Relationships Between Knee and Ankle Strength and Horizontal Deceleration Performance at Different Sprint Distances in Multi-Directional Sports Athletes

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Abstract

The aim of this study was to investigate the relationships between knee and ankle strength and horizontal deceleration performance following different sprint distances. Fifty-seven (n=41 male, n=16 female) youth team-sports athletes completed: a) 5-m and 10-m horizontal deceleration ability (HDA) tests; b) concentric (60°/s, 180°/s) and eccentric (30°/s) relative peak torque (PT) measurements of the knee extensor (KE) and flexor (KF) muscles and the ankle plantarflexion (APF) and dorsiflexion (ADF) muscles in an isokinetic dynamometer. Pearson's correlation coefficients revealed that concentric at 60°/s and eccentric at 30°/s KE were mostly related to deceleration performance both in $HDA_{5\text{-m}}$ (r=-0.50 to -0.61, p<0.05) and $HDA_{10\text{-m}}$ tests (r=-0.50 to -0.63, p<0.05). Moreover, a significant correlation was observed between concentric APF and average deceleration (DEC_{avg}) measured from $HDA_{5\text{-m}}$ test in both the dominant leg (DL) and non-dominant leg (NDL) (r=-0.52 to -0.53, p<0.05), but not to 10-m horizontal deceleration performance. The current results indicate that deceleration performance varies in its demands on knee and ankle strength across different sprint distances. Athletes who frequently decelerate over short distances should focus not only on strengthening their knee strength but also on prioritizing ankle strength.

Key Words: concentric, eccentric, isokinetic, strength, speed

Introduction

Horizontal deceleration is a locomotor skill critical for reducing whole-body momentum and for performing the vast array of change of direction movements commonly performed by athletes in multi-directional sports (Ashton & Jones, 2019; Hewit et al., 2011). Despite its importance, it is a component of performance that has historically had much less attention in empirical research. Given the elevated intensity of impact forces and loading rates experienced by the lower limbs during horizontal deceleration, athletes must appropriately attenuate and distribute these forces throughout the joints, muscles, and connective tissue structures of the lower limbs (Harper & Kiely, 2018). Consequently, horizontal deceleration ability (HDA) refers to an athlete's capacity to rapidly reduce their horizontal velocities while efficiently modulating and attenuating the forces involved in the braking phase (Harper, McBurnie, et al., 2022). Therefore, horizontal deceleration is crucial for executing technical skills and, ultimately, contributing to both successful offensive and defensive outcomes that can lead to goal-scoring opportunities in multi-directional sports (Harper, McBurnie, et al., 2022; Martínez-Hernández et al., 2023).

While rapid horizontal deceleration can assist athletes in creating space for key aspects of competition (e.g., scoring goals or defending against an attacker), the accompanying loads also pose a significant risk of injuries (Rhodes et al., 2021). Using systematic video evidence, previous studies have observed horizontal deceleration to be a common situational factor in anterior cruciate ligament (ACL) injuries (Cochrane et al., 2007; Johnston et al., 2018; Waldén et al., 2015). This is likely due to the high peak impact forces and eccentric loading rates imposed when braking during horizontal deceleration (Harper, McBurnie, et al., 2022) and an inability to generate the required deceleration to adequately and safely reduce momentum when closing down and approaching opponents at high movement speeds (Gokeler et al., 2023). Beyond ACL injuries, frequent and intense horizontal decelerations are strong contributors to other lower-limb athletic injuries such as hamstring strains (Harper & Kiely, 2018; Lakomy & Haydon, 2004). For example, in rugby, 18% of hamstring injuries have been shown to occur during the deceleration phase after sprinting (Kerin et al., 2022). High-intensity horizontal deceleration necessitates the engagement of multiple lower-limb muscle groups with high demand for eccentric muscle actions, leading to heightened muscle tension, soft tissue damage, and compromised structural integrity of muscle fibers (Gastin et al., 2019).

Considering the crucial role of horizontal deceleration in successful sports performance and the substantial risk of injury it presents to athletes, it is essential to thoroughly investigate the effect of lower-limb joint strength on horizontal deceleration performance. Early studies have proposed that there are four primary neuromuscular determinants of deceleration including: 1) eccentric strength, 2) reactive strength, 3) power (including rate of force development (RFD)), and 4) dynamic balance (Hewit et al., 2011; Kovacs et al., 2008). However, it is important to emphasize that most of these conclusions are anecdotal and lack empirical support (Harper, McBurnie, et al., 2022). More recently, the relationships between knee strength capacities and horizontal deceleration performance have been more thoroughly investigated (Harper et al., 2020; Harper, Cohen, et al., 2022; Harper et al., 2021; Zhang et al., 2021). Harper et al. were the first to explore correlations between horizontal deceleration performance and knee flexor (KF) and knee extensor (KE) strength, in both eccentric and concentric modes (Harper et al., 2021). They concluded that in addition to eccentric KE strength, concentric KE and KF strength at higher joint angular velocities had some of the strongest correlations with the horizontal deceleration distance and the time it takes to stop (r = -0.76 and r = -0.78, respectively) (Harper et al., 2021). Zhang et al. (Zhang et al., 2021) also investigated correlations between the fast strength capacity of the knee muscles and horizontal deceleration performance (i.e., horizontal braking force, power, and impulse) in female soccer players. Their findings revealed strong correlations between the eccentric (30°/s) and concentric (60°/s, 240°/s) peak torques (PTs) of KE, as well as the concentric (240°/s) PT of the KF ($r = -0.75$ to -0.54), and the metrics related to horizontal deceleration performance. The authors highlighted that concentric KF strength was essential for maintaining dynamic trunk stability, which in turn helped reduce the risk of lower-limb joint injuries (Zhang et al., 2021).

However, it is imperative to acknowledge that the sprint distance for the deceleration ability test in the studies mentioned above was both 20-m. Taking into account that short-distance deceleration has its own unique kinematic profile, the current conclusions may not be applicable to athletes who frequently need to decelerate over shorter distances. Moreover, no study has explored the relationships between other lower-limb joint strength and horizontal deceleration performance, despite the fact that the ankle plays an integral role as the first major joint to come into contact with the ground, inherently providing load cushioning from a sports anatomy perspective. (Jia et al., 2022). As such, during horizontal deceleration ankle joint dorsiflexion and plantar-flexion joint angular velocities have been reported to be around 380 and 480 degrees per second, respectively, signifying the force demands and loading severity placed on this joint. In addition, both Behan et al. (Behan et al., 2018) and Jakobsen et al. (Jakobsen et al., 2011) demonstrated the importance of ankle plantar flexor (APF) RFD in facilitating swift adjustments and postural control during highly dynamic sporting maneuvers like horizontal deceleration where a sequence of muscle activation occurs from distal to proximal lower limb joints. Consequently, it has been proposed that the reactive strength of the ankle also plays a substantial role in horizontal deceleration performance.

To the author's knowledge, there is currently no research examining how ankle strength capacities may influence horizontal deceleration performance following sprint distances commonly performed by team-sport athletes (Taylor et al., 2017). Therefore, the aim of this study was to investigate the relationships between the eccentric and concentric relative PTs of the knee and ankle joints and horizontal deceleration performance following 5-m and 10-m sprint distances. It was hypothesized that both knee and ankle PTs would be significantly correlated with horizontal deceleration performance with moderate to strong correlations.

Materials and methods

Experimental design

A cross-sectional research design was used to investigate the relationships between knee and ankle concentric and eccentric PTs and horizontal deceleration performance. A familiarization session was conducted 48 hours prior to the first testing session to familiarize participants with the protocols of the 5-m and 10-m HDA tests, and lower-limb isokinetic strength tests and to obtain anthropometric measurements. All subjects were asked to indicate their lateral preference for kicking a ball, with the dominant limb (DL) identified as the preferred kicking leg and the supporting leg identified as the non-dominant limb (NDL). Subjects completed two testing sessions separated by at least 48 hours. In the first test session, subjects commenced with a 15-minute standardized warm-up (e.g., jogging, dynamic stretching, and 3 sub-maximal sprints) before performing three trials of a 10-m maximal sprint test, and the 5-m and 10-m HDA tests. All tests were conducted on the basketball court and the interval between different tests was a 2-min passive recovery period. In the second test session, the knee and ankle isokinetic strength test was measured by an isokinetic dynamometer (IsoMed 2000, D. & R. Ferstl GmbH, Hemau, Germany).

Subjects

Fifty-seven youth team-sport (soccer and basketball) athletes (n = 41 male, n = 16 female, age 17.4 ± 4.5 yrs, height 178.1 ± 9.7 cm, body mass 71.9 ± 13.6 kg) volunteered to participate in this study. All tests were conducted during the off-season. To be included in the study participants were required to have no neuromuscular or musculoskeletal injury of the lower limb in the past 6 months.

Ethical consent was provided by the XXX Research Ethics Committee (approval number: XXX) in accordance with the Helsinki Declaration. Following ethical approval all participants signed a voluntary informed written consent form prior to research commencement. The sample size calculation was conducted by a priori analysis using G*power software (3.1; University of Dusseldorf, Dusseldorf, Germany) with the methods of "Correlation: Bivariate normal model,0" with Correlation ρ H1 = 0.5, α level = 0.05, statistical power = 0.8, and Correlation ρ H0 = 0. A total sample size of

29 participants would be required.

***** Please insert Table 1 about here *****

Procedures

Maximal horizontal sprint test

All subjects were instructed to perform 3 maximal effort 5-m and 10-m sprints, with 1-min rest between trials. A total of six trials were assessed using the *MySprint* app, which has been established as a reliable and valid tool for measuring sprint performance (Romero-Franco et al., 2017). Participants started from a crouching position (staggered-stance) with the right hand on the ground, initiating their own start without taking a step backward or using a 'rocking motion,' and sprinting as fast as possible until they crossed the finish line. The iPhone 12 (Apple Inc., USA) was positioned on a tripod at the finish line to capture the entire sprint test, using slow-motion cameras recording at 240 frames per second. The start and finish of each trial were determined as the first frame in which their right thumb left the ground and the first frame in which their pelvis aligned with the marker at the finish line, respectively. The best 5-m and 10-m sprint time in seconds (s) was recorded as a criterion time for the HDA test, similar to previous procedures (Harper et al., 2023).

Horizontal deceleration ability (HDA) test

The procedures used to evaluate horizontal deceleration performance were adapted from previous studies (Harper et al., 2023; Zhang et al., 2021). All subjects were asked to wear the same model footwear (Run Cushion Grip, Decathlon, France) to complete all the HDA tests. Subjects were instructed to start in a staggered stance and sprint as fast as possible over the mark at 5-m and 10-m, before performing a maximal horizontal deceleration. After the 'start deceleration to complete stop' phase, subjects were asked to backpedal to the finish line (i.e., the 5m/10m sprint finish line), creating a clear “stop” event and signifying the end of the deceleration phase (Figure 1).

***** Please insert Figure 1 about here *****

To ensure that participants decelerated as close to the 5-m and 10-m marks as possible, any 5-m and 10-m time from the HDA tests that was 5% greater than the individual’s best time achieved during the maximal sprint test was excluded from the analysis. In such cases, the participant was asked to repeat the test following a 2-min recovery period. All data (e.g., velocity (m/s), time (s), and distance (m)) during the HDA test were collected by a radar device (Stalker ATS II, Applied Concepts, Inc., Dallas, TX, USA) sampling at 47 Hz, which was attached to a tripod positioned 5-m behind the starting line at a height of 0.9-m above the ground to approximately align with the participants center of mass. The radar device was connected to a laptop with the Stalker ATS system software (Version 5.0, Applied Concepts, Inc., Dallas, TX, USA) for data acquisition. The raw data were processed in Stalker ATS software using the same procedures as those outlined by Harper et al. (2020). The participants completed three trials of the 5-m and 10-m HDA tests, with a 2-minute passive recovery (i.e., sit or stand) between each trial. The trial with the highest average deceleration (m/s^2) was used for further analysis. Average deceleration was calculated using all instantaneous deceleration values calculated from the start (V_{peak}) to the end (V_0) of the deceleration phase, with instantaneous deceleration calculated using the following equation:

$$Deceleration\ (m \cdot s^{-2}) = \frac{(v_{peak} - v_0)}{(t_f - t_i)}$$

Where *v* was the velocity (m/s), *t* was the time (s), *f* was the final time, and *i* is the initial time.

Isokinetic dynamometer strength testing

The IsoMed-2000 isokinetic dynamometer is used to assess the knee and ankle strength of both lower limbs. Angular velocities of 60°/s and 180°/s in concentric/concentric were conducted for the KF/KE/ADF/APF, and angular velocities of 30°/s in eccentric/eccentric were conducted for the KF/KE/ADF/APF. Prior to isokinetic tests, participants performed a 10-minute warm-up by running at a self-selected pace on an indoor track. Then, they proceeded to perform a 10-minute session of dynamic stretching exercises targeting the lower limbs under the supervision of researchers. Before each test, all participants performed 3-5 sub-maximal practice trials in tested movements and angular velocities as a specific warm-up to ensure the correct execution. The test order was set as follows: (1) KF/KE and (2) ADF/APF. The DL was the first to be tested, followed by the NDL. The order of isokinetic testing was the same for all participants: concentric-contraction at low angle velocity, concentric-contraction at high angle velocity, eccentric-contraction mode. During the tests, enthusiastic verbal support was given to incentivize participants to finish the trial as hard and fast as possible. Peak torque refered to the maximum torque produced throughout the isokinetic range of motion for each repetition. All participants performed 5 maximal repetitions of each test with a 2-minute interval between each movement, side, mode, and angle velocity. The highest relative PTs (N.m/kg) value observed across the 5 maximal repetitions were used for final analyses.

Knee isokinetic strength test

The participants were instructed to be seated at 75° of flexion at the hip joint and attached from the thigh to the dynamometer with Velcro straps. They were stabilized using the shoulder apparatus of the dynamometer for the upper body and with stabilization straps for the waist and distal femur. The alignment of the knee joint axis with the dynamometer axis of rotation was set to be the lateral condyle of the femur, and the leg was left loose. A static gravitational correction was applied to negate the influence of the gravity-effect torque at the position of 30° of KF. The range of movement was set from 10° (0° = full knee extension) to 90°.

Ankle isokinetic strength test

The participants were instructed to lie in a supine position on the seat of the dynamometer, with their hips and knees fully extended. Their barefoot was placed on the foot adapter, which was connected to the head of the dynamometer and secured with two velcro straps. The axis of rotation of the lever arm was aligned with the axis of rotation of the lateral malleolus. Straps were used to fix the waist and thigh of the tested leg, while shoulder straps and pads were used to secure the shoulders in the ventral-dorsal and cranial-caudal directions. The participants were asked to cross their arms in front of the chest. After fixation, each participant's limb was weighed by the isokinetic dynamometer to allow correction for gravity. The ankle neutral position was set to 0°, and the range of ankle movement started from 15° dorsiflexion to 40° plantar flexion.

Statistical Analyses

Data are presented as means ± standard deviation. A Shapiro-Wilk test confirmed a normal data distribution of all variables. Pearson's product-moment correlation coefficients (*r*) were calculated to examine the relationships between knee and ankle concentric and eccentric relative PTs and horizontal deceleration performance related metrics, using SPSS for Windows (Version 26.0; SPSS, Chicago, IL, USA). The magnitude of correlations was interpreted as (Harper et al., 2021): small (0.11–0.29), moderate (0.30–0.49), large (0.50–0.69), very large (0.7–0.89), and almost perfect (0.90–0.99). The value of *p* was set at 0.05 significance level.

Results

The kinematic and kinetic metrics measured from 5-m and 10-m HDA tests are shown in Table 1. The knee and ankle strength for both DL and NDL are shown in Table 2. All significant and large correlation coefficients between knee and ankle strength and 5-m and 10-m deceleration performance related metrics in DL and NDL are presented in Table 3.

Relationships between knee, ankle strength and 5-m deceleration performance

Significant and large correlations were found between eccentric KE in both the DL and NDL, as well as concentric KE at 60°/s in the DL, and TTS in the $HDA_{5\text{-m}}$ test (Table 3). In addition, concentric KE and APF at 60°/s, as well as eccentric KE in both the DL and NDL, were largely related to DEC_{avg} in the $HDA_{5\text{-m}}$ test (Table 3).

Relationships between knee, ankle strength and 10-m deceleration performance

Concentric at 60°/s and eccentric KE were significantly and largely related to DEC_{avg} and HBF in the $HDA_{10\text{-m}}$ test (Table 3). Moreover, only concentric KE at 60°/s in the DL had a significant and large correlation with HBP in the $HDA_{10\text{-m}}$ test.

***** Please insert Table 1-3 about here *****

Discussion and Implication

To our knowledge, this was the first study to investigate the relationships between knee and ankle strength and horizontal deceleration performance following a 5-m and 10-m sprints. The present conclusions partly align with the original hypothesis. There are significant and strong correlations between the eccentric and concentric relative PTs of the knee and horizontal deceleration performance following 5-m and 10-m sprint distances, while those of the ankle only have a significant and strong correlation with the metrics of 5-m horizontal deceleration performance. Specially, the concentric KE at 60°/s (5-m: r = -0.50 to -0.56; 10-m: r = -0.51 to -0.57) and eccentric KE at 30°/s (5-m: r = -0.50 to -0.61; 10-m: r = -0.50 to -0.63) PTs were mostly related to horizontal deceleration performance measured from the 5-m and 10-m HDA tests. Moreover, concentric APF in both the DL and NDL were significantly and largely related to 5-m but not to 10-m horizontal deceleration performance, which may suggest that shorter deceleration distances have unique ankle strength demands.

Previous research to date only has focused on knee strength and horizontal deceleration performance (Graham-Smith et al., 2018; Harper et al., 2021; Zhang et al., 2021). According to the study by Harper et al.(Harper, McBurnie, et al., 2022), rapid horizontal deceleration is characterized by short ground contact times, high impact ground reaction forces and loading rates, and insufficient lower-limb strength would result in reduced performance, increased risk of injury, and greater severity of muscle damage. Thus, it is evident that lower-limb strength plays a vital role in generating and attenuating braking force during rapid horizontal deceleration (Harper, McBurnie, et al., 2022). As such, gaining a more comprehensive understanding of how strength of the lower-limb joints (e.g., hip, knee, and ankle) contribute to horizontal deceleration performance is of critical importance. In this study, we observed that the concentric APF at 60°/s in both the DL (r = -0.53, $p < 0.01$) and NDL (r = -0.52, $p < 0.01$) were significantly and largely related to DEC_{avg} at 5-m HDA test, which highlighted the importance of APF strength in contributing to greater horizontal deceleration when deceleration is performed from shorter sprinting distances and lower sprinting speeds (Hewit et al., 2011). Research in the biomechanics of a 75° cutting task has also revealed that peak APF moment (r = 0.65, $p < 0.01$) is strongly associated with quicker times (Marshall et al., 2014), attributed to the efficient utilization of the stretch-shortening cycle during the braking phase of the deceleration steps (Green et al., 2011).

Interestingly, all ankle strength was not correlated to 10-m horizontal deceleration performance, but knee strength was still observed to be correlated with those metrics in the 10-m HDA test. This novel finding revealed that as sprint distance increases, the relative PTs of APF may have a diminishing impact on horizontal deceleration performance. One possible explanation was that the demands for braking and the strength that are required are primarily influenced by the approach velocity prior to deceleration. For example, the approach velocity in the 10-m horizontal deceleration test (6.56 ± 0.37 m/s) was around 20% greater than that attained during the 5-m horizontal deceleration test (5.16 ± 0.40 m/s). As a result, the contribution of ankle strength may decrease during the $HDA_{10\text{-}m}$ test, while knee strength may have a more important role during the braking phase. It should also be noted that ground contact time when braking from higher movement speeds is also shorter (McBurnie et al., 2022), therefore less time is available for torque production by the muscles around the ankle joint. It is plausible therefore, that the assessment of ankle strength at lower angular velocities may not reflect the fast strength required by these muscle groups. Even so, the importance of ankle strength should not be overlooked, as the analysis of enforced horizontal deceleration during sub-maximal runs has shown that the ankle-to-knee attenuates between 68 and 77% of the impact forces emanating from foot ground contact (Gageler et al., 2013). Stronger ankle muscles enable athletes to maintain postural balance and minimize the risk of injury (Han et al., 2015). More specifically, the soleus is the primary muscle contributing to APF torque generation during horizontal deceleration, helping to maintain the centre of mass behind the lead foot braking limb, thereby prolonging the time in which horizontal braking force can be applied (Mateus et al., 2020). Therefore, we suggest that exercising the muscles around the ankle (e.g., standing and seated calf raises) are useful supplementary strength exercises, which may in turn, help indirectly contribute to enhanced horizontal deceleration performance (Hall et al., 2018).

As expected, our results are aligned with previous studies that have investigated the correlations between knee strength and horizontal deceleration performance (Graham-Smith et al., 2018; Harper et al., 2021; Zhang et al., 2021). For example, Harper et al. (Harper et al., 2021) indicated that both DL and NDL concentric KE and KF strength at 180°/s had the highest correlations with horizontal deceleration ability (r = -0.76 to -0.78 and r = -0.54 to -0.55, respectively), with eccentric KE strength measured at 60°/sin both DL and NDL also having significant large correlations with horizontal deceleration time (r = -0.63 to -0.64) and distance to stop (r = -0.54 to -0.55) following a 20-m sprint. A similar conclusion was also observed in the study conducted by Zhang et al. who reported higher eccentric torque of KE measured at lower joint angular velocity had a large correlation to the maximum braking force (r = -0.61, p = 0.020) and impulse (r = -0.75, p = 0.002) required for a 20-m horizontal deceleration. This can be attributed to the leading leg being positioned ahead of the center of mass when the foot contacts the ground, during horizontal deceleration. At this precise moment, strength in the KE muscles will be required to resist the forward momentum of the body, which has been shown in previous research (Hewit et al., 2011; Lockie et al., 2014). However, it is worth noting that all relationships between concentric and eccentric KF strength and horizontal deceleration performance were non-significant in this study, which differs from the findings of Harper et al. (2018). According to the hypothesis by Zhang et al. (2021), KF strength may primarily contract in an “isometric” way during the braking phase. This explanation is plausible but needs further validation. Therefore, considering the findings of this study, it can be concluded that when horizontal deceleration is performed from shorter sprint distances, the strength of KE remains a crucial factor for rapid horizontal deceleration performance. Accordingly, strength and conditioning strategies that can increase both eccentric and concentric KE strength are important for better horizontal deceleration performance. Evidence from practical applications further suggested that, in addition to focusing on the enhancement of the KE strength, knee joint stability also should not be overlooked (Lehnert et al., 2018; Lehnert et al., 2017). Therefore, incorporating training exercises targeting the hamstring muscle group, such as Nordic curls, into daily routines seems essential. This approach is important for both acute and long-term training improvements in specific athletic performance and for injury risk prevention (Lehnert et al., 2017). In addition, although this study did not investigate it, the relationships between eccentric strength and hamstring-to-quadriceps strength ratio of the knee during high speeds (> 180°/s), considering the characteristics of short ground contact time and high eccentric load rates during deceleration, are definitely worth exploring (Stastny et al., 2018).

The present study has certain limitations. Firstly, the cross-sectional design prevented identifying causal relationships between the variables under investigation. As an example, our study found that the relative PTs of APF were significantly related to 5-m horizontal deceleration performance, but this does not mean that athletes can necessarily achieve better horizontal deceleration performance by improving their APF strength; this needs to be further confirmed by intervention studies. Secondly, the findings reported in this study may only apply to a similar population group; therefore, caution should be exercised when applying the results of this study to athletes in another competitive level or sports, as proficiency in motor performance may vary among different sporting populations.

Conclusions

The present study demonstrated that individuals with greater knee and ankle strength produced superior horizontal deceleration performance. Interestingly, the deceleration performance with different sprint distances may have different demands on the knee and ankle strength. Specifically, ankle strength is more crucial when decelerating from slower sprint velocities. At the same time, the significance of the knee joint becomes more pronounced as the approach velocity increases. Therefore, we suggest that athletes who frequently engage in short horizontal decelerations (~5m) during competition prioritize training to enhance their ankle and knee strength, with a specific focus on KE and APF muscle groups. On the other hand, improving knee strength may have a greater potential for enhancing the performance of athletes who frequently engage in decelerations performed from higher movement speeds and from longer sprint distances.

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Disclosure of interest statement

No potential conflict of interest was reported by the authors.

TABLE AND FIGURE LEGENDS

Figure 1. Visual Representation of the study design.

Table 1. The descript data of horizontal deceleration performance related metrics.

Table 2. Relative PTs (N·m/kg) of knee and ankle strength in dominant leg (DL) and non-dominant leg (NDL).

Table 3. Pearson's significant and large correlation results between knee and ankle strength and 5-m and 10-m deceleration performance related metrics in DL and NDL

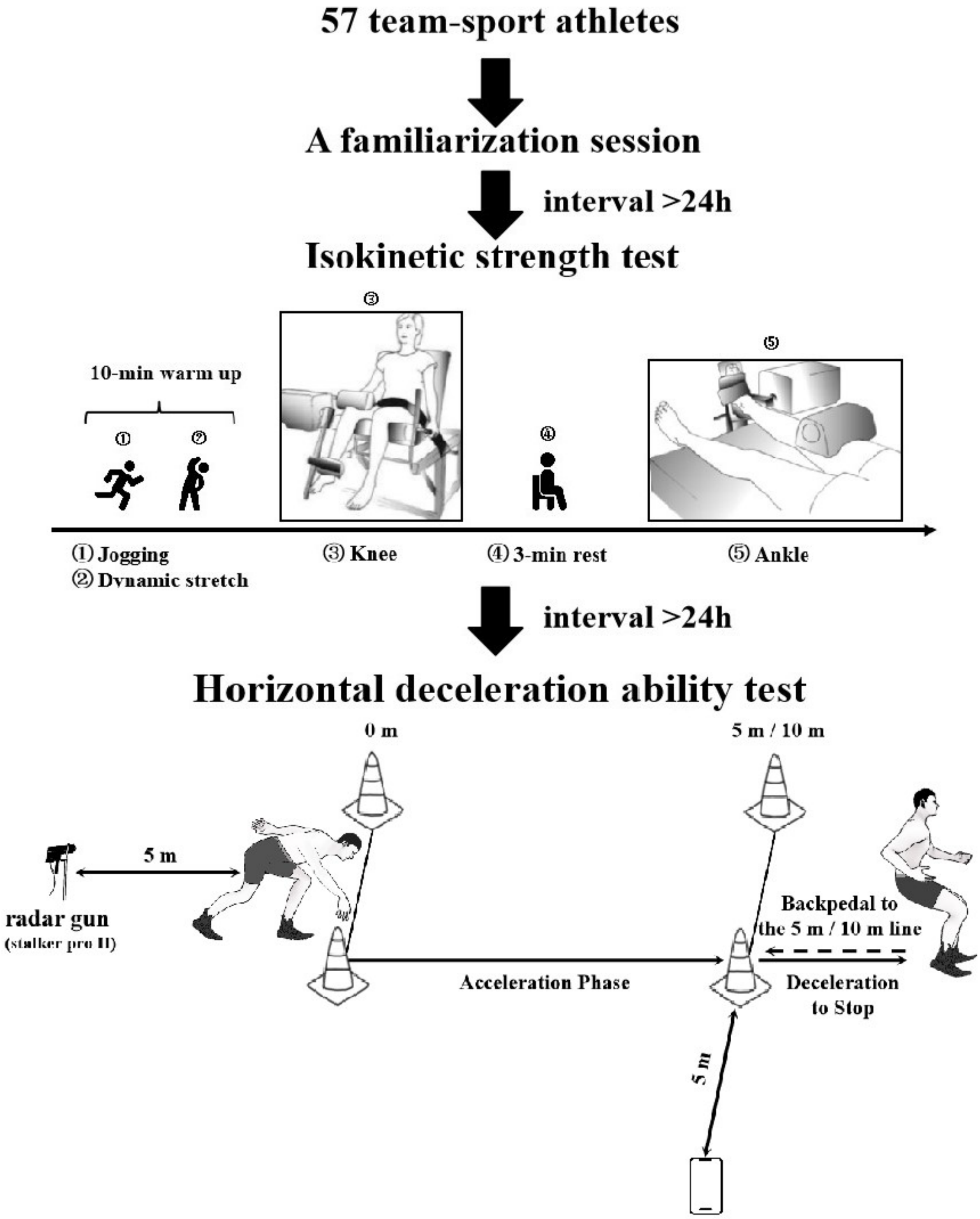

Figure 1. Visual Representation of the study design.

Table 1. The descriptive data of horizontal deceleration performance related metrics.

	DTS (m)	TTS (S)	DEC_{avg} (m/s^2)	HBF (N)	HBP (W)	HBI (N·s)
5-m	3.40	1.18	-3.97	-286.00	-880.53	329.89
	0.62	0.18	0.69	69.80	294.83	74.11
10-m	5.41	1.52	-3.90	-280.03	-1012.89	414.46
	1.23	0.30	0.77	67.05	292.56	90.78

Noting: DTS = distance to stop; TTS = time to stop; DEC_{avg} = average deceleration; HBF = horizontal braking force; HBP = horizontal braking power; HBI = horizontal braking impulse.

Table 2. Relative PTs (N·m/kg) of knee and ankle strength in dominant leg (DL) and non-dominant leg (NDL).

	DL			NDL		
	CON		ECC	CON		ECC
	60°/s	180°/s	30°/s	60°/s	180°/s	30°/s
KF	1.42 ± 0.34	1.31 ± 0.30	1.52 ± 0.51	1.32 ± 0.36	1.21 ± 0.35	1.58 ± 0.49
KE	2.42 ± 0.62	1.88 ± 0.45	2.53 ± 0.82	2.30 ± 0.59	1.74 ± 0.44	2.43 ± 0.75
ADF	0.34 ± 0.11	0.27 ± 0.07	0.58 ± 0.13	0.31 ± 0.12	0.25 ± 0.09	0.56 ± 0.28
APF	1.14 ± 0.37	0.73 ± 0.23	1.84 ± 0.67	1.18 ± 0.36	0.74 ± 0.22	1.94 ± 0.74

Noting: CON = concentric; ECC = eccentric; KE = Knee extensor; KF = Knee flexor; APF = ankle plantar flexor; ADF = ankle dorsiflexor.

Table3. Pearson’s significant and large correlation results between knee and ankle strength and 5-m and 10-m deceleration performance related metrics in both the DL and NDL

		Variable	Pearson's *r*	rating	*p* value
5-m	TTS	Ecc_{30}-KE-NDL	-0.50 (-0.69 to -0.27)	large	< 0.001
		Con_{60}-KE-DL	-0.50 (-0.69 to -0.28)	large	< 0.001
		Ecc_{30}-KE-DL	-0.50 (-0.68 to -0.26)	large	< 0.001
	DEC	Con_{60}-KE-NDL	-0.51 (-0.68 to -0.27)	large	< 0.001
		Ecc_{30}-KE-NDL	-0.61 (-0.74 to -0.43)	large	< 0.001
		Con_{60}-KE-DL	-0.56 (-0.71 to -0.36)	large	< 0.001
		Ecc_{30}-KE-DL	-0.54 (-0.69 to -0.35)	large	< 0.001
		Con_{60}-APF-NDL	-0.52 (-0.71 to -0.29)	large	< 0.001
		Con_{60}-APF-DL	-0.53 (-0.70 to -0.33)	large	< 0.001
10-m	DEC_{avg}	Con60-KE-NDL	-0.50 (-0.65 to -0.32)	large	0.002
		Ecc30-KE-NDL	-0.63 (-0.75 to -0.47)	large	< 0.001
		Con60-KE-DL	-0.57 (-0.71 to -0.40)	large	< 0.001
		Ecc30-KE-DL	-0.61 (-0.74 to -0.45)	large	< 0.001
	HBF	Con60-KE-NDL	-0.51 (-0.70 to -0.29)	large	< 0.001
		Ecc30-KE-NDL	-0.50 (-0.66 to -0.32)	large	< 0.001
		Con60-KE-DL	-0.52 (-0.67 to -0.37)	large	< 0.001
	HBP	Con60-KE-DL	-0.51 (-0.63 to -0.34)	large	< 0.001

Noting: CON = concentric; ECC = eccentric; KE = Knee extensor; KF = Knee flexor; APF = ankle plantar flexor; ADF = ankle dorsiflexor; TTS = time to stop; DEC_{avg} = average deceleration; HBF = horizontal braking force; HBP = horizontal braking power.

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