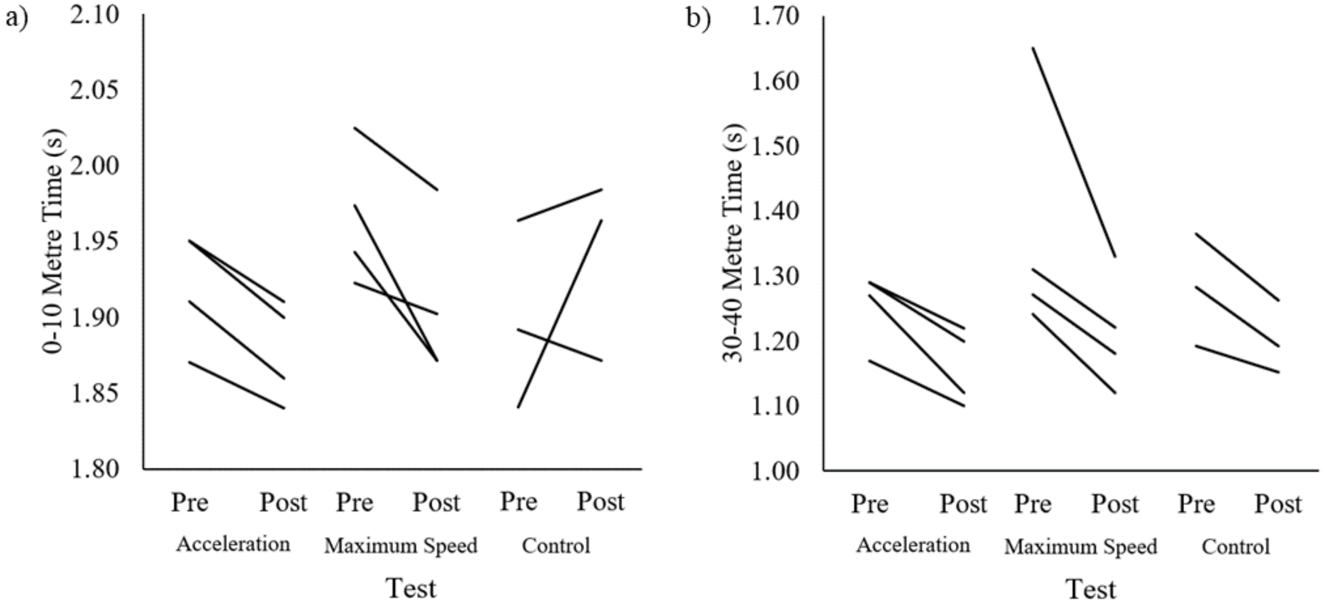

Figure 2: Sprint performance by group at pre-test and post-test at (A) 0 – 10-metre split and (B) 30 – 40-metre split.

Table 3: Pre- and post-test eccentric knee flexor strength, and hamstring muscle architecture variables for all participants.

	Peak left force (N)			Peak right force (N)			Peak bilateral force (N)			Fascicle length (cm)			Pennation angle (°)			Muscle thickness (cm)		
	Pre	Post	Diff (%)	Pre	Post	Diff (%)	Pre	Post	Diff (%)	Pre	Post	Diff (%)	Pre	Post	Diff (%)	Pre	Post	Diff (%)
Acceleration																		
P1	372	365	-2	426	424	0	399	395	+1	8.69	10.79	+24	19.76	15.66	-21	2.25	2.28	+1
P2	299	346	+16	280	325	+20	290	341	+18	9.87	10.86	+10	16.02	15.20	-5	2.22	2.26	+2
P3	378	364	-4	375	362	-3	377	363	-4	6.58	8.72	+33	24.01	16.02	-33	2.15	2.18	+1
P4	461	516	+12	502	495	-1	482	506	+5	8.28	10.87	+31	15.76	13.06	-17	2.15	2.23	+4
Mean	378	398	+5	396	404	+2	387	401	+4	8.36	10.31	+23	18.89	14.99	-21	2.19	2.24	+2
SD	66	79		93	71		79	73		1.36	1.06		3.87	1.33		0.05	0.04	
Maximum speed																		
P5	339	414	22	449	482	+7	394	448	+14	7.18	8.85	+23	18.13	16.58	-9	2.11	2.14	+1
P6	303	316	+4	383	357	-7	343	337	-2	9.26	10.57	+14	14.52	14.42	-1	2.24	2.25	0
P7	355	314	-12	342	322	-6	349	318	-9	8.38	10.76	+28	17.09	16.04	-6	2.39	2.42	+1
P8	359	361	+1	400	400	0	380	381	0	8.40	9.72	+16	13.15	12.28	-7	2.04	2.10	+3
Mean	339	351	+4	394	390	-1	367	371	+1	8.31	9.98	+20	15.72	14.83	-6	2.20	2.23	+1
SD	26	47		44	69		24	58		0.85	0.88		2.29	1.93		0.15	0.14	
Control																		
P9	315	381	+21	353	366	+4	334	374	+12	7.18	6.80	-5	16.97	17.62	+4	2.10	2.10	+0
P10	358	362	+1	422	376	-11	390	369	-5	10.13	9.48	-6	13.47	16.37	+21	2.28	2.18	-4
P11	324	340	+5	319	334	+5	322	337	+5	11.21	10.39	-7	13.04	13.93	+7	2.49	2.42	-3
Mean	332	361	+9	365	359	-2	349	360	+3	9.51	8.89	-7	14.49	15.92	+10	2.29	2.23	-3
SD	23	21		52	22		36	20		2.09	1.87		2.16	1.88		0.20	0.17	

Note: Diff (%): differences between pre- and post-test in percentage.

3.4. BF_{LH} muscle architecture

Intra-rater reliability results of the sonographer are presented in Table 4 (Freeman, 2022). The absolute changes in BF_{LH} fascicle length and eccentric knee flexor strength from pre-test to post-test are visualised in Figure 3 and representative images are included in Supplementary Figure 1. All eight of the participants that took part in structured acceleration or maximum speed sprint training increased fascicle length and decreased pennation angle, as detailed in Table 4. Fascicle lengths were tracked weekly to provide more detailed information. This is reported in Figure 4 which details changes in BF_{LH} fascicle length for acceleration and maximum speed participants. Means and standard deviation for the soreness scores for the acceleration and maximum speed training interventions are displayed in Supplementary Figure 2.

Table 4: Descriptive statistics and test-retest reliability data for the architectural characteristics of the BF_{LH} at rest.

Variable	Mean ± SD		ICC [95% CI]	TE Mean [95%CI]	MDC_{95}
	Rater 1	Rater 2			
Muscle Thickness (cm)	2.52 ± 0.29	2.53 ± 0.33	0.92 [0.76, 0.96]	0.09 [0.03, 0.15]	0.26
Fascicle Length (cm)	8.88 ± 1.31	8.80 ± 1.29	0.96 [0.93, 0.99]	0.36 [0.24, 0.48]	0.99
Pennation Angle (°)	15.59 ± 3.17	15.16 ± 2.58	0.94 [0.83, 0.97]	0.44 [0.31, 0.76]	1.22

Note: ICC = Intraclass Correlation Coefficient, TE = Typical Error, MDC_{95} = Minimal Detectable Change at 95% Confidence Intervals.

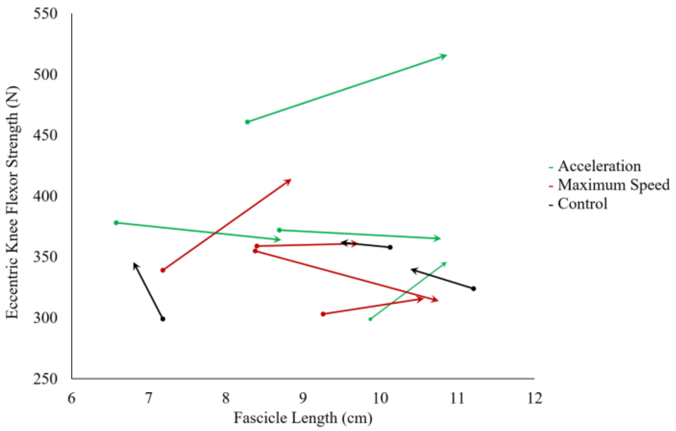

Figure 3. Pre and post-test changes in eccentric knee flexor strength and BF_{LH} fascicle length.

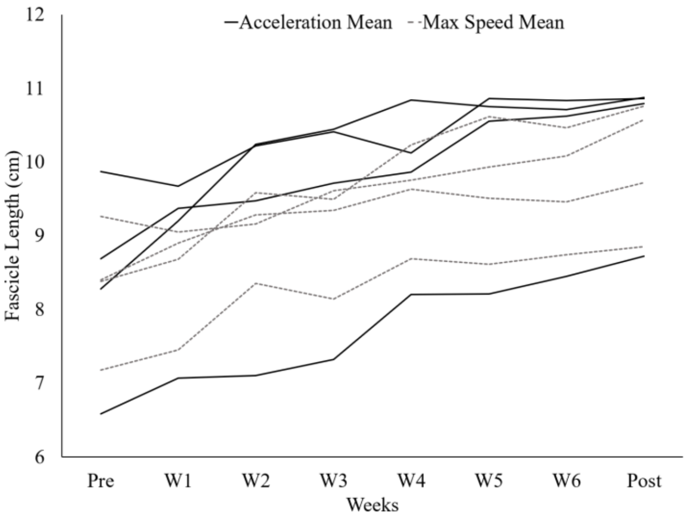

Figure 4. Weekly changes in fascicle length for the acceleration (solid line black line) and maximum speed (dotted grey line) interventions.

4. Discussion

This is the first study to investigate the effects of an acceleration specific and maximum speed specific sprint training programs on eccentric knee flexor strength, BF_{LH} fascicle length, sprint performance. Previous investigations have utilised a combination of both acceleration and maximum speed in the intervention design (Freeman et al., 2019), or have also included resisted sprint training (Mendiguchia et al., 2020). All participants in this study complete each of the 12 allocated sessions across the 6-week training period. Furthermore, the means from 4 participants only represent trends, and any conclusions presented with caution. However, findings from both interventions suggest that sprint training improves eccentric knee flexor strength (Freeman et al., 2021; Mendiguchia et al., 2020) and increase BF_{LH} fascicle length (Mendiguchia et al., 2020). The inclusion of an acceleration specific and maximum speed stimulus is entirely novel in this study design. Prior investigations highlighted the differences between the two aspects of sprint mechanics in relation to the hamstrings (Higashihara et al. 2017). The current study employed a more specific free-sprint (no additional resistance, assistance, or gradient change) acceleration stimulus, which is similar training methods used in field sport athletes. The allocated time to speed training per week aligns with the time allocation for sprint training reported by high-performance managers in Australian Rules football (Freeman et al., 2021).

4.1. Eccentric knee flexor strength

Eccentric knee flexor strength remained unchanged, as described by the 1% increases for both interventions. This finding is contrary to previously reported findings assessing the influence of sprint training on eccentric knee flexor strength, where a combination of sprint training methods increased eccentric knee flexor strength in adolescent athletes (Freeman et al., 2019). The baseline measurements for both training groups were above previously reported thresholds (Opar et al., 2014). Therefore, an explanation may be that the stimulus provided by free sprinting alone may not be enough to elicit adaptations in eccentric knee flexor strength, particularly in athletes with high initial values of eccentric knee flexor strength.

4.2. BF_{LH} architecture

Large increases in BF_{LH} fascicle length were observed for both acceleration and maximum speed interventions (23% and 20%, respectively) in this study. Conversely, the control participants in this study decreased by 0.62 cm (7%). These findings are supportive of Mendiguchia et al. (2020), where athletes completing a sprint training program involving resisted sprints, accelerations and maximum speed repetitions increased fascicle length by 1.66 cm (16%). The increases in fascicle length for both training groups were complemented by decreases in pennation angle. The inverse is true for the control group who decreased fascicle length and increased pennation angle. This indicates that the sprint exposure for both groups was likely adequate to improve fascicle length and may prove as viable training strategy to address this modifiable risk factor. Furthermore, the information displayed in Figure 4 should be considered from a trainability perspective. Twelve sessions of either acceleration or maximum speed sprinting was sufficient to improve BFLH fascicle length, a known modifiable risk factor for HSI (Timmins, et al., 2015b), by more than the MDC_{95}.

Subsequently, a key finding from this study is the short period of hamstring architectural adaptation. Approximately three weeks of training was sufficient to see an increase in fascicle length outside the MDC_{95} (Figure 4). This is an important point for strength and conditioning practitioners, as six sessions of either acceleration or maximum speed training is compliant with typical speed training time allocations in elite field sport (Freeman et al., 2021). Moreover, given the low time constraints, low levels of soreness, and minimal equipment requirements, sprint training is applicable across a range of different elite and non-elite field sports.

4.3. Sprint performance

As expected, both acceleration training and maximum speed training improved sprint performance outcomes (Figure 2). This finding was expected and supports previous investigations in this area (Lockie et al., 2012; Rumpf et al., 2015). The relatively large improvement in maximum speed may be explained by participant 3. However, with this individual's data removed, maximum speed qualities improved by 7% for the acceleration training group. Additionally, the maximum speed training intervention improved acceleration qualities by 3% and maximum speed qualities by 9%. Whilst the relationship between improved acceleration and improved maximum velocity has previously been established (Morin et al., 2012; Rabita et al., 2015; Robbins & Young, 2012; Slawinski et al., 2017; Vescovi & McGuigan, 2008), sprint training studies have typically only assessed the influence of acceleration training on acceleration performance or maximum speed training on maximum speed sprinting performance (Rumpf et al., 2015). The control intervention in this study also tested slightly faster for 0 – 10-metre time and 0 – 40-metre time. The slight increase in eccentric strength observed in the control group may be attributed to the acceleration increase, as previously documented (Ishøi et al., 2017). However, at present there is no explanation for the increase in eccentric strength, as control subjects were instructed to maintain normal training loads, and not to add or increase the load of any specific hamstring or sprinting exercises. This is an unexpected finding; therefore, larger scale studies should be performed to further confirm these findings.

5. Practical applications

This study provides a pilot protocol to assess changes in sprint performance, eccentric knee flexor strength, and BF_{LH} architecture in field sport athletes. The training interventions were completed with minimal soreness (Supplementary Figure 2) and were of an appropriate duration to see changes in sprint performance and muscle architecture in this instance. This should be repeated on a larger scale to confirm initial findings. In addition, this study directly outlines the effect of training a specific speed quality (e.g., maximum speed) on a separate speed quality (e.g., acceleration maximum speed).

In addition, this study is also the first to document the effects of a maximum speed training using gradual build ups, opposed to maximum speed training with a hard acceleration. As neither of these findings have been previously documented in peer-reviewed literature, it presents as a novel finding from this study. This may be best explained however, by a retrospective investigation into the 40-yard dash completed at the National Football League Combine, that determined that a higher maximum velocity was important for higher acceleration (Clarke et al., 2019). Theoretically, V_{max} may serve as a barrier to acceleration performance, therefore a high V_{max} will facilitate a better acceleration phase (Clarke et al., 2019). This theory supports the findings of this study, where the average improvement in the maximum speed split (30 – 40 m) was 0.11 s, coinciding with an improvement of 0.06 s in the acceleration component (0 – 10 m).

Broadly, this study aimed to determine the effects of acceleration and maximum speed sprint training on eccentric knee flexor strength, BF_{LH} fascicle length and sprint performance. The results indicate that both interventions; acceleration and maximum speed, likely increase BF_{LH} fascicle length and reduce pennation angle. This is in support of the one other study to investigate a combined sprint training protocol on BF_{LH} adaptations (Mendiguchia et al., 2020) . There was no clear change in eccentric knee flexor strength observed, however strength has previously been reported to increase following spring training (Freeman et al., 2019; Ishøi et al., 2017; Mendiguchia et al., 2020; Timmins et al., 2021). As expected, both sprint training methods improved sprint performance, however maximum speed sprint training appeared to improve acceleration and maximum speed sprint times to a greater degree.

This study has a number of limitations. Firstly, the reduced sample power as result of the COVID-19 pandemic and resultant restrictions make drawing broader conclusions more difficult. However, the preliminary findings of increased fascicle length and sprint performance cannot be easily dismissed. More so, this provides further evidence that sprint training still needs to be pursued at a larger, higher-powered level. Secondly, the athletes in this study were amateur footballers with a regular training history. Therefore, this protocol should be repeated with the same methodology, with a larger sample size, in both elite populations and athletes with very little training history. The practical applications of these findings add further weight to the notion that sprint training is a possible intervention to reduce the risk of HSI in field sport athletes. This study exposed athletes to approximately 150 m to 300 m of sprinting per week for six weeks, volumes that align with best practice recommendations for sprint training (Haugen et al., 2019).

Furthermore, a potential key benefit is the influence sprinting produces on BF_{LH} architecture. This study reported an average increase in fascicle length of 1.95 cm and 1.67 cm for acceleration and maximum speed interventions respectively. This increase is only slightly smaller than the findings of Presland et al (2018). The additional benefit of sprinting is the concomitant injury and performance benefits associated with sprinting, which is vital to success in field sports (den Hollander et al., 2016; Faude et al., 2012; Ross et al., 2015). There is a clear need for both acceleration and maximum speed sprinting in field sports. As both interventions delivered increased fascicle length, both may be appropriate at different times during a cycle of training. However, given the carryover benefits of maximum speed training on improvements in acceleration, perhaps earlier prioritisation of maximum speed training may provide the best ‘bang for buck’ stimulus to reduce the risk of HSI, and improve sprint performance in field sport athletes.

Conflict of Interest

The authors declare no conflict of interests.

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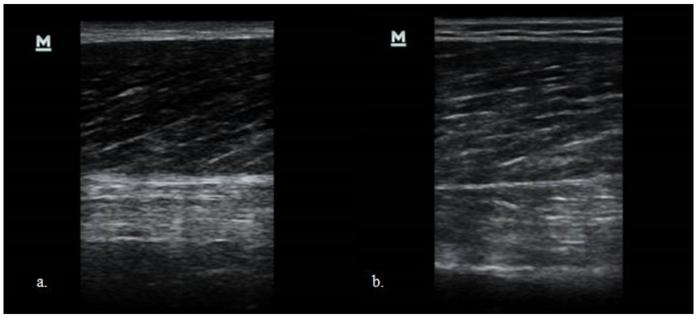
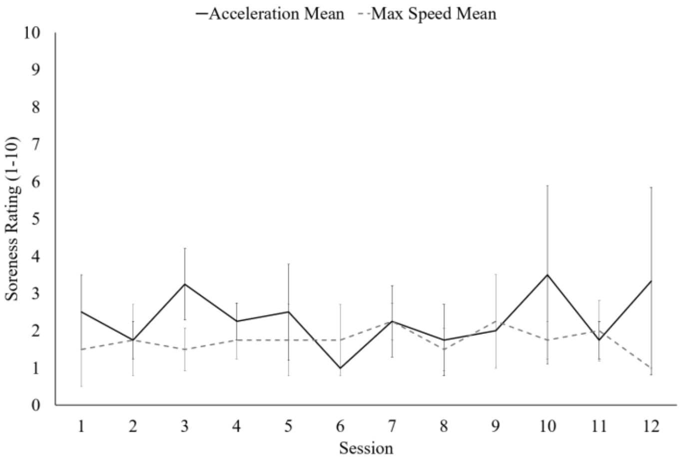
Supplemental materials



Supplementary Figure 1: Representative ultrasound images of the $\mathrm{BF}_{\mathrm{LH}}$ from Participant 1 (a) and Participant 6 (b).



Supplementary Figure 2: Soreness reported 24h post sprint exposure for the acceleration intervention (black lines) and maximum speed intervention (grey dashed lines).