Soccer-Specific Endurance and Running Economy in Soccer Players With Cerebral Palsy

Saichon Kloyiam, Sarah Breen, and Philip Jakeman
University of Limerick, Ireland

Joe Conway
Irish National Cerebral Palsy Soccer Team, Dublin

Yeshayahu Hutzler
Zinman College, Israel

The purpose of this study was to describe running economy, soccer specific endurance, and selected kinematic running criteria in soccer players with cerebral palsy (SPCP) and to compare them with values of position-matched players without CP. Fourteen international, male soccer players with cerebral palsy completed the “Yo-Yo” intermittent recovery run level 1 (IRL-1) test to assess soccer-specific endurance and a submaximal running test on a treadmill to determine running economy. The mean IRL-1 distance covered by the SPCP of the Irish CP team was found to be 43–50% below the mean distance attained by position-matched soccer players without disability, while running economy was found to be within the range of that reported for able-bodied athletes. No relationship could be found between the level of CP-ISRA classification and soccer-specific endurance or running economy in this group of elite level SPCP. Though small in number, these data support a further examination of the relationship between CP classification and sport-specific performance.

**Keywords:** soccer, cerebral palsy, running economy, endurance, Yo-Yo test

Cerebral palsy (CP) is a sensory and neuromuscular deficit caused by a nonprogressive brain defect or lesion occurring during the prenatal, intra partum or early postnatal period. It affects body function or structure, depending on severity and type of CP. It is typically associated with limitations in gross motor function and

Saichon Kloyiam, Sarah Breen, and Philip Jakeman are with the Department of Physical Education and Sport Sciences, Faculty of Education and Health Sciences, University of Limerick, Limerick, Ireland. Joe Conway is Medical and Sports Officer with the Irish National Cerebral Palsy Soccer Team, Dublin, Ireland. Yeshayahu Hutzler is with the Zinman College of Physical Education and Sport Sciences, Wingate Institute, Israel and the Israel Sport Center for the Disabled.
muscle tone that often cause falls and injury, muscle weakness, and early fatigue (Bax et al., 2005).

Soccer for people with cerebral palsy (CP soccer) is a 7-a-side game with two 30 min halves. The field and the goals are smaller and it is played without off-sides. All players must have a Cerebral Palsy International Sport and Recreation Association (CP-ISRA) classification ranging from class 5 to class 8 (CPISRA, 2009), with a requirement for one class 8 and two class 5 players playing on the pitch at all times during the game. In this respect, the CP-ISRA classification has an effect on the structure and effective performance of the team. The CP-ISRA classification is based upon the neurological impairment of the player. As the training regimen (i.e., power training) adopted by soccer players with cerebral palsy (SPCP) becomes more advanced, the possibility exists that an increase in training adaptation may not only affect the ability to play soccer but also overall functional capacity of the person with CP. For instance, power training performed by able-bodied soccer players has been suggested by several authors to improve work economy by 5–15%, mainly explained by increased rate-of-force production (Osteras, Helgerud, & Hoff, 2002; Paavolainen, Hakkinen, Hamalainen, Nummela, & Rusko, 1999). In this case, a classification system based on neurological impairment may no longer be appropriate in matching the performance level of SPCP as constituted by the CP-ISRA classification. Should this situation arise, it could allow a team to gain unfair advantage, as the disability classification would not adequately reflect their sporting prowess.

Soccer is a sport that in addition to speed, agility, and skill requires well-developed cardiopulmonary functional capacity for prolonged energy production (Bangsbo, Mohr, & Krstrup, 2006; Iaia, Rampinini, & Bangsbo, 2009; Mohr, Krstrup, & Bangsbo, 2003; Reilly & Williams, 2003; Stolen, Chamari, Castagna, & Wisloff, 2005). Assessment of cardiopulmonary capacity provides a quantitative evaluation of endurance fitness informs a coach as to appropriate training regimens and provides an objective measure of training adaptation.

Endurance in soccer can be measured using the soccer-specific Yo-Yo intermittent recovery run level 1 test (Yo-Yo IRL 1; Bangsbo, Iaia, & Krstrup, 2008; Castagna, Impellizzeri, Chamari, Carlomagno, & Rampinini, 2006). The Yo-Yo IRL 1, developed and validated by Bangsbo in 1994 (Bangsbo, 1994), is a modification of the multistage 20 m shuttle run test. It mimics soccer movement that is intermittent and involves short periods of high intensity running followed by recovery (Castagna, et al., 2006). Previous studies that have measured the change in muscle glycogen following completion of the test confirm that soccer-specific endurance is reflected by the distance covered during the Yo-Yo IRL 1 (Bangsbo et al., 2008). The distance covered during the test has also been shown to predict on-field distance covered and hence the endurance capacity of the player under investigation (Bangsbo et al., 2008; Krstrup et al., 2003).

The distance attained in the Yo-Yo IRL 1 distance depends on the player’s agility and the ability to repeatedly perform high-intensity aerobic work (Bangsbo et al., 2008). The latter is, in part, influenced by the economy of effort exerted by the players running economy (RE). Running economy is the amount of energy required to maintain a submaximal running speed and is measured by the oxygen cost per unit of body mass per unit distance run (ml/kgBM/km; Astorino, 2008; Foster & Lucia, 2007; Hausswirth & Lehenaff, 2001; McArdle, Katch, & Katch, 1986; Saunders, Pyne, Telford, & Hawley, 2004). Previous studies indicate that
better running economy contributes to greater endurance capacity, for example, further distance covered, during a soccer match (Stolen et al., 2005).

Although CP soccer has a shorter overall duration than regular soccer (90 vs. 60 min), it is still well within the time frame requiring aerobic performance and is expected to place similar cardiopulmonary demands on SPCP as on regular soccer players. So far, no scientific information has been retrieved with regard to physiological and biomechanical performance in adult SPCP. However, studies in nonathletic children and adolescents with CP indicate poorer aerobic capacity and higher oxygen cost of the participants with CP (Lundberg, 1976; Stackhouse, Binder-Macleod, & Lee, 2005; Unnithan, Clifford, & Bar-Or, 1998; Unnithan, Dowling, Frost, & Bar-Or, 1996; Verschuren & Takken, 2010). The kinematics of walking in youth and adults with CP (e.g., increased limb asymmetry, reduced stride length, and increased stride time) has been linked to their reduced walking economy (Unnithan et al., 1996). It is still unknown to what degree running kinematics in elite athletes with CP may be linked to their RE.

The purpose of the current study was to describe soccer-specific endurance, running economy, and selected kinematic running criteria in elite adult SPCP and to compare them with values of position-matched players without CP.

The working hypothesis was that soccer-specific endurance and running economy would differ according to CP-ISRA classification and that players with CP would have lower soccer-specific endurance and be less economical in running compared with position-matched soccer players without disability.

**Method**

**Participants**

Ethical approval for the study was granted by University Research Ethics Committee, which acts in accordance with the Declaration of Helsinki. All participants of the Irish cerebral palsy national soccer team were invited to participate in the study. Two players were injured and could not participate. The remaining 14 elite SPCP players completed a written, informed consent before participation. The participants were between 18–40 years old and were classified according to CP-ISRA within class 5 and class 8. Participants’ data including their body composition is reported in Table 1. All participants followed a regimen of soccer training, eight to nine hours per week, and had competition experience ranging from 1 to 8 years. The training sessions consisted of tactical, psychological, aerobic, and strength and conditioning. None of the players had current illness or injury.

**Measurement of Soccer-Specific Endurance**

The Yo-Yo IRL 1 was performed to evaluate soccer-specific endurance. The test has been used by previous studies with soccer players without disability (Castagna et al., 2006; Krustrup et al., 2003; Mohr et al., 2003; Rampinini et al., 2010; Veale, Pearce, & Carlson, 2010). Clear instruction on the test procedure was given and participants were fully habituated to the test protocol before proceeding. A personalized warm-up preceded each test. The participants ran 2 × 20 m bouts followed by a 10 s active recovery period before proceeding to the next bout. The graded
increase in running speed was paced by auditory signal recorded and transmitted via an audio CD player. The participants continued running until they were unable, following a verbal warning, to maintain the required running speed. Peak heart rate was recorded using a telemetered heart rate monitor (Polar Electro MODEL, Oulo, Finland). The distance covered by each participant was used as a measure of the individual’s soccer-specific endurance.

### Table 1 Participants’ Demographics

<table>
<thead>
<tr>
<th>CP</th>
<th>Position</th>
<th>Age (Years)</th>
<th>Height (cm)</th>
<th>Body Mass (kg)</th>
<th>Fat Mass (kg) (%Fat Mass)</th>
<th>BMI Weight (kg)/Height² (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>goalkeeper</td>
<td>21</td>
<td>171.5</td>
<td>67.7</td>
<td>13.8 (20.2%)</td>
<td>23</td>
</tr>
<tr>
<td>5</td>
<td>midfield</td>
<td>18</td>
<td>161.0</td>
<td>57.7</td>
<td>9.9 (18.0%)</td>
<td>22</td>
</tr>
<tr>
<td>6</td>
<td>goalkeeper</td>
<td>33</td>
<td>170.6</td>
<td>75.0</td>
<td></td>
<td>26</td>
</tr>
<tr>
<td>7</td>
<td>striker</td>
<td>39</td>
<td>171.0</td>
<td>72.7</td>
<td>15.7 (21.9%)</td>
<td>25</td>
</tr>
<tr>
<td>7</td>
<td>midfield</td>
<td>29</td>
<td>173.0</td>
<td>76.1</td>
<td>20.2 (26.6%)</td>
<td>25</td>
</tr>
<tr>
<td>7</td>
<td>midfield</td>
<td>22</td>
<td>177.0</td>
<td>68.5</td>
<td>10.8 (15.9%)</td>
<td>22</td>
</tr>
<tr>
<td>7</td>
<td>midfielder</td>
<td>26</td>
<td>180.0</td>
<td>90.7</td>
<td>25.6 (28.6%)</td>
<td>28</td>
</tr>
<tr>
<td>7</td>
<td>defender</td>
<td>21</td>
<td>168.0</td>
<td>75.1</td>
<td>20.3 (27.6%)</td>
<td>27</td>
</tr>
<tr>
<td>7</td>
<td>defender</td>
<td>33</td>
<td>178.0</td>
<td>84.7</td>
<td>25.2 (29.2%)</td>
<td>27</td>
</tr>
<tr>
<td>7</td>
<td>midfielder</td>
<td>22</td>
<td>181.0</td>
<td>83.0</td>
<td>16.3 (19.8%)</td>
<td>25</td>
</tr>
<tr>
<td>7</td>
<td>striker</td>
<td>17</td>
<td>189.0</td>
<td>80.0</td>
<td></td>
<td>22</td>
</tr>
<tr>
<td>7</td>
<td>midfielder</td>
<td>18</td>
<td>170.5</td>
<td>63.5</td>
<td></td>
<td>22</td>
</tr>
<tr>
<td>8</td>
<td>midfielder</td>
<td>20</td>
<td>180.3</td>
<td>71.0</td>
<td>8.8 (12.3%)</td>
<td>22</td>
</tr>
<tr>
<td>8</td>
<td>midfielder</td>
<td>29</td>
<td>183.0</td>
<td>85.1</td>
<td>16.5 (19.5%)</td>
<td>25</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td></td>
<td>24.9 (6.8)</td>
<td>175.3 (7.2)</td>
<td>75.1 (9.1)</td>
<td>16.6 (5.7)</td>
<td>24.4 (2.2)</td>
</tr>
</tbody>
</table>

CP = CP-ISRA classification; BMI = Body mass index; Fat mass was assessed by whole body DXA scan; SD = Standard Deviation.

Measurement of Running Economy

Running economy was assessed by a submaximal steady-state running test on a motorized treadmill. Participants received practices breathing through a mouth piece till fully habituated with it. They were fully familiar with running on a treadmill as they regularly used treadmill ergometry as a part of their trainings. Participants received clear instruction as to the test procedure. They put in a mouth piece, and a Polar heart rate monitor was positioned around the participant’s chest before a 5 min warm-up run on the treadmill at a self-selected speed. For the determination of running economy, steady-state oxygen uptake (plateau of > 1.5 ml/kg/min) was measured by indirect calorimetry using an automated metabolic cart (Amis 2000, Innovision AS, Denmark) at a submaximal steady-state running, dependent on the ability of the participant. Steady-state oxygen uptake was determined when two
successive one-minute values differed by less than 2ml/kg/min. A steady-state was achieved within 5–8 min. The data were averaged with one-minute intervals. The test ended with a 5 min cool down run on the treadmill.

Gait Analysis

The following kinematic variables were observed during running at a steady state speed of 12 kph on the treadmill: stride length, stride frequency, vertical displacement, stance time, flight time, and angle of touchdown. Gait was recorded at 50 frames per second in the front view (frontal plane) and at 300 frames per second in the side view (sagittal plane). Gait analysis was performed from the positional change in retroreflective markers placed on the 5th metatarsal, upper calcaneus (lateral metatarsal [near leg]), medial metatarsal (far leg), lateral epicondyle and greater trochanter. Silicon Coach 7.0 software was used for the gait analysis (Button, van Deursen, & Price, 2008; Crowther, Spinks, Leicht, Quigley, & Golledge, 2008). Touchdown angle was measured at the ankle and was relative to the shank.

Data Analysis

Data are presented as the mean (standard deviation) and range. Running economy was normalized to kg of body mass (BM) using the following formula: \( \text{RE} = \frac{\text{oxygen consumption per kg body mass per minute divided by speed (km/h)/60 and presented as ml/kg BM /km}}{60} \). A Pearson correlation was computed to estimate the relationship between running economy and Yo-Yo IRL 1 distance, and a Spearman rank correlation was computed to estimate the relationship between running economy and stride length within the group of well-trained SPCP. The significance level was set at \( p < .05 \).

Results

Participants

The participants’ demographics (age, height, and body mass) are presented in Table 1. Eleven participants performed the Yo-Yo IRL 1 test. Ten participants completed the running economy measurement; however, it was not possible to attain steady-state oxygen consumption in one subject and this data were excluded from the running economy analysis. Seven participants completed both tests (Table 2).

On average, participants achieved 103% of their age-related maximal heart rate in completion of the Yo-Yo IRL test, indicating attainment of maximal effort. Table 2 provides the mean Yo-Yo IRL 1 distances covered by the SPCP of the Irish Cerebral Palsy soccer team compared with data reported in the extant literature. The mean Yo-Yo IRL 1 distance covered by the SPCP of the Irish CP team was found to be 43–50% below the mean distance of those without disability (Table 2). Position-specific differences were also observed. The mean distance covered by attackers with cerebral palsy was 46% shorter, midfielders with cerebral palsy 51% shorter, and the defender with cerebral palsy 64% shorter than the mean distance of soccer players without disability at the same position reported by Mohr et al. (2003; Figure 1). Considerable variability of the Yo-Yo IRL 1 distance was also evident between and
Table 2  Yo-Yo Intermittent Recovery Run Test Level 1 (Yo-Yo IRL 1) Distances of the Irish CP Soccer Team Compared With Those of Soccer Players Without Disability in the Extant Literature

<table>
<thead>
<tr>
<th>Study</th>
<th>Nationality</th>
<th>Level of Performance</th>
<th>n</th>
<th>Yo-Yo IRL1 Distance (m)</th>
<th>Yo-Yo IRL1 Distance Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Castagna et al., 2006</td>
<td>n.a</td>
<td>Amateur</td>
<td>24</td>
<td>2138 (364)</td>
<td>1774–2502</td>
</tr>
<tr>
<td>Rampinini et al., 2010</td>
<td>n.a</td>
<td>Amateur</td>
<td>12</td>
<td>1827 (292)</td>
<td>1535–2119</td>
</tr>
<tr>
<td>Veale et al., 2010</td>
<td>Australian</td>
<td>Elite junior</td>
<td>20</td>
<td>1910 (230)</td>
<td>1680–2140</td>
</tr>
<tr>
<td>Mohr et al., 2003</td>
<td>Danish</td>
<td>National</td>
<td>24</td>
<td>2040 (60)</td>
<td>1980–2100</td>
</tr>
<tr>
<td>Present study</td>
<td>Irish</td>
<td>International CP</td>
<td>10</td>
<td>993 (397)</td>
<td>596–1390</td>
</tr>
</tbody>
</table>

All data are the mean (SD) and range (min-max)
Kloyiam et al. within CP-ISRA classification. The participant classified CP5 covered 1760 m. The participants classified CP7 covered between 520 and 1360 m and the participants classified CP8 covered between 720 and 1280 m (Table 3).

Table 3 summarizes the data for running economy. A lower oxygen cost, depicting better running economy, was found in four out of nine SPCPs. Values for these SPCP subjects were 4–16% better than the average running economy (200 ml/kg body mass/km) of runners without disability (Winter, Davison, Bromley, & Mercer, 2007), independent of CP classification; no relationship was found between the Yo-Yo IRL 1 distance (m) attained and running economy (ml/kg body mass/km; \( r = 0.29, p = 0.53 \)) in the CPSP athletes.

Analysis of the biomechanical data obtained from treadmill running at 12 kph is also presented in Table 3. Variable asymmetry in the mean absolute difference in the angle of touch down between the right and left feet of 17° (11°; 5–36°) was observed; the difference between feet was found to be significant for all subjects \( (p < .05) \). Normal asymmetry for passive ankle ROM in males is 4° (Ferrario, Turci, Lovecchio, Shirai, & Sforza, 2007). No relationship between RE and stride length was observed \( (R = -0.248; p = 0.520) \).

**Discussion**

The purpose of the current study was to investigate soccer-specific endurance, running economy, and selected kinematic running criteria in elite SPCP and to compare these performance outcomes to reference values of soccer players without a disability. In the following, we will discuss each of these issues separately and finally provide a common conclusion.
Soccer Players With Cerebral Palsy

According to the data of the current study, the Yo-Yo IRL 1 distance of the SPCP at all playing positions was shorter than that of soccer players without disability reported by Mohr et al. (2003). This outcome supports the hypothesis that SPCP have poorer soccer-specific endurance component compared with soccer players without disability and quantifies the magnitude of the effect of CP on endurance in elite soccer. In contrast, the effect of CP on running economy was not as expected. In this study, four out of nine SPCP demonstrated lower values for running economy than did able-bodied runners (Winter et al., 2007), and, with no clear relationship between running economy and endurance performance, a difference in running economy could not be proposed as a principal determinant of soccer-specific endurance in SPCP. Another factor that could contribute to a lower soccer-specific endurance score is VO$_{2\text{max}}$. Previous studies in children and young adults report lower VO$_{2\text{max}}$ in CP subjects (Lundberg, 1976; Stackhouse et al., 2005; Unnithan et al., 1996, 1998). One consequence of a lower VO$_{2\text{max}}$ could be the need to elevate the relative exercise intensity (in terms of oxygen uptake) required by the SPCP to undertake the same absolute exercise intensity, thereby reducing endurance. A potential mechanism accounting for a lower VO$_{2\text{max}}$ in persons with CP is high muscle tone (spasticity), which reduces venous return (Lundberg, 1976; Stackhouse et al., 2005; Unnithan et al., 1996, 1998). High muscle tone also inhibits muscle lactate clearance during exercise, which increases local muscle fatigue and lowers endurance (Lundberg, 1976; Stackhouse et al., 2005;

<table>
<thead>
<tr>
<th>CP</th>
<th>Position</th>
<th>Yo-Yo IRL 1 (m)</th>
<th>RE @12kph (mO$_2$/kg BM/km)</th>
<th>Stride Length (m)</th>
<th>Angle of Touchdown Left (°)</th>
<th>Right (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Goalkeeper</td>
<td>213</td>
<td>193</td>
<td>94</td>
<td>89</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Midfield</td>
<td>1760</td>
<td>201</td>
<td>2.81</td>
<td>73</td>
<td>103</td>
</tr>
<tr>
<td>6</td>
<td>Goalkeeper</td>
<td>400</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Striker</td>
<td>1120</td>
<td>214</td>
<td>2.38</td>
<td>98</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>Midfield</td>
<td>207</td>
<td>2.27</td>
<td>81</td>
<td>103</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Midfield</td>
<td>1360</td>
<td>192</td>
<td>2.15</td>
<td>105</td>
<td>92</td>
</tr>
<tr>
<td>7</td>
<td>Midfield</td>
<td>520</td>
<td>192</td>
<td>2.38</td>
<td>83</td>
<td>119</td>
</tr>
<tr>
<td>7</td>
<td>Defender</td>
<td>680</td>
<td>170</td>
<td>2.27</td>
<td>87</td>
<td>109</td>
</tr>
<tr>
<td>7</td>
<td>Midfield</td>
<td>1040</td>
<td>168</td>
<td>2.44</td>
<td>97</td>
<td>83</td>
</tr>
<tr>
<td>7</td>
<td>Striker</td>
<td>1040</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Midfielder</td>
<td>1000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Midfielder</td>
<td>1280</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Midfield</td>
<td>720</td>
<td>203</td>
<td>2.38</td>
<td>103</td>
<td>98</td>
</tr>
</tbody>
</table>

**Table 3 Running Economy (RE), Yo-Yo IRL 1 Distance and Biomechanical Data of Soccer Players With Cerebral Palsy by Classification**

Soccer-Specific Endurance

According to the data of the current study, the Yo-Yo IRL 1 distance of the SPCP at all playing positions was shorter than that of soccer players without disability reported by Mohr et al. (2003). This outcome supports the hypothesis that SPCP have poorer soccer-specific endurance component compared with soccer players without disability and quantifies the magnitude of the effect of CP on endurance in elite soccer. In contrast, the effect of CP on running economy was not as expected. In this study, four out of nine SPCP demonstrated lower values for running economy than did able-bodied runners (Winter et al., 2007), and, with no clear relationship between running economy and endurance performance, a difference in running economy could not be proposed as a principal determinant of soccer-specific endurance in SPCP. Another factor that could contribute to a lower soccer-specific endurance score is VO$_{2\text{max}}$. Previous studies in children and young adults report lower VO$_{2\text{max}}$ in CP subjects (Lundberg, 1976; Stackhouse et al., 2005; Unnithan et al., 1996, 1998). One consequence of a lower VO$_{2\text{max}}$ could be the need to elevate the relative exercise intensity (in terms of oxygen uptake) required by the SPCP to undertake the same absolute exercise intensity, thereby reducing endurance. A potential mechanism accounting for a lower VO$_{2\text{max}}$ in persons with CP is high muscle tone (spasticity), which reduces venous return (Lundberg, 1976; Stackhouse et al., 2005; Unnithan et al., 1996, 1998). High muscle tone also inhibits muscle lactate clearance during exercise, which increases local muscle fatigue and lowers endurance (Lundberg, 1976; Stackhouse et al., 2005;
Unnithan et al., 1996, 1998). In addition, high levels of cocontraction of antagonist muscles in people with CP counteract force production during maximal intensity exercise and contribute to early fatigue of the active muscles (Lundberg, 1976; Stackhouse et al., 2005; Unnithan et al., 1996, 1998). Similar effects could also have been evident during submaximal exercise and may also contribute to reduced endurance capacity observed in this study.

When performing the Yo-Yo IRL 1, both aerobic and anaerobic pathways are involved (Bangsbo et al., 2008; McArdle et al., 1986). There is an increasing requirement for anaerobic metabolism at the higher levels of intensity of exercise demanded by the Yo-Yo IRL 1 test. Thus, a reduction in soccer-specific endurance may be present due to a reduced anaerobic capacity. Although the anaerobic capacity of SPCP was not measured in this study, Unnithan et al. (1998) reported an increase in the ratio of type I and type II muscle fibers in persons with CP. They proposed that upper motor lesions cause atrophy of type II muscle fibers, resulting in a greater proportion of type I muscle fiber. As yet, the true extent of the difference in metabolic capacity of SPCP is unknown, but a decrease in type II muscle fibers could result in a decrease of the anaerobic capacity (McArdle et al., 1986) that could be linked to the poor soccer specific endurance observed in the participants of this study.

The direct transfer of a soccer-specific test validated in a normative population to SPCP is not without reservation. Difficulty in turning and stopping is a characteristic of SPCP (CPISRA, 2009) that may have affected the total distance covered during the test. Therefore, an alternative evaluation of soccer-specific endurance in SPCP should be considered in which turning time is measured and omitted from the final score. Such an adaptation to a multistage shuttle test has been recently proposed for adolescent with CP (Verschuren, Takken, Ketelaar, Gorter, & Helders, 2006).

In this study a high variability in the soccer-specific Yo-Yo IRL 1 test of endurance capacity was evident within and between SPCP athletes of differing CP-ISRA classification. It has yet to be established whether players with a higher CP-ISRA classification (less affected) would attain greater distance in this test, but preliminary data provided by the current study indicate that the CP-ISRA classification of the player may not have a significant influence on performance in this soccer-specific test of endurance. Similarly, the extent to which the players’ cardiopulmonary capacity may be influenced by the level of disability classified by the CP-ISRA classification is still unclear. Other factors affecting the test performance may include player’s position (midfielders covered the longest distance) and motivation of the players before and during the test (Bangsbo et al., 2008). Since CP soccer teams include at least one CP 5 and two CP 8 players on the field at all times during the game, teams that have soccer players classified CP 5, but able to outperform CP 8 (as evidenced by the Yo-Yo IRL1 data from this study) would have an advantage. Classification based on neurological impairments alone may not ensure fair competition. Physiological and skill related functional assessment of classification in other team sports of athletes with disability (mainly wheelchair basketball) has been adopted to validate the classification system (Vanlandewijck et al., 2004). Our findings indicate a potential need for a similar functional validation study of the classification system for SPCP.
Running Economy

Oxygen consumption during the submaximal steady-state running on the treadmill indicates that SPCP may not necessarily require more energy than soccer players without disability to run at the same pace. The hypothesis that SPCP would show poorer running economy than able-bodied athletes is not supported by the data of the current study. This finding is also not in agreement with previous studies reporting a higher oxygen cost during walking and running in CP compared with their able-bodied counterparts (Stackhouse et al., 2005; Unnithan et al., 1996, 1998).

The low oxygen cost of running observed in the SPCP recruited to this study may have resulted from a high level of training adaptation, the effect of which may reduce the level of spasticity and cocontraction during exercise thus lowering the overall contribution to oxygen cost provided by involuntary movement. Previous studies that have shown improved firing rate, motor unit recruitment, and synchronization of the exercising muscles resulting from soccer training lend support to this argument (Castagna et al., 2006; Mohr et al., 2003; Paavolainen et al., 1999). Furthermore, small-sided soccer games have been proved to enhance fitness and currently used as trainings for developing physical capacities and technical and tactical skills, which may have attributed to finer motor unit recruitment and synchronization of working muscles (Hill-Haas, Dawson, Impellizzeri, & Coutts, 2011). Further research is required to relate the measured running economy to the level of spasticity and cocontraction during running in SPCP.

Difference in body mass between groups may have affected difference in running economy (Jensen, Johansen, & Karkkainen, 1999). The data presented in Jensen et al.’s study showed an averaged body mass of national standard track runners of 68 ± 6 kg (n = 10; running economy: 212 ± 14 ml/ kg body mass/km). The SPCP who had the best running economy (168 ml/kg body mass/km) in the current study had body mass of 83 kg, which is more than two standard deviations above the mean body mass of the track runners. For comparison between individuals with different body sizes, the absolute oxygen consumption is divided by individual body mass. The VO2 (ml/ kg body mass/min) is thus considered to be a mass-adjusted expression of oxygen consumption (Reilly & Williams, 1996); however, when applied to individuals with similar absolute oxygen cost (l/min) of running this method of comparison will always favor subjects with a higher body mass. As demonstrated in this study, a more appropriate reference would be the oxygen cost per kg of lean tissue mass, as it is the lean tissue mass that is metabolically active in running.

It is worth noting that running economy assessment is normally performed using treadmill ergometry. However, oxygen cost for over-ground running is likely to be 5–7% higher than that required for treadmill running, due to the influence of wind resistance (Pugh, 1970, 1971)

Gait Analysis

The data from the oxygen consumption and gait analysis inform how kinematic patterns of SPCP relate to energy consumption and generation during running. In the literature, higher oxygen cost of running has been attributed to shorter stride length (McArdle et al., 1986). This occurs because shorter stride length resulting in
higher stride rate causes more frequent braking and acceleration of the center of the body gravity and more oxygen required for muscle contraction (Reilly & Williams, 1996). However, gait analysis of the small number of SPCP in this study found no relationship between running economy at 12.0 kph and stride length, which does not support a change in stride length as a reason for the better running economy.

Asymmetry in the angle of touch down during landing probably resides within a compensation for unilateral neurological impairment of the individual. Larger angle of touch down (increased plantar flexion) may result from the fact that the affected limb is less able to conserve energy and stabilize the joints during movement. A higher degree of plantar flexion allows for greater energy conservation in the tendon, the plantar flexed foot acting like a vertical spring or pogo stick (Fonseca, Holt, Fetters, & Saltzman, 2004), contributing to greater joint stability. It is unknown whether SPCP would have a restriction of their stride length when running at the same speed compared with position-matched soccer players without disability.

**Limitations**

In the current study, the authors were looking at selected aspects of physiological conditioning (soccer specific endurance and running economy), which are of interest for soccer players. Assessment of these aspects is usually a part of an array of measurements including additional tests, such as vertical jump and 30m sprint time. For determining comprehensive profiles of SPCP, a battery of measurements should be performed.

The running economy of the SPCP in this study was studied by comparing with the running economy of runners in the extant literature. As the characteristics such as current fitness and training regimes of the runners were not specified in the literature, it is possible that the characteristics of both groups may have been different. To ensure true differences in running economy between SPCP and soccer players without cerebral palsy, a control group with similar characteristics relevant should be recruited.

This study expressed oxygen consumption per body mass to eliminate effects of body mass when comparing participants with a different body mass. For a comprehensive analysis on energy use with regard to biological aspects, data should be allometrically scaled after the data from SPCP and able bodied soccer players are collected on the treadmill.

It is important to note that running on a treadmill creates a higher frequency in stride, due to a shorter stride length. This may cause an extra burden on the hip flexor complex and can lead to tighter hips. It also tends to create tighter calves due to the treadmill belt moving as the leg transitions forward requiring them to work harder for the same result (Nelson, Dillman, Lagasse, & Bickett, 1972; Wank, Frick, & Schmidtbleicher, 1998). Thus, before having participants with cerebral palsy who have not had experience running on the treadmill run on the treadmill, one should make sure that the participants are fully habituated with the treadmill; give some time for the participants to practice. This is to prevent spasticity, which may cause falling and injuries during the measurement.

The sample size of the participants in this study is another limitation. Due to the small number of participants, generalizability of this study would not be applicable. This suggests further research should be conducted with larger samples.
Furthermore, the wide age range (18–40 years of age) may induce another potential barrier while attempting to find soccer-related data that matches this age range. Most elite able bodied football squads will very rarely include players of 40 years of age.

**Conclusion and Implications for Practice and Future Research**

Lower soccer-specific endurance was found in international, elite SPCP compared with position-matched soccer players without disability reported in the extant literature. In contrast, some SPCP in our sample showed improved running economy, but we were unable to clarify the reason why. Soccer-specific endurance estimated by the Yo-Yo IRL 1 performance was not affected by running economy and level of disability as classified by the CP-ISRA. The issues addressed by the current study indicate a requirement for a more comprehensive study of the performance capacity of SPCP to better inform the CP-ISRA classification procedure in soccer.

For soccer players and their respective coaches, an improvement in the Yo-Yo IRL 1 distance seems to be a valid and objective measure of performance and adaptation to training. Our study suggests this applies to SPCP as well. However, the large variability in Yo-Yo IRL 1 distance across the CP-ISRA classification (CPISRA, 2009) reported in this study implies that classifying SPCP based on the level of neurological impairment may not ensure fair competition, i.e., as determined by the strategies, skills, and talent of the players.

In future research, it might be of interest to assess the anaerobic component in SPCP as well. For this purpose an anaerobic sport test is necessary. The applicability of the test developed for ambulatory children and adolescents with CP (Verschuren, Bloemen, Kruitwagen, & Takken, 2010) should be examined for this purpose.

**Acknowledgment**

The authors would like to thank the soccer players and coaches of the Irish national cerebral palsy soccer team who were willing to participate in the study.

**References**


