SPORTSCIENCE · sportsci.org Latest issue
Perspectives / Training & Performance This issue

Physical and Physiological Testing of Soccer Players: Why, What and How should we Measure?

Thomas Haugen[1], Stephen Seiler[2]

Sportscience 19, 10-26, 2015 (sportsci.org/2015/TH.htm)
1 Norwegian Olympic Federation, Oslo, Norway. Email. 2 Faculty of Health and Sport Sciences, University of Agder, Kristiansand, Norway. Email. Reviewer: Martin Buchheit, Paris Saint-Germain Football Club, Paris, France..

Monitoring soccer players is important for evaluating individual and collective team behavior during training sessions and games, in addition to informing recovery strategies and load management. Modern micro-technology allows assessment of physical, technical and tactical performance parameters in “real-world” conditions. However, physical testing performed either in laboratories or on the pitch is required for individual training prescription, and to develop performance benchmarks for playing standards and playing positions. Anaerobic actions precede the majority of goals, and a large number of linear or repeated sprint tests with or without direction changes have been used in order to assess soccer players’ ability to create or close a gap. The Yo-Yo tests evaluate the players’ ability to repeatedly perform intense exercise. These tests have substantial correlations with high-intensity running distance covered in matches and are considered more valid than measures of maximal aerobic power. Commonly used change-of-direction tests do not mimic on-field movements, and the usefulness of repeated-sprint tests can be questioned, owing to the near-perfect relationship between best and average sprint times. In this presentation we outline minimum standards, percentiles, methodological concerns and future recommendations which hopefully can serve as bottom line information for soccer practitioners. KEYWORDS: endurance, fatigue, football, reliability, sprint, validity, Yo-yo.

Reprint pdf · Reprint docx · Slideshow pptx

Soccer is the world`s most popular sport: approximately 265 million players and 5 million referees and officials are actively involved, or 4% of the world population, according to FIFA, the International Federation of Association Football. The game is intermittent in nature and involves multiple motor skills, such as running, dribbling, kicking, jumping and tackling. Performance depends upon a variety of individual skills and their interaction and integration among different players within the team. Technical and tactical skills are considered to be predominant factors. For example, pass completion, frequency of forward and total passes, balls received and average touches per possession are higher among successful teams compared to less successful teams (Bradley et al., 2013; Dellal et al., 2011; Rampinini et al., 2019). However, individual physical and physiological capabilities (both aerobic and anaerobic) must also reach a certain level for players to be successful (Bradley et al., 2013; Haugen et al., 2013; Haugen et al., 2014; Krustrup et al., 2006; Tønnessen et al., 2013).

Teams from the best European leagues have tight game schedules, long seasons and relatively short pre-season periods, limiting the possibilities for long-term physical conditioning planning (Carling et al., 2015). As long as each player does his/her “job” satisfactorily on the field, all other physical and physiological considerations are secondary (Delgado-Bordonau and Mendez-Villanueva, 2012). In such settings, the main focus is to recover and prepare for the next game. Underperforming players may be replaced by other players in the short term, while they risk being sold to other clubs in the longer term. In contrast, academies and reserve teams prepare for future careers by developing soccer-specific motor skills and physiological capacity to an elite level. Key skills are developed to a high level, while other capabilities merely need to meet a minimum requirement (Bradley et al., 2013; Reilly et al., 2000; Tønnessen et al., 2013).

Many physical tests have been implemented in clubs and academies over the years to evaluate physical performance in soccer players. This long list includes linear sprinting, agility, repeated sprint ability, VO_2max, and Yo-Yo intermittent tests. However, in the last decade semi-automatic computerized player tracking technologies and global positioning systems (GPS) with integrated accelerometers have been extensively implemented in the best European soccer leagues for match analysis. This technology allows assessment of physical, technical and tactical performance parameters during training sessions and games. The advantage with such technology is obvious, as a large range of performance data can be assessed quickly and accurately in real-world conditions. The introduction of this technology has initiated a debate among professional practitioners and scientists regarding the value and usefulness of traditional off-field testing. Are soccer-related fitness tests still necessary? Is it reasonable to assume that future soccer laboratories will consist of micro-technology and purpose-built software only, replacing timing gates, force platforms and metabolic gas analyzers? Our goal with this presentation is to identify pros and cons with today's available physical performance assessment tools and present reasonable arguments regarding what information is needed to prescribe training and thereby enhance soccer performance.

Bradley PS, Carling C, Gomez DA, Hood P, Barnes C, Ade J, Boddy M, Krustrup P, Mohr M (2013). Match performance and physical capacity of players in the top three competitive standards of English professional soccer. Human Movement Science 32, 808-821

Carling C, Gregson W, McCall A, Moreira A, Wong DP, Bradley PS (2015). Match running performance during fixture congestion in elite soccer: research issues and future directions. Sports Medicine (in press)

Delgado-Bordonau J, Mendez-Villanueva A (2012). Tactical periodization: Mourinho's best-kept secret? Soccer NSCAA Journal 3, 28-34

Dellal A, Hill-Haas S, Lago-Penas C, Chamari K (2011). Small-sided games in soccer: amateur vs professional players' physiological responses physical and technical activities. Journal of Strength and Conditioning Research 25, 2371-2381

Haugen T, Tønnessen E, Seiler S (2013). Anaerobic performance testing of professional soccer players 1995-2010. International Journal of Sports Physiology and Performance 8, 148-156

Haugen T, Tønnessen E, Hisdal J, Seiler S (2014). The role and development of sprinting speed in soccer. International Journal of Sports Physiology and Performance 9, 432-441

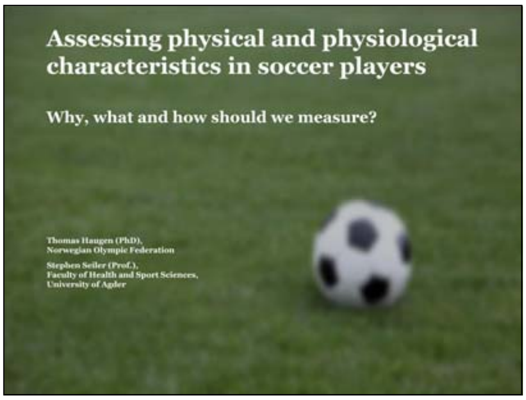
Krustrup P, Mohr M, Nybo L, Jensen JM, Nielsen JJ, Bangsbo J (2006). The Yo-Yo IR2 test: physiological response reliability and application to elite soccer. Medicine and Science in Sports and Exercise 38, 1666-1673

Rampinini E, Impellizzeri FM, Castagna C, Coutts AJ, Wisløff U (2019). Technical performance during soccer matches of the Italian Serie A league: effect of fatigue and competitive level. Journal of Science and Medicine in Sport 12, 227-233

Reilly T, Bangsbo J, Franks A (2000). Anthropometric and physiological predispositions for elite soccer. Journal of Sports Sciences 18, 669-683

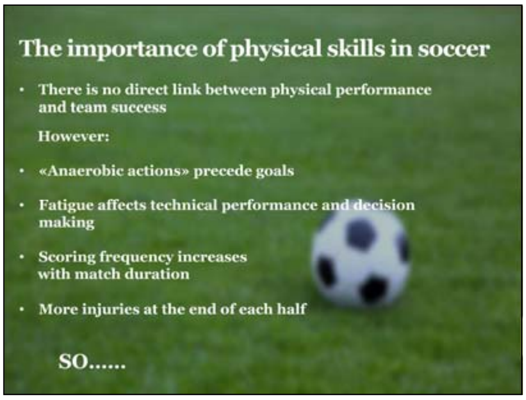
Tønnessen E, Hem E, Leirstein S, Haugen T, Seiler S (2013). Maximal aerobic power characteristics of male professional soccer players 1989-2012. International Journal of Sports Physiology and Performance 8, 323-329

Published June 2015

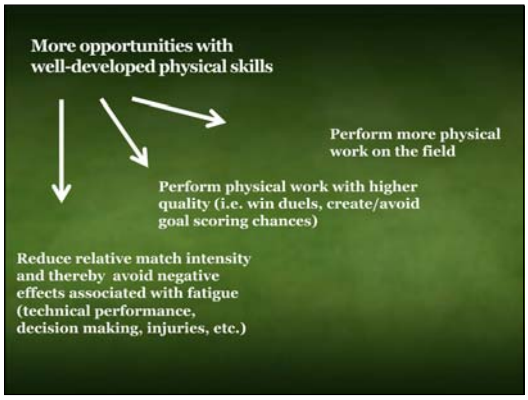


This presentation is mainly based on Thomas Haugen's doctoral thesis «The Role and Development of Sprinting Speed in Soccer» plus other soccer-related studies carried out by the same authors in the time period 2011-2014. Professor Stephen Seiler played the adversarial role of «main supervisor» throughout the entire process.

In this presentation, we evaluate a large number of commonly used physical tests for soccer players and outline minimum standards for elite players. Moreover, we identify pros and cons/limitations with today's available physical performance assessment tools and present reasonable arguments regarding what information is needed to potentially prescribe individual training intervention and thereby enhance overall soccer ability. Hopefully, our recommendations can serve as bottom line information for soccer practitioners.



Performance in soccer depends upon a variety of individual skills and their interaction and integration among different players within the team. Technical and tactical skills are considered to be predominant factors. For example, pass completion, frequency of forward and total passes, balls received and average touches per possession are higher among successful teams compared to less successful teams.[10,28,87] However, individual physical and physiological capabilities (both aerobic and anaerobic) must also reach a certain level for players to be successful.[10,48-51,68,90,105] Faude et al.[39] analyzed videos of 360 goals in the first German national league and observed that anaerobic actions preceded the majority of goals scored, both for the scoring and assisting player. Rampinini et al.[87] observed a significant decline between the first and second half for several technical measures (involvements with the ball, short passes and successful short passes) in Italian Serie A players. Similar findings have been reported in a group of young soccer players, and the decline in technical performance had a significant relationship with physical fitness level.[86] Fatigue affects both scoring frequency[31] and injury rate.[36,59]



Game analyses have revealed a reverse relationship between ball possession and distance covered.[10] That is, inferior technical skills must be compensated for with more physical work. In contrast, teams with superior technical skills can perform the games at a lower relative work rate than their opponents.

Faude et al.[39] concluded that power and speed abilities are important within decisive situations in professional football and, thus, should be included in fitness testing and training.

Injuries affect team performance negatively in professional soccer.[44] According to Ekstrand,[37] coaches affect team injury rate more than doctors or physical therapists. Robust injury databases covering the best European leagues show that injury rates within teams to a large extent are affected by the team coach's overall conditioning program.[37]

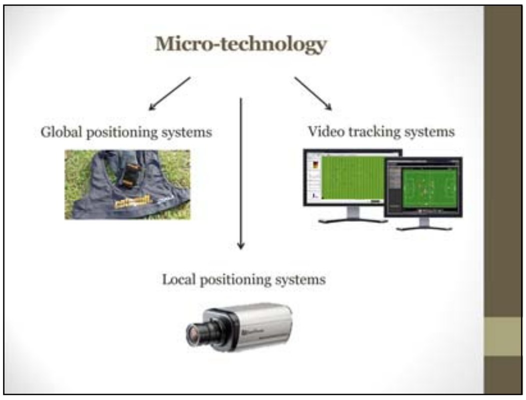
Assessing soccer players is important to evaluate both individual and collective team behavior during training sessions and matches.[7,15,22,25] According to Mendez-Villanueva & Buchheit,[78] soccer players should also perform less valid (non-specific) tests to get a clearer understanding of underlying causes and physical performance factors. Such information can in turn be used as framework for individual and collective training prescriptions, informing recovery strategies and load management. However, Bradley & Krustrup question the use and impact of non-specific tests. They argue that only soccer-specific tests that has undergone evaluation and critiquing by applied scientists should be used.[78]

According to Hopkins,[61] a good (sport-specific) test should be derived from logical reasoning, for example based on game analyses. Moreover, physical tests should somehow be related to a criterion measure. For example, a soccer-specific endurance test may be validated against e.g. high-intensity running in games. A good test should also track training related changes within athletes (e.g. seasonal variations in physical capacity).

Reliability is a quantitative expression of the reproducibility of the test when it is repeated.[61] High reliability (measured as typical variation in scores from repeated tests under the same conditions) is required if we want to track small training-related changes. A test is considered reliable if this variation, called the typical error (TE), is smaller than the smallest worthwhile change (SWC).[61]

According to Buchheit & Mendez-Villanueva,[78] soccer-specific tests should add value (e.g. identify underlying factors that limit the test results) and not just confirm the coaches' assumptions. Finally, we argue that a good test should lead to minimal negative consequences on overall soccer conditioning in terms of fatigue or injury.

Many physical tests have been validated and implemented in clubs and academies over the years to evaluate physical performance in soccer players. This long list includes linear sprinting, agility, repeated sprint ability, VO_2max, Yo-Yo intermittent tests, etc.[5,6,12,49,50,51,64,67,68,99,100,102,105] However, a marked trend has arisen the last decade, as semi-automatic computerized player tracking technologies and global/local positioning systems with integrated accelerometers have been extensively applied in the best European soccer leagues for match analysis.[22,25] This technology allows assessment of physical, technical and tactical performance parameters during training sessions and games. The advantage with such technology is obvious as a large range of performance data can be assessed quickly and accurately in "real-world" conditions. The introduction of modern match analysis technology has initiated a debate among professional practitioners and scientists regarding the value and usefulness of traditional off-field testing.[78] Are soccer-related fitness tests still necessary? Is it reasonable to assume that future soccer laboratories will consist of micro-technology and purpose-built software only, replacing timing gates, force platforms and metabolic gas analyzers?



Video tracking of soccer players was introduced for the first time by Van Gool et al.[107] at the end of the 1980s. More than 50 scientific studies have been published the last five years, mainly using Amisco or Prozone.[22] Global positioning systems (GPS) are satellite-based navigation systems originally built for military purposes. This technology was introduced to sport science at the end of the 1990s[94] and enables three-dimensional measurements of athletes over time. Lightweight devices are placed in players' clothing. Local positioning systems (LPS) provide similar assessments, but data are captured by local base stations instead of satellites.[15,65]

In most soccer leagues, players are not allowed to wear units/devices during matches. Thus, video tracking systems are typically used for match analysis purposes, while GPS/LPS are typically used to monitor training sessions.[15]

Buchheit et al.[15] observed disagreements across varying game analysis systems/technologies. For example, Prozone's video tracking system overestimates high-intensity running by trivial to moderate margins, and accelerations are small-to-very largely greater with LPS. Fortunately, available calibration equations can integrate the systems with a moderate typical error of the estimate.[15]

Time motion analyses are typically predefined by absolute speed zones that vary across studies. For example, running velocity cut-offs ranging from 18 to 30 $km \cdot h^{-1}$ have been used to distinguish sprinting from high speed running.[50] However, several authors argue that relative thresholds also should be provided.[73,77]

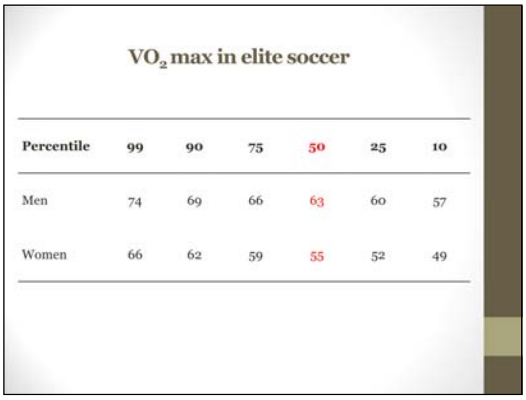
GPS and LPS are more sensitive to acceleration and changes-of-directions than video tracking, but reliable results require multiple measurements. The higher velocities, the shorter activity durations and more changes-of-directions, the poorer reliability and validity.[25] Compared to video tracking systems, GPS and LPS incorporate metabolic cost measurements (individual power generation, work rate patterns and physiological stress), assessment of body contacts and collisions between players.[25]

All currently available game analysis tools are expensive and require experienced analysts.

Most professional outfield soccer players run 10-12 km per match.[10,17,18,32,69,84,109] Fullbacks and wide midfielders cover more distance than central midfielders, central defenders and forwards.[32] Only 1-2% of total distance covered is with the ball. About 65-75% of the covered distance is walking or easy jog, 20-30% fast jog or moderate running, while 8-12% is high intensity running or sprinting.[84,109] Average heart rate in games is 80-90% of HRmax, and level of blood lactate is 3-9 mM measured just after end of match.[69]

Numerous contextual variables have been identified for distance covered (both total distance and high-intensity running distance): first vs. second half, opponent, ball possession, match status, match location, tactics/formation, league, time of year, physical capacity of players, etc.[7,10,11,18,19,32,63,65,69,77,84,85,87,109]

Overall, soccer performance places demands on individual and team aerobic capacity, but how much?

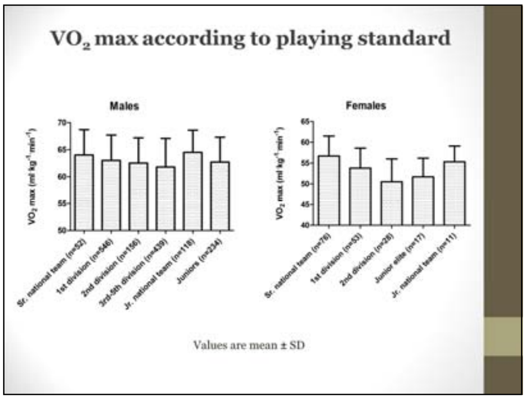


VO_2 max in elite soccer

Percentile	99	90	75	50	25	10
Men	74	69	66	63	60	57
Women	66	62	59	55	52	49

This slide presents percentiles for VO_2 max ($ml \cdot min^{-1} \cdot kg^{-1}$) among male (n=598) and female (n=152) elite players.[51,105] The tests were performed at the Norwegian Olympic Training Center in Oslo during the time period 1989-2012. All included athletes played in the two highest divisions in Norway, and/or were members of the national team, but played for international clubs. A review by Stølen et al.[102] confirms that VO_2max in male elite soccer players is in the (wide) range 50-80 $ml \cdot min^{-1} \cdot kg^{-1}$.

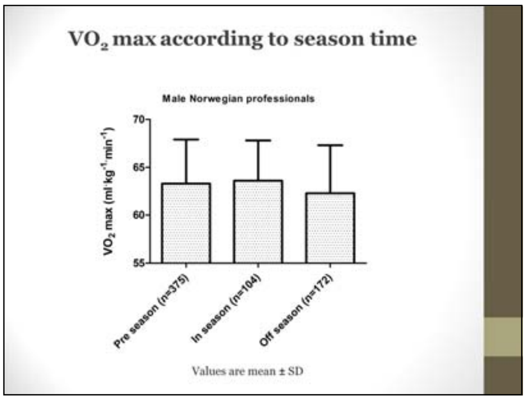
VO_2 max was the most commonly used laboratory test to assess aerobic capacity in soccer players in the 80s and 90s.[35,102]



The importance of high maximal aerobic power in modern soccer has been heavily debated, and numerous studies of players' VO_2 max have been published over the years.[102] These figures show that VO_2 max does not differ between players who differ in playing standard at the higher levels.[51,105]

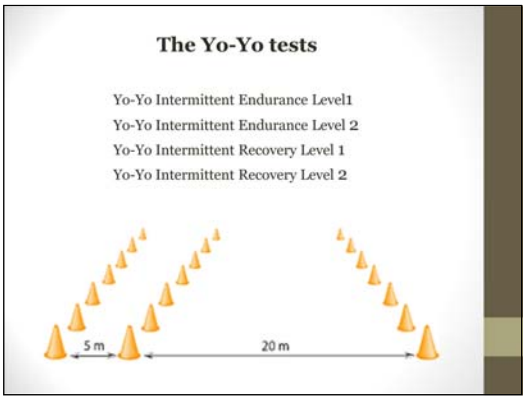
Ekblom[35] concluded already in 1986 that 60-65 $ml \cdot min^{-1} \cdot kg^{-1}$ was sufficient to play at international level in male soccer. One decade later, Reilly et al.[91] claimed that VO_2 max is not a sensitive measure of performance capability in soccer and suggested that VO_2 max > 60 ml represents a threshold to possess the physiological attributes for success in male elite soccer. Recent findings[105] support the claims by Ekblom and Reilly et al.

Group mean values 52-57 $ml \cdot min^{-1} \cdot kg^{-1}$ for women seem to be sufficient to play at a high level.[51,102] Pitch size and number of players are identical in male and female soccer, but women have on average 15% lower aerobic capacity. Perhaps VO_2 max is a more important determinant in female soccer?

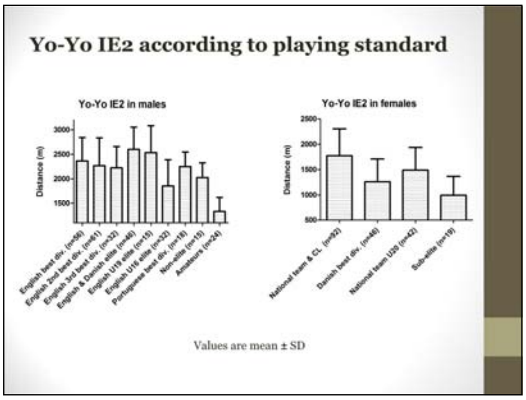


Professional soccer players have lower relative uptake during off-season compared to pre-season and in-season by a small, non-significant margin.[105] Overall, there are only small differences in VO_2 max within categories (playing standard, positions, seasonal variations). VO_2 max among male professional players has not changed over the last two decades.[105] However, there has been a slight, but non-significant trend towards lower VO_2 max values over an 18 year period of testing in female national team players.[51]

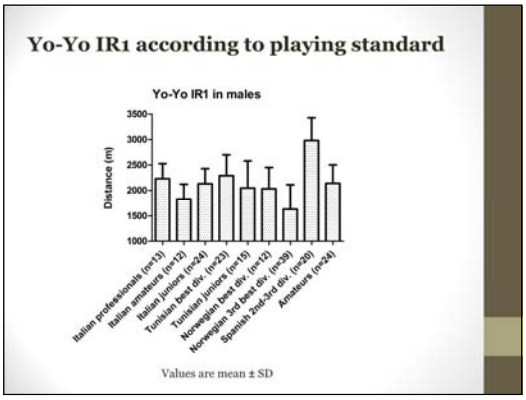
Even though the VO_2 max test detects underlying physiological changes, the test is impractical , time consuming, laboratory-based (off-field) and have questionable relevance to intermittent exercise.[6] The test does not take into account one of the most important aspect of running performance, that is running economy. However, running velocity at VO_2 max can be a useful marker. Finally, the VO_2 max test requires expensive equipment and experienced test leaders.



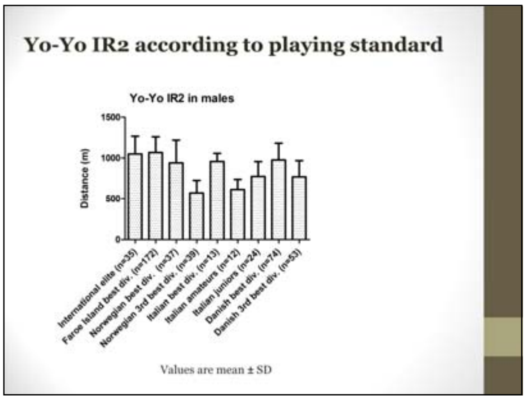
The intermittent Yo-Yo tests were developed and introduced in the 90s by Jens Bangsbo and his associates at the University of Copenhagen, as they questioned the relevance of the laboratory based VO_2max test.[6] The Yo-Yo tests consist of 20+20 m shuttle runs with incremental intensity and come in four different versions: Yo-Yo IR1, Yo-Yo IR2, Yo-Yo IE1 & Yo-Yo IE2. Recoveries between each run are 5 s for IE-tests and 10 s for IR tests. Level 1 tests begin at lower speed, with smaller incremental increases compared to level 2 tests. The IE versions are more aerobic than IR, and level 2 tests are more intensive than level 1. Test scores are reported as completed level or completed distance in meters. The Yo-Yo tests take several underlying performance variables into account: Aerobic capacity, running economy, change-of-direction and recovery abilities. Correlations between VO_2 max and Yo-Yo test performance is ~0.7.[6,67,68] Correlations between Yo-Yo test performance and high-intensity running distance covered in games have been reported in the range 0.54-0.76.[6,9,10,12,67,68] Due to their practicality and low expenses, the Yo-Yo tests have been widely applied to assess players' abilities to repeatedly perform high-intensity exercise. IR1, IR2 and IE2 are most used in elite soccer.



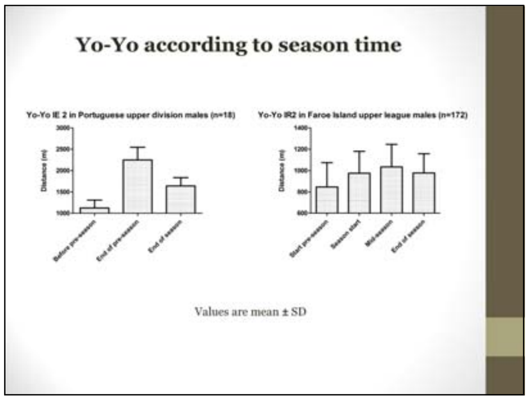
This slide shows reported Yo-Yo IE2 test results across studies involving soccer players.[9,10,12,20,70,96,97] Bradley et al.[10] observed no significant differences among the three upper leagues in England (trivial/small effect magnitudes).



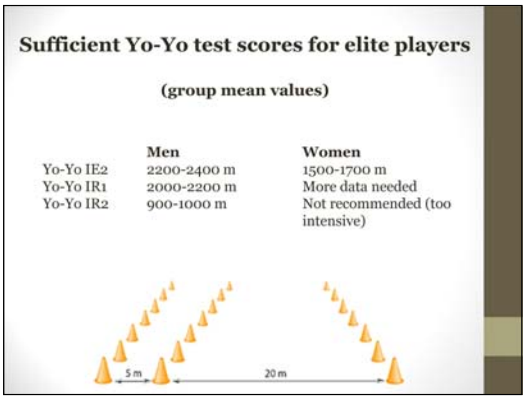
This slide presents Yo-Yo IR1 test results across soccer-related studies.[20,23,38,45,64,79,89] Notice the results for a sample of Italian Serie A players and results from a Spanish sample from 2nd and 3rd division teams. Would it be beneficial for e.g. Italian Serie A players to improve their IR1 performance (team average) from 2200 to 3000 m and thereby reach the same level as the Spanish 2nd-3rd division players?



This slide presents Yo-Yo IR2 test results among different European players samples.[38,64,68,80,89] Interesting to note that the ENTIRE upper league on Faroe Island (n=172) achieve the best average results.

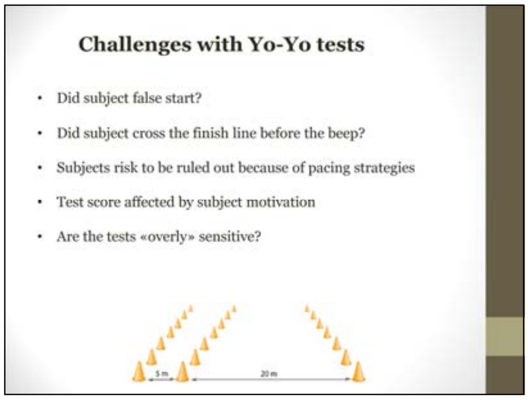


This slide shows seasonal variations in Yo-Yo test performance.[80,96] Interesting to note that the Portuguese players managed to improve their test score by 100% during the pre-season period. Is it reasonable to argue that the least intensive Yo-Yo tests are more sensitive to track training-related changes, compared to the most intensive Yo-Yo test versions?



Overall, Yo-Yo test performance (mean) does not differ between players who differ in playing standard at the higher levels, and it is more a matter of reaching a certain minimum. Previous slides show that the entire Faroe Island league (Yo-Yo IR2) , Spanish 2nd-3rd division players (Yo-Yo IR1) and Scandinavian soccer players have achieved the best Yo-Yo results. Bradley et al.[10] observed no Yo-Yo IE2 performance differences across the three upper leagues in England. In conclusion, aerobic endurance/capacity is not a performance distinguishing variable in elite soccer.

Mendez-Villanueva & Buchheit[78] point out that the Yo-Yo tests in isolation provide limited information regarding which underlying performance variable(s) that potentially limit a poor test score. If the main aim is to improve a player's ability to perform high-intensity intermittent exercise (in games), additional tests are required to determine whether the poor test performance is due to aerobic capacity, running economy, change-of-direction, recovery abilities, etc.



Several methodological challenges arise when performing the Yo-Yo tests, and the challenges increase with larger test groups. Firstly, what is considered a legal start? Is everything OK as long as the athletes' feet are behind the line at the time of beep? Or should we allow no movement/momentum what so ever prior to the beep? Clearer regulations are needed here. Most dedicated software have a built-in countdown procedure (e.g. "3-2-1-beep"), allowing the athletes to "predict" the time of beep. Would it be easier to "judge" the starts if no countdown procedures were provided? This would probably lead to poorer test results, but perhaps strengthen reliability.

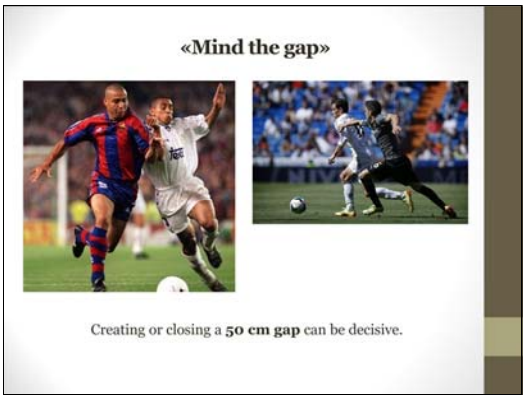
Secondly, how do we judge whether the athletes reached the finish line before the beep? Must one foot be in contact with the ground at or after the finish line? Is it enough that one body part has reached the finish line, regardless of the vertical level? Or should we only consider the torso (chest), as performed in athletics running events? Overall, clearer testing guidelines would improve Yo-Yo test validity and reliability.

Another concern with the Yo-Yo tests is that subjects risk to achieve poorer than optimal results due to faulty pacing strategies. In order to maximize the test results, it is crucial to run as slow as possible but still reach the finish line at the time of beep. Additional measures (e.g. heart rate, blood lactate) are perhaps needed to verify whether exhaustion occurred.

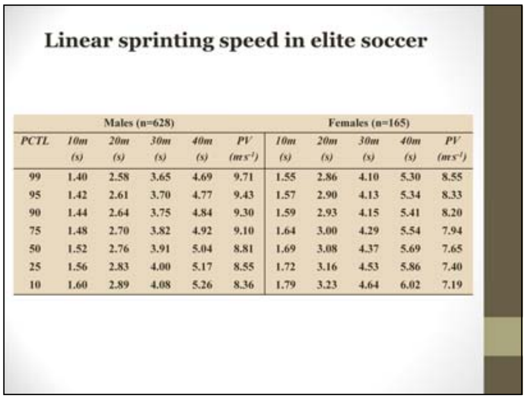
Finally, are the tests "overly" sensitive? Seasonal variations up to 100% are reported. Are small changes in physical condition magnified? Are we identifying differences that have little performance relevance? Interpretation should likely be similar to time-to-exhaustion tests, where outcome changes are ~15x larger than underlying physiological changes.

Observed top speed (team average) in males (31-32 km·h^{-1})[85] corresponds to 1.12-1.16 s for a 10-m sprint interval.

Players typically perform ~1 sprint/acceleration per minute per match.[65] Mean sprint duration is 2-4 s, and 90% of all sprints are shorter than 20 m.[17,85,109] About 70% of all sprints start from a run, potentially magnifying the importance of peak velocity.[32] A linear sprint precedes 45% of all goals, usually without defender or ball.[39]



According to Hopkins et al.,[60] the smallest worthwhile performance enhancement/change in team sport is 0.2 of the between-subject standard deviation. Based on robust database material,[48,49] this corresponds to ~0.02 s over a 20-m sprint. In practical settings, a 30-50 cm difference (~0.04-0.06 s over 20-m sprint) is probably enough in order to be decisive in one-on-one duels by having body/shoulder in front of the opposing player.[50] Thus, the ability to either create such gaps (as performed by Garreth Bale in the right picture) or close those gaps (as performed by Roberto Carlos in the left picture) can be the difference between winning and loosing the game. But, how fast is fast enough?



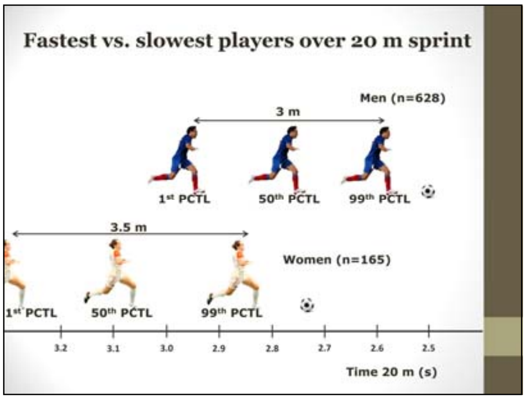
	Males (n=628)					Females (n=165)				
PCTL	10m (s)	20m (s)	30m (s)	40m (s)	PV (m·s^{-1})	10m (s)	20m (s)	30m (s)	40m (s)	PV (m·s^{-1})
99	1.40	2.58	3.65	4.69	9.71	1.55	2.86	4.10	5.30	8.55
95	1.42	2.61	3.70	4.77	9.43	1.57	2.90	4.13	5.34	8.33
90	1.44	2.64	3.75	4.84	9.30	1.59	2.93	4.15	5.41	8.20
75	1.48	2.70	3.82	4.92	9.10	1.64	3.00	4.29	5.54	7.94
50	1.52	2.76	3.91	5.04	8.81	1.69	3.08	4.37	5.69	7.65
25	1.56	2.83	4.00	5.17	8.55	1.72	3.16	4.53	5.86	7.40
10	1.60	2.89	4.08	5.26	8.36	1.79	3.23	4.64	6.02	7.19

PV = peak velocity

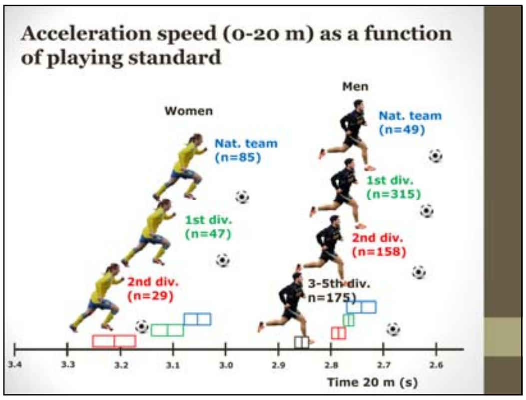
The table shows percentiles (PCTL) for sprint performance in male and female elite players.[50] The tests were performed at the Norwegian Olympic Training Center in Oslo in the time period 1995-2010. Included athletes all played in the two highest divisions in Norway, and/or were members of the national team, but played for international clubs. A floor pod placed on the start line was used for time initiation.

The table shows that the 75th -25th percentile difference is 0.13 and 0.16 s over 20 m sprint for male and female players, respectively, equivalent to a ~5% performance difference. Based on average velocity over the distance, the fastest quartile is ~ 1 m ahead of the slowest quartile over 20 m. Similarly, the 90th -10th percentile difference over 20 m sprint is equivalent to more than 2 m. Furthermore, the 10% fastest players run 1 m further than the 10% slowest players for each second during peak sprinting.

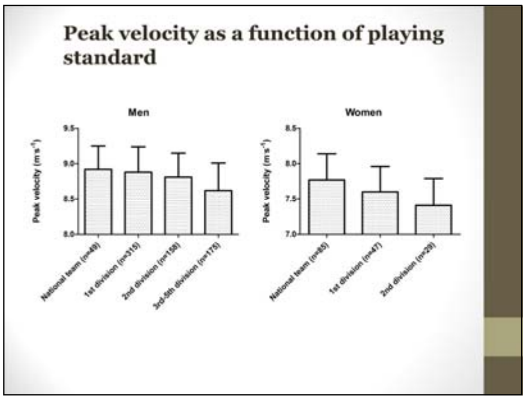
Mendez-Villanueva et al.[76] reported a strong relationship between sprint test performance and peak velocities reached in games.



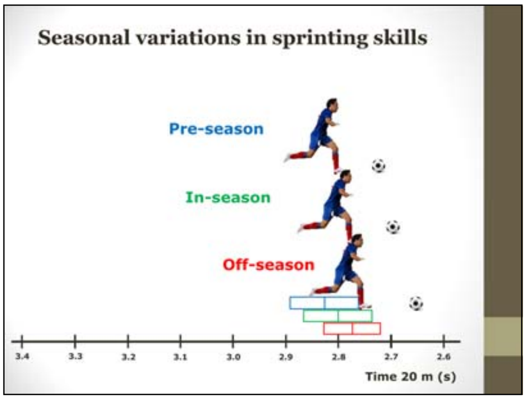
This 20 m "photo finish picture" shows the difference between the fastest and slowest elite players, expressed in percentiles. The fastest males are more than 3 m ahead of the slowest players in a 20 m sprint. The differences are even bigger among females. The fastest female players are capable of beating ~25 % of all male players in a 20 m sprint.[48-50]



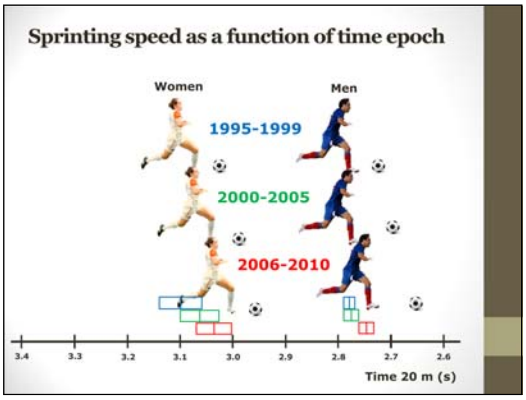
0-20 m sprinting speed trends predictably across playing level in both male and female soccer.[48,49] 95% CIs are located at the timeline beneath the athletes. The magnitudes of the differences are in most cases large enough (~50 cm) to create or close a gap. There are larger time differences across female categories compared to the males.



Peak velocity trends predictably across playing standard in both male and female soccer, though with smaller differences among categories than acceleration speed.[48,49]

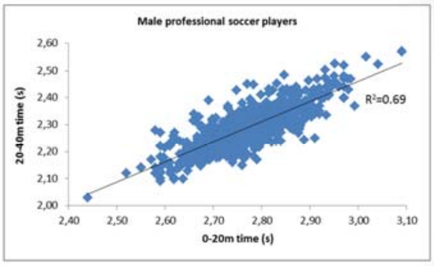


Thirty players in our database performed sprint tests at different times of season, allowing a repeated measures analysis. The results suggest that male players run faster off-season by a small, non-statistically significant margin compared to in-season and pre-season. Cross-sectional data from the same database confirm these results. There seems to be a reversed relationship between sprint performance and aerobic capacity/endurance according to time of season, as the latter capabilities have shown poorest tests scores off-season.[105] Sprint performance is negatively affected by constraints with overall team conditioning.[52,56]



Our robust database material provided us the opportunity to evaluate the evolution of sprint performance in soccer players over a 15 yr period. As we see, both male and female elite players have become faster over time,[48,49] indicating that sprinting speed becomes more and more important in modern soccer. Interestingly, VO_2 max among the same groups of male professional players has not changed over time.[105] In fact, we actually observed a slight, but non-significant trend towards lower VO_2max values over an 18 year period of testing in female national team players.[51]

Acceleration-peak velocity relationship



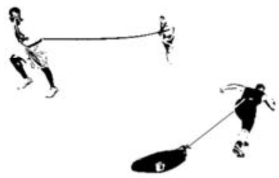
Conclusion: Fast for 20 m, very likely fast for 40 m.

Practically all soccer related studies have used testing distances in the range 5-40 m.[50] The present figure shows a very strong relationship between 0-20 m and 20-40 m sprint performance.

Data source: Electronic timing data (n=401) from the Norwegian Olympic Training Center, 1995-2010.[49]

Assisted and resisted sprint tests

Valuable for individual training prescription



Typical sprint testing provides limited information regarding which underlying performance variable(s) that potentially limit a poor test score. An increase in sprinting velocity can only be achieved by upsetting the balance between accelerating and retarding impulses. This can only be achieved by streamlining the sprinting movement pattern (technique) and/or expanding physiological resources (improved power).[55] In order to profile athletes, and thereby provide individual training prescriptions, we recommend to test athletes under assisted and resisted conditions as well, with assisted/resisted force corresponding to e.g. 5-7% of body mass. Relatively better performance obtained with resistance indicates that technical training should be prioritized. Similarly, relatively better assisted sprint performance indicates that muscular power training should be prioritized. It is, however, important to keep in mind that the time hindrance produced by resistance is larger than the time aid produced by assistance of the same intensity (e.g. head wind vs. tail wind) due to sliding filament mechanisms (muscle force production declines with increasing velocity of contraction).[110] Thus, robust test result databases should be developed to assist practitioners.

Repeated sprint ability/performance

- **Repeated sprint ability**
  - **Fatigue index**
  - **Percentage decrement score**
- **Repeated sprint performance**
  - **Total time**
  - **Mean time of all sprints**

Repeated sprint ability (RSA) is the ability to perform repeated sprints with brief recovery intervals (<60 s), so called repeated-sprint exercise.[42] Two indices have mainly been used to evaluate RSA; the fatigue index or the percentage decrement score. Fatigue index is the relative drop-off in performance from the best to the worst sprint. The percentage decrement score compares actual performance to a "maximized" performance where the best trial is replicated in the formula.[43]

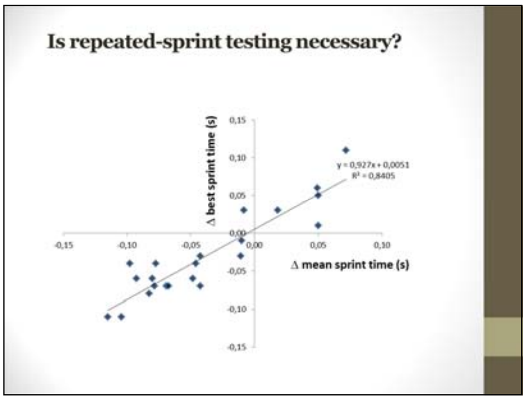
Intermittent sprint exercise (RSE) is the ability to perform repeated sprints with sufficient recovery intervals (>60 s) to recover between the sprints.[42] Such repeated sprint performance is measured as total time or mean time of all sprints.

Repeated-sprint test protocols in soccer studies

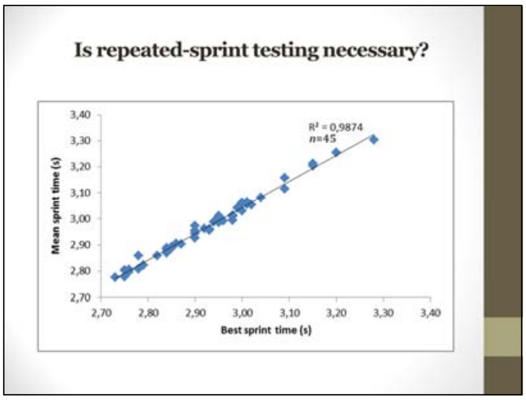
Study	Test protocol	TSD (m)	Recovery (s)
Krustrup et al., 2010[69]	3x30m	90	25
Gabbett, 2010[41]	6x20m	120	< 15
Aziz et al., 2007[2]	6x20m	120	20
Aziz et al., 2008[3]	8x20m	160	20
Mujika et al., 2009[81]	6x30m	180	30
Dellall et al., 2013[29]	10x20m	200	25
Dupont et al., 2010[33]	7x30m	210	20
Chaouachi et al., 2010[23]	7x30m	210	25
Meckel et al., 2009[75]	6x40m	240	~ 25
Meckel et al., 2009[75]	12x20m	240	~ 17
Impellizzeri et al., 2008[63]	6x20+20m	240	20
Bangsbo et al., 1994[5]	7x34.2m	240	20-25
Wong et al., 2010[112]	9x30m	270	25
Tønnessen et al., 2011[104]	10x40m	400	60
Dupont et al., 2010[33]	15x40m	600	25
Little & Williams, 2007[72]	15x40m	600	~ 8-12
Little & Williams, 2007[72]	40x15m	600	~ 20-30

Arranged based on total sprint distance (TSD)

The interpretation and usefulness of repeated sprint tests have been questioned over the years.[82,98] Based on the short recovery periods between each sprint, most RSA test protocols simulate the most intensive game periods, leading to a possible overrating of the aerobic demands.[50] A review of previously published research involving repeated sprint testing of soccer players shows that protocols vary tremendously. According to Balsom et al.,[4] it is easier to induce sprinting fatigue during a RSA protocol when sprint distance is 40 m, compared to 15 m. But, is this relevant for soccer? Moreover, Haugen et al.[52,56] observed no performance decline when junior soccer players repeated twelve or fifteen 20-m sprints with 60 s of recovery. However, a significant decline in performance has been observed already after 3-4 repetitions during 40-m sprints, even with 6 min. recovery periods.[47] Thus, protocol variable manipulation (sprint distance, rest duration and repetitions) can dramatically influence interpretation of results and effect of training.

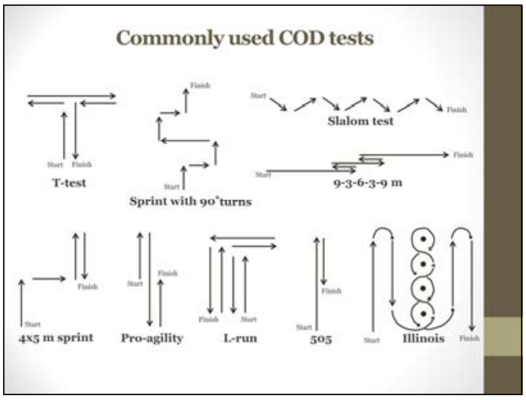


This figure shows a very high correlation between change in best sprint time and change in average sprint time in a 12x20 m repeated sprint test (start every 60 s) after a 9-week sprint training intervention.[52] Buchheit & Mendez-Villanueva[16] reported that changes in repeated-sprint performance could be predicted/monitored by changes in maximal sprint speed and maximal aerobic speed.



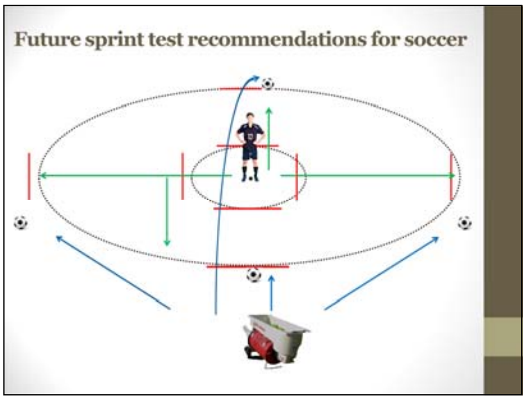
This figure shows a near-perfect correlation between best and average sprint time in a 15x20 m repeated sprint test (start every 60 s).[56] High correlation between "best sprint time" and "mean sprint time" in repeated sprint tests (r=0.8) has also been observed when recovery between 20-m sprints is as short as 25 s.[29] Pyne et al.[83] reported that total time in a RSA test was highly correlated with single sprint performance and concluded that RSA was more related to sprinting speed than aerobic capacity. Recent findings by Buchheit[14] confirm this relationship.

A player performs hundreds of direction changes in a match.[8] However, most of them are initiated at low intensity/velocity. Change of direction usually happens in first step, followed by a linear run/sprint. Only 10-12% of all explosive actions are sprint-brake-sprint actions. The most typical "explosive action" is a direction change (up to 100-120 angular degrees), immediately followed by a 5-20 m linear sprint. When the situation has ceased, the player jogs back to position.[8]



In research literature, tests are typically designed as zig–zag running, 90-180° turns, shuttle runs, lateral and backwards running.[99,101] Typical COD tests do not mimic movement patterns in games.[50] In soccer, most CODs are reactions to stimuli, while all CODs in tests are planned. Midfielders perform relatively better on agility tests compared to linear sprinting.[99,100] Kinetic energy = ½ mv^2, so COD tests will favor small players over bigger, faster players.

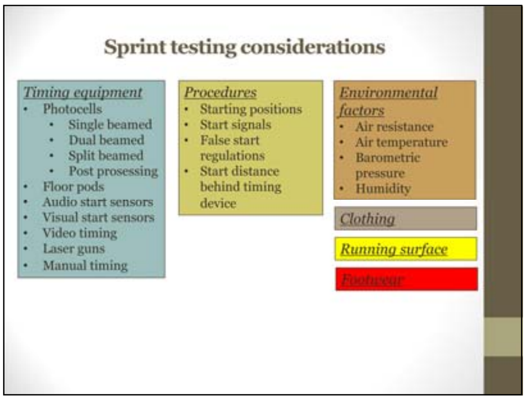
There are small correlations among strength/power measures and agility test results.[74] Moreover, there are small to moderate correlations among linear sprints and agility testing results.[71,108]



Is it possible to develop a sprint test that takes into account all soccer-related aspects (unplanned COD, linear and repeated sprint, even the dueling aspect)?

Setup details (suggestions): Inner circle 2 m diameter, outer circle 12 m diameter. Timing technology (marked as red lines) cover four sprinting directions (green arrows); forward, backward, to the left and to the right. A ball machine (as in e.g. tennis) sends the balls in four directions randomly (blue arrows). Time triggering occurs at the time of «ball release». Multiple trials (e.g. 3-5 trials to each direction x 4 directions = 12-20 repetitions in total) with e.g. 30-60 s recovery time in between. Performance can be stated as total time or mean sprint time, but also interesting with mean time for each direction to reveal individual strengths and weaknesses in COD. Time from «ball release» to first timing unit (inner circle) reflects cognitive processes, reaction time and COD-strategies. Time from first (inner circle) to second unit (outer circle) reflects 10-m linear sprinting ability.

Such a test is logical, based on movement patterns derived from game analyses. However, the main challenge is available, reliable and practical technology (time triggering at the moment of «ball release», in addition to triggering devices covering all directions). If proper technology is developed (wearable units preferred), would it be possible to test two players simultaneously to include the dueling aspect? We present an idea; can someone come up with technical solutions?



Varying technology, procedures and unaccounted extraneous variables can affect sprint running and change-of-direction (COD) performance with immediate effect.[58] Thus, highly stringent methodological requirements are needed to detect "true" changes in performance.

General testing recommendations (for sprint/COD):

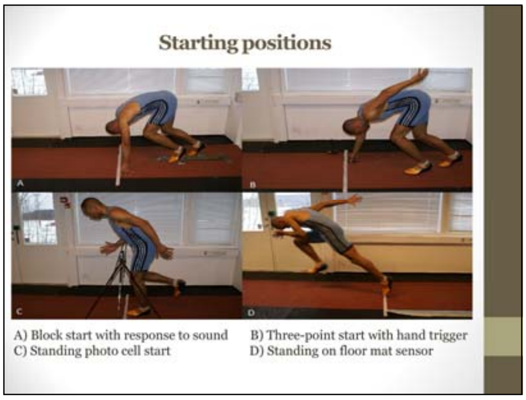
1) Dual beamed photo cells, laser guns and high-speed video timing are the most accurate tools. Manual timing and single-beamed photo cells should be avoided due to large absolute errors.[46,47,53,58,113]

2) ≥20-30 m intervals are required to guarantee an accurate evaluation of sprint speed.[13]

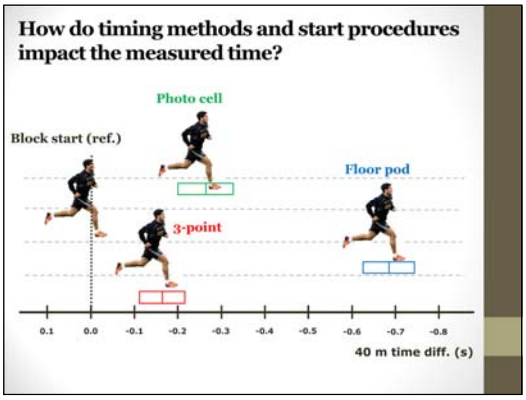
3) Testing should be performed indoor to avoid influence of varying air resistance, temperature and precipitation.[58]

4) Standardized procedures, footwear, surface and clothing.[58]

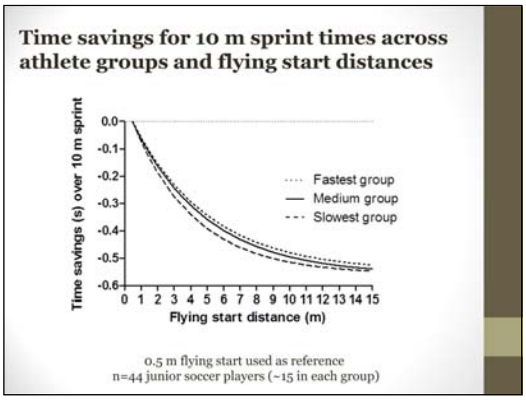
5) Multiple trials to decrease measurement noise.[103]



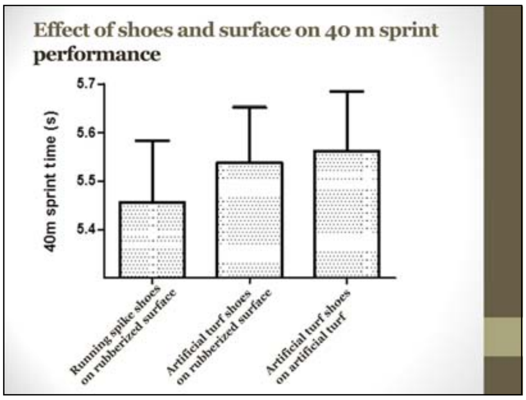
Different start positions (either from fixed position or leaning backward before rolling forward) are commonly used in soccer. The impact of different starting positions and hardware devices on monitored sprint performance can be huge.[34,47]



3-point starts with floor pod, photocell start and standing starts with floor pods yield 0.17, 0.27 and 0.69 s better 40 m sprint times, respectively, compared to block starts.[47] The differences are caused by inclusion/exclusion of reaction time, center of gravity placement and velocity at time triggering. Overall, the use in combination of different starting procedures and triggering devises can cause up to very large sprint time differences, which may be many times greater than the typically changes in performance associated with several years of conditioning.[55,92,106]



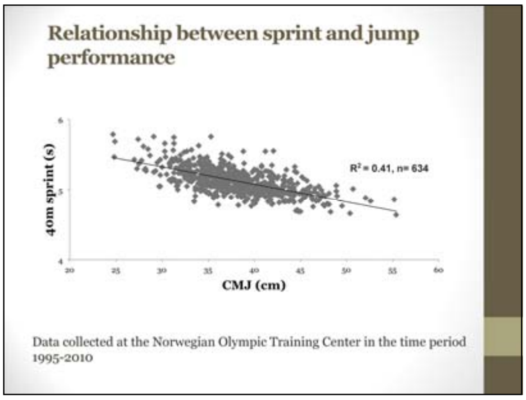
Regarding flying starts, the time saving magnitudes are significantly influenced by starting distance behind the initial timing gate, sprint distance and athlete performance level.[57] Increasing the start distance behind initial timing gate (flying start distance) from 0.5 to 1.5 m leads to a performance enhancement of ~0.15 s,[57] which represents the difference between the 50th and 95th percentile in male soccer players.[50] Time saving differences over 10 m sprints among groups of varying sprint performance standards increase to approximately 5 m of flying start distance and decrease thereafter.[57] The between-group differences observed are likely caused by varying sprint velocity development profiles.



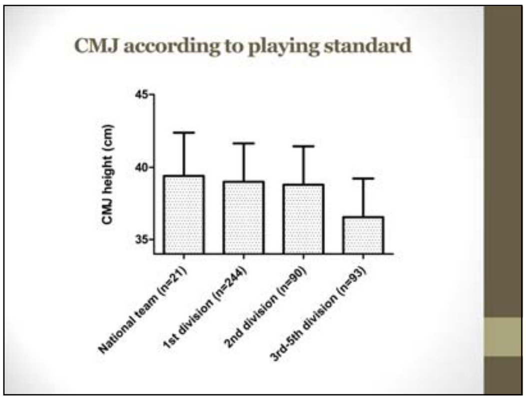
Sprint times for soccer players are affected by the conditions under which they are run. Footwear affects sprint performance more than type of floor surface. Running spike shoes yield significantly ~0.05s better sprint times for both 0-20 m acceleration and 20-40 m maximal sprint compared to artificial turf soccer shoes, while floor surface affects sprint performance by a trivial and non significant margin (0.02-0.03 s over 40m).[54] Group mean values between fastest and slowest sprinting conditions (spike shoes on rubberized turf vs. artificial turf shoes on artificial turf) showed 0.11-0.14 s difference in 40 m sprint performance. These observed differences are larger than the typical variation from test to test and most short-term sprint training intervention effects.[50]

The importance of vertical jump abilities in soccer players is heavily debated. Faude et al.[39] reported that jumps are one of the most frequent actions prior to goals, both for the scoring and assisting player. Based on these observations, they concluded that jumping (in addition to sprinting) should be included in fitness testing and training, as such actions are important within decisive situations in professional soccer. In contrast, Rampinini et al.[84] stated that the utility of assessing vertical jump performance is questionable as such skills have little relevance to soccer play.

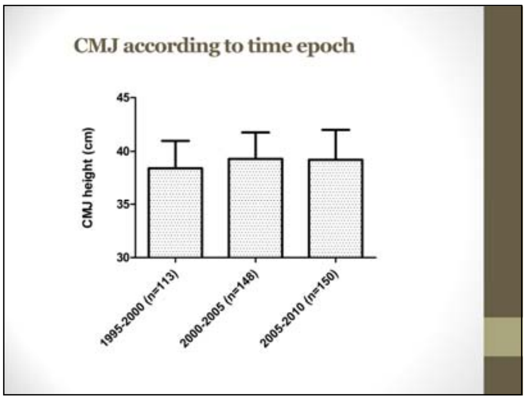
Differences in testing procedures (i.e. with or without arm swing), equipment (i.e. contact mats vs. force platforms) and software complicate comparisons across studies. Future studies should take into account both individual stature and jump height to evaluate «maximal vertical reach»



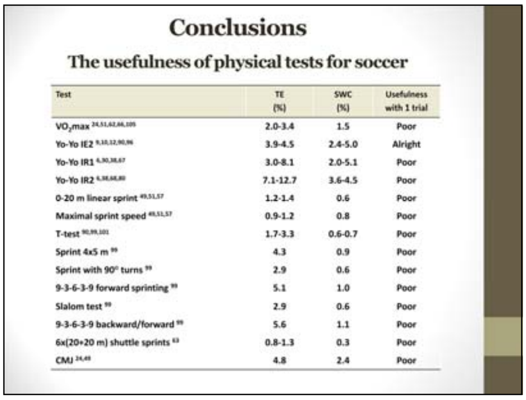
The correlation between sprint and CMJ performance in soccer players is 0.64. Stølen et al.[102] claim that well-developed strength in lower limbs is important for soccer players, as this basic quality influences power performance and skills like sprinting, turning and change of direction. Wisløff et al.[111] reported a large correlation between maximal strength, sprint performance and vertical jump height, while Salaj & Markovic[93] concluded that jumping, sprinting and change of direction speed are specific independent variables that should be treated separately. Taken the arguments and observations together, it is likely that individuals with poor leg extension power relative to sprint performance should prioritize power development to a greater extent compared to their counterparts in order to enhance sprint performance.



CMJ performance (mean) does not differ between players who differ in playing standard at the higher levels. CMJ (without arm swing) values (group means) in the range 37-42 and 26-33 cm have been reported for male and female elite performers.[1,21,48,49,100]



Our data showed that CMJ height increased by a small margin between the first two epochs for then to remain stable. The same professional players showed positive development in sprinting speed across the corresponding time epochs (slide 28).[49]



Conclusions

The usefulness of physical tests for soccer

Test	TE (%)	SWC (%)	Usefulness with 1 trial
VO_2max [24,51,62,66,105]	2.0-3.4	1.5	Poor
Yo-Yo IE2 [9,10,12,90,96]	3.9-4.5	2.4-5.0	Alright
Yo-Yo IR1 [4,30,38,67]	3.0-8.1	2.0-5.1	Poor
Yo-Yo IR2 [4,38,68,80]	7.1-12.7	3.6-4.5	Poor
0-20 m linear sprint [49,51,57]	1.2-1.4	0.6	Poor
Maximal sprint speed [49,51,57]	0.9-1.2	0.8	Poor
T-test [90,99,101]	1.7-3.3	0.6-0.7	Poor
Sprint 4x5 m [99]	4.3	0.9	Poor
Sprint with 90° turns [99]	2.9	0.6	Poor
9-3-6-3-9 forward sprinting [99]	5.1	1.0	Poor
Slalom test [99]	2.9	0.6	Poor
9-3-6-3-9 backward/forward [99]	5.6	1.1	Poor
6x(20+20 m) shuttle sprints [63]	0.8-1.3	0.3	Poor
CMJ [24,49]	4.8	2.4	Poor

When evaluating the usefulness of physical tests in soccer players, the following variables need to be considered:

a) The typical error of measurement (TE)

b) The smallest worthwhile change (SWC)

According to Hopkins, the usefulness of a test is poor if TE>SWC, and good if TE<SWC.[61] The present table shows that the usefulness of most tests are considered poor when using this approach.

Does new technology move testing out of lab? We argue that the answer to this question depends on the situation. High-standard soccer teams have tight game schedules, long seasons and relatively short pre-season periods, limiting the possibilities for long-term physical conditioning planning.[19] As long as each player does his/her “job” satisfactorily on the field, all other physical and physiological considerations are secondary.[27] In such settings, the main focus is to recover and prepare for the next game. Underperforming players may be replaced by other players in the short term, while they risk to be sold to other clubs in longer terms. Game analyses and similar assessments of training sessions are the most important tools for evaluating individual and collective behavior.

In contrast, academies and reserve teams prepare for future career by developing soccer-specific motor skills and physiological capacity until they reach an elite level. The key skills must be maximized, while other capabilities merely need to meet a minimum requirement.[10,91,105] In such settings, it is important to profile and diagnose players by the use of both specific and non-specific tests for then to develop targeted training prescriptions.

Summary of testing recommendations

Physical demand	Remarks
Aerobic endurance	A certain minimum is needed Yo-Yo more practical and valid compared to $VO_{2\,max}$
Linear acceleration and peak velocity	Distinguishes players of varying standards Equipment, procedures and conditions are critical
Change-of-direction	Most sprints in games are linear Most tests do not mimic on-field movements
Repeated sprinting	Best sprint tells most of story Short sprints induce little fatigue, long sprints are not game specific
Vertical jump	A certain minimum is needed Equipment and procedures are critical

References

1. Arnason A, Sigurdsson SB, Gudmundsson A, Holme I, Engebretsen L, Bahr R. Physical fitness, injuries, and team performance in soccer. Med Sci Sports Exerc. 2004;36:278-285.
2. Aziz AR, Mukherjee S, Chia MY, Teh KC. Relationship between measured maximal oxygen uptake and aerobic endurance performance with running repeated sprint ability in young elite soccer players. J Sports Med Phys Fitness. 2007;47:401-407.
3. Aziz AR, Mukherjee S, Chia MY, Teh KC. Validity of the running repeated sprint ability test among playing positions and level of competitiveness in trained soccer players. Int J Sports Med. 2008;29:833-838.
4. Balsom PD, Seger JY, Sjödin B, Ekblom B. Maximal-intensity intermittent exercise: effect of recovery duration. Int J Sports Med. 1992;13:528-533.
5. Bangsbo J. The physiology of soccer, with special reference to intense intermittent exercise. Acta Physiol Scand Suppl. 1994;619:1-155.
6. 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. 2008;38: 37-51.
7. Barnes C, Archer DT, Hogg B, Bush M, Bradley PS. The evolution of physical and technical performance parameters in the English Premier League. Int J Sports Med. 2014;35:1095-1100.
8. Bloomfield J, Polman R, O`Donoghue P. Deceleration and turning movements performed during FA Premier League soccer matches. In: Reilly T, Korkusuz F (eds). Science and football VI; the proceedings of the sixth world congress on science and football. Taylor & Francis, London 2008:174-181.
9. Bradley PS, Mohr M, Bendiksen M, Randers MB, Flindt M, Barnes C, Hood P, Gomez A, Andersen JL, Di Mascio M, Bangsbo J, Krustrup P. Sub-maximal and maximal Yo-Yo intermittent endurance test level 2: heart rate response, reproducibility and application to elite soccer. Eur J Appl Physiol. 2011;111:969-978.
10. Bradley PS, Carling C, Gomez Diaz A, Hood P, Barnes C, Ade J, Boddy M, Krustrup P, Mohr M. Match performance and physical capacity of players in the top three competitive standards of English professional soccer. Hum Mov Sci. 2013;32: 808-821.
11. Bradley PS, Dellal A, Mohr M, Castellano J, Wilkie A. Gender differences in match performance characteristics of soccer players competing in the UEFA Champions League. Hum Mov Sci. 2014;33:159-171.
12. Bradley PS, Bendiksen M, Dellal A, Mohr M, Wilkie A, Datson N, Orntoft C, Zebis M, Gomez-Diaz A, Bangsbo J, Krustrup P. The application of the Yo-Yo intermittent endurance level 2 test to elite female soccer populations. Scand J Med Sci Sports. 2014;24:43-54.
13. Buchheit M, Simpson BM, Peltola E, Mendez-Villanueva A. Assessing maximal sprinting speed in highly trained young soccer players. Int J Sports Physiol Perform. 2012;7:76-78.
14. Buchheit M. Repeated-sprint performance in team sport players: associations with measures of aerobic fitness, metabolic control and locomotor function. Int J Sports Med. 2012;33:230-239.
15. Buchheit M, Allen A, Poon TK, Modonutti M, Gregson W, Di Salvo V. Integrating different tracking systems in football: multiple camera semi-automatic system, local position measurement and GPS technologies. J Sports Sci. 2014;32:1844-1857.
16. 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. 2014;32:1309-1317.
17. Burgess DJ, Naughton G, Norton KI. Profile of movement demands of national football players in Australia. J Sci Med Sport. 2006;9:334-341.
18. Carling C. Interpreting physical performance in professional soccer match-play: should we be more pragmatic in our approach? Sports Med. 2013;43:655-663.
19. Carling C, Gregson W, McCall A, Moreira A, Wong DP, Bradley PS. Match Running Performance During Fixture Congestion in Elite Soccer: Research Issues and Future Directions. Sports Med. 2015 Feb 19. [Epub ahead of print]
20. Castagna C, Impellizzeri FM, Chamari K, Carlomagno D, Rampinini E. Aerobic fitness and yo-yo continuous and intermittent tests performances in soccer players: a correlation study. J Strength Cond Res. 2006;20:320-325.
21. Castagna C, Castellini E. Vertical Jump performance in Italian Male and Female National-Teams Soccer Players. J Strength Cond Res. 2012;27:1156-1161.
22. Castellano J, Alvarez-Pastor D, Bradley PS. Evaluation of research using computerised tracking systems (Amisco and Prozone) to analyse physical performance in elite soccer: a systematic review. Sports Med. 2014;44:701-712.
23. Chaouachi A, Manzi V, Wong del P, Chaalali A, Laurencelle L, Chamari K, Castagna C. Intermittent endurance and repeated sprint ability in soccer players. J Strength Cond Res. 2010;24:2663-2669.
24. Clark NA, Edwards AM, Morton RH, Butterly RJ. Season-to-Season Variations of Physiological Fitness within a Squad of Professional Male Soccer Players. J Sports Sci Med. 2008;7:157-165.
25. Cummins C, Orr R, O'Connor H, West C. Global positioning systems (GPS) and microtechnology sensors in team sports: a systematic review. Sports Med. 2013;43: 1025-1042.
26. da Silva JF, Guglielmo LG, Bishop D. Relationship between different measures of aerobic fitness and repeated-sprint ability in elite soccer players. J Strength Cond Res. 2010;24:2115-2121.
27. Delgado-Bordonau J & Mendez-Villanueva A. Tactical periodization: Mourinho's best-kept secret? Soccer NSCAA Journal 2012;3:28–34.
28. Dellal A, Hill-Haas S, Lago-Penas C, Chamari K. Small-sided games in soccer: amateur vs. professional players' physiological responses, physical, and technical activities. J Strength Cond Res. 2011;25:2371-2381.
29. Dellal A, Wong WD. Repeated sprint and change-of-direction abilities in soccer players: effects of age group. J Strength Cond Res. 2013;27:2504-2508.
30. Deprez D, Fransen J, Lenoir M, Philippaerts R, Vaeyens R. The Yo-Yo intermittent recovery test level 1 is reliable in young high-level soccer players. Biol Sport. 2015; 32:65-70.
31. Dixon MJ, Robinson ME. A birth process model for association football matches. Journal of the Royal Statistical Society: Series D (The Statistician) 1998;47:523–538.
32. di Salvo V, Baron R, Tschan H, Calderon Montero F, Bachl N, Pigozzi F. Performance characteristics according to playing position in elite soccer. Int J Sports Med. 2007;28:222-227.
33. Dupont G, McCall A, Prieur F, Millet GP, Berthoin S. Faster oxygen uptake kinetics during recovery is related to better repeated sprinting ability. Eur J Appl Physiol. 2010;110:627-634.
34. Duthie GM, Pyne DB, Ross AA, Livingstone SG, Hooper SL. The reliability of ten-meter sprint time using different starting techniques. J Strength Cond Res. 2006; 20: 246-251.
35. Ekblom B. Applied physiology of soccer. Sports Med. 1986;3:50-60.
36. Ekstrand J, Hagglund M, Walden M. Injury incidence and injury patterns in professional football: the UEFA injury study. Br J Sports Med. 2011;45:553-558.
37. Ekstrand J. Injuries in top class football – coaches are more important than doctors? Presentation at the 8th world congress on science and football. Copenhagen, 2015.
38. Fanchini M, Castagna C, Coutts AJ, Schena F, McCall A, Impellizzeri FM. Are the Yo-Yo intermittent recovery test levels 1 and 2 both useful? Reliability, responsiveness and interchangeability in young soccer players. J Sports Sci. 2014; 32:1950-1957.
39. Faude O, Koch T, Meyer T. Straight sprinting is the most frequent action in goal situations in professional soccer. J Sports Sci. 2012;30:625-631.
40. Ferrari Bravo D, Impellizzeri FM, Rampinini E, Castagna C, Bishop D, Wisloff U. Sprint vs. interval training in football. Int J Sports Med. 2008;29:668-674.
41. Gabbett TJ. The development of a test of repeated-sprint ability for elite women's soccer players. J Strength Cond Res. 2010;24:1191-1194.
42. Girard O, Mendez-Villanueva A, Bishop D. Repeated-sprint ability - part I: factors contributing to fatigue. Sports Med. 2011;41:673-694.
43. Glaister M. Multiple-sprint work: methodological, physiological, and experimental issues. Int J Sports Physiol Perform. 2008;3:107-112.
44. Hägglund M, Waldén M, Magnusson H, Kristenson K, Bengtsson H, Ekstrand J. Injuries affect team performance negatively in professional football: an 11-year follow-up of the UEFA Champions League injury study. Br J Sports Med. 2013;47:738-742.
45. Hammouda O, Chtourou H, Chaouachi A, Chahed H, Bellimem H, Chamari K, Souissi N. Time-of-day effects on biochemical responses to soccer-specific endurance in elite Tunisian football players. J Sports Sci. 2013;31:963-971.
46. Harrison AJ, Jensen RL, Donoghue. A comparison of laser and video techniques for determining displacement and velocity during running. Meas Eval Phys Ed Exerc Sci. 2005;9:219-231.
47. Haugen T, Tonnessen E, Seiler SK. The difference is in the start: impact of timing and start procedure on sprint running performance. J Strength Cond Res. 2012;26: 473-479.
48. Haugen T, Tønnessen E, Seiler S. Speed and countermovement jump characteristics of elite female soccer players 1995-2010. Int J Sport Physiol Perform. 2012;7:340-349.
49. Haugen T, Tønnessen E, Seiler S. Anaerobic performance testing of professional soccer players 1995-2010. Int J Sport Physiol Perform. 2013;8:148-156.
50. Haugen T, Tønnessen E, Hisdal J, Seiler S. The role and development of sprinting speed in soccer. Int J Sports Physiol Perform. 2014;9:432-441.
51. Haugen T, Tønnessen E, Hem E, Leirstein S, Seiler S. VO2max Characteristics of Elite Female Soccer Players 1989-2007. Int J Sports Physiol Perform. 2014;9:515-521.
52. Haugen T, Tønnessen E, Leirstein S, Hem E, Seiler S. Not quite so fast: Effect of training at 90% sprint speed on maximal and repeated sprint ability in soccer players. J Sports Sci. 2014;32:1979-1986.
53. Haugen T, Tønnessen E, Svendsen IS, Seiler S. Sprint time differences between single- and dual-beam timing systems. J Strength Cond Res. 2014;28:2376-2379.
54. Haugen T, Tønnessen E, Seiler S. Unpublished material, 2014.
55. Haugen T, Tønnessen E, Seiler S. 9.58 and 10.49: Nearing the citius end for 100-m? Invited commentary. Int J Sports Physiol Perform. 2015;10:269-272.
56. Haugen T, Tønnessen E, Øksenholt Ø, Haugen FL, Paulsen G, Enoksen E, Seiler S. Sprint conditioning of junior soccer players: effects of training intensity and technique supervision. PLoS One. 2015;10:e0121827.
57. Haugen T, Tønnessen E, Seiler S. Correction factors for photocell sprint timing with flying start. Int J Sports Physiol Perform. 2015 (in press).
58. Haugen T, Buchheit M. Sprint performance monitoring: methodological and practical considerations. Unpublished material, 2015.
59. Hawkins RD, Fuller CW. A prospective epidemiological study of injuries in four English professional football clubs. Br J Sports Med. 1999;33:196-203.
60. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc. 2009;41:3-13.
61. Hopkins WG. How to Interpret Changes in an Athletic Performance Test. Sportscience 2004;8:1-7 (www.sportsci.org/jour/04/wghtests.htm)
62. Howley, ET, Bassett JR, DR, Welch, HG. Criteria for maximum oxygen uptake: review and commentary. Med Sci Sports Exerc. 1995;27:1292-1301.
63. Impellizzeri FM, Rampinini E, Castagna C, Bishop D, Ferrari Bravo D, Tibaudi A, Wisloff U. Validity of a repeated-sprint test for football. Int J Sports Med. 2008;29:899-905.
64. Ingebrigtsen J, Bendiksen M, Randers MB, Castagna C, Krustrup P, Holtermann A. Yo-Yo IR2 testing of elite and sub-elite soccer players: performance, heart rate response and correlations to other interval tests. J Sports Sci. 2012;30:1337-1345.
65. Ingebrigtsen J, Dalen T, Hjelde GH, Drust B, Wisløff U. Acceleration and sprint profiles of a professional elite football team in match play. Eur J Sport Sci. 2015;15: 101-110.
66. Kirkeberg JM, Dalleck LC, Kamphoff CS, Pettitt RW. Validity of 3 protocols for verifying VO2 max. Int J Sports Med. 2011;32:266-270.
67. Krustrup P, Mohr M, Amstrup T, Rysgaard T, Johansen J, Steensberg A, Pedersen P.K, Bangsbo J. The yo-yo intermittent recovery test: physiological response, reliability, and validity. Med Sci Sports Exerc. 2003;35:697-705.
68. Krustrup P, Mohr M, Nybo L, Jensen JM, Nielsen JJ, Bangsbo J. The Yo-Yo IR2 test: physiological response, reliability, and application to elite soccer. Med Sci Sports Exerc. 2006;38:1666-1673.
69. Krustrup P, Zebis M, Jensen JM, Mohr M. Game induced fatigue patterns in elite female soccer. J Strength Cond Res. 2010;24:437-441.
70. Krustrup P, Bradley PS, Christensen JF, Castagna C, Jackman S, Connolly L, Randers MB, Mohr M, Bangsbo J. The Yo-Yo IE2 test: physiological response for untrained men versus trained soccer players. Med Sci Sports Exerc. 2015;47:100-108.
71. Little T, Williams A. Specificity of acceleration, maximum speed, and agility in professional soccer players. J Strength Cond Res. 2005;19:76-78.
72. Little T, Williams AG. Effects of sprint duration and exercise: rest ratio on repeated sprint performance and physiological responses in professional soccer players. J Strength Cond Res. 2007;21:646-648.
73. Lovell R, Abt G. Individualization of time-motion analysis: a case-cohort example. Int J Sports Physiol Perform. 2013;8:456-458.
74. Marcovic G. Poor relationship between strength and power qualities and agility performance. J Sports Med Phys Fitness. 2007;47:276-283.
75. Meckel Y, Machnai O, Eliakim A. Relationship among repeated sprint tests, aerobic fitness, and anaerobic fitness in elite adolescent soccer players. J Strength Cond Res. 2009;23:163-169.
76. Mendez-Villanueva A, Buchheit M, Simpson B, Peltola E, Bourdon P. Does on-field sprinting performance in young soccer players depend on how fast they can run or how fast they do run? J Strength Cond Res. 2011; 25: 2634-2638.
77. Mendez-Villanueva A, Buchheit M, Simpson B, Bourdon PC. Match play intensity distribution in youth soccer. Int J Sports Med. 2013;34:101-110.
78. Mendez-Villanueva A, Buchheit M. Football-specific fitness testing: adding value or confirming the evidence? J Sports Sci. 2013;31:1503-1508.
79. Mohr M, Mujika I, Santisteban J, Randers MB, Bischoff R, Solano R, Hewitt A, Zubillaga A, Peltola E, Krustrup P. Examination of fatigue development in elite soccer in a hot environment: a multi-experimental approach. Scand J Med Sci Sports. 2010;20:125-132.
80. Mohr M, Krustrup P. Yo-Yo intermittent recovery test performances within an entire football league during a full season. J Sports Sci. 2014;32:315-327.
81. Mujika I, Spencer M, Santisteban J, Goiriena JJ, Bishop D. Age-related differences in repeated-sprint ability in highly trained youth football players. J Sports Sci. 2009;27:1581-1590.
82. Oliver JL. Is a fatigue index a worthwhile measure of repeated sprint ability? J Sci Med Sport. 2009;12:20-23.
83. Pyne DB, Saunders PU, Montgomery PG, Hewitt AJ, Sheehan K. Relationships between repeated sprint testing, speed, and endurance. J Strength Cond Res. 2008; 22:1633-1637.

84. Rampinini E, Bishop D, Marcora SM, Ferrari Bravo D, Sassi R, Impellizzeri FM. Validity of simple field tests as indicators of match-related physical performance in top-level professional soccer players. Int J Sports Med. 2007;28:228-235.
85. Rampinini E, Coutts AJ, Castagna C, Sassi R, Impellizzeri FM. Variation in top level soccer match performance. Int J Sports Med. 2007;28:1018-1024.
86. Rampinini E, Impellizzeri FM, Castagna C, Azzalin A, Ferrari Bravo D, Wisløff U. Effect of match-related fatigue on short-passing ability in young soccer players. Med Sci Sports Exerc. 2008;40:934-942.
87. Rampinini E, Impellizzeri FM, Castagna C, Coutts AJ, Wisløff U. Technical performance during soccer matches of the Italian Serie A league: effect of fatigue and competitive level. J Sci Med Sport. 2009;12:227-1233.
88. Rampinini E, Sassi A, Morelli A, Mazzoni S, Fanchini M, Coutts, AJ. Repeated-sprint ability in professional and amateur soccer players. Appl Physiol Nutr Metab. 2009;34:1048-1054.
89. Rampinini E, Sassi A, Azzalin A, Castagna C, Menaspà P, Carlomagno D, Impellizzeri FM. Physiological determinants of Yo-Yo intermittent recovery tests in male soccer players. Eur J Appl Physiol. 2010;108:401-409.
90. Rebelo A, Brito J, Maia J, Coelho-E-Silva MJ, Figueiredo AJ, Bangsbo J, Malina RM, Seabra A. Anthropometric characteristics, physical fitness and technical performance of Under-19 soccer players by competitive level and field position. Int J Sports Med. 2013;34:312-317.
91. Reilly T, Bangsbo J, Franks A. Anthropometric and physiological predispositions for elite soccer. J Sports Sci. 2000;18:669-683.
92. Sander A, Keiner M, Wirth K, Schmidtbleicher D. Influence of a 2-year strength training programme on power performance in elite youth soccer players. Eur J Sport Sci. 2013;13:445-451.
93. Salaj S, Markovic G.J. Specificity of jumping, sprinting, and quick change-of-direction motor abilities. J Strength Cond Res. 2011;25:1249-1255.
94. Schutz Y, Chambaz A. Could a satellite-based navigation system (GPS) be used to assess the physical activity of individuals on earth? Eur J Clin Nutr. 1997;51:338–339.
95. Shalfawi SA, Haugen T, Jakobsen TA, Enoksen E, Tønnessen E. The Effect of Combined Resisted Agility and Repeated Sprint Training Vs. Strength Training on Female Elite Soccer Players. J Strength Cond Res. 2013;27:2966-2972.
96. Silva JR, Magalhães JF, Ascensão AA, Oliveira EM, Seabra AF, Rebelo AN. Individual match playing time during the season affects fitness-related parameters of male professional soccer players. J Strength Cond Res. 2011;25:2729-2739.
97. Silva JR, Magalhães J, Ascensão A, Seabra AF, Rebelo AN. Training status and match activity of professional soccer players throughout a season. J Strength Cond Res. 2013;27:20-30.
98. Spencer M, Fitzsimons M, Dawson B, Bishop D, Goodman C. Reliability of a repeated-sprint test for field hockey. J Sci Med Sport. 2006;9:181-184.
99. Sporis G, Jukic I, Milanovic L, Vucetic V. Reliability and factorial validity of agility tests for soccer players. J Strength Cond Res. 2010;24:679-686.
100. Sporis G, Jukic I, Ostojic SM, Milanovic D. Fitness profiling in soccer: physical and physiologic characteristics of elite players. J Strength Cond Res. 2009;23:1947-1953.
101. Stewart PF, Turner AN, Miller SC. Reliability, factorial validity, and interrelationships of five commonly used change of direction speed tests. Scand J Med Sci Sports. 2014;24:500-506.
102. Stølen T, Chamari K, Castagna C, Wisløff U. Physiology of soccer: an update. Sports Med. 2005;35:501-536.
103. Taylor KL, Cronin J, Gill ND, Chapman DW, Sheppard J. Sources of variability in iso-inertial jump assessments. Int J Sports Physiol Perform. 2010;5:546-558.
104. Tønnessen, E, Shalfawi, S, Haugen, T, Enoksen, E. The effect of 40-m repeated sprint training on maximum sprinting speed, repeated sprint endurance, vertical jump and aerobic capacity in young elite male soccer players. J Strength Cond Res. 2011;25:2364-2370.
105. Tønnessen E, Hem E, Leirstein S, Haugen T, Seiler S. Maximal aerobic power characteristics of male professional soccer players, 1989-2012. Int J Sports Physiol Perform. 2013;8:323-329.
106. Tønnessen E, Svendsen I, Olsen IC, Guttormsen A, Haugen T. Performance development in adolescent track and field athletes according to age, sex and sport discipline. PLoS ONE 2015 (in press).
107. Van Gool D, Van Gerven D, Boutmans J. The physiological load imposed on soccer players during real match-play. In: Reilly T, Lees A, Davis K, Murphy WJ, editors. Science and football I. London: E. & F.N. Spon; 1988, p. 51–59.
108. Vescovi JD, McGuigan MR. Relationships between sprinting, agility, and jump ability in female athletes. J Sports Sci. 2008;26:97-107.
109. Vigne G, Gaudino C, Rogowski I, Alloatti G, Hautier C. Activity profile in elite Italian soccer team. Int J Sports Med. 2010;31:304-310.
110. Ward-Smith AJ. New insights into the effect of wind assistance on sprinting performance. J Sports Sci. 1999;17:325-34.
111. Wisløff U, Castagna C, Helgerud J, Jones R, Hoff J. Strong correlations of maximal squat strength with sprint performance and vertical jump height in elite soccer players. Br J Sports Med. 2004;38:285-288.
112. Wong PL, Chaouachi A, Chamari K, Dellal A, Wisloff U. Effect of preseason concurrent muscular strength and high-intensity interval training in professional soccer players. J Strength Cond Res. 2010;24:653-660.
113. Yeadon, MR, Kato, T, and Kerwin, DG. Measuring running speed using photocells. J Sports Sci. 1999;17:249-257.