

Terje Næss Kjøsnes

The development of physical performance during elite soccer matches - can motion analysis contribute to identify fatigued footballers?



Master Thesis in Exercise Physiology and Sport Sciences
Faculty of Medicine
Department of Circulation and Medical Imaging
NTNU

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Abbreviations

15-min	Fifteen minutes
ACC _{freq}	Acceleration frequency
ATP	Adenosine tri-phosphate
Ca ²⁺	Calcium
CD	Central defenders
CM	Central midfielders
DCS	Distance covered by sprinting
DNG	Do not need goal
d.w.	Dry weight
EMG	Electromyography
F	Forwards
GPS	Global positioning system
HIR	High-intensity running
HSR	High-speed running
MVC	Maximal voluntary contraction
NG	Need goal
PL	Player load
VHIR	Very high-intensity running
TDC	Total distance covered
WD	Wide defenders
WM	Wide midfielders

Abstract

Background: The physical performance of soccer players at the end of matches, measured by motion analysis variables, could potentially contribute to identify how fatigued they are. Such information would be valuable for the coaching staff in order to optimize the players' training load and avoid injuries in the following days. Further knowledge regarding the development of physical performance during competitive games is, however, needed. **Purpose:** The aim of this study was to investigate the development of physical performance variables during elite soccer matches, to compare end-game work rate of substitutes with players starting the game and to analyse if the need for a goal affected physical performance in the latter part of matches. **Methods:** 47 footballers playing for a top-level team in the Norwegian elite division were monitored during 64 domestic league matches. A local positioning system was used to measure acceleration frequency (ACC_{freq}) and distance covered in total (TDC), by high-speed running (HSR) and when sprinting (DCS), whereas triaxial accelerometers quantified player load (PL). **Results:** All physical performance variables were significantly reduced in the final 15-min compared to the first 15-min of matches ($p < 0.01$). TDC, ACC_{freq} and PL were significantly lower in the last 15-min than in all of the other 15-min periods ($p < 0.05$). Substitutes were superior to starters in terms of end-game TDC, HSR, DCS, ACC_{freq} and PL ($p < 0.05$). The players covered a greater distance in total in the final 15-min of games when they were in need of a goal (losing or drawing) compared to when they were winning ($p < 0.05$), whereas no significant differences were found for HSR, DCS, ACC_{freq} and PL. **Conclusion:** Physical performance is severely compromised at the end of elite soccer matches, and the superior work rate of substitutes compared to starters implies that a substantial amount of the decrements is due to fatigue. Hence, the end-game performance of motion analysis variables could provide information of the players' physical condition if interpreted in a context where the awareness of situational confounders is present.

Introduction

Physical demands in soccer

Soccer is a physical demanding sport. During a ninety-minute match the players cover typically 9-14 km in an intermittent and acyclic exercise pattern (1-5). The work performed is mainly at submaximal intensity predominantly taxing the aerobic energy system, interspersed with frequent high-intensity bouts, which in a greater extent rely on the anaerobic energy pathways. Match analysis studies have shown that about 2500-2800 meters are covered with high-intensity running ($>14.8 \text{ km}\cdot\text{h}^{-1}$) in elite soccer (1, 2, 4), whereas sprinting ($>25.2 \text{ km}\cdot\text{h}^{-1}$) accounts for about 200-260 meters (2, 6). Additionally, numerous explosive bursts of activity are performed including accelerations, decelerations, changes of direction, tackles, shots, jumps and duels for possession, requiring forceful contractions of the working muscles (7-10). As a result of this interval based exercise pattern, the average intensity of a match is 80-90 % of maximal heart rate (10-14), whereas individual blood lactate scores have been reported to exceed $12 \text{ mmol}\cdot\text{l}^{-1}$ (15), underlining the elevated physiological stress put upon footballers under matches. In general, midfielders are reported to cover a greater distance than forwards and defenders (1, 2, 4, 8) with central defenders achieving the lowest score (4, 16-18). Furthermore, footballers in wide positions of the field (wide defenders & midfielders) tend to perform a greater amount of HIR than players in central positions (1, 2), indicating that the physical demands are highly influenced by playing position.

Fatigue in soccer

Neuromuscular fatigue can be defined as “any exercise induced reduction in force or power regardless of whether the task can be sustained or not” (19). It is a complex, multifactorial phenomenon whose mechanisms are highly influenced by the demands of the task being performed (i.e. type, frequency, duration and intensity of the exercise) (20).

Post-match physical performance tests have revealed that soccer players are fatigued to some extent after matches. When investigating sprint performance in Italian elite players, Rampinini et al. (21), found that both the agility ability (180°

turn) and the ability to accelerate (0-15m performance) was significantly impaired after a match compared to pre-match tests. These abilities seem to be highly dependent on the working muscles' capability to produce force (22) and indicate that a football match compromises this. The 11 % reduction in maximal voluntary contraction (MVC) of the quadriceps muscles found in the same study supports the notion. Other researchers have also documented significant decrements in post-match strength and sprint tests. Ascensao et al. (14) reported that 20 meter sprint time increased by ~7% in trained Portuguese players, which is similar to the ~9% deterioration found by Magalhães and colleagues (23). The latter authors additionally documented a significant decline in counter movement jump performance, a tendency that also has been reported in Danish soccer (24). Isokinetic strength tests of the lower limbs show reductions in peak torque in the knee extensors and flexors at various shortening speeds during both eccentric and concentric muscle contractions after games (14, 23, 25, 26). Furthermore, it seems that the ability to repeat high intensity movements is attenuated, as repeated sprint ability has been shown to diminish (27). Altogether, the performance impairment in these tests indicate that the players' force and/or power production ability is reduced following ninety minutes of soccer, and even though little information consists concerning end-game physical tests, one might assume that some of the fatigue also is apparent in the latter part of the matches as well.

End-game physical performance

Mounting evidence suggests that the physical performance is reduced at the end of soccer matches. When investigating physical performance of players in the elite division in Italy, Rampinini et al. (9) documented that the distance covered in total and with very high-intensity running (VHIR) ($>19 \text{ km}\cdot\text{h}^{-1}$) was significantly reduced by 2% and 7%, respectively, in the second half compared to the first. Similar findings have been observed in the French elite division (28). Contradictory, even though documenting significant decrements in total distance covered, the amount of distance covered at the highest velocities have been showed to be similar in the two halves in English and Scottish soccer (1, 18). However, comparison of halves may not be a sensitive enough analytical design

to detect eventual differences in physical performance between the start and the end of games. Analysis of smaller sections of the matches, such as 5-or 15-minute intervals, may therefore be more informative (29). In a recent study, Bradley et al. (1) showed that English elite players performed 21% less HIR and had 28% longer recovery time between VHIR periods in the last fifteen minutes compared to the first fifteen minutes of games, and that these reductions applied for all playing positions. Decrements in the amount of high-intensity work have also been reported in other European leagues, as Mohr and colleagues (8) showed that players in the elite divisions in Italy and Denmark had a reduction in HIR of 45% and 35%, respectively, when the same periods were compared. Furthermore, these end-game declines have correspondingly been documented in the top division in France (28), although not with the same magnitude (12%). Additionally, the distance covered by sprinting (DCS) seems to be reduced towards the end of matches, as Mohr et al. (30) found that the average sprint distance in the last fifteen minutes of the game was about one third of the amount performed in the first fifteen minutes for Spanish players. However, these numbers were considerably higher than the 18% reduction seen in English professionals (1), and may have been affected by the very hot environment (>30°C) and the lower velocity threshold defining a sprint (>22 km·h⁻¹) in the experiment. Nonetheless, both studies reported that total sprint distance was significantly reduced at the end of the first and the second half.

Physiological explanations for end-game fatigue

The occurrence of end-game fatigue seen in soccer can be caused by several physiological phenomena in the neuromuscular pathways. Central fatigue is referred to as an impairment in voluntary activation of the working muscles, due to a decrease in the number and/or discharge rate of active motor units (31). This has been documented in elite players in Italy, as their maximal voluntary activation of the quadriceps muscles, estimated through interpolated twitch techniques, was significantly reduced after a ninety-minute game (21). Furthermore, the central fatigue indicators were significantly related to the reduction in post-game sprint- and MVC performance. However, the authors also showed that the muscle function of the quadriceps muscles, determined using

electrical stimulation, was impaired after the game, indicating that mechanisms in the peripheral parts of the neuromuscular chain also play a part in causing end-game fatigue in soccer. Plausible explanations for this local fatigue are structural damage to the working muscle fibres due to the intense actions repeatedly performed during matches (26), inadequate Ca^{2+} release from the sarcoplasmic reticulum (32) and accumulation of inorganic phosphate in the intramuscular environment (31, 33). However, although several mechanisms in the neuromuscular system have been associated with the appearance of fatigue, none of them have been identified as the dominant factor causing fatigue in soccer. Instead it seems that interactions between these mechanisms lead to a cascade of events which decrease the muscles' force generating capacity (31).

A factor highly likely to affect the reduction in physical performance in the latter part of matches is the availability of glycogen in the working muscles. The energy-yielding intracellular phosphate stores are continuously recharged through the catabolic processes in carbohydrate-, lipid- and to a small extent protein metabolism (34). Given that the breakdown of carbohydrates yields a faster ATP turnover than lipid catabolism (35), glycogen is the most important energy source for prolonged high-intensity exercises such as soccer (34, 36). A reduction in a player's glycogen stores increases the reliance on lipids as an energetic fuel and slows down the rate of high-energy phosphate reproduction. Saltin (37) observed that footballers' muscle glycogen levels after matches fell below the required level to maintain maximal glycolytic rate ($\sim 200 \text{ mmol}\cdot\text{kg}^{-1} \text{ d.w.}$), and that players with lower glycogen stores covered less distance in total and at high intensities than those with superior values. Contrary, others have found post-game concentrations of about $200 \text{ mmol}\cdot\text{kg}^{-1} \text{ d.w.}$ (38), suggesting that the stores are not depleted. However, blood samples taken during soccer matches have shown that blood lactate concentration declines in the later stages of the game, whereas plasma free fatty acids are increased (27, 39), indicating a change in substrate utilization towards the end of games. Additionally, even though documenting concentrations of $150\text{-}350 \text{ mmol}\cdot\text{kg}^{-1} \text{ d.w.}$ after games, Krstrup et al. (27) revealed through histochemical analysis that about half of the individual muscle fibers in the quadriceps were depleted. Moreover, this

reduction was associated with a decrease in sprint performance immediately after the game. Thus, such a depletion of glycogen in some of the working muscle fibers may lead to impairment in the physical performance at the end of matches (15).

Dehydration and hyperthermia have also been proposed as causes responsible for the occurrence of end-game fatigue (15). Given that the rules of the game restrict opportunities for rehydration, negative fluid balances are often observed in footballers after matches (26). A moderate fluid loss of 1-2 % of body mass, similar to the values reported in thermoneutral conditions in soccer (40), could lead to cardiovascular stress and an elevated core temperature (15). Indeed, individual core temperature values exceeding 40 C° have been reported in soccer players (41), possible high enough to impair voluntary activation of the working muscles (42). Furthermore, researchers have observed a correlation between net-fluid loss (>2% of body mass) and the fatigue index in a post-match sprint test ($r = 0.73$, $p < 0.05$) for Spanish professionals playing in a hot environment (30). However, the average core temperature during competitive settings in thermoneutral conditions in soccer has been shown to be around ~ 39 - 39.5 C° (15), which is below values typical for fatigue (40). And as Mohr and colleagues (43) found no significant difference in core temperature between the end of the first and the second half in Danish footballers, the impact of hyperthermia on end-game fatigue in thermoneutral environments has been questioned.

Impact of situational variables on physical performance

Fatigue may not necessarily be the only contributor to end-game reductions in physical performance. Castellano et al. (44) documented that game location (home vs. away), game outcome (winning, drawing, losing) and the level of the opposition affected the work rate in soccer matches. The Spanish elite players in the study covered a higher distance when they played at home, when they were losing and when the level of the opponent was high. Lago-Penás (45) also highlighted the effect score line has on physical performance, as footballers have been shown to perform significantly less high-intensity activity when winning than when losing or drawing. The author argued that teams have a more

attacking strategy when they are in need of a goal than when they are not, and may therefore have a higher work rate when they are pursuing a goal. Furthermore, Bradley and colleagues (46) reported position-specific trends in the English Premier League with central defenders covering significantly more distance with HIR and attackers significantly less during matches that were heavily lost versus won, indicating that the match itself has an influential effect on the players' physical performance. Match importance did, however, not affect the results in the study. Nevertheless, the impact of situational factors is apparent. Thus, it is of great importance that these confounders are taken in to consideration when analyzing the influence of fatigue on end-game performance, as they might bias the results.

However, when comparing HIR and DCS for players who played the entire match with the performance of substitutes, Mohr et al. (8) showed that fatigue arguably plays a significant role in the observed decrements in physical performance. The authors found that the amounts of HIR and DCS in the last fifteen minutes of the games were 25% and 63% higher for the substitutes, respectively. A similar pattern has been documented in the elite division in England, as the starters performed 15% less HIR in average than the players that replaced them (46). Furthermore, Carling and colleagues (47) showed that midfield substitutes in a French elite team covered a significantly higher distance in total and with VHIR compared to other midfielders that had been on the pitch the whole game. Moreover, the substitutes had a lower recovery time between the VHIR periods. These results show that players who are rested (substitutes) have a superior physical performance towards the end of the matches compared to those who are not (starters). And assuming that the possibilities for engaging in high-intensity activities are equal for the substitutes and the players starting the games, these findings imply that end-game fatigue is apparent in soccer as the confounding effect of situational factors is diminished in the studies.

Motion analysis in soccer

Motion analysis has been applied for the study of work rates in professional soccer since the classical study of Reilly and Thomas in 1976 (48). Traditionally,

manual video analysis has been used as the methodical approach when investigating the physical performance of players (8, 11, 49, 50). Fortunately, during the last decade newer devices such as semi-automatic video systems and global- (GPS) and local positioning systems have entered the market of sports tracking. They are, given their automatic nature, much less time consuming than the traditional approach (29). Hence, it is easier to collect information about the players' work rates. Today, many of the European top clubs apply information from motion analysis when monitoring training load and evaluating physical performance in match and training. Furthermore, science has acknowledged these systems as they have been used in studies conducted on players from the elite divisions in England (1, 2, 51), France (28), Italy (9), Scotland (18) and Spain (4).

Underestimation of high-intensity work

An area in motion analysis that has gained considerable interest during the last years is that of high-intensity work. The amount of work at high-intensities has been shown to be an important indicator of physical performance in soccer, as it seems to differentiate between performance levels (8) and correlate with training status (52). However, most scientific studies have documented high-intensity work as distance covered at velocities over certain thresholds (i.e. $\sim 15\text{km}\cdot\text{h}^{-1}$, $\sim 20\text{ km}\cdot\text{h}^{-1}$ and $\sim 25\text{ km}\cdot\text{h}^{-1}$), leading to a lack of information as much of the force demanding work in soccer is performed at low velocities. Accelerations, defined as the rate of change in velocity (53), should be considered as an important aspect of high-intensity work as they have a high energy cost. In fact, performing an acceleration from low velocities can equal or even exceed the power output required to maintain higher velocities (54). Varley et al. (7) showed that accelerations often fail to reach the velocity threshold of high-intensity running. Thus, studies reporting merely the distance covered at high velocities neglects this, consequently underestimating the amount of high-intensity work performed by the players.

Accelerations is of particular interest when investigating fatigue, given Newton's second law of motion:

$$\text{Force} = \text{mass} \cdot \text{acceleration} \leftrightarrow \text{acceleration} = \text{Force} \cdot \text{mass}^{-1}$$

Neuromuscular fatigue negatively affects the working muscles force production (21, 25, 26), and as mass (body weight) is a constant (except for the eventual loss of body fluid), the ability to accelerate should be expected to deteriorate in fatigued athletes. Akenhead and colleagues (55) found that acceleration performance was compromised during match play in English soccer, as the distance covered by the players when accelerating ($>1 \text{ m} \cdot \text{s}^{-2}$) was significantly lower in the final fifteen minutes of matches compared to the first fifteen minutes. Moreover, when investigating the physical performance of Australian elite soccer players, Varley et al. (7) documented that wide midfielders had a significant lower amount of maximal accelerations in the second half compared to the first. Additionally, the authors found a trend towards a similar pattern for wide defenders. No differences were found between the two halves for central players (CD, CM and F). However, the comparison of halves may not be a sensitive enough analytical design in order to detect differences between start- and end-game performance. Position specific analyses of smaller sections of matches, such as fifteen minutes periods, are therefore needed.

Furthermore, the two-dimensional systems traditionally used for motion analysis in soccer compute the players' physical load solely based upon when the footballers travel from one location to another. Hence, the analyses of differences in running speed and distance fail to include force demanding elements such as tackles, passes, shots, jumps, decelerations and turns, which altogether occur several hundred times during games (8-10, 28). Such movements can cause a significant physical stress on the players, even though if the distance and speed of the displacement of location are small, and should be included when analyzing physical performance in soccer. However, although these actions can be easily counted, the load obtained from them has not been objectively measured before. Triaxial accelerometers could be used as analytical tools for such a task since

they are sensitive motion sensors that can record acceleration of body movement in three dimensions: mediolateral (x), anteriorposterior (y) and vertical (z). These systems have previously been applied to investigate the physical demands in basketball (56) and Australian football (57, 58), and have been shown to be reliable when assessing work rates in intermittent team sports (59).

The variables acceleration frequency (ACC_{freq}) and player load based on accelerometer recordings (PL) could provide valuable information regarding high-intensity movements at low velocities, previously neglected by traditionally approaches to motion analysis. Thus, by including these variables as complementary additions to distance covered at different speeds, the evaluation of physical performance in soccer will be more informative and holistic.

Motion analysis as a tool for monitoring

The focus on monitoring in soccer has increased in recent years as footballers competing both domestically and internationally may play two or even three matches a week, leaving time for recovery and training scarce. Research has shown that strength and power capabilities may be impaired several days after matches for fatigued players (14, 23). Additionally, a congested fixture schedule seems to increase the injury rate (18, 60), especially in terms of muscle injuries in the tie area (60), possible due to fatigue-induced physiological alterations in the players (61, 62). Thus, information about the players' physical condition is of considerable interest for coaches and medical staff in order to optimize training stimulus and avoid injuries. The external physical performance variables of motion analysis may indirectly reflect internal physiological conditions, and the end-game performance of these variables could provide additional information concerning the degree of fatigue in the players. However, further knowledge about the development of physical performance during matches is needed, particularly in terms of the newer variables ACC_{freq} and PL. Moreover, it is important to take into account that contextual factors may affect the relationship between internal conditions and the external physical performance variables. To

our knowledge, no other researchers have investigated the potential effect score line may have on end-game work rate in soccer.

Purpose of the study

The purpose of the present study was to investigate the development of physical performance in Norwegian male elite footballers' during competitive matches.

The primary hypothesis was that total distance covered, high-speed running, sprinting, player load and acceleration frequency would be significantly lowered in the last fifteen minutes of the games in comparison to the first fifteen.

Secondly, it was hypothesized that substitutes would have a higher end-game work rate than players starting the games, and that the physical performance in the last part of the matches would be superior for the players when their team was in need of a goal compared to when they were winning.

Methods

Subjects and match sample

Physical performance variables in domestic competition were analysed for players from a professional team competing in the Norwegian elite division. A total of 64 league matches from five different seasons (2009-2013) were included in the study. The team finished top 3 in the league every season during the data collection period, and competed in the UEFA Europa League on two occasions. 47 subjects were included in the analysis, consisting of 9 central defenders, 7 wide defenders, 10 central midfielders, 15 wide midfielders and 6 forwards. Some of the players were used in different positions across, but not within, the analysed matches. Goalkeepers were excluded (n=4), given that their physical demands in games are considerable lower than outfield players. All matches were played at home on natural grass.

Methodical approach

In order to investigate the development of the physical performance variables during games, the ninety-minute matches were divided into six separate fifteen-minute periods. Period one to six corresponded to the minutes 1-15, 16-30, 31-45, 46-60, 61-75 and 76-90 of official match time, respectively. Additional time was not included in the analysis. Only subjects that completed the whole game were included. When comparing end-game physical performance of substitutes with starters, the last fifteen minutes of matches were analysed for players entering the games in the period between the 46th and the 75th minute (substitutes) and for players playing the entire match (starters). Due to a low number of subjects and observations from the other playing positions, wide midfield was the only position used for this part of the analysis. Lastly, to examine if the players had a higher end-game work rate when they were in need of a goal (NG) versus when they did not need a goal (DNG), the matches were divided into two groups. The matches (n=33) where the team was leading when entering the final fifteen minutes of the game and won at the end were classified as the DNG group, whereas the games (n=15) where the team was not in the lead when entering the last fifteen minutes and where they did not win at the end were classified as the NG group. Games with a draw score line were included in

the NG group because the team was a top-level team expected to win every home game regardless of opposition. 16 matches were excluded from this part of the analysis due to a change in score line in the last fifteen minutes of the matches (n=15), altering the team's need for a goal, or because the team was trailing with more than one goal in the 75th minute (n=1), possibly affecting the players' motivation.

Measuring devices

A fully automatic sport tracking system (ZXY Sport Tracking System, Radionor Communications AS, Trondheim, Norway) was used to investigate the players' match activities. This system has been shown to be a highly reliable tool for the tracking of soccer players (Dalen and Ingebrigtsen et al., unpublished). During the games the subjects wore a small body sensor (ZXY Sport Chip, Radionor Communications AS, Trondheim, Norway) around their waists, which continuously transferred data through a micro wave radio channel to ten RadioEye™ sensors (ZXY Positioning Sensor, Radionor Communications AS, Trondheim, Norway) surrounding the pitch. By receiving these frequently transmitted data (20 Hz) the stationary location sensors could compute the subjects' physical position on the field. Total distance, high-speed running, sprinting distance and number of accelerations were calculated from the positional data.

Player load was based on acceleration measurements from a triaxial accelerometer sensor (ZXY 3D Accelerometer, Radionor Communications AS, Trondheim, Norway). The sensor was placed at the subjects' lumbar spine, attached to a specially designed belt, tightly wrapped around the players' waists. In order to exclude acceleration gravity from the final calculations, the signal was high-pass filtered. The sensitivity of the accelerometer is 184 µg/LSB, with a static noise of 1 mg (Dalen and Ingebrigtsen et al., unpublished), and it registers data at frequency of 20 Hz.

Match activities

Locomotion categories

The following locomotion categories were used in the study: walking (0-7.1 km·h⁻¹), jogging (7.2-14.3 km·h⁻¹), running (14.4-19.7 km·h⁻¹), high-speed running (19.8-25.1 km·h⁻¹) and sprinting (≥ 25.2 km·h⁻¹). These velocity thresholds are similar to those used in previous research (1, 2, 63). Ultimately, total distance (sum of distance covered regardless of velocity), high-speed running and sprinting distance were reported in the results.

Acceleration and player load

To be recorded as acceleration three criteria had to be fulfilled; firstly, the start of the movement had to reach the minimum limit of 1 m·s⁻². Secondly, during the event the acceleration had to exceed 2 m·s⁻² at some point. Lastly, the acceleration had to remain above 2 m·s⁻² for at least half a second.

Player load is the square sum of the high-passed filtered acceleration values for the mediolateral (x), anteriorposterior (y) and vertical (z) axes. The values were additionally downscaled (divided with 800) for practical reasons. Consequently, the player load represents the downscaled values of the players' total acceleration: $(X^2 + Y^2 + Z^2) \cdot 1^{-800}$.

Statistical analysis

All statistical analysis was performed using SPSS version 21 (IBM, New York, USA). Data was considered normally distributed by examination of quantile - quantile (QQ) plots. The differences between 15-min periods were examined using repeated measures ANOVA. A Greenhouse-Geisser correction was made if the assumption of sphericity was violated. When significant F-values were found a post-hoc test with Bonferroini adjustment was applied to determine which specific means that differed. Independent sample t-tests were used to compare end-game physical performance of substitutes and subjects playing the whole game, whereas a linear mixed model with match type (NG/DNG) as factor was applied in order to examine if score line affected work rate in the latter part of

matches. Results are presented as mean \pm standard deviation, unless otherwise stated. Significance level was set to $p < 0.05$.

Results

15-minute periods

Distance covered

The players covered a significantly higher total distance (TDC) in the first 15-min of the games than in all of the following 15-min periods (1898 ± 174 m vs. 1815 ± 191 m, 1796 ± 198 m, 1814 ± 193 m, 1753 ± 193 m and 1705 ± 210 m, $p < 0.01$) (Figure 1). Furthermore, the TDC in the final 15-min of matches (1705 ± 210 m) was significantly lower than all of the other 15-min periods ($p < 0.01$).

The distance covered in the second- (1815 ± 191 m), third- (1796 ± 198 m) and fourth 15-min period (1814 ± 193 m) was superior to the fifth (1753 ± 193 m) ($p < 0.01$), while there was no significant difference in TDC between the second-, third- and fourth 15-min period.

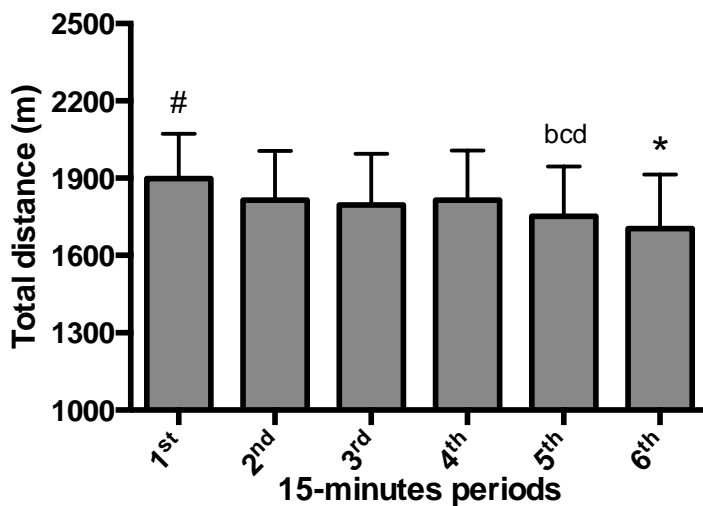


Figure 1. The development of total distance covered during matches. Data are presented as mean \pm standard deviation. * = significant lower than all other periods ($p < 0.01$), # = significant higher than all other periods ($p < 0.01$), b = significant lower than 2nd period ($p < 0.01$), c = significant lower than 3rd period ($p < 0.01$), d = significant lower than 4th period ($p < 0.01$).

Players performed more high-speed running (HSR) in the first 15-min period (164 ± 72 m) than in the fifth (146 ± 74 m) and final one (136 ± 78 m) ($p < 0.01$) (Figure 2). Moreover, the HSR in the second- (157 ± 76 m), third- (154 ± 79 m) and fourth- (163 ± 82 m) 15-min period was higher than in the last period (136 ± 78 m) ($p < 0.01$), whereas the fourth- also was greater than the fifth 15-min period (163 ± 82 m vs. 146 ± 74 m, $p < 0.01$). No significant difference in HSR was

found between the 15-min periods 1-4. The players sprinted significantly more in the first- (43.5 ± 27.5 m), third- (41.2 ± 27.3 m), fourth- (44.5 ± 29.4 m) and fifth- 15-min period (42.2 ± 26.2 m) compared to the last (35.9 ± 26.9 m) ($p < 0.05$), while there was no significant difference in distance covered by sprinting (DCS) between the first five 15-min periods. TDC, HSR and DCS was 10% (193 m, $p < 0.01$), 17% (28 m, $p < 0.01$) and 17% lower (7.6 m, $p = 0.01$), respectively, in the last 15-min of the games compared to the first 15-min.

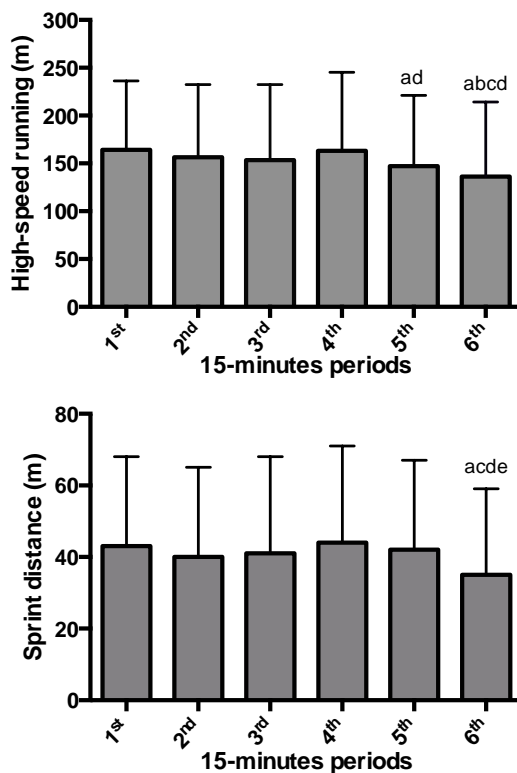


Figure 2. The development of high-speed running and sprinting during matches. Data are presented as mean \pm standard deviation. a = significant lower than 1st period ($p < 0.05$), b = significant lower than 2nd period ($p < 0.05$), c = significant lower than 3rd period ($p < 0.05$), d = significant lower than 4th period ($p < 0.05$), e = significant lower than 5th period ($p < 0.05$).

As for position specific patterns the TDC in the first 15-min of the games was significantly higher than in all of the following 15-min periods for every playing position ($p < 0.05$), with the exception of wide midfielders (WM) where the first-only differed significantly from the fifth- and last 15-min period ($p < 0.05$) (Table 1). TDC was 12.5%, 8.7%, 10%, 9%, and 10.5% lower in the last 15-min period compared to the first for central defenders (CD), wide defenders (WD), central midfielders (64), wide midfielders and forwards (F), respectively ($p < 0.01$).

Furthermore, distance covered in the fourth 15-min period was superior to the TDC in the fifth- and last 15-min period for all playing positions ($p<0.05$), whereas CD, WD, CM and WM also covered a higher distance in the second- and third 15-min period compared to the final 15-min ($p<0.05$).

CD covered less (29.2%, $p<0.01$) distance at high-speed running (HSR) in the last- compared to the first 15-min period of the games. WD, CM and F covered a significant longer distance as HSR in the fourth 15-min period compared to final one ($p<0.05$). Moreover, the second- and third 15-min period was higher than the last for WD ($p<0.05$). No significant differences were found between the 15-min periods when investigating position specific patterns in DCS, except for the last 15-min period being lower than the fourth for CM ($p=0.03$).

Table 1. Distance covered for the different playing positions during matches.

Distance covered (m)	Match time (min)					
	1 st period 0-15	2 nd period 16-30	3 rd period 31-45	4 th period 45-60	5 th period 61-75	6 th period 76-90
Total						
CD (n=97)	1772 ± 113	1680 ± 135 ^a	1640 ± 149 ^a	1650 ± 128 ^a	1594 ± 128 ^{a,b,d}	1550 ± 144 ^{a,b,c,d}
WD (n=108)	1925 ± 145	1885 ± 164 ^a	1872 ± 170 ^a	1863 ± 149 ^a	1799 ± 152 ^{a,b,c,d}	1757 ± 187 ^{a,b,c,d}
CM (n=90)	2016 ± 149	1920 ± 149 ^a	1895 ± 159 ^a	1931 ± 152 ^a	1875 ± 151 ^{a,d}	1816 ± 199 ^{a,b,c,d}
WM (n=36)	2014 ± 176	1937 ± 164	1943 ± 155	1970 ± 155	1898 ± 190 ^{a,d}	1832 ± 165 ^{a,b,c,d}
F (n=52)	1794 ± 153	1654 ± 160 ^a	1658 ± 151 ^a	1708 ± 196 ^a	1643 ± 174 ^{a,d}	1605 ± 194 ^{a,d}
High-speed runs						
CD (n=97)	113 ± 53	100 ± 49	93 ± 47 ^a	84 ± 41 ^a	80 ± 37 ^{a,b}	80 ± 52 ^a
WD (n=108)	207 ± 65	215 ± 78	216 ± 75	209 ± 67	195 ± 67	180 ± 78 ^{b,c,d}
CM (n=90)	156 ± 74	153 ± 68	143 ± 67 ^c	172 ± 79	149 ± 65	134 ± 64 ^d
WM (n=36)	201 ± 73	180 ± 57	191 ± 68	200 ± 78	194 ± 78	167 ± 77
F (n=52)	160 ± 50	132 ± 45 ^{a,d}	130 ± 58 ^{a,d}	172 ± 72	138 ± 63 ^d	134 ± 76 ^d
Sprint						
CD (n=90)	25.8 ± 22.6	23.8 ± 19.9	23.8 ± 21.4	17.8 ± 17.7	19.8 ± 18.6	17.9 ± 21.3
WD (n=103)	59.1 ± 37.5	61.1 ± 36.1	64.2 ± 34.8	63.2 ± 36.2	60.8 ± 35.1	53.5 ± 36.5
CM (n=81)	31.7 ± 26.5	33.3 ± 29.2	27.9 ± 25.6	39 ± 35	35.4 ± 29.2	26.1 ± 25.9 ^d
WM (n=35)	56.9 ± 43.9	45.4 ± 28.7	51.3 ± 44.7	58.4 ± 39.8	60.9 ± 37.2	47.8 ± 35.7
F (n=46)	53.6 ± 27.8	36.9 ± 24.1	39.3 ± 27	53.9 ± 46.2	42.4 ± 31.3	39.9 ± 28.3

Data are presented as mean ± standard deviation. CD = central defenders, WD = wide defenders, CM = central midfielders, WM = wide midfielders, F = forwards, a = significant lower than 1st period ($p<0.05$), b = significant lower than 2nd period ($p<0.05$), c = significant lower than 3rd period ($p<0.05$), d = significant lower than 4th period ($p<0.05$).

Accelerations and player load

The player load (PL) was significantly higher in the first 15-min of the games (2404 ± 434) compared to the following 15-min periods (2186 ± 407 , 2168 ± 376 , 2241 ± 404 , 2084 ± 391 and 1997 ± 383) ($p < 0.01$) (Figure 3). Moreover, PL in the last 15-min of matches (1997 ± 383) was significantly lower than in all of the other 15-min periods ($p < 0.01$). The PL in the second- (2186 ± 407), third- (2168 ± 376) and fourth (2241 ± 404) 15-min period was superior to the fifth (2084 ± 391) ($p < 0.01$), whereas the fourth- also was higher than the second- and third 15-min period (2241 ± 404 vs. 2186 ± 407 and 2168 ± 376 , $p < 0.01$). There was no significant difference in PL between the second- and third 15-min period.

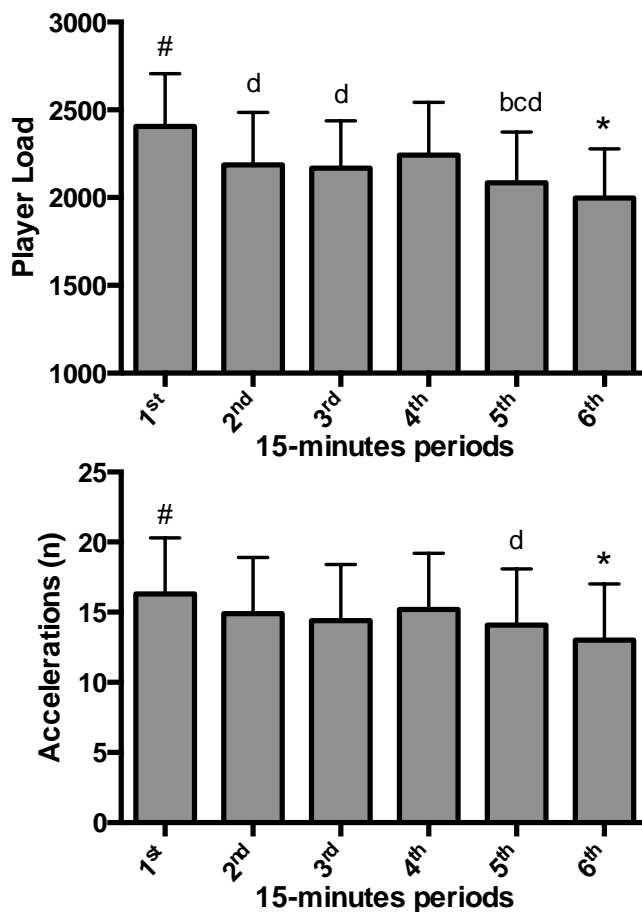


Figure 3. The development of player load and acceleration frequency during matches. Data are presented as mean \pm standard deviation. * = significant lower than all other periods ($p < 0.05$), # = significant higher than all other periods ($p < 0.05$), b = significant lower than 2nd period ($p < 0.05$), c = significant lower than 3rd period ($p < 0.05$), d = significant lower than 4th period ($p < 0.05$).

In terms of acceleration frequency (ACC_{freq}), the first 15-min period of the games was significantly higher than the following 15-min periods (16.3 ± 4.9 vs. 14.9 ± 4.7 , 14.4 ± 4.4 , 15.2 ± 4.9 , 14.1 ± 4.7 and 13 ± 4.6 , $p < 0.05$), while the last 15-minutes period (13 ± 4.6) was significantly lower than all of the others ($p < 0.05$). Additionally, the players performed a lower number of acceleration in the fifth 15-min period than in the fourth (14.1 ± 4.7 vs. 15.2 ± 4.9 , $p = 0.02$). No significant differences in ACC_{freq} were found between the second-, third- and fourth 15-min period. The reduction in ACC_{freq} and PL in the last 15-min compared to the first 15-min of matches corresponded to 20% (3.3, $p < 0.01$) and 17% (407, $p < 0.01$), respectively.

Table 2. Accelerations and player load for the different playing positions during matches.

	Match time (min)					
	1 st period (0-15)	2 nd period (16-30)	3 rd period (31-45)	4 th period (46-60)	5 th period (61-75)	6 th period (76-90)
Accelerations						
CD (n=74)	14.5 ± 4.3	12 ± 3.6 ^a	12.2 ± 4.2 ^a	12.4 ± 3.9 ^a	11.1 ± 4.1 ^a	10.2 ± 4 ^{a,c,d}
WD (n=82)	17.9 ± 5.3	16.8 ± 5.1	15.7 ± 4.2 ^a	16.8 ± 5.1	16 ± 4.7	14.3 ± 5 ^{a,b,d}
CM (n=64)	15.8 ± 4.9	14.5 ± 4.2	14.1 ± 4.1	14.8 ± 4.2	13.7 ± 3.8 ^a	13.4 ± 3.7 ^a
WM (n=28)	17.5 ± 4.4	18.1 ± 4.0	16.0 ± 4.6	17.2 ± 5.4	15.5 ± 4.3	15.1 ± 4.1 ^b
F (n=37)	16.5 ± 4.4	14.4 ± 4.2	14.8 ± 3.9	16.7 ± 4.4	15.1 ± 4.3	13.8 ± 4.2 ^d
Player load						
CD (n=97)	2510 ± 438	2292 ± 447 ^a	2225 ± 431 ^a	2316 ± 448 ^a	2148 ± 434 ^{a,b,d}	2072 ± 429 ^{a,b,c,d}
WD (n=108)	2087 ± 305	1943 ± 285 ^a	1949 ± 287 ^a	2005 ± 282 ^a	1846 ± 274 ^{a,b,c,d}	1770 ± 255 ^{a,b,c,d,e}
CM (n=90)	2632 ± 435	2386 ± 408 ^a	2358 ± 353 ^a	2436 ± 416 ^a	2306 ± 401 ^{a,d}	2187 ± 378 ^{a,b,c,d,e}
WM (n=36)	2521 ± 419	2301 ± 377 ^a	2288 ± 341 ^a	2400 ± 372	2209 ± 304 ^{a,d}	2090 ± 306 ^{a,b,c,d}
F (n=52)	2397 ± 251	2083 ± 259 ^a	2099 ± 206 ^a	2156 ± 246 ^a	2009 ± 248 ^{a,d}	1941 ± 329 ^{a,c,d}

Data are presented as mean ± standard deviation. CD = central defenders, WD = wide defenders, CM = central midfielders, WM = wide midfielders, F = forwards, a = significant lower than 1st period ($p < 0.05$), b = significant lower than 2nd period ($p < 0.05$), c = significant lower than 3rd period ($p < 0.05$), d = significant lower than 4th period ($p < 0.05$), e = significant lower than 5th period ($p < 0.05$).

As for position specific patterns PL was significantly higher in the first 15-min of the games compared to the following 15-min periods for all positions ($p < 0.05$), except WM where there was no significant difference between the first- and fourth 15-min period (Table 2). All playing position had a significant reduction in PL in the final 15-min period compared to the first ($p < 0.05$). The percentage drop ranged from 15.2% to 19.0%, where WD had the lowest decrement and F the highest. The PL in the last 15-min was significantly lower than in the first

four 15-min periods for all positions ($p < 0.05$), except for the non-significant difference between the second- and last 15-min period seen in forwards ($p = 0.08$). Additionally, the PL in the fifth 15-min period was superior to the last in CM and WD ($p < 0.05$), whereas all positions had a higher player load in the first- and fourth 15-min period compared to the fifth ($p < 0.05$)

CD had a significant drop in ACC_{freq} in the last 15-min compared to the first 15-min of the games (4.3, 29.7%, $p < 0.01$) (Table 2). This was also the case for WD (3.6, 20.1%, $p < 0.01$) and CM (2.4, 15.2%, $p < 0.01$). Furthermore, WM (2.4, 13.7%, $p = 0.15$) and F (2.7, 16.4%, $p = 0.11$) tended to perform a higher number of accelerations in the first 15-min period than in the final one in matches, but these decrements were not significant. In comparison to the last 15-min period, WD and WM had a superior ACC_{freq} in the second 15-min period, whereas CD, WD and F performed significantly more accelerations in the fourth 15-min period of the matches ($p < 0.05$).

Substitutes versus starters

Table 3. Physical performance in the last fifteen minutes of matches for substitutes and starters.

	Starters (n=36)	Substitutes (n = 23)	p-value
Total distance (m)	1832 ± 165	1967 ± 270*	0.02
HSR (m)	167 ± 76	235 ± 77*	0.01
Sprint (m)	47.8 ± 35.4	70 ± 40.3*	0.02
Accelerations (n)	15.1 ± 4.1 †	18.1 ± 3.9* †	0.02
Player load	2090 ± 302	2259 ± 275*	0.03

Data are presented as mean ± standard deviation. HSR = High-speed running, *significant different from starters ($p < 0.05$), †n = 28, †n = 16.

Players that had been on the pitch the whole game covered significant less distance in total (135 m, $p = 0.02$), with HSR (68 m, $p = 0.01$) and when sprinting (22.2 m, $p = 0.02$) than the substitutes in the last fifteen minutes of matches (Table 3). They also performed significantly less accelerations (3, $p = 0.02$) and significant less load (169, $p = 0.03$). The percentage difference between the two groups corresponded to 6.9%, 28.9%, 31.7%, 17% and 13.4% for TDC, HSR, DCS, ACC_{freq} and PL, respectively.

Effect of score line

Table 4. Effect of score line on physical performance in the last 15 minutes of matches.

	Match type		p-value
	Need goal (n=65)	Do not need goal (n=176)	
Total distance (m)	1777 ± 176	1704 ± 167*	0.03
HSR (m)	145 ± 59	131 ± 54	0.13
Sprint (m)	36 ± 24.1	32.3 ± 20.4	0.38
Accelerations (n)	12.8 ± 3.2	13.2 ± 2.7	0.5
Player load	2108 ± 316	2076 ± 305	0.41

Data presented as mean ± standard deviation. HSR = high-speed running, *significant different from need goal group (p<0.05).

The players covered a significantly higher distance in total (73 m, p=0.03) when they were in need of a goal (NG) than when they did not need a goal (DNG) (Table 4). No significant differences were found between the NG- and the DNG group regarding HSR, DCS, ACC_{freq} or PL.

Discussion

The main findings of the present study were that 1) physical performance gradually decreases during soccer matches, 2) TDC, HSR, DCS, ACC_{freq} and PL were significantly lower in the last fifteen minutes of matches compared to the first fifteen, 3) substitutes had a significantly higher end-game work rate than the players starting the game, 4) TDC was significantly higher in the last fifteen minutes of games when the team needed a goal compared to when they did not, whereas no significant differences were found for HSR, DCS, ACC_{freq} or PL.

End-game physical performance

When comparing the last 15-min of matches with the first 15, the Norwegian elite players in this study had a reduction in TDC, HSR and DCS of 10%, 17% and 17%, respectively. To our knowledge, the study conducted by Carling and colleagues (28) on French elite players is the only one besides ours that has investigated the development of TDC in different 15-min periods, and the 7% decrease seen in their results is similar to our findings. Diminutions in TDC during games have also been found in the premier divisions in England (2%) (1), Italy (2%) (9) and Scotland (1.6%) (18). However, these studies analyzed the difference between halves, and not among smaller sections of the games such as 5- or 15-min periods. Thus, greater dissimilarities may have been found by comparing the first-and last 15-min of matches, as this seems to be a more informative analytical design when analyzing potential variations between start- and end-game physical performance (29). Furthermore, in line with previous research, the footballers in our study covered a lower distance at high velocities towards the end of the matches. Although applying a higher velocity threshold (19.8- vs. 14.4 km·h⁻¹), the 17% reduction in HSR in the last 15-min is comparable to the decrements observed in the French- (12%) (28) and English (21%) (1) elite leagues. Additionally, the 7% drop in DCS mirrors the results found by Bradley and colleagues (7%) (1), implying that some of the impairment in sprint capability seen immediately after matches (14, 21) also might be apparent in the latter part of games. Altogether, the observed decrements in

distance covered in total and at high velocities in the current study are similar to other European elite leagues.

As hypothesized, the players performed significantly less accelerations in the last 15-min than in the first 15-min of games (20%). Furthermore, when comparing the different 15-min periods, the ACC_{freq} was significantly lowest in the final period, whereas the penultimate period (61-75 min) was inferior to the first and fourth one. Thus, our results show that the quantity of accelerations performed by footballers is severely compromised towards the end of matches. A reduced acceleration performance in the latter part of games has also been observed in English professionals (55), and is to be suspected as it echoes Newton's second law of motion. Numerous post-game tests show that the working muscles' force generating capability is impaired after matches (21, 25, 26), and some of this fatigue is likely to be present at the end of games as well. Consequently, as mass is a constant (body weight of players), the ability to accelerate should be expected to deteriorate in fatigued players. This notion is underlined by the close association between maximal strength and acceleration performance (22), and has been documented by Rampinini and colleagues (21) as the fatigued elite players in their study had significant decrements in 0-15 m sprint performance compared to baseline values.

Although documenting a drop in the quantity of accelerations towards the end of matches, even greater decrements might have been found by investigating the quality of these high-intensity movements. Peak acceleration values may potentially reflect internal physiological conditions in a better way than merely the number of accelerations performed. Thus, this is an area that should be addressed by future research. However, it should be noted that extremely accurate analytical devices are needed for such a challenge since small errors in the measuring process could bias the results to a great extent. Nevertheless, our study provides additional evidence to the rather slim body of knowledge concerning the development of acceleration performance during soccer matches.

In the present study we introduced a new physical performance variable based on triaxial accelerometer recordings, called player load. Including such a variable is advantageous since soccer specific movements like tackles, jumps, duels for possession, decelerations and changes of directions can be incorporated in the analysis. These actions require forceful contractions of the working muscles and can cause a significant physical stress upon the players, even though if the displacement of the players' location on the pitch is small. Thus, the variable provides additional knowledge concerning the footballers' workload, previously neglected by the two-dimensional positioning systems.

As expected the PL was reduced at the end of matches. PL in both the final- and the penultimate 15-min period was significantly lower than in the 15-min periods preceding them. This decrement may be owed to reductions in several types of movement patterns, since the load measured in this variable can be obtained in different ways. Thus, the observed diminutions in TDC, HSR, DCS and ACC_{freq} will all lead to reductions in PL. However, given that the load is calculated based on squared acceleration values, rapid and explosive actions will result in high scores, while movements where the acceleration is low, like running fast at a constant velocity, tends to be severely underestimated. Accordingly, the major part of the decrements may be a reflection of a diminishment in the quantity and/or quality of rapid movements, possibly resulting from fatigue impaired power capabilities (26). If so, the variable could potentially be a sensitive indicator of fatigue. Yet, such an interpretation requires caution, as we do not know the different movement patterns' relative contribution to the observed decrements. Future research should address this problem.

Altogether, TDC, ACC_{freq} and PL were significantly lower in the last 15-min of matches than in all of the prior 15-min periods. Furthermore, in comparison to the final 15-min, DCS was greater in the first-, third-, fourth- and fifth 15-min periods, whereas the amount of HSR was superior in the first four ones. Interestingly, decrements were also observed in the penultimate 15-min period, as TDC and PL were significantly higher in 15-min periods 1-4, while HSR and ACC_{freq} were greater in the first and fourth one. Hence, the physical performance

was clearly reduced at the end of games. Reduced glycogen stores have been suggested as the primary physiological reason explaining such decrements (15, 36). A diminution in the working muscles' availability for glycogen increases the reliance on fat as source for energy and decreases the rate of ATP turnover (35). Consequently, the players may be forced to reduce their working intensity (34) and the ability to repeat high-intensity movements might be impaired (27). This could possibly explain why the reductions in distance covered at high velocities were observed. Furthermore, low glycogen stores may reduce the release of Ca^{2+} from the sarcoplasmic reticulum resulting in a diminished force generating capability (65). This capability could additionally be attenuated by other neuromuscular factors such as structural damage to the working muscle fibers (26), accumulation of inorganic phosphate in the intramuscular environment (33) and a reduced discharge rate of recruited motor units (31). An impairment in the working muscles' force production (21, 26), as well as in the rate this force is developed (25), is likely to have a negative impact on the players' abilities to accelerate and perform other explosive movements. Consequently, such fatigue-induced alterations might account for some of the diminutions in ACC_{freq} and PL. Lastly, dehydration and hyperthermia have been suggested to cause end-game fatigue, especially in hot and humid environments (30). However, the impact of those mechanisms in thermoneutral conditions has been questioned (40), and as the temperature in Norway rarely exceeds 20° C they are likely to play a minor part when explaining the decrements in work rate.

Position-specific patterns

As for position-specific decrements, almost identical patterns were seen across positions with regards to TDC and PL. The diminution patterns also seemed to be similar for the different positions in terms of ACC_{freq} , as CD, WD and CM performed significantly less accelerations in the final 15-min period compared to the first one. Although not reaching the level of statistical significance, WM ($p=0.15$) and F ($p=0.11$) tended to have the same drop in acceleration performance. The absent of significant reductions could possibly be explained by the lower number of observations from these positions, as the team normally

played with only one F, whereas the WM were often substituted. Additionally, due to errors from the tracking company, acceleration values from the 2009 season could not be included in the analysis, reducing the number of observations on this variable even further.

Moreover, few positions-specific significant differences were found between start- and end-game performance regarding distance covered at high velocities. This may be attributed to the large match-to-match variability seen for these variables. Gregson and colleagues (66) documented that the coefficient of variation in English elite soccer was 16% and 30% for HSR and DCS, respectively, reflecting the rather high standard deviation found in our study. Because these variables seem to be highly affected by the demands of the match itself, a large number of observations is needed to detect systematic differences between start- and end-game performances (66). When investigating English elite footballers, Bradley et al. (1) found that every playing position covered a lower distance at high intensities ($>14.4 \text{ km}\cdot\text{h}^{-1}$) in the final 15-min of matches compared to the first 15-min, with the magnitude of the reductions being similar across positions ($\sim 20\%$). As all positions in the present study tended to perform an inferior amount of HSR and DCS at the end of matches compared to the start (Table 1), one might suspect that significant differences may have been induced for these variables as well if more observations had been included. Nevertheless, the current study shows that diminutions in physical performance seem to occur in every playing position on the field in the latter part of games.

Effect of score line on physical performance

The players covered a higher distance in total in the last 15-min of matches when they were in need of a goal compared to when they were not. Somewhat surprisingly, there was no significant difference between the two groups with regards to the other physical performance variables. Previous research has shown that footballers' work rate is higher when losing than winning (18, 44), possibly attributed to the more attacking style of play when in need of a goal (45). Our results failed to clearly support these findings. However, in addition to

covering a greater distance in total, the players tended to perform a higher amount of HSR (9%, $p=0.13$) when they were in need of a goal compared to when they were not. Given that a large sample size is required to detect real systematic changes in distance covered at high velocities (66), the number of observations in our study may have been insufficient to induce a significant difference for this variable. Hence, as TDC was significantly elevated and HSR tended to be higher when in need of a goal, the hypothesis cannot be rejected. Furthermore, due to few observations from some of the playing positions in the NG group, position-specific patterns were not analyzed. Researchers have previously documented that the score line might affect physical performance in different ways across positions (46). Thus, even though if the score line did not affect the end-game work rate to a great extent for the team as a whole, greater dissimilarities might have been found for some of the positions. For instance, players in attacking positions may be more involved in the play when chasing a goal compared to players with more profound defensive responsibilities (67), possibly affecting the work rate differently across positions. Score line's potential effect on the various playing positions' end-game work rate should therefore be addressed by future research.

Substitutes versus starters

TDC, HSR and DCS was greater in the last 15-min of matches for substitutes compared to players starting the game. This is in line with previous research conducted on the English (46), French (47) and Italian (8) elite leagues, stating that the distance covered in total and at high velocities is superior for substitutes in comparison to starters. Furthermore, the current study shows that the substitutes have a higher ACC_{freq} and PL at the end of matches. To our knowledge, this is a novel finding, indicating that the end-game performance of high-intensity movements at low velocities also might be greater for the players starting on the sideline than for the ones playing the whole game. Given the numerous post-game tests stating reductions in physical performance capabilities for starters (14, 21, 23, 26), a superior end-game work rate is to be suspected for players that are rested compared to those who are not. This could possibly be attributed to intact intramuscular glycogen stores, as well as more

preserved power production abilities. And assuming that the possibilities for engaging in match activities are equal for substitutes and starters, fatigue is presumably the major cause explaining the differences in physical performance between the two groups, since the confounding effects of situational factors are diminished. Alternatively, one might argue that some of the dissimilarities could be attributed to motivational factors, as the substitutes may have an unusual high work rate when coming off the bench due to their desire to impress the coach. However, this notion has been contradicted, as Carling et al. (47) showed that the work rate of forwards during their first 10-min as substitutes was inferior to their performances recorded during the initial 10-min when starting the games, whereas no difference were found for midfielders.

Perspectives

The superior work rate of substitutes compared to starters found in our- and previous studies (8, 46, 47), suggest that fatigue is likely to account for a great deal of the physical performance decrements in the latter part of matches. Diminutions in end-game work rate may therefor provide valuable knowledge regarding the physical state of the players. This is important information for coaches and medical staff, as fatigued footballers seem to have an increased risk of injuries (60-62) and reduced strength- and power capabilities (14, 21, 23, 26). However, the relationship between internal physiological conditions and external physical performance variables may be affected by situational confounders. Previous research has shown that factors such as the score line, quality of opposing team and match location may influence the work rate during games (44, 45). Furthermore, given that the players' physical performance is self-regulated, motivational aspects and pacing strategies (40) could also have an impact on the observed decrements. Consequently, it is of great importance that the interpretation of physical performance is conducted in a context where the awareness of these confounders is present (45). If so, motion analysis could provide valuable information of the players' physical condition, making it easier for the coaching staff to optimize training stimulus and avoid injuries.

Study limitations

A limitation to this study is that all of the analyzed subjects played for the same club. Therefore, the observed patterns might only be a reflection of this particular team, and not the Norwegian league as a whole. In addition, the matches were played exclusively at the team's home venue. This might have affected the results, as match location has been documented to influence physical performance in soccer (44). Furthermore, due to a low number of observations from other playing positions, wide midfielders were the only players used for the analysis when comparing the work rate of substitutes and starters. Hence, the results cannot with certainty be generalized to the other playing positions. Further research is warranted to investigate if acceleration performance and PL is greater for substitutes than starters across all positions. Additionally, given the independency of the samples, it cannot be ruled out that dissimilarities in physical capabilities may have accounted for some of the differences between the two groups. Lastly, the number of observations may have been insufficient in order to detect real systematic differences between start- and end-game physical performances at a positional level. This applies especially to HSR and DCS, as these variables have a high coefficient of variation (66).

Conclusion

The present study demonstrated that acceleration frequency and load based on accelerometer recordings, as well as distance covered in total and at high velocities, are reduced in the latter part of soccer matches. The superior end-game work rate of substitutes compared to players starting the match implies that a substantial amount of the decrements is caused by fatigue. Thus, motion analysis could provide valuable information concerning the players' physical condition if aware of contextual confounders when interpreting the data.

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