Motion analysis of match-play in elite U12 to U16 age-group soccer players

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Abstract
The aim of this study was to quantify the motion demands of match-play in elite U12 to U16 age-group soccer players. Altogether, 112 players from two professional soccer clubs at five age-group levels (U12–U16) were monitored during competitive matches (n=14) using a 5 Hz non-differential global positioning system (NdGPS). Velocity thresholds were normalized for each age-group using the mean squad times for a flying 10 m sprint test as a reference point. Match performance was reported as total distance, high-intensity distance, very high-intensity distance, and sprint distance. Data were reported both in absolute (m) and relative (m·min⁻¹) terms due to a rolling substitute policy. The U15 (1.35±0.09 s) and U16 (1.31±0.06 s) players were significantly quicker than the U12 (1.58±0.10 s), U13 (1.52±0.07 s), and U14 (1.51±0.08 s) players in the flying 10 m sprint test (P<0.001). The U16 age-group covered significantly more absolute total distance (U16>U12, U13, U14), high-intensity distance (U16>U12, U13, U14, U15), very high-intensity distance (U16>U12, U13), and sprint distance (U16>U12, U13) than their younger counterparts (P<0.05). When the data are considered relative to match exposure, few differences are apparent. Training prescription for youth soccer players should consider the specific demands of competitive match-play in each age-group.

Keywords: Time–motion analysis, elite youth soccer, global positioning system, GPS, maturation

Introduction
In recent years, the development of complex semi-automated video analysis systems (e.g. ProZone®, Amisco Pro®) has enabled the efficient and detailed tracking of both players and referees during elite soccer match-play (Di Salvo, Gregson, Atkinson, Tordoff, & Drust, 2009; Weston, Castagna, Impellizzeri, Rampinini, & Abt, 2007), using multiple cameras that are a permanent fixture at club stadia. However, competitive matches at elite youth team level usually take place at training ground facilities, where such technology is not available. To date, few studies have considered the match-play demands of elite youth soccer across a range of age-groups.

The match conditions for youth soccer at the elite level vary, with pitch size and length of game being age dependent. Previous studies of the motion demands of elite youth soccer players have assigned player movement into arbitrary speed categories (e.g. walking, jogging, running) using video analysis and observational coding (Capranica, Tessitore, Guidetti, & Figura, 2001; Stroyer, Hansen, & Klausen, 2004). One of the limitations of such methods is determining the exact point at which a player crosses movement category thresholds, leading to concerns about both the inter- and intra-rater reliability of such systems. Furthermore, video-based observational coding has been shown to underestimate both total distance covered and high-intensity running when compared with a 5 Hz non-differential global positioning system (NdGPS) and semi-automated video-analysis systems (P<0.001; Randers et al., 2010). Castagna and colleagues (Castagna, D’Ottavio, & Abt, 2003) used fixed velocity thresholds for speed zones (e.g. high-intensity run: 3.64–5.0 m·s⁻¹; maximal speed run: >5.0 m·s⁻¹), thereby allowing direct comparisons to be made between individuals regarding the absolute work performed in each speed zone. However, the time constraints inherent when using triangulation to assess the movement of one player at a time resulted...
in a relatively small sample size from one age-group (age: 11.8 ± 0.6 years; n = 11), thus limiting the inferences that can be drawn regarding player development across a range of age-groups. Recent developments in NdGPS technology offer the potential to overcome the logistical issues and restrictions of other time–motion analysis methods, and can provide a means of quantifying athlete-motion without space limitations or the need for fixed equipment.

The match-play demands of elite senior players have previously been described in detail (Bangsbo, Norregaard, & Thorso, 1991; Mohr, Krstrup, & Bangsbo, 2003; Reilly & Thomas, 1976), with recent studies reporting the distance covered by players in a range of age-groups. Recent developments in NdGPS technology offer the potential to overcome the logistical issues and restrictions of other time–motion analysis methods, and can provide a means of quantifying athlete-motion without space limitations or the need for fixed equipment.

The match-play demands of elite senior players have previously been described in detail (Bangsbo, Norregaard, & Thorso, 1991; Mohr, Krstrup, & Bangsbo, 2003; Reilly & Thomas, 1976), with recent studies reporting the distance covered by players in a series of defined speed thresholds (running, 4.0–5.5 m · s⁻¹; high-speed running, 5.5–7.0 m · s⁻¹; sprinting, >7 m · s⁻¹; Bradley et al., 2009). Due to the innate differences in performance capabilities between elite-level junior and senior players, it would be inappropriate to apply the speed thresholds commonly used with elite senior players to an elite youth player. As sprint performance has been reported to be positively related to the age of elite youth players (Mujika, Spencer, Santisteban, Goiriena, & Bishop, 2009), one approach to normalize thresholds for youth players could be to use age-specific ranges of measured sprint velocities, considered relative to those displayed by senior players. Understanding the match-play demands of elite youth soccer could have practical implications for training prescription, talent identification, and the quantification of player training loads. In particular, understanding the demands of match-play across a range of age-groups may provide insight into the development profile of players at the different levels. Therefore, the aim of the present study was to assess the motion demands of elite youth soccer players in the U12 to U16 age groups.

Methods

Participants

After receiving written consent from both players and their parents, 112 elite youth male soccer players aged 11–16 years representing two professional English clubs participated in the study. The participants were categorized into five age-groups, classed as under 12 (U12; n = 22), under 13 (U13; n = 20), under 14 (U14; n = 25), under 15 (U15; n = 21), and under 16 (U16; n = 24). All participants generally undertook 4.5 h of soccer training each week plus one competitive match at weekends. The U15 and U16 age-groups also undertook 1.5 h of strength training and conditioning per week as part of their usual training programme. All procedures received approval from the Institutional Review Board and the University’s Faculty Research Ethics Committee.

Match configuration

All games were played in accordance with the rules outlined by the English Football Association, and were refereed by qualified officials. All age-groups played with 11 players, and adopted a “rolling substitute” policy, whereby each individual player can interchange with any substitutes an unlimited number of times during the match. The U12 and U13 age-groups played on a three-quarter-size soccer pitch (77 × 60 m); the U14, U15, and U16 groups played on a full-sized pitch (99 × 65 m). Match configuration varied between groups, with U12, U13, U14, and U15s playing 3 × 25 min periods, or 2 × 25 min plus 2 × 12.5 min periods. The U16 age-group played 2 × 40 min periods.

Experimental design

Data were collected from each age-group for a total of 14 competitive matches (U12, n = 2; U13, n = 3; U14, n = 4; U15, n = 3; U16, n = 2), with all individual match observations being included in the final data set, and each individual player (n = 112) being included for only one match.

Speed zones were normalized using the mean flying 10 m sprint times for each age-group, allowing comparisons to be drawn between age-groups based on average speed characteristics. Following a thorough warm-up, each participant completed five 20 m sprints, with timing gates placed at 10 m and 20 m, allowing a “flying” 10 m sprint time to be obtained for each individual using the fastest recorded time. As sprint distances in soccer rarely exceed 20 m (Carling, Bloomfield, Nelsen, & Reilly, 2008; Di Salvo et al., 2007; Stølen, Chamari, Castagna, & Wisloff, 2005), a 20 m sprint with 10 m flying recorded time was deemed appropriate in this study for the assessment of peak velocity (v_peak), which has previously been shown to produce highly reliable results with elite soccer players (Barnes, 2006). Individual v_peak (v_peakInd) scores were used to calculate mean v_peak for each age-group (v_peakGrp), which were compared relative to the mean measured v_peak for a sample of elite senior players (v_peakSnr; n = 13; mean ± s: age 21.2 ± 0.8 years; height 1.79 ± 0.04 m; mass 74.7 ± 5.6 kg). The [v_peakSnr / v_peakGrp] ratio was then applied to the commonly used thresholds for senior players (Th-S; Bradley et al., 2009) (Table I) to produce age-group specific speed zones, according to the formula:

\[
(v_{\text{peakSnr}} / v_{\text{peakGrp}}) \times \text{Th-S}
\]
Table I. Speed zone thresholds (m·s⁻¹) by age-group calculated from 10 m flying time.

<table>
<thead>
<tr>
<th>Speed zone (m·s⁻¹)</th>
<th>Senior</th>
<th>1.20</th>
<th>0.50</th>
<th>2.00</th>
<th>4.00</th>
<th>5.50</th>
<th>7.00</th>
<th>7.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 m flying time (mean ± s)</td>
<td>U16</td>
<td>1.31 ± 0.06*</td>
<td>0.46</td>
<td>1.83</td>
<td>3.66</td>
<td>5.04</td>
<td>5.64</td>
<td>6.41</td>
</tr>
<tr>
<td></td>
<td>U15</td>
<td>1.35 ± 0.09*</td>
<td>0.44</td>
<td>1.78</td>
<td>3.56</td>
<td>4.89</td>
<td>6.22</td>
<td>6.22</td>
</tr>
<tr>
<td></td>
<td>U14</td>
<td>1.51 ± 0.08</td>
<td>0.40</td>
<td>1.59</td>
<td>3.18</td>
<td>4.37</td>
<td>5.56</td>
<td>5.56</td>
</tr>
<tr>
<td></td>
<td>U13</td>
<td>1.52 ± 0.07</td>
<td>0.39</td>
<td>1.58</td>
<td>3.16</td>
<td>4.34</td>
<td>5.53</td>
<td>5.53</td>
</tr>
<tr>
<td></td>
<td>U12</td>
<td>1.58 ± 0.10</td>
<td>0.38</td>
<td>1.52</td>
<td>3.04</td>
<td>4.18</td>
<td>5.32</td>
<td>5.32</td>
</tr>
</tbody>
</table>

*Significantly different to U12, U13, and U14 (P < 0.001). Senior thresholds (Th-S) are shown in italic. Speed zones represent: 1, standing; 2, walking; 3, jogging; 4, running; 5, high-speed running; 6, sprinting.

Before each game, all starting outfield players were fitted with a NdGPS unit (MinimaxX, Catapult Innovations, Canberra, ACT, Australia), which operated at a sampling frequency of 5 Hz. Units were worn between the shoulder-blades in custom-made, tight-fitting vests to reduce movement artifact. Previous studies have reported that the reliability of NdGPS is compromised during high-intensity activity using a sampling frequency of 1 Hz (Coultts & Duffield, 2010). More recently, it has been reported that 5 Hz NdGPS appeared more accurate than 1 Hz when measuring distance and velocity for movement patterns at higher velocities, while there was still some discrepancy compared with the criterion measure (Duffield, Reid, Baker, & Spratford, 2009). We previously found that 5 Hz NdGPS displayed good accuracy (%error < 1%) and reliability (CV < 5%) compared with trundle-wheel measured total distance for soccer-specific courses derived from semi-automated video analysis data (Prozone®) for position-specific bouts of activity (Portas, Harley, Barnes, & Rush, in press).

Post-game analysis enabled the quantification of total distance covered (sum of zones 1–6), and distance covered at high-intensity (zones 4, 5, and 6), very high-intensity (zones 5 and 6), and at sprinting pace (zone 6) in line with previous studies (Bradley et al., 2009) (Table I). Data are presented in both absolute (m) and relative (m·min⁻¹) terms to allow direct comparisons to be made between groups without bias to individual variations in match exposure. Data were excluded from the analysis for injured players who had to withdraw from the game. For all data, mean ± s satellite coverage (located satellites) was 7.1 ± 2.3; mean horizontal dilution of precision was <2.3.

Statistical analyses

Statistical analyses were conducted using SPSS v.16.0 (SPSS Inc., Chicago, IL). Before using parametric statistical procedures, the assumptions of normality and sphericity were verified. Differences in flying 10 m sprint time (s), match exposure (min), absolute (m) and relative (m·min⁻¹) distances covered were analysed using a one-way analysis of variance (ANOVA), with a Tukey post hoc test applied to explore exact differences between age-groups. Effect size (Cohen’s d [95% confidence interval]) was reported for each significant variable to assess the magnitude of the observed difference. The relationship between match exposure (min) and workload (m) was analysed by simple linear regression, from which the Pearson correlation was calculated, and coefficients of determination (r²) reported for each relationship. Statistical significance was set at P < 0.05.

Results

Flying 10 m sprint time

The U15 (1.35 ± 0.09 s) and U16 (1.31 ± 0.06 s) age-groups displayed faster flying 10 m sprint times than the U12 (1.58 ± 0.10 s), U13 (1.52 ± 0.07 s), and U14 (1.51 ± 0.08 s) age-groups (P < 0.001). Sprint times between the U12, U13, and U14 age-groups, and between the U15 and U16 age-groups were not different (P > 0.05).

Match exposure

The U16 age-group had longer match exposure (71.0 ± 26.4 min) than the U15 age-group (50.8 ± 11.7 min; P = 0.034). Differences in match exposure between other age-groups (U12: 57.2 ± 10.2 min; U13: 60.5 ± 16.5 min; U14: 54.9 ± 21.0 min) were non-significant (P > 0.05). Individual player match exposure ranged from 13 to 97 min. There were significant positive correlations between match exposure and absolute total distance (r² = 0.739; P < 0.001), high-intensity distance (r² = 0.542; P < 0.001), very high-intensity distance (r² = 0.378; P < 0.001), and sprint distance (r² = 0.236; P < 0.001).

Total distance

Absolute total distance (m) was significantly higher at U16 level (23.5 m · min⁻¹) than at U12 (18.7 m · min⁻¹) and U14 (118.7 ± 12.2 m · min⁻¹) than at U12 (103.7 ± 5.8 m · min⁻¹; P = 0.026; d = 1.6 [0.2, 2.9]) and U13 (98.8 ± 23.5 m · min⁻¹; P = 0.001; d = 1.1 [0.5, 2.3]).
Figure 1. Absolute (m) and relative (m \cdot \text{min}^{-1}) total distance (TD), high-intensity distance (HID), very high-intensity distance (VHID), and sprint distance (SPR) for all age-groups. Mean and range of data are illustrated, together with the mean data label. *Significantly greater than (a, U12; b, U13; c, U14; d, U15; P < 0.05).
1.7]) levels. Relative total distance was also higher at U16 level \((115.2 \pm 15.8 \text{ m} \cdot \text{min}^{-1})\) than at U13 \((98.8 \pm 23.5 \text{ m} \cdot \text{min}^{-1}; P = 0.014; d = 0.8 \ [0.2, 1.5])\) level (Figure 1B).

**High-intensity distance**

High-intensity distance (m) was higher at U16 level \((2481 \pm 1044 \text{ m})\) than at U12 \((1713 \pm 371 \text{ m}; P = 0.006; \ d = 1.0 \ [0.3, 1.7])\), U13 \((1756 \pm 520 \text{ m}; P = 0.008; \ d = 0.9 \ [0.2, 1.5])\), U14 \((1841 \pm 628 \text{ m}; P = 0.013; \ d = 0.7 \ [0.2, 1.3])\), and U15 \((1755 \pm 591 \text{ m}; P = 0.013; \ d = 0.9 \ [0.2, 1.5])\) levels (Figure 1C). When the data are considered in relative (m \(\cdot \text{min}^{-1}\)) terms, no differences were observed in high-intensity distance \((P > 0.05)\) between age-groups (Figure 1D). High-intensity distance accounted for \([\text{mean (range)} 30.4\% (17.1-42.6\%)\) of total match distance for all age-groups, and for 9.2\% \((5.0-14.0\%)\) of total match exposure.

**Very high-intensity distance**

Very high-intensity distance (m) was higher at U16 level \((951 \pm 479 \text{ m})\) than at U12 \((662 \pm 180 \text{ m}; P = 0.045; \ d = 0.8 \ [0.2, 1.6])\) and U13 \((644 \pm 259 \text{ m}; P = 0.022; \ d = 0.8 \ [0.1, 1.5])\) levels (Figure 1E). In relative terms (m \(\cdot \text{min}^{-1}\)), very high-intensity distance was higher at U14 level \((14.3 \pm 3.8 \text{ m} \cdot \text{min}^{-1})\) than at U13 \((11.1 \pm 4.7 \text{ m} \cdot \text{min}^{-1}; P = 0.026; \ d = 0.8 \ [0.1, 1.4])\) level (Figure 1F). Very high-intensity distance accounted for \([\text{mean (range)} 11.9\% (4.5-22.7\%)\) of total match distance for all age-groups, and for 3.1\% \((1.0-5.0\%)\) of total match exposure.

**Sprint distance**

Sprint distance (m) was higher at U16 level \((302 \pm 184 \text{ m})\) than at U12 \((174 \pm 64 \text{ m}; P = 0.033; \ d = 0.9 \ [0.1, 1.8])\) and U13 \((167 \pm 96 \text{ m}; P = 0.016; \ d = 0.9 \ [0.2, 1.7])\) levels (Figure 1G). Relative sprint distance (m \(\cdot \text{min}^{-1}\)) was higher at U14 level \((4.7 \pm 2.4 \text{ m} \cdot \text{min}^{-1})\) than at U13 \((2.9 \pm 1.7 \text{ m} \cdot \text{min}^{-1}; P = 0.006; \ d = 0.9 \ [0.3, 1.5])\) level (Figure 1H). Sprinting accounted for \([\text{mean (range)} 3.6\% (0.3-8.8\%)\) of total match distance for each age-group, and for 1.01\% \((0.0-2.0\%)\) of total match exposure.

**Discussion**

The purpose of this study was to assess the motion demands of elite youth soccer players across different age-groups during competitive match-play. This is the first study to consider match-performances in speed zones calculated relative to group-derived speed characteristics, and to report these distances in both absolute (m) and relative (m \(\cdot \text{min}^{-1}\)) terms. The main findings of the study were that the U16 age-group displayed higher absolute total distance \((U16 > U12, U13, U14)\), high-intensity distance \((U16 > U12, U13, U14, U15)\), very high-intensity distance \((U16 > U12, U13)\), and sprint distance \((U16 > U12, U13)\) than their younger counterparts. However, when the data are considered relative to match exposure, few differences in match work rate are found between groups (total distance: U15 > U12, U13; U16 > U13; very high-intensity distance: U14 > U13; sprint distance: U14 > U13). The older age-groups (U15, U16) were also quicker than their younger counterparts (U12, U13, U14) when tested using a flying 10 m sprint protocol \((P < 0.001)\).

The findings of this study suggest that the work rate profiles of elite youth soccer players are similar between the U12–U16 age-groups, when the thresholds used to define movement categories are corrected relative to age-specific velocity characteristics. Castagna et al. (2003) reported the activity profile of U12 soccer players using set velocity thresholds for various movement categories, and reported that 9\% of total match time was spent at high-intensity, using a threshold to define high-intensity work of movement above 13 km \(\cdot \text{h}^{-1}\) \((3.61 \text{ m} \cdot \text{min}^{-1})\). In comparison, the U12 group in the present study spent 10.8\% of time at high intensity, the threshold in our study being slightly lower at 3.04 m \(\cdot \text{s}^{-1}\) \((10.94 \text{ km} \cdot \text{h}^{-1})\), based on age-specific velocity characteristics. In addition, mean sprint distance during match-play was reported as \(114 \pm 73 \text{ m}\) \((34–250 \text{ m})\) by Castagna et al. (2003), which is lower than that reported for the U12 group in the present study \((174 \pm 64 \text{ m}[85–262 \text{ m}])\), despite a higher sprinting threshold being applied in the current study \((5.32 \text{ m} \cdot \text{s}^{-1})\) for the U12 group, compared with 5 m \(\cdot \text{s}^{-1}\) used by Castagna et al. (2003). The mean match exposure of the U12 age-group in the present study \((57.2 \pm 10.2 \text{ min})\) was similar to the total match time reported by Castagna et al. (60 min). Therefore, the higher sprint distances reported in the present study may partly be influenced by the higher total playing time (75 min), match-to-match variability between studies, differences in the assigned velocity categories for sprints, and also by methodological differences between studies (NdGPS vs. camera-based triangulation). Furthermore, the analysis of sprinting using NdGPS must be made with caution due to the reported accuracy of NdGPS during high-intensity activity (Duffield et al., 2009).

In the present study, speed zones were normalized for each age-group using the mean measured sprint...
performance for each group, relative to that measured for the senior group. Semi-automated video analysis systems categorize workloads into absolute speed zones that are generally standardized for all players. While the use of absolute speed-zones may provide useful information regarding the performance capacity of players, they do not account for the underlying individual physiological capacity that distinguishes different standards of play. Abt and Lovell (2009) suggested a method for individualizing high-intensity speed thresholds based on the measured second ventilatory threshold in elite soccer players. However, the use of such treadmill-based tests that require maximal effort to volitional exhaustion may be unsuitable for youth soccer players for both economical and logistical (time constraints, treadmill familiarization) reasons. The method presented in this study may be used to make between-group comparisons based on the capabilities of different age-groups, or different standards of play. Limitations to this method, however, are that individual variations in speed capacity within age-groups are not accounted for. Error may also be introduced by individualizing group thresholds based on $v_{\text{peak}}$ as this may also be influenced by other factors, including anaerobic capacity and running mechanics.

A significant increase in measured peak speed was observed between the U14 and U15 age-groups in the present study ($P < 0.05$), with no differences in U12–U14 levels, or between U15 and U16 age-groups ($P > 0.05$). These findings are in line with those of Mujika et al. (2009), who reported improved sprint performance between U14 and U15 age-groups ($P < 0.05$), with no further improvement after U15 level. It has been suggested that such improvements are likely related to the influence of maturation on maximal-effort exercise, and in particular differences in height and weight across age-groups (Mujika et al., 2009). Stratton and colleagues (Stratton, Reilly, Williams, & Richardson, 2004) suggest that the average age at the onset of puberty is 13.5 years (U14) for boys, and that age at peak height velocity in sub-elite players occurs from 13.8 to 14.2 years (U14 to U15). It might therefore be implied that the physical performance characteristics measured in the present study (peak speed) were influenced by maturation status. However, as match-performance data were considered relative to these group-derived peak speed characteristics, no differences were observed in match performances between the U14 and U15 age-groups. In addition, the significantly higher absolute high-intensity distance at U16 level compared with the younger age-groups may be due to a high match exposure ($71.0 \pm 26.4$ min), as high-intensity distance showed a strong ($r^2 = 0.542; P < 0.001$) correlation with match exposure. Alternatively, such differences may be attributed to an increased oxygen uptake capacity in mature children (Armstrong & Welsman, 1994), which has previously been reported to increase soccer performance (Helgerud, Engen, Wisløff, & Hoff, 2001).

Future research of the effect of maturation on physical performance during competitive match-play in elite youth soccer players should further investigate the findings of the present study. Such data could be used to identify players with the ability to play at a particular level, and to prepare players for the demands of successive playing levels through the modification of training loads according to the specific demands of match-play.

Conclusions

The present study highlights the importance of assessing match activities at youth team level in relative (m · min$^{-1}$) as well as absolute (m) terms due to variations in individual match exposure and the rolling substitute policy. Due to variations in performance characteristics across age-groups at youth team level, measures of match performance should be considered relative to age-group performance characteristics. In particular, when categorizing player motion into speed zones, thresholds should be “normalized” relative to individual or group-derived speed capabilities, one method being the assessment of flying 10 m sprint time.

The relative match-play demands of elite youth soccer players appear to be consistent across the ages of U12–U16. However, players become significantly faster during this time, in particular between the U14 and U15 age-groups. Prescription of training drills for youth soccer players should consider the specific demands of competitive match-play in each age-group, with maturation being considered as an indicator of performance capacity.

References


