Strength and Conditioning Recommendations for Female Athletes: The Gaelic Footballer

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Strength and Conditioning Recommendations for Female Athletes: The Gaelic Footballer

John David Duggan, MSc, CSCS,[1,2] Karen Keane, PhD,[1] Jeremy Moody, PhD,[2,3] Paul J. Byrne, PhD, CSCS,[4] Shane Malone, PhD, CSCS,[5] Kieran Collins, PhD,[5] and Lisa Ryan, PhD[1]
[1]Department of Sport, Exercise & Nutrition, School of Science & Computing, Atlantic Technological University, (ATU), Galway Campus, Galway, Ireland; [2]School of Sport and Health Sciences (Sport), Cardiff Metropolitan University, Cyncoed Campus, Cardiff, United Kingdom; [3]School of Physical Education and Sports, Nisantasi University, Istanbul, Turkey; [4]Department of Health and Sport Sciences, South East Technology University, Carlow Campus, Carlow, Ireland; and [5]Gaelic Sports Research Centre, Technological University Dublin-Tallaght Campus, Dublin, Ireland

ABSTRACT

Ladies Gaelic football (LGF) is a traditional, amateur Gaelic sport played by female athletes. LGF is an invasion-based field sport involving high-intensity, intermittent match play. There is currently a paucity of research on intercounty (elite level) LGF despite a growing interest in the male version of the game. This article aims to provide strength and conditioning recommendations for LGF with particular focus on the intercounty level of play. Recommendations within this article include a needs analysis, female injury epidemiology, physical and physiological demands, female physiology, strength training, and specific conditioning guidelines based on the sport. Additional recommendations include an LGF-specific testing battery, a proposed periodization cycle, and sports-specific speed and agility development.

INTRODUCTION

Ladies Gaelic football (LGF) is one of the most popular amateur, field-based female sports in Ireland governed by the Ladies Gaelic Football Association (LGFA). There are currently over 200,000 registered members, which is 40% more than women's soccer in England (83). It is an intermittent, multidirectional invasion-based sport where the game's component principles (defense and attack) are similar to other invasion-based sports (Australian football and soccer). The primary objective of LGF is to displace the defense and goalkeeper by sending the ball through the opponent's goalposts (similar to rugby goalposts), either below the crossbar for 3 points (goal) or above for a point (42). In addition, since 2020, when teams are awarded a 45-m free kick, teams are awarded 2 points when the kick goes over the bar (83).

Address correspondence to John David Duggan, john.duggan@atu.ie.

A team comprised 15 players, with the option of using 5 substitutes (127). Each team includes a goalkeeper, 2 lines of 3 defensive players (full back and half back), 2 midfielders, and 2 lines of attacking players (half forward and full forward) (Figure 1). LGF matches comprised 2 30-minute halves and are played on a rectangular pitch, 144 m in length and 88 m in width (96). The primary skills of LGF include high catching, handling, kicking over short and long distances, solo running with the ball, passing the ball by hand, blocking, and intercepting (127). The game's physical demands include high-speed running, accelerations, decelerations, and change of direction-based movement (96).

Each year, there are 2 major competitions at the intercounty (elite) level in LGF, the National League and the All-Ireland Championship. The National League occurs from January to March, whereas the All-Ireland Championship occurs from May to July. During the competitive phases of the season, LGF players may compete in up to 18 matches depending on their team's progress through each competition. Despite the amateur ethos of Gaelic games, intercounty LGF players balance full-time employment with 5 technical and tactical sessions per week and 2 resistance training-based sessions each week (43).

KEY WORDS:
ladies Gaelic football; Gaelic games; strength; power; periodization; athletic performance; female physiology; testing; injury prevention

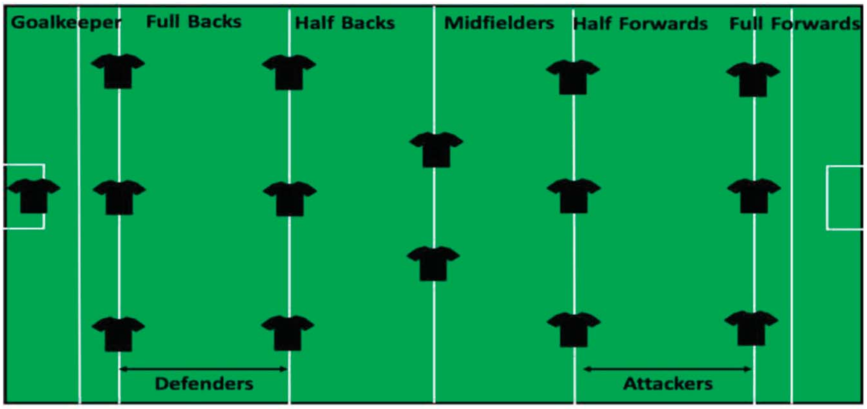

Figure 1. Positional layout for Gaelic games.

As in many research areas, sports science research lacks female-specific inquiries, leading to the misapplication of findings from male to female athletes (33). This article aims to provide practitioners with recommendations on strength and conditioning (S&C) for intercounty LGF players. These practical recommendations include a needs analysis, biomechanical demands, physiological demands, injury epidemiology, considerations for LGF players, development of biomotor qualities, testing battery, and practical applications specific to LGF players. The recommendations within this article will focus on female Gaelic team sports where possible. Comparisons will be made with similar female team sports and male Gaelic football when appropriate.

NEEDS ANALYSIS

The purpose of a needs analysis is to assist LGF practitioners in designing and implementing effective program design, the appropriate selection of tests within a testing battery, and the specific injury epidemiology of the sport. This process enables the practitioner to design training programs based on the specific positions in the sport and facilitate optimal performance. In LGF, more successful teams use their superior possession to create more scoring opportunities and force the opposition into turnovers/unforced errors (83). Furthermore, LGF has more goals and scoring frequency per min than the male game (83). Winning teams in LGF also demonstrate greater productivity, scoring 3.51 times per 10 possessions, as opposed to the losing team's 2.49 times per 10 possessions (83). The biomechanical demands of Gaelic football include jumping, landing, sprinting, acceleration, deceleration, multiplanar movements, directional changes, and evasion through planting and cutting actions (104). The movement demands specific to LGF include the punt kick, instep kick, inside kick, hand pass, pick up, and solo run (11) (Table 1). This highlights the importance of aerobic capacity, speed, and other physical biomotor qualities for successful performance in LGF. S&C practitioners can use this information to increase the specificity in their programming and potentially reduce injury risks in LGF players.

PHYSIOLOGICAL DEMANDS

Limited data exist on the performance profiling of LGF. A player's aerobic capacity substantially contributes to maximal and submaximal performance in female and male Gaelic games match play (42). A well-developed aerobic system is required for players to adequately recover between periods of play and between maximal and submaximal work bouts reducing the likelihood of making decisions under a fatigued state (143). The average relative maximal oxygen consumption values for successful ladies Gaelic footballers tend to be high, supporting the concept that aerobic power greatly contributes to playing the game. Keane et al. (80) reported a mean relative maximal oxygen consumption value of 49.9 ± 4.2 $mL \cdot kg^{-1} \cdot min^{-1}$ and 42.0 ± 6.8 $mL \cdot kg^{-1} \cdot min^{-1}$ for intercounty LGFs and elite collegiate players, respectively. Intercounty LGF aerobic capacity values are comparable with elite female soccer players (51.9 ± 5.1 $mL \cdot kg^{-1} \cdot min^{-1}$) and female Australian football (50.4 ± 6.9 $mL \cdot kg^{-1} \cdot min^{-1}$) players (39,163).

The use of heart rate (HR) measurement has been suggested to be an indirect measure of exercise intensity in female team sports (44). In male U18 GF, HRpeak was observed as $81.6 \pm 4.3\%$ during 60 minutes of match play (36). In addition, in adult male GF, mean HRpeak values were reported as 192 ± 9 $b \cdot min^{-1}$ and average HR as 162 ± 10 $b \cdot min^{-1}$ (54). The application of HR monitoring allows LGF S&C practitioners to replicate the game's demands in training and stimulate an individualized aerobic stimulus (44). Previous research suggested that spending 7–8% of training time at >90% HRpeak would provide adequate stimulus for maintaining/increasing aerobic fitness across a season (22). LGF S&C practitioners could use this information to manipulate the constraints within a modified game to elicit a specific physiological adaptation while developing the technical and tactical elements (137).

PHYSICAL DEMANDS

Owing to the increased professionalization of female team sports, there has been an increase in research analyzing the physical demands of invasion-based field sports (24,152). Despite the plethora of global positioning system (GPS) research in the male versions of Gaelic team sports (98,107), research in LGF is still embryonic. The running performance of elite intercounty LGF has recently been investigated, reporting that players covered $7,319 \pm 1,021$ m

Table 1
Biomechanical movements specific to ladies Gaelic football (100,148)

Movement	Definition
In play (with football)	
Kick pass	Striking action made with the foot in attempt to transfer the football to a teammate
Inside kick pass	Striking action made with the instep (medial) of the foot when shooting or passing
Outside kick pass	Striking action made with the outside (lateral) of the foot when shooting or passing
Hand pass	Striking action made with the hand/fist in attempt to transfer the football to a teammate
Method of travel	
Solo	When a player transfers the football onto their foot and the ball returns to hand, allows the player 4 more steps
Bounce	When a player bounces the ball into the ground and the football returns to hand, allows player 4 steps with the ball. Two subsequent bounces are deemed foul play. Players must alternate between a solo and a bounce to travel with the football
Methods of possession	
Pick up	When the football is picked up off the ground when stationary or when rolling/moving
Catch	Football is caught anywhere below the head, with one or 2 hands to control the ball for next action
High catch	Football is caught above the head, with one or 2 hands to control the ball for next action
Player possession	When the player has control of the football with their hands or feet
Team possession	When one team have possession of the football
Tackle	When the defending player tries to dispossess the football attacking player in possession of the ball to turn over the possession of play
Turnover	When the ball is transferred from one team to the other

in total distance and 1,547 ± 432 m in high-speed running (HSR) distance during match play (96). Half backs, midfielders, and half forwards covered greater distances than full backs and full forwards (96). Furthermore, there were significant reductions in HSR and accelerations and decelerations across halves of play (96).

High-intensity activities need to be considered to gain a more insightful overview of match demands (44). In elite LGF, the middle 3 positional lines covered the greatest high speed and very high running distances compared with the other positions (96). Further research is necessary for LGF to aid practitioners in replicating the demands of the game in training and to provide an optimal conditioning stimulus.

Accelerations and decelerations are both important components of match play in female team–based sports, contributing to increased mechanical stress levels and overall biomechanical load, which can significantly affect performance potential (62). In elite LGF, players completed 42 ± 6 accelerations ($\geq$3 $m \cdot s^{-2}$) and 53 ± 9 decelerations ($\leq$3 $m \cdot s^{-2}$) during the competitive match play (97). The development of enhanced physical attributes may enable LGF players to better tolerate high-intensity match play, which may provide greater resilience to sports-specific injuries (42). This information can assist LGF S&C practitioners in informing the training process by quantifying the game's physical demands, objectifying training prescriptions, monitoring individual athletes' training load, and assisting with return to play/performance protocols. Specific practical applications include replicating percentage of game demands using $m \cdot min^{-1}$, enabling practitioners to develop a deeper understanding of training drills when replicating specific game intensities. Finally, it enables practitioners to differentiate between extensive and intensive training units within the weekly microcycle.

CONSIDERATIONS FOR WORKING WITH FEMALE GAELIC FOOTBALLERS

THE MENSTRUAL CYCLE

From 13–50 years of age, females experience a circamensal rhythm called the menstrual cycle (MC), whereby large fluctuations in estrogen and progesterone are observed (110). A regular MC lasts an average of 28 days (ranging from 21 to 45 days) and consists of 2 main phases, the follicular and luteal phases. As females train and compete during all stages of their MC, the potential impact on injury and performance should be considered (48,110).

The MC is a modifiable injury risk factor in female athletes, as cyclical fluctuations in reproductive hormones influence musculoskeletal tissues such as muscle, tendon, and ligament (73). Reports show that female team sport athletes are 3–6 times more likely to obtain an anterior cruciate ligament (ACL) injury than their male counterparts (113). However, there is disagreement about the influence of sex hormones on female ACL injury rates (55). Recently, Martin et al. (106), reported that injury rates were 47 and 32% greater in the late follicular phase than in the early follicular and luteal phases. However, caution is needed in the interpretation of these studies as the methodological process (small sample size), ecological validity, and terminology (phase definition and confirmation) may have affected the original results (48).

Previous research on contractile strength during the MC has led to contradictory results (81,133). Recent research has suggested that a resistance training stimulus in the follicular phase during the MC could intensify estrogen's anabolic effect on muscle (84,151). It has also been theorized that estrogen could augment myosin function benefiting force production (91). Furthermore, during eccentric exercise, estradiol could cause a myogenic activation of the satellite cells which can assist with muscle repair and regeneration during the MC (60,114). Additional research has also advocated the periodization of strength training between the follicular and luteal phases to augment anabolic effects during the MC in trained athletes (146,160).

Further research advocates using combined strength and power training throughout the MC (84). A meta-analysis suggested that strength-related biomotor qualities were negligibly affected by the MC, and there was no need to adjust the MC phase to enhance performance (8). Some research has been conducted in the area with conflicting findings to date and no consensus on whether performance is affected by MC phases (47). A meta-analysis reported that exercise performance might be trivially reduced during the early follicular phase of the MC compared with other phases (110). However, there was large between-study variation, and much of the research was rated low quality. A recent systematic review found that many studies investigating the link between MC phases and performance in elite female athletes are cross-sectional in design, conducted in a laboratory setting, and/or assessed subjectively through questionnaires. This makes it difficult to extrapolate the findings (111).

Two recent studies exploring athletes' experiences and perceptions of the MC in relation to training and performance highlighted individual responses with variations in physiological and psychological symptoms as well as impact on training and competition (17,61). As such, it is recommended that players/practitioners track MCs and symptoms to improve awareness of any phase-related effects on individual performance, with a view to consideration of management strategies (50,130). Female athletes should be integral in decision-making when managing individual MC symptoms to minimize negative impacts and maximize performance outcomes (13,48).

HORMONAL CONTRACEPTION

Many hormonal contraceptives are available, including oral contraceptives (OCs), implants, injections patches, and intrauterine systems (47). OCs seem to be the most popular, with Martin et al. (105) reporting that 49.5% of 430 elite female athletes surveyed from 24 different sports were currently using OCs and 69.8% using OCs previously. This study also revealed that female athletes reported the ability to regulate menstruation during competition/training as a positive effect of OC consumption (120). Similar results were also reported in elite female soccer players. 86% of the cohort stated they used OCs to predict or control their MCs and for pain management (122).

There has been conflicting evidence on OC consumption and athletic performance throughout the literature (47,121). A recent study analyzing the effects of eccentric exercise suggested higher creatine kinase values during the withdrawal phase. However, there were no differences in countermovement jump performance and muscle soreness between OC phases (130). In female team handball athletes, knee extensor, flexor isokinetic, and isometric strength performance were not affected by the different phases of OC consumption (126). In female team sports athletes (n = 10) who were taking the OC pill, reactive strength varied significantly throughout the OC cycle (178 ± 40 cm s^{-1} versus 158 ± 29 cm s^{-1}), especially during the withdrawal phase (125). The use of OC during a 10-week progressive overload resistance-based training program established a greater increase in muscle mass and a significant increase in type 1 muscle fiber cross sectional area compared with the non-OC control group. However, using the OC did not significantly increase muscular strength (37).

Moreover, OC usage increased GH responses acutely after heavy, resistance-based exercises (87). The most recent meta-analysis reported that OC use might result in slightly inferior exercise performance compared with naturally menstruating women. However, any effect is most likely trivial (47). Further research is necessary to determine whether the use of OC has positive, negligible, or detrimental effects on female athletic performance (124). From a practical perspective, an individualized approach should be taken based on each athlete's response to OC use.

INJURY EPIDEMIOLOGY

Owing to the intermittent, multidirectional nature of LGF, players are inherently at the risk of injury (117,129). It was reported that 58% of injuries in club (subelite) LGF involved the lower limb and 24% involved the upper limb (35). The most common lower-limb injuries involved the knee (33%), followed by the hamstring (20%) and ankle (20%) (10,35). When considering collegiate LGF, lower-limb injuries were the most prevalent (67.09%) and caused the greatest injury burden (276.17 days absent per 1,000 hours) (120). Hamstring injuries were the most common (21.52%), followed by knee (12.66%), quadriceps (11.39%), and ankle (10.31%). Moreover, knee injuries cause the greatest injury burden (106.46 days absent per 1,000 hours) (Table 2) (120).

Table 2
Injuries in collegiate ladies Gaelic footballers (120)

Region	Number	% (95% CI)	Injury burden[a] (95% CI)
Head/neck	10	12.66 (12.57–12.75)	31.74 (26.96–37.37)
Head	8	10.13 (10.05–10.21)	27.55 (23.12–32.83)
Face	1	1.27 (1.24–1.29)	3.53 (2.16–5.76)
Eye	1	1.27 (1.24–1.29)	0.66 (0.21–2.05)
Upper limb	11	13.92 (13.83–14.02)	55.10 (48.68–62.37)
Shoulder	1	1.27 (1.24–1.29)	1.32 (0.59–2.94)
Elbow	2	2.53 (2.49–2.57)	9.26 (6.84–12.53)
Forearm	3	3.80 (3.75–3.85)	21.38 (17.52–26.09)
Wrist	2	2.53 (2.49–2.57)	18.73 (15.15–23.17)
Hand and fingers	3	3.80 (3.75–3.85)	4.41 (2.84–6.83)
Trunk	3	3.80 (3.75–3.85)	7.93 (5.72–11.00)
Lower back	1	1.27 (1.24–1.29)	4.41 (2.84–6.83)
Pelvis	1	1.27 (1.24–1.29)	1.54 (0.74–3.24)
Buttocks	1	1.27 (1.24–1.29)	1.98 (1.03–3.81)
Lower limb	53	67.09 (66.89–67.29)	276.17 (261.30–291.90)
Hip	2	2.53 (2.49–2.57)	9.26 (6.84–12.53)
Groin	2	2.53 (2.49–2.57)	7.05 (4.99–9.97)
Quadriceps	9	11.39 (11.31–11.48)	31.30 (26.55–36.89)
Hamstrings	17	21.52 (21.40–21.63)	66.12 (59.05–74.05)
Knee	10	12.66 (12.57–12.75)	106.46 (97.37–116.39)
Shin	3	3.80 (3.75–3.85)	12.78 (9.88–16.54)
Calf	1	1.27 (1.24–1.29)	1.10 (0.46–2.65)
Ankle	8	10.31 (10.05–10.21)	39.89 (34.49–46.15)
Foot and toes	1	1.27 (1.24–1.29)	2.20 (1.19–4.10)
Others	2	2.53 (2.49–2.57)	—

[a]Days per 1,000 hours.

Reports show that female team sports athletes are 3–6 times more likely to obtain an ACL injury than their male counterparts (113,161). Furthermore, anatomical and hormonal aspects could contribute to the high incidence of ACL injuries in female athletes, including joint laxity, limb alignment, intercondylar notch proportions, ligament size, and hormonal fluctuations (70,72). Gender-specific neuromuscular deficits have been identified in female athletes and include hamstring injuries, coronal plane knee control (ligament dominance), and core dysfunction (trunk dominance) (73). Research demonstrates that females have reduced knee flexion angles, increased knee valgus angles, increased quadriceps activation, and decreased hamstring activation compared with male athletes (46,94). Such altered motor control strategies may lead to an increased load on the ACL, which could contribute to the increased risk of injury in female athletes (72). These neuromuscular deficits are linked with the potential inability to efficiently dissipate ground reaction forces (GRFs) and the reduced control of their center of mass (142).

Neuromuscular changes leading to suboptimal biomechanics, such as increased knee valgus on ground contact, can exacerbate symptoms (72). Most ACL injuries have been reported to come from noncontact mechanisms (deceleration, change of direction, and unplanned landing) (72,73). Therefore, alternative training modalities are valuable (resistance training, plyometrics, and development of athletic motor skill competencies) to support structural components, improve neuromuscular control of the knee joint, and possibly reduce the incidence of noncontact ACL injuries in field-based sports (119). LGF S&C practitioners need to design athletic motor skill competencies which develop optimal knee positions and mimic movement patterns specific to the demands of their sport (147).

DEVELOPMENT OF PHYSICAL BIOMOTOR QUALITIES

LGF requires the players to have well-developed biomotor skills, such as strength, power, reactive strength, speed, agility, flexibility, balance, and endurance. The variety of biomotor qualities requires focus from both a resistance training and on-field conditioning perspective. Owing to the unique positional demands of LGF, practitioners may need to prioritize certain biomotor qualities throughout the season, ensuring players are prepared for the physical demands of training and match play. Overall, the role of the LGF S&C practitioner is to reduce the likelihood of injury and improve the physical performance of individual athletes through S&C modalities with sound scientific-practical application.

Strength. In LGF, strength, endurance, mobility, and speed are all essential biomotor qualities of the game (108). The development of muscular strength and power is an important attribute in LGF players, enabling them to tolerate the physical demands of the sport (80). Strength training can elicit the following neurological adaptations in female athletes: increasing the number of sarcomeres in series, adaptation of the fiber type, and modification of pennation angles, all of which have the potential to increase force production (29,74). From a morphological perspective, strength training in LGF athletes can elicit adaptations, including increased cross-sectional area of muscle fibers, preferential recruitment of type II fibers, and a shift in fiber subtype expression (type IIX–IIA) (28,86).

In female-based team athletes, high levels of strength are correlated with superior vertical jump, sprint, and change of direction speed performance (141). Faster female athletes can produce greater vertical force and eccentric and isometric strength capacity during a change of direction task, thus emphasizing the importance of strength development in invasive-based sporting tasks (141). The relative 1 repetition maximum back squat strength for experienced female athletes has been suggested as >1.6 body weight, with athletes below this ratio potentially more susceptible to lower-extremity injuries (21). It has been hypothesized that once an athlete reaches the optimal ratio of back squat relative strength, there may be a plateau of diminishing returns. Other more advanced strength training modalities will have to be used to elicit further physiological adaptations (144).

There is a plethora of research to demonstrate the efficacy of resistance training female athlete populations to enhance performance and reduce injury risk factors (71,121). Furthermore, increased muscular strength for athletic performance has been advocated by Suchomel et al. (144,145), who suggest that strength correlated with the rate of force development (RFD), mechanical power output, and sports-specific movements (running, jumping, and striking) as well as increased ability to perform on-field sports-specific skills.

Lower-body strength in male GF players was strongly correlated with 10-m and 20-m sprint times, repeated sprint ability, and enabled them to tolerate weekly spikes in training load (95). It was also demonstrated in male club level GF that players with a higher level of lower-body strength could tolerate higher mechanical loads during match play and had reduced postmatch muscle damage (38). Therefore, greater muscular strength can contribute to athletes' superior performance during sports-specific tasks and reduce the risk of injury (144,145). Strength training programs for LGF players, which include weightlifting, ballistic, complex training, and plyometric movements, would likely enhance neural drive, neural activation rates, and intermuscular coordination (42). The possible adaptations of using strength training modalities include the individual ability to increase RFD by enabling the female athlete to generate more force in less time (28,61). It was demonstrated that females who engaged in a 20-week, multijoint, strength-based training improved strength neural adaptations, ($p < 0.05$) with no change in the muscle cross-sectional area (56). It has also been suggested that chronic resistance training in females led to increased biological activity of circulating growth hormone (9,85). Advanced training methods, such as complex training, have improved athletic capabilities in female athletes with a high training age (31). For specific LGF strength development guidelines, see Figure 2.

Power. The ability for athletes to achieve technical competency requires them to perform specific motor skills as quickly as possible with a relatively high degree of force production (29). Sporting actions in team-based sports, including LGF, generally occur in <0.3 seconds. Therefore, it is important to train power (the ability to produce force at high and low velocities) across a variety of loads (154) (Figure 1). A plethora of different training modalities can be used to increase power (ballistic, weightlifting, and stretch-shortening cycle [SSC] type activities) in LGF (58). The ability of an athlete to produce force over a diverse range of velocities through manipulation of the force-velocity curve theoretically produces greater improvements in maximal power output. It enables a greater transfer effect to athletic performance (30,58).

Ballistic training refers to exercises in which the athlete can bypass any deceleration phase to accelerate throughout an entire range of motion until the point of projection (take-off or release) (29,30). Loaded and unloaded training modalities (squat jumps, weightlifting derivatives, and medicine ball throws) have been advocated to increase maximal power output and athletic movement qualities (93). This training can elicit advantageous training stimuli, including increased RFD, by augmenting neural activation and increasing intra and interneuromuscular coordination (28,30). These ballistic-type movements share kinetic and kinematic similarities with sporting movements such as sprinting and jumping, which have postulated to transfer to sports performance (1,28). In addition, these ballistic-type modalities have been advocated to enable female athletes to produce higher forces and velocities

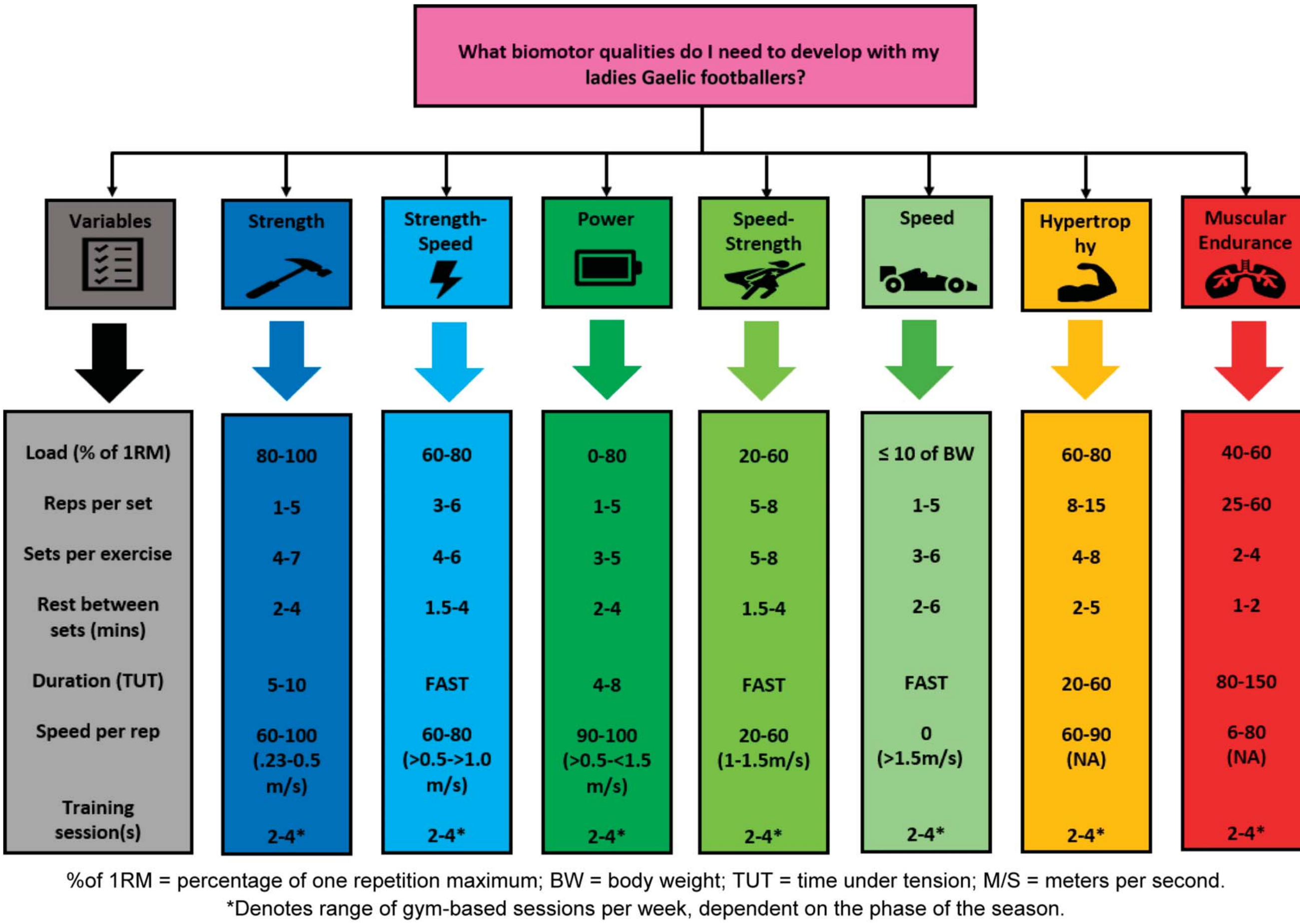

Figure 2. Biomotor quality development guidelines for LGF players. Based on data from Ref. (140). % of 1RM = percentage of 1 repetition maximum; BW = body weight; M/S = meters per second; TUT = time under tension. *Range of gym-based sessions per week, dependent on the phase of the season.

(28). For specific LGF power development guidelines, see Figure 2.

Plyometrics. Plyometric activities use a fast SSC using modalities including, but not exclusive to, high-velocity jumping or rebounding exercises (103). The SSC consists of an eccentric contraction (rapid stretch), an amortization phase (isometric period), and an immediate concentric muscle contraction (155). This mechanism takes advantage of the neural and the musculo-tendon arrangement to produce maximal force quickly by preactivation and release of elastic energy produced (9). The SSC can be characterized as fast and slow SSC. A fast SSC consists of a short GCT (<0.25 ms) and smaller angular displacements observed in depth jumps, whereas a slow SSC consists of a longer GCT (>0.25 ms) with larger angular displacements observed in countermovement jumps (136,155). A caveat of this arbitrary dichotomy is that it may not differentiate the stress imposed on individual athletes.

In collegiate LGF players, a reactive strength index of 1.22 ± 0.47 has been reported, suggesting that LGF players need to develop their SSC capacity further (26). To assist LGF players developing their SSC capacity, previous meta-analyses demonstrated that plyometric jump training is effective as a means to improve vertical jump height in female soccer players and that long-term (<10 weeks) plyometric training is effective in improving vertical jump performance in female athletes (123,142). Specific movements that facilitate fast and slow SSC capabilities will increase musculotendinous stiffness and potentially enhance and maximize power output in explosive movements (162). It has been suggested that combining plyometric or ballistic movement efforts with other resistance training methods (complex training) can lead to enhanced performance as opposed to plyometric training alone (31). Moreover, another key factor that should be considered is the athlete's training status when designing a plyometric training program. Athletes with a low training age should be exposed to low-intensity plyometric progressions with adequate volume and progression as they become more proficient (144). For specific LGF plyometric development guidelines, see Figure 2.

Speed. Speed is a desirable attribute associated with successful sporting performance (66). Rapid acceleration and sprinting are important to allow LGF players to reach the ball before the opposition (127). Tucker and Reilly (153) reported mean 30-m sprint times among LGFs to be 5.2 ± 0.2 seconds. Linear sprinting can be broken down into 3 distinct phases, acceleration, transition, and maximum velocity phases (75). Acceleration is an important attribute in all field-based sports involving locomotion. During the acceleration phase, athletes must increase the degree of horizontal propulsive force to overcome inertia, reduce GCT, increase stride length, and increase power output and speed (34). Technical development and speed training could improve acceleration and top-end linear velocity, especially for players in the wide defensive and attacking-based positions (63). The development of both acceleration and high-speed running mechanics can develop stride length and decrease GCT, while optimizing ground reactive forces and decreasing injury rates (158). Faster athletes can produce a greater vertical impulse in a shorter GCT (158). A further goal of maximal velocity sprinting is to achieve a high stride frequency combined with an optimal stride length (159). For injury, sprinting is a common mechanism of injury in LGF (120,150). In elite LGF, it was reported that players accumulated 630 ± 287 m of very high-speed running distance and reached a maximal velocity of 25.8 ± 1.48 $km \cdot h^{-1}$ during competitive match play (96). These data may assist LGF S&C practitioners in improving acceleration and maximal velocity mechanics, improving performance, and reducing the risk of posterior-chain injuries (57). Furthermore, to mitigate against potential hamstring injuries during the terminal swing phase of sprinting, practitioners are recommended to focus on a multifactorial approach, which includes a balanced approach to the development of a healthy hamstring, including slow, high-load eccentric contractions at both the proximal and distal end of the hamstring (12), as well as the muscle belly itself with the development of efficient maximal velocity sprinting mechanics using front-side mechanics drilling constraints (112). In conclusion, LGF athletes must be exposed to adequate maximal velocity sprinting (>90% of their maximal velocity) throughout the season, which may reduce hamstring injuries (95). Please see Table 5 for specific LGF speed recommendations.

Agility. LGF players must accelerate, decelerate, stop, start, and change direction (COD) at various speeds (80). The literature shows that female team sport athletes use multidirectional movements between 500 and 3,000 times during a game or once every 2–4 seconds (149). In male GF, reports show that players complete 1,899 COD-based movements in a game with most COD actions being ≤90° (148). Players rarely sprint in straight lines without having to stop or change direction. Suppose a female athlete cannot move effectively in an open, chaotic environment. In that case, they will be unable to apply their technical skills to the tactical requirements of the game.

Agility is the ability of a rapid whole-body movement, which involves a COD in response to a stimulus (139). Agility has 2 components, a COD speed component and a perceptual decision-making component (139). The plant phase in COD movements surpasses the magnitude of GRFs of acceleration and the maximal velocity phase of sprinting (141). This reinforces the use of traditional strength training to enhance the athlete's capability to produce and handle large GRFs (144). Greater eccentric strength is associated with faster COD performance, as stronger athletes can decelerate more rapidly during the penultimate step from faster approach velocities (141). However, the development of perceptual/decision making components (visual processing, pattern recognition, perceptual awareness, and timing) of agility is also essential for the individual athlete to master the complex, dynamic movement patterns specific to field-based invasion sports (90). In conclusion, the development of both reactive and nonreactive components of agility is fundamental. It exists in perpetuity along a continuum based on the individual needs of each LGF player. Please see Table 5 for specific LGF agility recommendations.

CONDITIONING

Effective conditioning is an important aspect of LGF players enabling players to meet and tolerate the demands of the game (42). It has been suggested that poor aerobic fitness was one contributing factor to increasing the likelihood of injuries in elite male GFs (40). Furthermore, enhanced physical conditioning may facilitate positive physiological adaptations including augmented metabolic clearance, decreased neuromuscular fatigue, and a greater tolerance to eccentric loading during GF match play (38). A well-developed aerobic performance capacity can enable female team sport players to maintain higher performance levels in games (79). It is important that practitioners incorporate physical, technical, and tactical subprinciples to maximize training time availability, especially in an amateur LGF setting (99). The utilization of high-intensity interval training (HIIT) has become a popular training modality to effectively condition female team sport athletes (15,16). HIIT involves the utilization of repeated short to long repetitions of high-intensity exercise with recovery periods interspersed throughout the selected HIIT modality (16). The agile nature of HITT can allow LGF S&C practitioners to elicit specific physiological, neurological, and morphological adaptations to meet the desired conditioning objectives of the game (41). Practitioners can manipulate up to 9 different variables when using HITT modalities including work interval intensity and duration, rest interval intensity, exercise modality, repetitions, series, and recovery between series (15,16). The various HIIT types enables a higher percentage of $\dot{V}O_2$max to be reached, while also increasing blood lactate and associated byproducts (H^+ ions), which can elicit improvements in both aerobic and anaerobic energy systems (i.e., increased $\dot{V}O_2$max, lactate threshold, and buffering capacity) (89). In addition, neuromuscular adaptations such as the increased activation of type IIa muscle fibers occur through manipulating the various HIIT types (5).

HIIT can also enable practitioners to individualize exercise intensity through various different traditional laboratory and field-based testing modalities (15,16). One such field-based method is the 30-15 intermittent fitness test (30-15_{IFT}) in which intensities can be prescribed based on the final percentage velocity (% vIFT) reached during the test (14,19). The 30-15_{IFT} was developed to elicit HRmax and $\dot{V}O_2$max and offer quantities for anaerobic speed reserve (ASR), accelerations, and decelerations abilities (78). The ASR is the difference between an individual athlete's maximal velocity and their v$\dot{V}O_2$max (also known as maximal aerobic speed). This is considered a combination of both maximal aerobic and anaerobic energetic capacities (134,135). A higher ASR reduces the relative intensity of exercise which causes lower anaerobic energy system utilization and reduces the impact of peripheral physiological disturbances (decreased accumulation of fatigue inducing metabolites such as H^+ and Pi) (18). The ASR can enable LGF S&C practitioners to create individual high-intensity locomotive profiles to individualize training load demands and more accurately prescribe conditioning intensities (20,63). The ASR can also be used as a proxy measure to prescribe supramaximal HIIT intensities (64,134). The 30-15_{IFT} is potentially appealing to LGF S&C practitioners as it is inexpensive, enables the evaluation of entire squads, time effective, and requires minimal equipment (32). The utilization of an 8-week HIIT program in female soccer players led to an increase in $\dot{V}O_2$max values ($p = 0.015$) compared with a traditional endurance-based program (23).

HIIT can be classified into 5 different conditioning types, long, short, and sprint-interval training (LI-T, ShI-T, and SIT); repeated sprint training, referred to as repeated sprint ability (RSA); and small-sided games (SSGs or game-based training) (Table 3) (16). Long intervals HIIT (Table 3) comprises work periods that are ≥60 seconds in duration and a lower intensity of both v$\dot{V}O_2$max or ≤85% vIFT (15,16). LI-T has been proposed to elicit the following physiological adaptations: enhanced $\dot{V}O_2$max, lactate threshold, and running economy (6,68,78). An 8-week interval HIIT program consisting of 4 × 4 minutes of 90–95% HRmax interspersed with 3 minutes of active recovery at 70% HRmax resulted in an increase in $\dot{V}O_2$max ($p < 0.01$) compared with long, slow distance, and lactate threshold training modalities (69). This type of HITT modality can enable LGF S&C practitioners to progressively overload the cardiopulmonary system to equip the LGF players for the aerobic demands of match play.

ShI-T (Table 3) consists of intervals of 10–60 seconds work with an intensity of 100–120% v$\dot{V}O_2$max or 85–105% vIFT with a work-to-rest ratio of 1:1-1:2 (15,16). The practitioner can manipulate this HIIT modality to elicit aerobic, anaerobic, and/or neuromuscular adaptations. The effects of short-interval HITT have been investigated in elite male soccer players in which training sessions consisted of 12–15 intervals (120% of v$\dot{V}O_2$max) with 15 seconds passive recovery (45). The ShI-T intervention led to an 8.1% ($p < 0.001$) improvement in maximal aerobic speed (8.1 ± 1.5%, $p < 0.001$) and a decrease in 40-m sprint times (−3.5 ± 1.5%, $p < 0.001$) (45). ShI-T can enable LGF players to accumulate volume and intensity of both high-speed running and mechanical work to replicate the intermittent nature of match play. Furthermore, ShI-T can be more appealing to LGF players as the Gaelic football can be integrated into the conditioning.

SIT (Table 3) consists of 4–6 × 30 seconds sprints with a prolonged recovery duration of 3–4 minutes (15,16). SIT has been reported to elicit the following physiological adaptations: enhancing muscular enzyme activity, which augments anaerobic and aerobic system productivity, increases the ability to buffer H^+ ions effectively, and delay the negative effects of acidosis on muscular contractile function (77,131). SIT training positively affects neuromuscular adaptations including increasing muscle fiber recruitment and synchronization (131). SIT can enable team sport athletes to recover quicker during intense periods of match play and increase their ability to partake in the amount of high-intensity periods during the game (82). In male GFs, a 2-week SIT intervention increased $\dot{V}O_2$max by 31% ($p \leq 0.05$) compared with 17% in a high-volume endurance training program (82).

RSA (Table 3) is the capability to perform numerous sprints interspersed by brief recovery periods (7). RSA is a critical component of high-intensity intermittent female team sports (52). Training for RSA could, for example, constitute short sprints (<10 seconds, 20–40 m, 3–4 sets with 6–7 repetitions) with brief recovery periods (<60 seconds). RSA is a complex, multifaceted modality, which is related to neuromuscular aspects (maximal sprint speed and motor activation) and metabolic aspects (oxidative phosphorylation for phosphocreatine recovery and H+ buffering) (7). RSA work-to-rest ratios are recommended to be 1:5, as this will enable sufficient recovery periods for the aerobic system to resynthesize adenosine triphosphate and phosphocreatine (15). It has been theorized that developing RSA would

Table 3
HIIT modality recommendations in ladies Gaelic footballers

HIIT format	HITT duration	HITT intensity	Modality	Rest duration	Rest intensity	Intra set recovery	Primary physiological adaptations
LI-T	<2 min >3 min	<100 $v\dot{V}O_2max$ (<90% V_{IFT}) ≥95% $v\dot{V}O_2max$ (80% V_{IFT})	Straight line 6–10 × 2 min Straight line 5–8 × 3 min 4–6 × min	2 min >3 min	Passive Passive	Passive Passive	Aerobic = $\dot{V}O_2max$ and lactate threshold
ShI-T	≥20 s <15 s	<100 $v\dot{V}O_2max$ (<89% V_{IFT}) <120 $v\dot{V}O_2max$ (<100% V_{IFT})	Straight line (3–4 sets × 8 reps 10/20 s) Straight line (2 sets × 6–8 reps 15/15 s)	≥20 s	55% $v\dot{V}O_2max$	120 s (passive) 180 s (passive)	Aerobic = $\dot{V}O_2max$ Anaerobic = lactate threshold
SIT	>20 s	All out (90–95% of max velocity)	Sports specific (Linear/curvelinear 6–10 × 40–60 m)	≤2 min	Passive	1:6	Aerobic and anaerobic
RST	<4–10 s	All-out	45–90° COD (position specific), explosive efforts 2–3 RST (each >6 sprints)	≤2 min	Passive 55% of $v\dot{V}O_2max$ (40% V_{IFT})	>120 s (passive)	Aerobic, anaerobic and neuromuscular
GBT	3–4 min	RPE > 7	Sport-specific SSG = 6–10 × 2 min MSG = 5–8 × 3 min LGG = 4–6 × 4 min	≤2 min	Passive 55% of $v\dot{V}O_2max$ (40% V_{IFT})	120 s (passive)	Aerobic, anaerobic, and neuromuscular
Other run type	**Duration**	**Intensity**	**Modality**	**Rest duration**	**Rest intensity**	**Intraset recovery**	
Tempos	15–30 s	(65–80% of max velocity)	Straight line running (85–120 m)	≤2 min	40–70 s	>120 s (passive)	Aerobic

Based on data from Refs. (15) and (16).

COD = change of direction; GBT = game-based training; HIIT = high-intensity interval training; LI-T = long-interval training; LSG = large-sided game; MSG = medium-sided game; RPE = rate of perceived exertion; RST = repeated sprint training; ShI-T = short-interval training; SIT = sprint-interval training; SSG = small-sided game; V_{IFT} = peak speed reached in the 30-15 intermittent fitness test; $\dot{V}O_2max$ = maximal oxygen uptake; $v\dot{V}O_2max$ = minimal speed associated with maximal oxygen uptake.

enhance the athlete's tolerance to withstand lactate and improve sports-based performance (18). Therefore, integrating an RSA training stimulus, including repeated fast-running efforts interspersed with short recovery intervals, would allow the athlete to develop game-specific fitness and replicate worst-case scenarios in match play (18). Including COD into HIIT modalities can also elicit specific physiological adaptations, including increased blood lactate, oxygen uptake, and HR (67). Implementation of RST can prepare LGF players for the unique positional aerobic, anaerobic, and neuromuscular responses to match play.

Game-based training (GBT or SSGs) (Table 3) has gained popularity as a conditioning modality in male Gaelic football (97,100). GBT can enable LGF S&C practitioners to develop physical, technical, and tactical aspect capabilities in a time-efficient manner (99). During this type of conditioning modality, the intensity can be manipulated in many ways, including varying exercise type (tactical constraints, number of players, and specific conditions), field dimensions, and manipulation of time constraints (25). Increasing pitch dimension and decreasing player number typically increases the intensity and anaerobic training stimulus (97,100). Alternatively, decreasing pitch size and increasing playing numbers will typically decrease intensity and stimulate an aerobic training response (25,97). In elite female soccer, players covered more relative sprint distance during larger-sided games with greater acceleration in smaller pitch dimensions (102). There was also a greater amount of time spent at >85% of HRmax (69.8% ± 2.5) during smaller-sided games (102). GBT may need to be supplemented with other HIIT modalities to ensure all physiological demands are met in female team–based athletes (51,88).

To elicit appropriate physiological responses in game-based training in team-based sports, a work-to-rest ratio of 2:1 or 1:1 should be considered (76). In addition, the area per player formula ($m^2 \times$ player), which is determined by the total pitch (144 × 88 m) area divided by the number of outfield players, can assist practitioners in designing bespoke GBT training for LGF (76) (Table 4). LGF S&C practitioners need to be cognizant of the limitations of using GBT as a conditioning modality, including variability in work intensities which can be difficult to control/manipulate, the potential increase in contact injuries, athlete's technical ability required, and playing numbers needed to use this approach effectively (88).

Tempo running has also become popular in team-based sports (132) (Table 3). Tempo running was first used in sprint athletes as a recovery modality in between high-intensity training day (65). Traditional tempo training consisted of 100–300 m of running with short recoveries at an intensity between 60 and 70% of maximal velocity to improve cardiovascular fitness (65). From a team sport perspective, tempo runs consist of 1–3 sets ranging from 100 to 130 m with a work duration of 20–40 seconds, a rest duration of 40–75 seconds, and an intraset recovery between 40 and 120 seconds. Running velocities can be determined by the individual athlete's percentage maximal velocity (65–85%) (65). It is recommended that tempo runs should be used to progressively accumulate high-speed running density, as opposed to a conditioning modality (132). The tempo-based running can enable LGF S&C practitioners to prescribe running volume based on the individual player's match play high-speed running velocity (65–85% Vmax). Please see Table 3 for recommendations on implementing HITT strategies throughout the LGF season.

Table 4
SSG pitch density for utilization in LGF training

Players	Length	Width
2v2	20.6	12.6
3v3	30.1	18.9
4v4	41.2	25.2
5v5	51.5	31.5
6v6	61.8	37.8
7v7	72	44
8v8	82.3	50.3
9v9	92.6	56.6
10v10	102.9	63
11v11	113.2	69.2
12v12	123.5	75.5
13v13	133.8	81.8
14v14	144	88

The area per player formula ($m^2 \times$ player) (76) which is determined by the total pitch (144 × 88 m) area divided by the number of outfield players.

LGF = ladies Gaelic football; SSG = small-sided game.

PROPOSED PERFORMANCE TESTING BATTERY

Performance testing provides LGF S&C practitioners with relevant information about the components of the sport (11). Performance testing enables progress monitoring, affects training prescription, provides an objective return-to-play metrics for injured players, and identifies individual strengths and weaknesses in LGF (4). Testing requires consideration and specific alignment to meet the specific demands of LGF. Collecting long-term performance testing data can provide practitioners and relevant stakeholders with valuable and in-depth analysis of LGF players. A proposed testing battery for LGF players is provided in Table 5.

PRACTICAL APPLICATIONS

PERIODIZATION

The process of periodization facilitates the practitioner to design a training plan in which the goal is to potentiate biomotor qualities and decrease potential fatigue (156). Nonlinear periodization is recommended for sports where the requirement is to peak at different times during the season (156). The LGF season is divided into 4 stages: off-season (8–10 weeks), preseason (6–8 weeks), transition phase (2–4

Table 5
Performance testing battery specific to ladies Gaelic footballers

Biomotor quality	Test	Reference	Sport*	Normative values
Anthropometry	Stature and mass, skinfold assessment in accordance with the International Society for the Advancement of Kinanthropometry (ISAK), %BF	(128) (80)	Intercounty Gaelic footballers Intercounty Gaelic footballers	1.66 ± 0.08 m 65.9 ± 8.3 kg 1.67 ± 0.09 m 65.0 ± 8.0 kg
Power	CMJ—slow SSC which involves both eccentric and concentric actions (27) SLJ—CMJ with horizontal emphasis, subjects use a CMJ with an arm swing to horizontally project themselves forward. Distance measured from the rear of the heel(s) in cm (80)	(27) (80)	Intercounty Camogie players Elite Gaelic football	27.49 ± 3.11 cm 1.40 ± 0.20 cm
Reactive strength	RSI Efficiency of an athlete's SSC. RSI = jump height (meters) contact time in seconds (s) (26) 10/5 RJT Participants perform a CMJ followed by 10 maximal rebound jumps with the best 5 averaged with ground contact time <0.25 for RSI (26) 5_{max} RJT Participants compete a CMJ followed by 4 maximal rebound jumps. RSI calculated for each maximal jump by = jump height (meters) contact time in seconds (s) (26)	(27) (26) (26)	Intercounty Camogie players Collegiate Gaelic footballers Collegiate Gaelic footballers	RSI = 1.18 ± 0.21 m/s RSI = 1.22 ± 0.47 m/s RSI = 1.23 ± 0.48 m/s
Speed	Linear speed test Using timing gates to enhance reliability athletes should perform 0–10 m to measure acceleration and 0–30/40 m to measure maximal speed (66)	(26)	Intercounty Camogie players	5 m = 1.20 ± 0.08 s 10 m = 2.02 ± 0.08 s 20 m = 3.45 ± 0.11 s
COD	T test or 505 test for protocol, see (141)	(141)	Basketball	505 = 2.69 ± 0.28 s T test = 11.75 ± 1.15 s
Strength	3RM testing protocol see (115) LB: 3RM hex bar deadlift, 3RM barbell front squat, and 3RM back squat UB: 3RM bench press; 3RM chin up for 3RM testing protocol Predicting 1RM: Epley (49) formula (0.033 × reps × repetition weight) + repetition weight IMTP: Athletes stand at midthigh position of the power clean with a fixed bar, vertical trunk with shoulders in line with the bar. The athlete pulls the fixed bar with as much force for 6 s while standing on force plates (164)	(115) (26) (164)	International female rugby league Intercounty Camogie players Premiership rugby players	e1RM (kg) Bench press: Backs = 64 kg Forwards = 67.7 kg Back squat: Backs = 85.2 kg Forwards = 99.3 kg Peak force (N) 1,938.46 ± 300.17 N Relative force (N/kg) 28.72 ± 4.17 N/kg Backs = 2,560.8 N Forwards = 2, 729.8 N
Repeated sprint ability (RSA)	RSA test 6 × 20 m maximal sprint efforts on a 15 s cycle. At the completion of sprint, participants perform a 10 m deceleration and a 10 m active recovery (53)	(53)	Elite international soccer players	20.9 ± 0.5 s

Table 5
(continued)

Aerobic endurance	$30\text{-}15_{IFT}$ (see description below) (32) Estimate $\dot{V}O_2max$ using $30\text{-}15_{IFT}$ for females: $\dot{V}O_2max$ ($mL \cdot kg^{-1}\ min^{-1}$) = 28.3 − (2.15 × 2) − (0.741 × A) − (0.0357 × W) + (0.0586 × A × V_{IFT}) + (1.03 × V_{IFT}) V_{IFT} = final running speed, a = age, W = weight (32) MAS: Set distance: 1.2 km time trial Distance run in meters (m)/time in seconds (s) = 100% MAS (2). Set time trial MAS: 5-min running time trail for each athlete, to determine MAS Distance run in meters (m)/time in seconds (s) = 100% MAS To determine distance travelled in a timeframe multiply % MAS by time of interval, for example, 4.8 m/s × 15 s = 72 m (2) YYIRTL1 test consists of 2 × 20 m shuttle runs at increasing speeds interspersed with 10 s active recovery. The test begins at 10 km/h and progressively increases until the participant fails to reach the line. YYIRTL1 tests predominately aerobic capacities (3) Predicted $\dot{V}O_2max$ ($mL \cdot kg^{-1}\ min^{-1}$) = YYIRTL1 distance (m) × 0.0084 + 36.4 (3)	(32) (138) (101) (92) (92) (27) (116) (116)	Elite soccer players Elite international soccer players Elite international soccer players AFL AFL Intercounty Camogie players 1st division soccer players 2nd division soccer players	V_{IFT} in km/h 17.1 ± 1.0 km/h 18.6 ± 1.5–19.8 ± 1.20 km/h 19.2 ± 1.20 km/h Time (min:s) 5.18 ± 0.14 3.74 m/s 871.11 ± 199.43 m 1,224 ± 255 m 826 ± 160 m

*Female team sport only.

$30\text{-}15_{IFT}$ = 30-15 intermittent fitness test; 1RM = 1 repetition maximum; 3RM = 3 repetition maximum; %BF = percentage of body fat; AFL = Australian Football League; CMJ = countermovement jump; COD = change of direction; FI = fatigue index; E1RM = estimated 1 repetition maximum; IMTP = isometric midthigh pull; ISAK = International Society for the Advancement of Kinanthropometry; KG = kilograms; KM/H = kilometers per hour; LB = lower body; M = meters; M/S = meters per second; MAS: maximal aerobic speed; N = newtons; N/kg = newtons per kilogram; RSAT = repeated sprint ability test; RJT = rebound jump test; RSA = repeated sprint ability; RSI = reactive strength index; $S_{fastest}$ = fastest sprint time; $S_{slowest}$ = slowest sprint time; SJ = squat jump; SJL = standing long jump; SSC = stretch-shortening cycle; UB = upper body; $\dot{V}O_2max$ = maximum amount of oxygen consumed per min; V_{IFT} = final velocity at 30:15 intermittent fitness test; YYIRTL1 = Yo-Yo intermittent endurance test level one.

weeks), and competitive phase (4–12 weeks) (Table 6). Therefore, LGF players must peak toward the end of the preseason for the National League competition and at the end of the transition phase for the start of the All-Ireland Championship. It is a priority to maintain performance for the duration of both competitions. It has been suggested that a more linear approach is viable during the off-season and into the preseason. Contrastingly, a nonlinear periodized approach is more appropriate for team sports during the in-season as there are often fluctuations in biomotor quality emphasis and training volume loads on a daily/weekly basis (157). One of the advantages of this agile approach is that sessions can be individualized and modified to reduce the residual fatigue of weekly competitive matches/training schedules. Furthermore, practitioners may need to microdose specific bio motor qualities to balance the sports-specific demands with the physical training requirements of the sport (118).

GENERAL PREPARATION PHASE

A general preparation phase is usually between 6 and 12 weeks and involves higher volumes, lower intensities, and a wide array of exercises (43). The phase aims to increase the athletes' tolerance to increased training loads, the demands of the game, and decrease any individual movement dysfunction. A further objective of this phase is to elicit secondary and tertiary training transfer effects. The residual fatigue during this phase can be high due to the higher volume of training (59). During this phase, up to 3–4 strength sessions may be completed per week (Table 7).

SPECIFIC PREPARATION PHASE

The specific preparation phase may be between 2 and 4 weeks and involves higher-intensity training with a reduction in volume (Table 8). This phase aims to develop sports-specific

Table 6
Periodization strategy for intercounty LGF

Month		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Competition focus		Off season		Preseason		National league			All-Ireland series			
Season phase		GPP		SPP		CP		Transition	CP			
Gym-based focus	P	Hyper		Str		Str-Sp		Str	Str-Sp			
	S	Str		Str-Sp		Sp-Str		Str-Sp	Sp-Str			
	T	Power		Power		Str		Sp-Str	Str			
See Figure 2 for specific guidelines												
Field-based focus speed		Wall drill variations Resisted marches, skips, and bounds Sled pushes and pulls SL run specific HIMAs (ankle knee and hamstring emphasis) SL run specific PIMAs (ankle knee and hamstring emphasis)		Resisted A skips, B skips, and C skips Sled pushes and pulls Dribbles Speed wickets 1/2kneeling acceleration starts (5–15 m) Speed build ups to (15–30 m)		Walk in accelerations (5–20 m) Speed top ups (>90% of MSS) Integrated speed into sports-specific training Curvilinear sprints (20–40 m)		A skips, B skips, and C skips Sled pushes and pulls Dribbles Speed wickets 1/2 kneeling acceleration starts (5–20 m) Speed build ups to (15–40 m)	Walk in accelerations (5–20 m) Speed top ups (>95% of MSS) Integrated speed into sports-specific training Curvilinear sprints (20–40 m)			
Field-based focus agility		Development of eccentric strength and force absorption capabilities		Development of agility-specific movements (inside and outside side step, shuffle step, crossover cut, split step, spin, deceleration, and turn) in a closed environment		Integrated agility into sports-specific training		Development of agility-specific movements (inside and outside side-step, shuffle step, crossover cut, split step, spin, deceleration, and turn) in a closed environment	Development of agility-specific movements (inside and outside side-step, shuffle step, crossover cut, split step, spin, deceleration, and turn) in an open, reactive environment Integrated agility into sports-specific training			
Field based focus conditioning		LI-T		ShI-T RST SIT		GBT Tempos		GBT ShI-T SIT	GBT Tempos			

CP = competitive phase; GBT = game-based training; GPP = general preparation phase; HIMA = holding isometric muscle actions; HYPER = hypertrophy; LGF = ladies Gaelic football; LI-T = long-interval training; M = meters; MSS = maximal sprint speed; SPP = specific preparation phase; SP-STR = speed-strength; STR = strength; STR-SP = strength-speed; P = primary; PIMA = pushing isometric muscle actions; RST = repeated sprint training; S = secondary; ShI-T = short-interval training; SIT = sprint-interval training; SL = single-leg; SPP = specific preparation phase; T = tertiary.

Table 7 Example of general preparation phase (GPP) in ladies Gaelic footballer			
GPP strength program			
Warm up	**Exercise**	**Set × reps**	**Rest time**
Myofascial	Self-directed foam rolling	5 min	NA
Mobility	Bretzel, 90/90 arm sweeps, 90/90 hip		
Activation	Four-way lunge, bear crawl, yoga push-up, and dowel OHS	3 × 4	120 s
Potentiation	Box drop landings		
Strength program	**Exercise**	**Set × reps**	**Rest**
1a	Hang clean shrug	3 × 5	120 s
2a	Front squat	3 × 6–8	
3a	RFESS	3 × 6–8	
3b	Run-specific SL BB HIMA (hip emphasis)	3 × 10 s (L/R)	
4a	DB bench press	3 × 6–8	
4b	Pull-up	3 × 6–8	
Core	**Exercise**	**Set × reps**	**Rest**
5a	Pallof press	3 × 8–12 (L/R)	60 s
5b	Cable side plank rows	3 × 8–12 (L/R)	

BB = barbell; DB = dumbbell; HIMA = holding isometric muscle actions; OHS = overhead squat; RFESS = rear foot elevated split squats; SL = single arm.

training modalities to facilitate a greater transfer of training from the weight-training room to the field (59) (Table 8). During this phase, a primary emphasis is placed on muscular strength, with a secondary emphasis on RFD & power development and a tertiary emphasis on strength endurance if needed (59).

Table 8 Example of specific preparation phase (SPP) in ladies Gaelic footballer			
SPP strength program			
Warm up	**Exercise**	**Set × reps**	**Rest time**
Myofascial	Self-directed foam rolling	5 min	NA
Mobility	Floor slides, chicken wings, and deadbugs	3 × 10	
Activation	Squat to stand, inchworm, lunge with elbow to instep, and SL RDLs	2 × 6	
Potentiation	Depth jumps	3 × 3	
Strength program	**Exercise**	**Set x reps**	**Rest**
1a	Run-specific SL BB PIMAs (ankle emphasis)	3 × 10 s (L/R)	120 s
2a	Trapbar DL	3 × 4–6	
2b	Box to box jump	3 × 3–5	
3a	Behind the neck push press	3 × 4–6	
3b	Overhead medicine ball slams	3 × 4–6	
4a	BB RDLs	3 × 4–6	
4b	SA DB row	3 × 4–6	
Core	**Exercise**	**Set reps**	**Rest**
5a	GHR	2 × 5	60 s
5b	Copenhagen plank	2 × 5 (L/R)	

BB = barbell; DL = deadlift; DB = dumbbell; GHR = glute hamstring raise; PIMA = pushing isometric muscle actions; RDL = Romanian deadlift; SA = single arm; SL = single leg.

Table 9
Example of the competitive phase (CP) in ladies Gaelic footballer

CP strength program			
Warm up	**Exercise**	**Set × reps**	**Rest**
Myofascial	Self-directed foam rolling	5 min	NA
Mobility	Cat/Camel, quadruped T-spine rotations, 90/90 shinboxs	3 × 8	
Activation	Warrior poses, spider crawls, duckwalks, and pogos	2 × 6	
Potentiation	Drop jumps into linear hurdle hops	3 × 3	
Strength program	**Exercise**	**Set × reps**	**Rest**
1a	PIMA hex bar DL	3 × 5 s	
2a	WP SL squat	3 × 3	
2b	SL horizontal hurdle hops	3 × 3 (L/R)	
3a	SL DB RDLs	3 × 3 (L/R)	
3b	DB hip prone iso switches	3 × 3 (L/R)	
4a	BO BB row	3 × 3–5	
4b	Supine MB chest throws	3 × 3–5	
Core	**Exercise**	**Set × reps**	**Rest**
5a	Front plank cable row	3 × 10 (L/R)	
5b	Isometric roman chair hamstring holds	3 × 5 s	

BB = barbell; BO = bent over; DL = deadlift; DB = dumbbell; MB = medicine ball; PIMA = pushing isometric muscle actions; RDL = Romanian deadlift; SL = single leg; WP = weight plate.

During this phase, up to 2–3 strength sessions may be completed weekly.

COMPETITIVE PHASE

The competitive phase (CP) block may last from 4 to 12 weeks, depending on how the team progresses through the All-Ireland series, which culminates in the All-Ireland Final on the first weekend of September each year (Table 9). The objective of this phase is to preserve the athlete as close to their physical peak as possible (156). There is generally a reduction in training loads that emphasizes general physical preparation with a focus on training which prioritizes sport-specific training that enhances technical skills and sports-specific fitness (59). The maintenance of in-season strength is an important biomotor quality and should always be considered in the longer-term planning of the CP phase. It has been suggested that to assist the practitioner to better structure CP, the CP can be split into the precompetitive (PPP) and main competitive phase (MCP) (59). In the PPP phase, friendly or challenge competitions are used to develop sports-specific fitness and technical and tactical components of the game (59). This phase allows the practitioner to evaluate the players' or teams' progress toward the competitive season (National League or All-Ireland series). The MCP phase's primary objective is to enhance preparedness and optimize performance. The competition schedule (National League or All-Ireland series) is prioritized during this phase. The daily manipulation of training volume and intensity is essential to cater to the dynamic demands of team sports (99). This vertically integrated approach allows for the manipulation of training units to prioritize the development of multiple physical and tactical attributes throughout the training week (99). Velocity-based technologies may enable practitioners to develop/optimize specific biomotor qualities and autoregulate the intensities based on the athletes' needs (157) (Figure 1). This phase is challenging for LGF S&C practitioners as various external factors (travel, media, competition scheduling, etc.) will affect the overall training load for the LGF player. In conclusion, biomotor qualities should be rotated/sequenced to reduce the rate of decay and optimize performance (109).

CONCLUSION

LGF is an amateur, invasion-based field sport in which S&C evidenced-based provision is lacking. This article aimed to provide practical recommendations, including a needs analysis (Table 1), biomechanical demands, physiological demands, injury epidemiology (Table 2), considerations for female LGF players, development of bio-motor qualities, a testing battery (Table 5), and practical applications specific to LGF players including a proposed season-long periodized plan (Table 6). Owing to the intermittent demands of the game, players must develop high levels of aerobic fitness, strength, power, and agility. The authors recommend specific training modalities to assist practitioners developing these biomotor qualities (Figure 2). Practitioners must be cognizant that the recommendations provided are guidelines and may need to be individualized based on the positional demands of LGF (Table 9).

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John David Duggan *is an S&C coach and assistant lecturer in Strength & Conditioning in Atlantic Technological University (ATU).*

Karen Keane *is a performance nutritionist and assistant lecturer in Public Health Nutrition at Atlantic Technological University (ATU).*

Jeremy Moody *is a Reader in Applied Strength and Conditioning and Programme Director for the MSc/MRes in Strength and Conditioning at Cardiff Metropolitan University*

Paul J. Byrne *is the Program Director and Work Placement Co-ordinator for the BSc Strength and Conditioning program at the South East Technology University.*

Shane Malone *is a lecturer in Sports Science & Health at the Technological University Dublin (TUD).*

Kieran Collins *is a Performance Scientist and Sport Science and Health Discipline Lead at the School of Biological, Health, and Sport Sciences at the Technological University Dublin (TUD).*

Lisa Ryan *is the Head of Department of Sports, Exercise, & Nutrition at the Atlantic Technological University (ATU).*

REFERENCES

1. Ayers JL, DeBeliso M, Sevene T, Adams KJ. Hang cleans and hang snatches produce similar improvements in female collegiate athletes. *Biol Sport* 33: 251–256, 2016.
2. Baker D. Recent trends in high-intensity aerobic training for field sports. *Prof J Strength Cond* 22: 3–8, 2011.
3. Bangsbo J, Iaia FM, Krustrup P. The Yo-Yo intermittent recovery test: A useful tool for evaluation of physical performance in intermittent sports. *Sports Med* 38: 37–51, 2008.
4. Bangsbo J. Performance in sports-with specific emphasis on the effect of intensified training. *Scand J Med Sci Sports* 25: 88–99, 2015.
5. Billat LV. Interval training for performance: A scientific and empirical practice. Special recommendations for middle- and long-distance running. Part II: Anaerobic interval training. *Sports Med* 31: 75–90, 2001.
6. Billat LV. Interval training for performance: A scientific and empirical practice. Special recommendations for middle-and long-distance running. Part I: Aerobic interval training. *Sports Med* 31: 13–31, 2001.
7. Bishop D, Girard O, Mendez-Villanueva A. Repeated-sprint ability-part II: Recommendations for training. *Sports Med* 41: 741–756, 2011.
8. Blagrove RC, Bruinvels G, Pedlar CR. Variations in strength-related measures during the menstrual cycle in eumenorrheic women: A systematic review and meta-analysis. *J Sci Med Sport* 23: 1220–1227, 2020.
9. Bobert MF, Gerritisen KG, Litjens MC, Van Soest AJ. Why is the countermovement jump height greater than squat jump height? *Med Sci Sport Exer* 28: 1402–1412, 1996.
10. Brown J, Papadopolos C, Pritchett R. Examination of injury in female Gaelic football. *Int J Exerc Sci* 6: 98–105, 2013.
11. Brown J, Waller M. Needs analysis, physiological response, and program guidelines for Gaelic football. *Strength Cond J* 36: 73–81, 2014.
12. Brown JR, Macklin I, Waller M. Using the Nordic hamstring exercise to reduce hamstring injuries in Gaelic football. *Strength Cond J* 42: 1–5, 2020.
13. Brown N, Knight CJ, Forrest Née Whyte LJ. Elite female athletes' experiences and perceptions of the menstrual cycle on training and sport performance. *Scand J Med Sci Sports* 31: 52–69, 2021.
14. Buchheit M, Al Haddad H, Millet GP, et al. Cardiorespiratory and cardiac autonomic responses to 30-15 intermittent fitness test in team sport players. *J Strength Cond Res* 23: 93–100, 2009.
15. Buchheit M, Laursen PB. High-intensity interval training, solutions to the programming puzzle: Part I: Cardiopulmonary emphasis. *Sports Med* 43: 313–338, 2013.
16. Buchheit M, Laursen PB. High-intensity interval training, solutions to the programming puzzle. Part II: Anaerobic energy, neuromuscular load and practical applications. *Sports Med* 43: 927–954, 2013.
17. Buchheit M, Mendez-Villanueva A, Delhomel G, Brughelli M, Ahmaidi S. Improving repeated sprint ability in young elite soccer players: Repeated shuttle sprints vs. explosive strength training. *J Strength Cond Res* 24: 2715–2722, 2010.
18. Buchheit M, Mendez-Villanueva A. Changes in repeated-sprint performance in relation to change in locomotor profile in highly-trained young soccer players. *J Sports Sci* 32: 1309–1317, 2014.
19. Buchheit M. The 30-15 intermittent fitness test: Accuracy for individualizing interval training of young intermittent sport players. *J Strength Cond Res* 22: 365–374, 2008.
20. Bundle MW, Hoyt RW, Weyand PG. High-speed running performance: A new approach to assessment and prediction. *J Appl Physiol* 95: 1955–1962, 2003.
21. Case MJ, Knudson DV, Downey DL. Barbell squat relative strength as an identifier for lower extremity injury in collegiate athletes. *J Strength Cond Res* 34: 1249–1253, 2020.
22. Castagna C, Impellizzeri FM, Chaouachi A, Manzi V. Preseason variations in aerobic fitness and performance in elite-standard soccer players: A team study. *J Strength Cond Res* 27: 2959–2965, 2013.
23. Clark JE. The use of an 8-week mixed-intensity interval endurance-training program improves the aerobic fitness of female soccer players. *J Strength Cond Res* 24: 1773–1781, 2010.
24. Clarke AC, Couvalias G, Kempton T, Dascombe B. Comparison of the match running demands of elite and sub-elite women's Australian Football. *Sci Med Football* 3: 70–76, 2019.
25. Clemente FM, Lourenço Martins FM, Mendes RS. Developing aerobic and anaerobic fitness using small-sided soccer games. *Strength Cond J* 36: 76–87, 2014.

26. Comyns TM, Flanagan EP, Fleming S, Fitzgerald E, Harper DJ. Inter-day reliability and usefulness of a reactive strength index derived from 2 maximal rebound jump tests. *Int J Sports Physiol Perform* 29: 1200–1204, 2019.
27. Connors PM, Browne DT, Earls D, Fitzpatrick P, Rankin P. The physical characteristics of elite camogie players. *J Sports Med Phys Fitness* 62: 1053–1060, 2022.
28. Cormie P, McGuigan MR, Newton RU. Adaptations in athletic performance after ballistic power versus strength training. *Med Sci Sports Exerc* 42: 1582–1598, 2010.
29. Cormie P, McGuigan MR, Newton RU. Developing maximal neuromuscular power. *Sports Med* 41: 17–38, 2011.
30. Cormie P, McGuigan MR, Newton RU. Developing maximal neuromuscular power: Part 2-training considerations for improving maximal power production. *Sports Med* 41: 125–146, 2011.
31. Cormier P, Freitas TT, Rubio-Arias JÁ, Alcaraz PE. Complex and contrast training: Does strength and power training sequence affect performance-based adaptations in team sports? A systematic review and meta-analysis. *J Strength Cond Res* 34: 1461–1479, 2020.
32. Čović N, Jelešković E, Alić H, et al. Reliability, validity and usefulness of 30-15 intermittent fitness test in female soccer players. *Front Physiol* 7: 510, 2016.
33. Cowley ES, Olenick AA, McNulty KL, Ross EZ. "Invisible Sportswomen" the sex data gap in sport and exercise science research. *Women Sport Phys Activity J* 29: 146–151, 2021.
34. Cronin J, Hansen KT. Resisted sprint training for the acceleration phase of sprinting. *Strength Cond J* 28: 42–51, 2006.
35. Crowley J, Jordan J, Falvey E. A comparison of Gaelic football injuries in males and females in primary care. *Ir Med J* 104: 268–270, 2011.
36. Cullen BD, Roantree MT, McCarren AL, et al. Physiological profile and activity pattern of minor Gaelic football players. *J Strength Cond Res* 31: 1811–1820, 2017.
37. Dalgaard LB, Dalgas U, Andersen JL, et al. Influence of oral contraceptive use on adaptations to resistance training. *Front Physiol* 10: 824, 2019.
38. Daly LS, Ó Catháin C, Kelly DT. Does physical conditioning influence performance attenuation and recovery in Gaelic football? *Int J Sports Physiol Perform* 17: 862–870, 2022.
39. Datson N, Hulton A, Andersson H, et al. Applied physiology of female soccer: An update. *Sports Med* 44: 1225–1240, 2014.
40. Dekkers T, O'Sullivan K, Blake C, McVeigh JG, Collins K. Epidemiology and moderators of injury in Gaelic football: A systematic review and meta-analysis. *J Sci Med Sport* 25: 222–229, 2022.
41. Dolci F, Kilding AE, Chivers P, Piggott B, Hart NH. High-intensity interval training shock microcycle for enhancing sport performance: A brief review. *J Strength Cond Res* 34: 1188–1196, 2020.
42. Duggan JD, Moody JA, Byrne P, McGahan JH, Kirszenstein L. Considerations and guidelines on athletic development for youth Gaelic athletic association players. *Strength Cond J* 44: 76–96, 2022.
43. Duggan JD, Moody JA, Byrne PJ, Ryan L. Strength and conditioning recommendations for female GAA athletes: The camogie player. *Strength Cond J* 42: 105–124, 2020.
44. Duggan JD, Moody JA, Byrne PJ, Cooper S-M, Ryan L. Training load monitoring considerations for female Gaelic team sports: From theory to practice. *Sports* 9: 84, 2021.
45. Dupont G, Akakpo K, Berthoin S. The effect of in-season, high-intensity interval training in soccer players. *J Strength Cond Res* 18: 584–589, 2004.
46. Ebben WP, Fauth ML, Petushek EJ, et al. Gender-based analysis of hamstring and quadriceps muscle activation during jump landings and cutting. *J Strength Cond Res* 24: 408–415, 2010.
47. Elliott-Sale KJ, McNulty KL, Ansdell P, et al. The effects of oral contraceptives on exercise performance in women: A systematic review and meta-analysis. *Sports Med* 50: 1785–1812, 2020.
48. Elliott-Sale KJ, Minahan CL, de Jonge XAKJ, et al. Methodological considerations for studies in sport and exercise science with women as participants: A working guide for standards of practice for research on women. *Sports Med* 51: 843–861, 2021.
49. Epley B. *Poundage Chart*. Lincoln, NE: Boyd Epley Workout, 1985.
50. Findlay RJ, Macrae EHR, Whyte IY, Easton C, Forrest Née Whyte LJ. How the menstrual cycle and menstruation affect sporting performance: Experiences and perceptions of elite female rugby players. *Br J Sports Med* 54: 1108–1113, 2020.
51. Gabbett TJ, Mulvey MJ. Time-motion analysis of small-sided training games and competition in elite women soccer players. *J Strength Cond Res* 22: 543–552, 2008.
52. Gabbett TJ, Wiig H, Spencer M. Repeated high-intensity running and sprinting in elite women's soccer competition. *Int J Sports Physiol Perform* 8: 130–138, 2013.
53. Gabbett TJ. The development of a test of repeated-sprint ability for elite women's soccer players. *J Strength Cond Res* 24: 1191–1194, 2010.
54. Gamble D, Spencer M, McCarren A, Moyna N. Activity profile, PlayerLoad™ and heart rate response of Gaelic football players: A pilot study. *J Hum Sport Exerc* 14: 711–724, 2019.
55. Granata K, Padua DA, Wilson S. Gender differences in active musculoskeletal stiffness: Part II: Quantification of leg stiffness in during functional hopping tasks. *J Electromyogr Kinesiol* 12: 127–135, 2002.
56. Grieco CR, Cortes N, Greska EK, Lucci S, Onate JA. Effects of a combined resistance-plyometric training program on muscular strength, running economy, and V[combining Dot above]O_2peak in Division I female soccer players. *J Strength Cond Res* 26: 2570–2576, 2012.
57. Guex K, Millet GP. Conceptual framework for strengthening exercises to prevent hamstring strains. *Sports Med* 43: 1207–1215, 2013.
58. Haff GG, Nimphius S. Training principles for power. *Strength Cond J* 34: 2–12, 2012.
59. Haff GG. Periodization and programming for individual sports. In: *NSCA's Essentials of Sports Science*. French D, Torres-Ronda L, eds. Leeds: Human Kinetics, 2022. pp: 27–43.
60. Haines M, McKinley-Barnard SK, Andre TL, et al. Skeletal muscle estrogen receptor activation in response to eccentric exercise up-regulates myogenic-related gene expression independent of differing serum estradiol levels occurring during the human menstrual cycle. *J Sports Sci Med* 17: 31–39, 2018.
61. Häkkinen K, Pakarinen A, Kallinen M. Neuromuscular adaptations and serum hormones in women during short-term intensive strength training. *Eur J Appl Physiol Occup Physiol* 64: 106–111, 1992.
62. Harper DJ, Kiely J. Damaging nature of decelerations: Do we adequately prepare players. *BMJ Open Sport Exerc Med* 4: e000379, 2018.
63. Harper DJ, Sandford GN, Clubb J, et al. Elite football of 2030 will not be the same as that of 2020: What has evolved and what needs to evolve? *Scand J Med Sci Sports* 31: 493–494, 2021.
64. Haugen T, Sandbakk Ø, Enoksen E, Seiler S, Tonnessen E. Crossing the golden training divide: The science and practice of training world-class 800- and 1500-m runners. *Sports Med* 51: 1835–1854, 2021.
65. Haugen T, Seiler S, Sandbakk Ø, Tonnessen E. The training and development of elite sprint performance: An integration of scientific and best practice literature. *Sports Med Open* 5: 44, 2019.
66. Haugen TA, Tønnessen E, Seiler S. Speed and countermovement-jump characteristics of elite female soccer players, 1995-2010. *Int J Sports Physiol Perform* 7: 340–349, 2012.
67. Haydar B, Haddad HA, Ahmaidi S, Buchheit M. Assessing inter-effort recovery and change of direction ability with the 30-15 intermittent fitness test. *J Sports Sci Med* 10: 346–354, 2011.
68. Helgerud J, Engen LC, Wisloff U, Hoff J. Aerobic endurance training improves soccer performance. *Med Sci Sports Exerc* 33: 1925–1931, 2001.
69. Helgerud J, Høydal K, Wang E, et al. Aerobic high-intensity intervals improve VO_2max more than moderate training. *Med Sci Sports Exerc* 39: 665–671, 2007.
70. Herzberg SD, Motu'apuaka ML, Lambert W, et al. The effect of menstrual cycle and contraceptives on ACL injuries and laxity: A systematic review and meta-analysis. *Orthop J Sports Med* 5: 232596711771878, 2017.
71. Hewett TE, Ford KR, Myer GD. Anterior cruciate ligament injuries in female athletes: Part 2, a meta-analysis of neuromuscular interventions aimed at injury prevention. *Am J Sports Med* 34: 490–498, 2006.
72. Hewett TE, Myer GD, Ford KR. Anterior cruciate ligament injuries in female athletes: Part 1, mechanisms and risk factors. *Am J Sports Med* 34: 299–311, 2006.
73. Hewett TE, Zazulak BT, Myer GD, Ford KR. A review of electromyographic activation levels, timing differences, and increased anterior cruciate ligament injury incidence in female athletes. *Br J Sports Med* 39: 347–350, 2005.
74. Hewett TE. Neuromuscular and hormonal factors associated with knee injuries in female athletes: Strategies for intervention. *Sports Med* 29: 313–327, 2000.
75. Hicks DS, Schuster JG, Samozino P, Morin JB. Improving mechanical effectiveness during sprint acceleration: Practical recommendations and guidelines. *Strength Cond J* 42: 45–62, 2020.
76. Hill-Haas SV, Dawson B, Impellizzeri FM, Coutts AJ. Physiology of small-sided games training in football: A systematic review. *Sports Med* 41: 199–220, 2011.
77. Iaia FM, Bangsbo J. Speed endurance training is a powerful stimulus for physiological adaptations and performance improvements of athletes. *Scand J Med Sci Sports* 20: 11–23, 2010.
78. Iaia FM, Ermanno R, Bangsbo J. High-intensity training in football. *Int J Sports Physiol Perform* 4: 291–306, 2009.
79. Kapteijns JA, Caen K, Lievens M, Bourgois JG, Boone J. Positional match running performance and performance profiles of elite female field hockey. *Int J Sports Physiol Perform* 16: 12951–13028, 2021.
80. Keane A, Scott MA, Dugdill L, Reilly T. Fitness test profiles as determined by the Eurofit test battery in elite female Gaelic football players. *J Strength Cond Res* 24: 1502–1506, 2010.
81. Keller MF, Harrison ML, Lalande S. Impact of menstrual blood loss and oral contraceptive use on oxygen-carrying Capacity. *Med Sci Sports Exerc* 52: 1414–1419, 2020.
82. Kelly DT, Tobin C, Egan B, et al. Comparison of sprint interval and endurance training in team sport athletes. *J Strength Cond Res* 32: 3051–3058, 2018.

83. Kelly G, McKenna O, Courtney S, et al. Benchmarking successful performances in elite ladies Gaelic football. *Inter J Perform Analy Sport* 22: 1–15, 2021.
84. Kissow J, Jacobsen KJ, Gunnarsson TP, Jessen S, Hostrup M. Effects of follicular and luteal phase-based menstrual cycle resistance training on muscle strength and mass. *Sports Med* 52: 2813–2819, 2022.
85. Knowles OE, Aisbett B, Main LC, et al. Resistance training and skeletal muscle protein metabolism in eumenorrheic females: Implications for researchers and practitioners. *Sports Med* 49: 1637–1650, 2019.
86. Kraemer WJ, Mazzetti SA, Nindl BC, et al. Effect of resistance training on women's strength/power and occupational performances. *Med Sci Sports Exerc* 33: 1011–1025, 2001.
87. Kraemer WJ, Nindl BC, Marx JO, et al. Chronic resistance training in women potentiates growth hormone in vivo bioactivity: Characterization of molecular mass variants. *Am J Physiol Endocrinol Metab* 291: 1177–1187, 2006.
88. Lacome M, Simpson BM, Cholley Y, Lambert P, Buchheit M. Small-sided games in elite soccer: Does one size fits all? *Int J Sports Physiol Perform* 13: 568–576, 2018.
89. Laursen PB, Jenkins DG. The scientific basis for high-intensity interval training: Optimizing training programmes and maximizing performance in highly trained endurance athletes. *Sports Med* 32: 53–73, 2002.
90. Liefeith A, Kiely J, Collins D, Richards J. Back to the Future -in support of a renewed emphasis on generic agility training within sports-specific developmental pathways. *J Sports Sci* 36: 2250–2255, 2018.
91. Lowe DA, Baltgalvis KA, Greising SM. Mechanisms behind estrogen's beneficial effect on muscle strength in females. *Exerc Sport Sci Rev* 38: 61–67, 2010.
92. Lundquist M, Nelson MJ, Debenedictis T, et al. Set distance time trials for predicting maximal aerobic speed in female Australian rules footballers. *J Sci Med Sport* 24: 391–396, 2021.
93. Maffiuletti NA, Aagaard P, Blazevich AJ, et al. Rate of force development: Physiological and methodological considerations. *Eur J Appl Physiol* 116: 1091–1116, 2016.
94. Malinzak RA, Colby SM, Kirkendall DT, Yu B, Garrett WE. A comparison of knee joint motion patterns between men and women in selected athletic tasks. *Clin Biomech* 16: 438–445, 2001.
95. Malone S, Hughes B, Doran DA, Collins K, Gabbett TJ. Can the workload-injury relationship be moderated by improved strength, speed and repeated-sprint qualities? *J Sci Med Sport* 22: 29–34, 2019.
96. Malone S, McGuinness A, Duggan JD, et al. The running performance of elite ladies Gaelic football with respect to position and halves of play. *Sports Sci Health*, 2022. Available at: https://doi.org/10.1007/s11332-022-00991-4.
97. Malone S, Solan B, Collins K. The Influence of pitch size on running performance during Gaelic football small-sided games. *Int J Perform Anal Sport* 16: 111–121, 2017.
98. Malone S, Solan B, Collins K. The running performance profile of elite Gaelic football match-play. *J Strength Cond Res* 31: 30–36, 2017.
99. Mangan S, Collins K, Burns C, O'Neill C. A tactical periodisation model for Gaelic football. *Int J Sports Sci Coaching* 17: 208–219, 2021.
100. Mangan S, Collins K, Burns C, O'Neill C. An investigation into the physical, physiological and technical demands of small-sided games using varying pitch dimensions in Gaelic football. *Int J Perform Anal Sport* 19: 971–984, 2019.
101. Manson SA, Brughelli M, Harris NK. Physiological characteristics of international female soccer players. *J Strength Cond Res* 28: 308–318, 2014.
102. Mara JK, Thompson KG, Pumpa KL. Physical and physiological characteristics of various-sided games in elite women's soccer. *Int J Sports Physiol Perform* 11: 953–958, 2016.
103. Markovic G, Mikulic P. Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric training. *Sports Med* 40: 859–895, 2010.
104. Marshall BM, Franklyn-Miller AD, King EA, et al. Biomechanical factors associated with time to complete a change of direction cutting maneuver. *J Strength Cond Res* 28: 2845–2851, 2014.
105. Martin D, Sale C, Cooper SB, Elliott-Sale KJ. Period prevalence and perceived side effects of hormonal contraceptive use and the menstrual cycle in elite athletes. *Int J Sports Physiol Perform* 13: 926–932, 2018.
106. Martin D, Timmins K, Cowie C, et al. Injury incidence across the menstrual cycle in international footballers. *Front Sports Act Living* 3: 616999, 2021.
107. McGahan JH, Mangan S, Collins K, et al. Match-play running demands and technical performance among elite Gaelic footballers: Does divisional status count? *J Strength Cond Res* 35: 169–175, 2021.
108. McIntyre MC. A comparison of the physiological profiles of elite Gaelic footballers, hurlers, and soccer players. *Br J Sports Med* 39: 437–439, 2005.
109. McMaster DT, Gill N, Cronin J, McGuigan M. The development, retention and decay rates of strength and power in elite rugby union, rugby league and American football: A systematic review. *Sports Med* 43: 367–384, 2013.
110. McNulty KL, Elliott-Sale KJ, Dolan E, et al. The effects of menstrual cycle phase on exercise performance in eumenorrheic women: A systematic review and meta-analysis. *Sports Med* 50: 1813–1827, 2020.
111. Meignié A, Duclos M, Carling C, et al. The effects of menstrual cycle phase on elite athlete performance: A critical and systematic review. *Front Physiol* 12: 654585, 2021.
112. Mendiguchia J, Castano-Zambudio A, Jimenez-Rayes P, et al. Can we modify maximal speed running posture? Implications for performance and hamstring injuries management. *Int J Sport Physiol Perform* 17: 374–383, 2022.
113. Mendiguchia J, Ford KR, Quatman CE, Alentorn-Geli E, Hewett TE. Sex differences in proximal control of the knee joint. *Sports Med* 41: 541–557, 2011.
114. Minahan C, Joyce S, Bulmer AC, Cronin N, Sabapathy S. The influence of estradiol on muscle damage and leg strength after intense eccentric exercise. *Eur J Appl Physiol* 115: 1493–1500, 2015.
115. Minahan C, Newans T, Quinn K, et al. Strong, fast, fit, lean, and safe: A positional comparison of physical and physiological qualities within the 2020 Australian women's rugby league team. *J Strength Cond Res* 35: 11–19, 2021.
116. Mujika I, Santisteban J, Impellizzeri FM, Castagna C. Fitness determinants of success in men's and women's football. *J Sports Sci* 27: 107–114, 2009.
117. Murphy JC, O'Malley E, Gissane C, Blake C. Incidence of injury in Gaelic football: A 4-year prospective study. *Am J Sports Med* 40: 2113–2120, 2012.
118. Murray T, Hansen DM. Off-season. In: *High Performance Training for Sport* (2nd ed). Joyce D, Lewindon D, eds. Leeds: Human Kinetics, 2022. pp: 301–315.
119. Myer GD, Ford KR, Palumbo JP, Hewett TE. Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. *J Strength Cond Res* 19: 51–60, 2005.
120. O'Connor S, Bruce C, Teahan C, McDermott E, Whyte E. Injuries in collegiate Ladies Gaelic footballers: A 2-season prospective cohort study. *J Sport Rehabil* 30: 261–266, 2021.
121. Oxfeldt M, Dalgaard LB, Jørgensen AA, Hansen M. Hormonal contraceptive use, menstrual dysfunctions, and self-reported side effects in elite athletes in Denmark. *Int J Sports Physiol Perform* 15: 1377–1384, 2020.
122. Parker LJ, Elliott-Sale KJ, Hannon MP, Morton JP, Close GL. An audit of hormonal contraceptive use in Women's super league soccer players; implications on symptomology. *Sci Med Football* 6: 153–158, 2021.
123. Ramirez-Campillo R, Sanchez-Sanchez J, Romero-Moraleda B, et al. Effects of plyometric jump training in female soccer player's vertical jump height: A systematic review with meta-analysis. *J Sports Sci* 38: 1475–1487, 2020.
124. Randell RK, Clifford T, Drust B, et al. Physiological characteristics of female soccer players and health and performance considerations: A narrative review. *Sports Med* 51: 1377–1399, 2021.
125. Rechichi C, Dawson B. Effect of oral contraceptive cycle phase on performance in team sport players. *J Sci Med Sport* 12: 190–195, 2009.
126. Reif A, Wessner B, Haider P, Tschan H, Triska C. Strength performance across the oral contraceptive cycle of team sport athletes: A cross-sectional study. *Front Physiol* 12: 658994, 2021.
127. Reilly T, Collins K. Science and the Gaelic sports: Gaelic football and hurling. *Eur J Sport Sci* 8: 231–240, 2008.
128. Renard M, Kelly DT, Chéilleachair NN, Catháin CÓ. Evaluation of nutrition knowledge in female Gaelic games players. *Sports* 8: 154, 2020.
129. Roe M, Blake C, Gissane C, Collins K. Injury scheme claims in Gaelic games: A review of 2007-2014. *J Athletic Train* 51: 303–308, 2016.
130. Romero-Parra N, Rael B, Alfaro-Magallanes VM, et al; IronFEMME Study Group. The effect of the oral contraceptive cycle phase on exercise-induced muscle damage after eccentric exercise in resistance-trained women. *J Strength Cond Res* 35: 353–359, 2021.
131. Ross A, Leveritt M. Long-term metabolic and skeletal muscle adaptations to short-sprint training: Implications for sprint training and tapering. *Sports Med* 31: 1063–1082, 2001.
132. Rowan A, Atkins S, Comfort P. A comparison of maximal aerobic speed and maximal sprint speed in elite youth soccer players. *Prof Strength Cond J* 53: 24–29, 2019.
133. Sakamaki-Sunaga M, Min S, Kamemoto K, Okamoto T. Effects of menstrual phase-dependent resistance training frequency on muscular hypertrophy and strength. *J Strength Cond Res* 30: 1727–1734, 2016.
134. Sandford GN, Kilding AE, Ross A, Laursen PB. Maximal sprint speed and the anaerobic speed reserve domain: The untapped tools that differentiate the world's best male 800 m runners. *Sports Med* 49: 843–852, 2019.
135. Sandford GN, Laursen PB, Buchheit M. Anaerobic speed/power reserve and sport performance: Scientific basis, current applications and future directions. *Sports Med* 51: 2017–2028, 2021.
136. Schmidtbleicher D. Training for power events. In: *Strength and Power in Sports*. Komi PV, ed. Oxford: Blackwell, 1992. pp: 381–385.
137. Schneider C, Hanakam F, Wiewelhove T, et al. A heart rate monitoring in team sports-A conceptual framework for contextualizing heart rate measures for training and recovery prescription. *Front Physiol* 9: 639, 2018.
138. Scott D, Norris D, Lovell R. Dose-response relationship between external load and wellness in elite women's soccer matches: Do customized

velocity thresholds add value? *Int J Sports Physiol Perform* 4: 1–7, 2020.
139. Sheppard JM, Young WB. Agility literature review: Classifications, training and testing. *J Sports Sci* 24: 919–932, 2006.
140. Siff M, Verkohoskansky Y. *Supertraining* (6th ed). Rome: Verkohoskansky SSTM, 2009.
141. Spiteri T, Nimphius S, Hart NH, et al. Contribution of strength characteristics to change of direction and agility performance in female basketball athletes. *J Strength Cond Res* 28: 2415–2423, 2014.
142. Stojanović E, Ristić V, McMaster DT, Milanovic Z. Effect of plyometric training on vertical jump performance in female athletes: A systematic review and meta-analysis. *Sports Med* 47: 975–986, 2017.
143. Strudwick A, Doran D, Reilly T. Anthropometric and fitness profiles of elite players in two football codes. *J Sports Med Phys fitness* 42: 239–242, 2002.
144. Suchomel TJ, Nimphius S, Bellon CR, Stone MH. The importance of muscular strength: Training considerations. *Sports Med* 48: 765–785, 2018.
145. Suchomel TJ, Nimphius S, Stone MH. The importance of muscular strength in athletic performance. *Sports Med* 46: 1419–1449, 2016.
146. Sung E, Han A, Hinrichs T, et al. Effects of follicular versus luteal phase-based strength training in young women. *Springerplus* 3: 668–710, 2014.
147. Taberner M, van Dyk N, Allen T, et al. Physical preparation and return to performance of an elite female football player following ACL reconstruction: A journey to the FIFA women's world cup. *BMJ Open Sport Exerc Med* 6: e000843, 2020.
148. Talty PF, McGuigan K, Quinn M, Jones PA. Agility demands of Gaelic football match-play: A time-motion analysis. *Int J Perform Anal Sport* 22: 195–208, 2022.
149. Taylor JB, Wright AA, Dischiavi SL, Townsend MA, Marmon AR. Activity demands during multi-directional team sports: A systematic review. *Sports Med* 47: 2533–2551, 2017.
150. Teahan C, O'Connor S, Whyte EF. Injuries in Irish male and female collegiate athletes. *Phys Ther Sport* 51: 1–7, 2021.
151. Thompson B, Almarjawi A, Sculley D, Janse de Jonge X. The effect of the menstrual cycle and oral contraceptives on acute responses and chronic adaptations to resistance training: A systematic review of the literature. *Sports Med* 50: 171–185, 2020.
152. Trewin J, Meylan C, Varley MC, Cronin J, Ling D. Effect of match factors on the running performance of elite female soccer players. *J Strength Cond Res* 32: 2002–2009, 2018.
153. Tucker L, Reilly T. Physiological and anthropometric characteristics of female Gaelic football players. Science and football v. In: Proceedings of the Fifth World Congress of Science and Football, 2005. pp. 27–30.
154. Turner AN, Comfort P, McMahon J, et al. Developing powerful athletes, part 2: Practical applications. *Strength Cond J* 43: 23–31, 2021.
155. Turner AN, Jeffreys I. The Stretch-Shortening Cycle: Proposed mechanisms and methods for enhancement. *Strength Cond J* 32: 87–99, 2010.
156. Turner A. The science and practice of periodization: A brief review. *Strength Cond J* 33: 34–46, 2011.
157. Weakley J, Mann B, Banyard H, et al. Velocity-based training: From theory to application. *Strength Cond J* 43: 31–49, 2021.
158. Weyand PG, Davis JA. Running performance has a structural basis. *J Exp Biol* 208: 2625–2631, 2005.
159. Weyand PG, Sternlight DB, Bellizzi MJ, Wright S. Faster top running speeds are achieved with greater ground forces not more rapid leg movements. *J Appl Physiol* 89: 1991–1999, 2000.
160. Wikström-Frisén L, Boraxbekk CJ, Henriksson-Larsén K. Effects on power, strength and lean body mass of menstrual/oral contraceptive cycle-based resistance training. *J Sports Med Phys Fitness* 57: 43–52, 2017.
161. Wild CY, Steele JR, Munro BJ. Why do girls sustain more anterior cruciate ligament injuries than boys? A review of the changes in estrogen and musculoskeletal structure and function during puberty. *Sports Med* 42: 733–749, 2012.
162. Wilson JM, Flanagan EP. The role of elastic energy in activities with high force and power requirements: A brief review. *J Strength Cond Res* 22: 1705–1715, 2008.
163. Wyckelsma V, Aughey R, McKenna M. Physiological responses and movement demands of elite women playing Australian football in the midfield position. *J Sci Med Sport* 13: 15–16, 2010.
164. Yao X, Curtis C, Turner A, et al. Anthropometric profiles and physical characteristics in competitive female English premiership rugby union players. *Int J Sports Physiol Perform* 16: 1234–1241, 2021.