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The Demands of Amputee Soccer Impair Muscular Endurance and Power Indices But Not Match Physical Performance

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We investigated the match demands (distances covered and acute physiological responses) of amputee soccer and its impact on muscular endurance and power. Measures such as heart rate, blood lactate concentration, subjective rating of perceived exertion, and time-motion characteristics were recorded in 16 Brazilian amputee soccer players during matches. Before and after matches, players completed a battery of tests: push-ups, countermovement vertical jump performance, and medicine ball throwing. Small differences were found between the first and second half for the distance covered in total and across various speed categories. Heart rate responses, blood lactate concentrations, and peak speed did

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not differ between halves, and all neuromuscular performance measures decreased after the match particularly after push-ups, although the rating of perceived exertion increased markedly compared with prematches. Although match physical performances were consistent across halves, the overall demands impaired test performance, especially for upper limb and closed kinetic chain exercise.

Keywords: disability sport, fatigue, football, match analysis

Soccer is arguably the world's most popular sport with over 265 million registered able-bodied participants worldwide (Kunz, 2007). Numerous versions of the sport have developed such as futsal, beach, and amputee soccer (AS). AS has gained popularity worldwide, particularly in countries that experience high rates of terrorist incidents and road traffic accidents (Simim et al., 2013). AS is a variation of conventional soccer in which all outfield players (defenders, midfielders, and forwards) have a lower limb amputation—use Canadian crutches for locomotion—and the goalkeepers have upper limb amputations (Simim et al., 2013, 2017). A Canadian crutch is a combination of an underarm crutch and an elbow crutch and features a cuff that fits around the elbow area for added comfort and support. The use of this type of crutch allows players to carry out soccer-specific activities (Simim et al., 2013). The scant literature on this subject has examined this unique soccer population but primarily focused on nutritional issues (Innocencio da Silva Gomes, Gonçalves Ribeiro, & de Abreu Soares, 2006), injuries (Kegel & Malchow, 1994), psychological factors (Lowther, Lane, & Lane, 2002), and physical capacity measures (Özkan et al., 2012; Simim et al., 2013, 2017). Thus, research has yet to examine the physiological and metabolic demands of AS match-play.

The physical demands of able-bodied soccer matches have traditionally been determined using match analysis in addition to physiological and metabolic measures (Mohr et al., 2010). Match analysis typically quantifies the total distance covered during a match and the proportion of the match spent at various speed ranges (Bradley et al., 2009; Castellano, Alvarez-Pastor, & Bradley, 2014). Although this approach still provides some insight into the game demands, it has some limitations such as failing to account for metabolically taxing accelerations and multidirectional movements (Bradley & Noakes, 2013). To further improve this approach, players heart rate (HR) responses, blood lactate concentrations, internal loads, and acceleration metrics are also commonly quantified to provide a more multifaceted insight into match demands (Akenhead & Nassis, 2016). More importance should be placed on this holistic approach when analyzing rarely studied soccer populations such as AS players as the demands could be even more unique given the physical and technical constraints placed on players during games (e.g., degree of amputation).

During able-bodied soccer, elite players sprint 30–50 times per match with high-intensity running accounting for ~10% of the total distance covered (Bradley & Noakes, 2013). The demands during intense periods of match-play cause muscle phosphocreatine degradation, peak blood lactate concentrations of 10–14 mM, and HR reaching ~95% HR_{max}. Thus, this clearly provides evidence that the aerobic and anaerobic systems are highly taxed during selected periods of match-play

(Krustrup et al., 2006). This may result in fatigue as evidenced by reductions in sprinting and jumping performance after games (Krustrup, Zebis, Jensen, & Mohr, 2010) and decrements in running performances between halves (Bradley et al., 2009). Due to the submaximal nature of soccer where players are typically working well within their physical capacity, it is very difficult to objectively verify fatigue using time-motion analysis alone. Fatigue in AS might also be highly complex, and thus, time-motion characteristics and game-induced decrements in neuromuscular measures (i.e., muscular endurance and power) must also be established to fully verify if the demands cause fatigue (Mohr, Krustrup, & Bangsbo, 2005). Particularly, given that AS players support the weight of the whole body with crutches, this could result in novel fatigue patterns in the muscles recruited (Simim et al., 2017).

Determining ways to examine fatigue in AS would allow sports scientists to optimize training to enable players to cope with these demands using overload stimuli in the form of sport-specific, resistance-based training complemented with high-intensity aerobic and anaerobic training. Thus, the aim of the present study was to investigate the demands (i.e., distances covered and acute physiological responses) of AS match-play and its impact on muscular endurance and power.

Methods

Subjects

Sixteen male Brazilian AS players (age: 32 ± 5 years; range: 25–42 years; body mass: 68.4 ± 9.9 kg; stature: 1.72 ± 0.07 m, and body fat: 14 ± 2.7%) participated in this study. All players were regularly involved in AS for at least 5 years and would typically train twice a week for 3 h and play 1–2 matches per week during a typical AS season. Table 1 details the AS players' level of amputation and their tactical role on the team. Players participated in the Soccer Cup Sao Paulo-Minas Gerais held in Brazil (eight teams divided in two groups of four teams each). We randomly selected four players from the four teams with the best national rank. The inclusion criteria for players were as follows: (a) >18 year old, (b) >6 months of experience as a competitive AS player, (c) unilateral lower limb amputation, (d) familiar with the testing battery, and (e) had played an entire competitive AS match on the day of the testing. All players were fully informed about the procedures and provided their written informed consent before data collection. The study was approved by the local institutional ethical committee and was performed in accordance with ethical standards in sport and exercise science research.

Design

Figure 1 depicts the experimental design of this study. The physical match demands (distances covered and acute physiological responses) and its impact on muscular endurance and power were observed after a single AS match for each player. (Four players were analyzed across four matches totaling 16 players.) All players performed a standardized battery of performance tests pre- and postmatch. These were conducted in a set order: push-up test, countermovement jump test, and a medicine ball throw. The recovery time between each test was 5 min. Prior to

Table 1 The Type and Level of Amputation in Addition to Positional Role of the Amputee Soccer Population Used in the Present Study

	Limb amputation		Level of amputation				Positional role		
	Right	Left	Hip	Transfemural	Knee	Transtibial	Defenders	Mid fielders	Forwards
Frequency	6	10	3	5	2	6	6	5	5
%	37.5	62.5	18.8	31.3	12.5	37.5	37.5	31.3	31.3

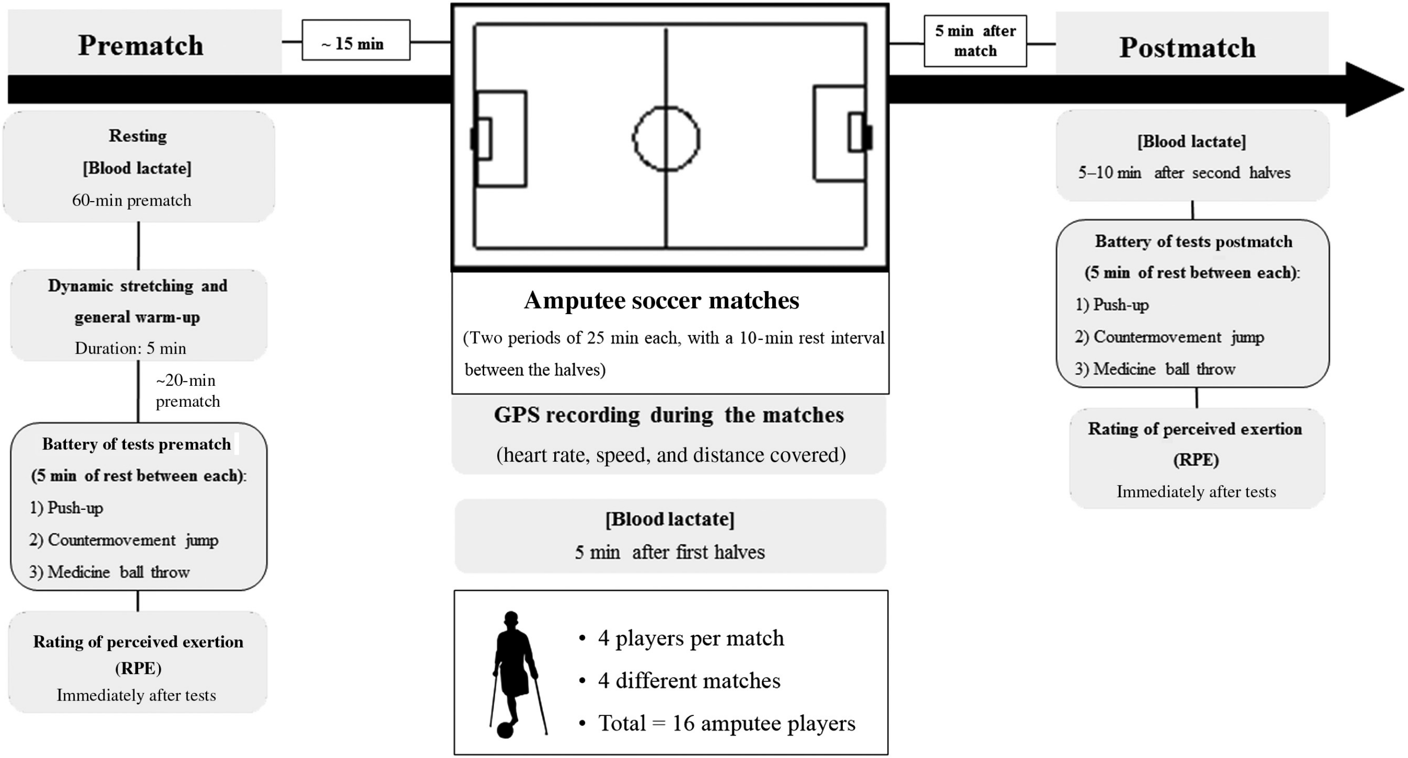

Figure 1 — Experimental design. GPS = global positioning system.

testing, all players performed a dynamic warm-up and stretching regime consisting of three repetitions of each test. The load imposed by the battery of tests was quantified immediately after testing using the rating of perceived exertion (RPE) with values ranging from 0 to 10.

All matches consisted of two 25-min halves with a 10-min rest interval between the halves and were played on a natural grass pitch (60 × 30 m). Games were played in environmental conditions of 19 ± 2 °C, relative humidity of 70 ± 19%, and atmospheric pressure of 912 ± 11 mm Hg. Players' match variables (distances covered in various speed categories and HR) were quantified using a validated (Moreira et al., 2013) global positioning system device (Garmin® Forerunner 405, 2.4 Hz; Garmin Ltd., Olathe, KS). Before the match, a HR monitor (Garmin Forerunner 405) was placed around the chest for continuous recordings throughout the match. The global positioning system and HR data were transferred to a computer via the Garmin Training Center® software. Capillary blood samples from a fingertip (25 µl) were collected before matches (baseline: 60 min prematch) and after the first (5 min after first halves) and second halves (5 min after match) and analyzed immediately for lactate concentration using a validated automated analyzer (ACCUSPORT®; Boehringer Mannheim, Castle Hill, Australia).

Neuromuscular Performance Tests

The push-up test was used to quantify muscular endurance of the chest, shoulders, and triceps muscle groups. The maximum number of repetitions completed in 60 s was used as the criteria measure (Simim et al., 2017). Subsequently, these values were divided by body mass to include a relative measure.

All players performed three countermovement jump with 30-s recovery between each jump. The players were instructed to use a preliminary movement by rapidly flexing the knee, before launching the body vertically. Jump height (centimeters) and power production (absolute and relative) were measured using an accelerometer (Myotest®, Sion, Switzerland). This accelerometer has previously been validated (Casartelli, Müller, & Maffiuletti, 2010).

Regarding the medicine ball throwing test, players were seated with their backs against the wall, researchers ensuring that the lower back remained in contact with the wall during the throwing motion. All players started by holding a 3-kg medicine ball in both hands and placing it against their chest. On a command, players would throw the ball explosively to ensure it covered the greatest distance possible. Each player had a minute to rest between each throw. All throws were measured to the nearest 0.1 cm.

Match Analysis Speed Categories

A Gaussian curve was plotted and subdivided into speed thresholds to quantify time-motion characteristics of AS players (Figure 2). The terms used to define these categories were similar to previous research (Rhodes, Mason, Malone, & Goosey-Tolfrey, 2015). It would be erroneous to use able-bodied descriptions for AS locomotion (e.g., jogging and sprinting); thus, the five basic categories were

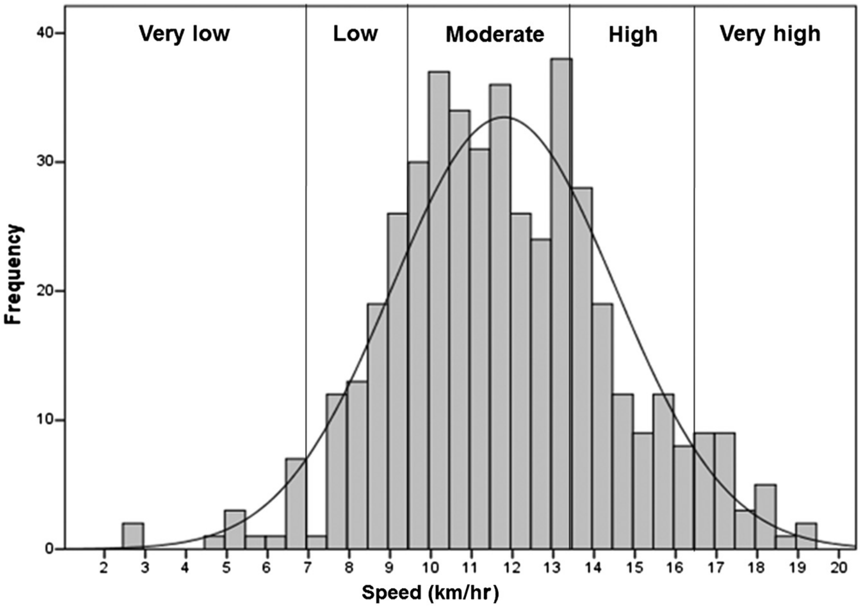

Figure 2 — Categorization of speed thresholds for amputee soccer players using a Gaussian curve of the average speed distribution.

defined as follows: very low (0–7 km/hr); low (7.1–9.5 km/hr); moderate (9.6–13.2 km/hr); high (13.3–16.8 km/hr); and very high (>16.9 km/hr).

Statistical Analysis

The data are presented as means ± standard deviations, relative differences (Δ%), and effect sizes (ES). All data were checked for normality using the Kolmogorov–Smirnov test. ES were interpreted using the scale of magnitudes proposed previously (Cohen, 1988). Paired sample *t* tests were used to determine if differences existed between the first and second halves of matches, in addition to pre- and postmatch muscular endurance and power. The chi-square test (χ^2) was used to determine whether there were differences among the observed frequencies in five speed categories. The calculated ES for the chi-square test was based on a previously used method (Dunst, Hamby, & Trivette, 2004). Repeated measures ANOVAs, followed by Bonferroni post hoc tests, were used to determine if positional differences were present. Statistical significance was set at $p < .05$.

Results

Only small practical differences were found between the first and second half for the total distance covered during matches (ES = 0.3; Δ = –6%; $p = .22$; Table 2) and

Table 2 Time-Motion Characteristics, HR Responses, Internal Loads, Blood Lactate Concentrations, and Frequency of Bouts Within Various Speed Thresholds During AS Match-Play

Variables	Match (*M* ± *SD*)	First half (*M* ± *SD*)	Second half (*M* ± *SD*)	ES	Δ%	*p*
Total distance (km)	5.65 ± 1.07	2.92 ± 0.69	2.74 ± 0.50	0.3	–6%	.22
Relative distance (m/min)	113 ± 21	117 ± 28	109 ± 20	0.3	–6%	.22
Average speed (km/hr)	4.84 ± 0.63	5.00 ± 0.60	4.69 ± 0.77	0.5	–6%	.04*
Peak speed (km/hr)	15.64 ± 2.02	15.66 ± 2.56	15.61 ± 1.93	0.02	–0.3%	.92
Average HR (bpm)	153 ± 15	151 ± 17	155 ± 17	0.2	3%	.28
Peak HR (bpm)	179 ± 14	177 ± 15.22	180 ± 15	0.2	2%	.31
	Baseline (*M* ± *SD*)	**First half (*M* ± *SD*)**	**Second half (*M* ± *SD*)**	**ES**	**Δ%**	***p***
Blood lactate (mM)	1.74 ± 0.51	6.18 ± 1.55	5.84 ± 1.89	0.2	–6%	.54
	Match, *n* (%)	**First half, *n* (%)**	**Second half, *n* (%)**	**ES**	**Δ%**	
Speed categories						
very low (0–7 km/hr)	15 (3)	9 (60)	6 (40)	0.4	–33%	$\chi^2 = 0.600$; $p = .44$
low (7.1–9.5 km/hr)	77 (17)	39 (51)	38 (49)	0.03	–3%	$\chi^2 = 0.013$; $p = .91$
moderate (9.6–13.2 km/hr)	241 (53)	131 (54)	110 (46)	0.2	–16%	$\chi^2 = 1.830$; $p = .18$
high (13.3–16.8 km/hr)	103 (22)	54 (52)	49 (48)	0.1	–9%	$\chi^2 = 0.243$; $p = .62$
very high (>16.9 km/hr)	23 (5)	9 (39)	14 (61)	0.4	56%	$\chi^2 = 1.087$; $p = .30$
Total	459 (100)	242 (53)	217 (47)	0.1	–10%	$\chi^2 = 1.362$; $p = .24$

Note. ES of <0.09, 0.10–0.49, 0.50–0.79, and >0.80 were considered trivial, small, moderate, and large, respectively. HR = heart rate; AS = amputee soccer; ES = effect size; Δ% = relative differences; bpm = beats per minute.

*$p < .05$.

Table 3 Neuromuscular Performance Indices Before and After AS Match-Play

Variables	Pre (*M* ± *SD*)	Post (*M* ± *SD*)	ES	Δ%	*p*
Push-up test (reps)	31 ± 5	25 ± 5	1.4	–20%	.01*
Relative push-up test (reps/kg)	0.47 ± 0.1	0.38 ± 0.1	1.0	–20%	.01*
CMJ (cm)	29.6 ± 7.1	28.1 ± 6.2	0.2	–5%	.02*
APLL (W)	2,303 ± 777	2,206 ± 727	0.1	–4%	.01*
RPLL (W/kg)	33.1 ± 8.8	31.8 ± 7.8	0.2	–4%	.03*
MBT (m)	4.44 ± 0.5	4.08 ± 0.5	0.8	–8%	.03*
RPE	3 ± 1	5 ± 2	1.6	66%	.01*

Note. ES of <0.09, 0.10–0.49, 0.50–0.79, and >0.80 were considered trivial, small, moderate, and large, respectively. AS = amputee soccer; ES = effect size; Δ% = relative differences; reps = repetition; CMJ = countermovement jump; APLL = absolute power of the lower limbs; RPLL = relative power of the lower limbs; MBT = medicine ball throw; RPE = rating of perceived exertion.

*$p < .05$.

Table 4 Positional Variation in Time-Motion Characteristics, Physiological Responses, and Neuromuscular Performances During Selected Periods of AS Matches

Variables	Defenders (*n* = 6)	Midfielders (*n* = 5)	Forwards (*n* = 5)
Total distance (km)			
first half	2.97 ± 0.7*	2.54 ± 0.9	3.22 ± 0.4
second half	2.65 ± 0.6	2.75 ± 0.5	2.83 ± 0.4
total	5.62 ± 1.3	5.29 ± 1.2	6.05 ± 0.6
ES	0.5 (moderate)	0.3 (small)	0.9 (large)
Δ%	–11%	8%	–12%
Relative distance (m/min)			
first half	119 ± 28*	102 ± 34	129 ± 15
second half	106 ± 25	110 ± 19	113 ± 17
total	112 ± 26	106 ± 23	121 ± 13
ES	0.5 (moderate)	0.3 (small)	0.9 (large)
Δ%	–11%	8%	–12%
Average HR (bpm)			
first half	154 ± 15	149 ± 14	149 ± 23
second half	157 ± 21	148 ± 13	159 ± 14
total	156 ± 17	149 ± 14	154 ± 16
ES	0.2 (small)	0.04 (small)	0.5 (moderate)
Δ%	2%	–0.4%	7%

(continued)

Table 4 ***(continued)***

Variables	Defenders ($n = 6$)	Midfielders ($n = 5$)	Forwards ($n = 5$)
Peak HR (bpm)			
first half	179 ± 14	173 ± 8	180 ± 23
second half	180 ± 17	173 ± 8	187 ± 17
total	180 ± 14	173 ± 8	184 ± 19
ES	0.1 (small)	0.03 (small)	0.3 (small)
Δ%	1%	0.1%	4%
Average speed (km/hr)			
first half	4.78 ± 0.7	5.14 ± 0.5	5.12 ± 0.6
second half	4.55 ± 0.1	5.12 ± 0.6	4.42 ± 0.6
total	4.67 ± 0.8	5.13 ± 0.5	4.77 ± 0.5
ES	0.3 (small)	0.04 (small)	1.2 (large)
Δ%	−5%	−0.4%	−14%
Peak speed (km/hr)			
first halff	15.68 ± 1.5	16.50 ± 2.4	14.80 ± 3.8
second half	15.90 ± 1.8	15.66 ± 2.7	15.22 ± 1.6
total	15.79 ± 1.4	16.08 ± 2.3	15.01 ± 2.6
ES	0.1 (small)	0.3 (small)	0.2 (small)
Δ%	1%	−5%	3%
Blood lactate (mM)			
basal	1.99 ± 0.6	1.70 ± 0.3	1.48 ± 0.5
first half	6.93 ± 1.5	5.54 ± 1.8	5.90 ± 1.2
second half	6.17 ± 1.9	5.74 ± 2.4	5.56 ± 1.7
ES	0.4 (small)	0.1 (small)	0.2 (small)
Δ%	−11%	4%	−6%
Push-up test (reps)			
pre	33 ± 4*	29 ± 3*	33 ± 5*
post	23 ± 6	26 ± 3	27 ± 5
ES	1.9 (large)	0.9 (large)	1.3 (large)
Δ%	−29%	−10%	−19%
Relative push-up test (reps/kg)			
pre	0.46 ± 0.11*	0.44 ± 0.04*	0.51 ± 0.13*
post	0.33 ± 0.10	0.39 ± 0.03	0.41 ± 0.10
ES	1.3 (large)	1.4 (large)	0.8 (large)
Δ%	−29%	−11%	−19%
CMJ (cm)			
pre	34.13 ± 2.4*	27.76 ± 7.8	25.90 ± 8.4
post	32.13 ± 2.7	26.22 ± 5.8	25.14 ± 7.7

(continued)

Table 4 *(continued)*

Variables	Defenders ($n = 6$)	Midfielders ($n = 5$)	Forwards ($n = 5$)
ES	0.8 (large)	0.2 (small)	0.09 (small)
Δ%	–6%	–6%	–3%
APLL (W)			
pre	2,850 ± 542*	2,007 ± 461	1,944 ± 982
post	2,718 ± 513	1,905 ± 449	1,893 ± 907
ES	0.3 (small)	0.2 (small)	0.05 (small)
Δ%	–5%	–5%	–3%
RPLL (W/kg)			
pre	38.83 ± 2.3*	31.00 ± 7.7	28.40 ± 11.9
post	37.17 ± 2.2	29.20 ± 5.7	27.80 ± 10.9
ES	0.7 (moderate)	0.3 (small)	0.05 (small)
Δ%	–4%	–6%	–2%
MBT (m)			
pre	4.38 ± 0.3*	4.64 ± 0.6	4.30 ± 0.5
post	3.78 ± 0.2	4.42 ± 0.6	4.08 ± 0.4
ES	2.1 (large)	0.4 (small)	0.5 (moderate)
Δ%	−14%	–5%	–5%
RPE			
pre	3 ± 1	3 ± 1	3 ± 1*
post	6 ± 2	5 ± 2	5 ± 2
ES	1.6 (large)	0.9 (large)	2.4 (large)
Δ%	70%	35%	100%

Note. ES of <0.09, 0.10–0.49, 0.50–0.79, and >0.80 were considered trivial, small, moderate, and large, respectively. Data are mean ± *SD*. Repeated measures ANOVA between positional role: total distance: $F(4, 23) = 1.116$, $p = .349$, $\eta^2 = .152$; relative distance: $F(2, 13) = 1.992$, $p = .176$, $\eta^2 = .235$; average HR: $F(2, 13) = 0.636$, $p = .545$, $\eta^2 = .089$; peak HR: $F(2, 13) = 0.474$, $p = .633$, $\eta^2 = .068$; average speed: $F(2, 13) = 2.183$, $p = .152$, $\eta^2 = .251$; peak speed: $F(2, 13) = 0.525$, $p = .604$, $\eta^2 = .075$; blood lactate: $F(2, 13) = 0.259$, $p = .775$, $\eta^2 = .038$; push-up test: $F(2, 13) = 3.955$, $p = .046$ (denotes significant difference [$p < .01$] between positional role), $\eta^2 = .378$; relative push-up test: $F(2, 13) = 2.867$, $p = .093$, $\eta^2 = .306$; countermovement jump test: $F(2, 13) = 0.429$, $p = .660$, $\eta^2 = .062$; APLL: $F(2, 13) = 0.425$, $p = .663$, $\eta^2 = .061$; RPLL: $F(2, 13) = 0.371$, $p = .697$, $\eta^2 = .054$; medicine ball throw: $F(2, 13) = 0.769$, $p = .483$, $\eta^2 = .106$; RPE: $F(2, 13) = 0.738$, $p = .497$, $\eta^2 = .102$. AS = amputee soccer; ES = effect size; HR = heart rate; bpm = beats per minute; reps = repetition; Δ% = relative differences; χ^2 = chi-square test; CMJ = countermovement jump; APLL = absolute power of the lower limbs; RPLL = relative power of the lower limbs; MBT = medicine ball throw; RPE = rating of perceived exertion.

*Significant difference ($p < .01$) between pre- and postmatch.

various speed categories (ES = 0.03–0.4; Δ = –33% to 56%; $p = .18$–$.91$). Table 2 shows that average HR (ES = 0.2; Δ = 3%; $p = .28$), blood lactate concentration (ES = 0.2; Δ = –6%; $p = .54$), and peak HR did not differ between halves (ES = 0.2; Δ = 2%; $p = .31$), but a small difference was found between the first and second half for average speed (ES = 0.5; Δ = –6%; $p = .04$). However, all muscular endurance and power performance variables decreased after the match, with pronounced declines for the absolute (ES = 1.4; Δ = –20%; $p < .01$) and relative push-up test (ES = 1.0; Δ = –20%; $p < .01$), although the RPE increased markedly compared with before matches (ES = 1.6; Δ = 66%; $p < .01$; Table 3).

Defenders and forwards were the playing positions to demonstrate declines in the total distance covered in the second half of matches (Table 4). Furthermore, defenders also illustrated a decrease in countermovement jump performance (ES = 0.8; Δ = –6%; $p < .01$), absolute power (ES = 0.3; Δ = –5%; $p < .01$), relative power (ES = 0.7; Δ = –4%; $p < .01$), and medicine ball throwing after a match (ES = 2.1; Δ = −14%; $p < .01$). All positions (defenders, midfielders, and forwards) demonstrated a decline for the absolute (ES = 0.9–1.9; Δ = −10% to 29%; $p < .01$) and relative push-up test postmatch (ES = 0.8–1.4; Δ = −11% to 29%; $p < .01$). The forwards position RPE scores increased postmatch by the largest magnitude (ES = 2.4; Δ = 100%; $p < .01$; Table 4).

Discussion

The present study is the first to investigate the match demands of AS and its impact on muscular endurance and power. These findings will contribute greatly to our understanding of the demands placed on AS players, and this work could be useful to support staff working within this sport. The match demands of able-bodied players typically include large samples (Di Mascio & Bradley, 2013), but the present study included just 16 AS players. The reader needs to consider this when interpreting the present findings, especially in light of the variable nature of time-motion characteristics of team sports players (Gregson, Drust, Atkinson, & Salvo, 2010) and that this would possibly be the case for AS players tracked across a minimal number of matches. More players would have been preferable, but this is an unavoidable drawback given the rarity of the sample (e.g., official AS matches) and the time-consuming testing protocol used (e.g., multiple measures taken before, during, and after matches). Despite these shortcomings, this approach still allows appropriate conclusions to be made regarding the impact of AS demands on physical match performance characteristics and muscular endurance, and power indices.

In elite able-bodied soccer, the average game intensity is ~85% of HR_{max}, a value that is close to the lactate threshold for most players (Stølen, Chamari, Castagna, & Wisløff, 2005). However, due to the intermittent nature of soccer, HR is >90% of HR_{max} for 20–30% of total playing time and peak HRs can reach 95–100% of HR_{max} (Helgerud, Rodas, Kemi, & Hoff, 2011). When AS players' HR were expressed relative to age-predicted maximal values, this produced comparable trends for average and peak values (81% and 95% HR_{max}, respectively) and highlights that aerobic energy production dominates energy provision in both soccer games. Moreover, elite able-bodied players perform up to 250 brief high-intensity actions during a game producing average and peak blood lactate concentrations in the range of 4–6 and 10–14 mM, respectively (Mohr et al., 2005). In comparison with the current study (i.e., AS players), the average lactate response (~5–6 mM) did not differ, but peak values were substantially lower than able-bodied players. Although the average blood lactate concentrations found within this study do indicate that players are taxing the anaerobic energy systems regularly between the first and second half of matches. The lower peak lactate concentrations observed for AS players are not related to the lower number of high-intensity bouts because, when expressed relative to a per minute basis, they seem to occur every 40–50 s in both AS and conventional soccer (Bradley et al., 2009). Thus, this finding could be related to markedly different peak speeds during match-play (15.5 vs. 32 km/hr), which is limited by crutch locomotion. The peak speeds within the present study are similar to those found for AS players completing the Yo-Yo Intermittent Recovery Test Level 1 (~15 km/hr), highlighting speed might be a limiting factor in this test rather than the players' physical capacity (Simim et al., 2013). These findings indicate the average anaerobic demands during AS match-play are similar to able-bodied players but could be different during intense periods.

All versions of the game (futsal and beach soccer, etc.) are characterized by sustained movement incorporating frequent bursts of high-intensity activity interspersed with recovery periods. In elite able-bodied soccer, players typically cover 10–13 km in total during a game with high-intensity accounting for 1–3 km (Stølen et al., 2005). The present study revealed that the total distance covered was only 5–6 km for AS players, which is substantially lower than able-bodied players (Barros et al., 2007), although the differences were related to the duration of each version of the game (50 vs. 90 min). Interestingly, when the data were corrected for the duration of match-play, no differences were evident. For instance, both conventional (Bradley & Noakes, 2013) and AS players typically cover ~110–120 m/min during games. Thus, given that the relative total distance covered is similar across able-bodied and AS players, this information provides very limited insight into the physical demands of AS players. Regarding more explosive metrics, able-bodied players produce 30–50 bouts of activity in the upper speed threshold across 90 min (>25.2 km/hr; Barnes, Archer, Hogg, Bush, & Bradley, 2014), which is substantially higher than the 20 bouts produced by AS players in the upper speed threshold (>16.9 km/hr). Although, when time is relative to total match duration, it is clear that conventional soccer and AS are similar in this nature. The reader must be aware of the limitation of the present study given that it fails to account for energy-demanding activities such as accelerations/decelerations and multidirectional movements that are metabolically taxing (Bradley & Noakes, 2013). Thus, it seems that conventional and AS soccer produce comparable physiological responses with some similarities in some time-motion characteristics such as the total distance covered.

A multitude of mechanisms have been proposed to explain fatigue development in able-bodied soccer, but researchers have failed to identify its precise cause (Mohr et al., 2005) or if this is different for players with an amputation. This is not surprising given the complexities of match running performance, which is influenced by a myriad of factors (Di Salvo, Gregson, Atkinson, Tordoff, & Drust, 2009) and the lack of research on disabled players. Research demonstrates that physical match performance declines from the first to the second half of elite able-bodied match-play (Di Salvo et al., 2009), although some observe minimal differences (Bradley & Noakes, 2013). The present study revealed similar distances between the first and second half of AS matches, and it seems that AS players do not experience a drop in physical match performance. Although reductions in match running performance in the second half or temporarily after the most intense period could be attributed to fatigue (Bradley et al., 2009; Di Mascio & Bradley, 2013), it is much more complex as this drop could be related to pacing strategies (Bradley & Noakes, 2013), contextual variables (Lago, 2009), or be related to the time the ball is out of play and the opportunity to engage in match activities (Carling & Dupont, 2011). However, given that soccer is a submaximal sport with players likely to be working within their physical capacity, it is very difficult to objectively identify fatigue using time-motion analysis (Bradley & Noakes, 2013; Paul, Bradley, & Nassis, 2015). One fruitful approach is to quantify game-induced fatigue by conducting physical performance tests before and after competitive matches (Paul et al., 2015). Using this approach, a study reported a decline of ~9% in repeated jumping performance and sprint times increased by ~2–3% in able-bodied players (Mohr et al., 2010). This is in agreement with the present findings that reveal that all muscular endurance and power performance measures decreased after the match, with pronounced declines for the push-up test (absolute and relative), although the RPE increased markedly compared with before matches. The postmatch muscle performance declines observed in the present study could be attributed to fatigue induced by the physical demands of AS match-play. Previous research on able-bodied soccer players has found depleted muscle glycogen stores in the *vastus lateralis* at the end of a match (Krustrup et al., 2006), declines in muscle creatine phosphate, intramuscular acidosis, or the accumulation of potassium in the muscle interstitium after intensified periods of match-play (Mohr et al., 2005). The fatigue experienced by AS players could be even more evident as ambulation with crutches expends 10–30% more energy than able-bodied individuals, resulting in increased energy expenditure and physical effort (Detrembleur, Vanmarsenille, De Cuyper, & Dierick, 2005; Mohanty, Lenka, Equebal, & Kumar, 2012). The markedly lower postmatch performances for the push-up test could be due to substrate depletion and/or metabolite accumulation in the upper body muscles. It seems that supporting the weight of the whole body with crutches across 50 min of AS soccer match-play has taxed the muscles recruited during the push-up test (chest, shoulders, and triceps muscle groups). Thus, the small muscle mass involved in supporting the body on crutches during AS match-play leads to substantial peripheral fatigue as evidenced by the lower push-up values postgame. As the push-up test is a closed kinetic chain exercise that is similar to the activity performed by the upper limbs during crutch locomotion. It seems reasonable to find a more pronounced decrement in this test than an open kinetic chain exercise like a medicine ball throw.

The specific physical demands and technical requirements for each playing position in conventional soccer is clearly documented (Bradley et al., 2009, 2011), and it is well-established that midfielders cover more total and high-speed distance than defenders or forwards (Bradley et al., 2009; Stølen et al., 2005). However, it was not the case in the current study across the three positions analyzed. Defenders, midfielders, and forwards did not differ in terms of total distance, relative distance, HR responses, average and peak speed, and blood lactate concentrations. This discrepancy is probably associated with the size of the pitch (both absolute and relative). While conventional soccer pitches are ~105 × 68 m (7,140 m^2) and ~357 m^2/outfield player, AS pitches are 60 × 30 m (1,800 m^2) or 150 m^2/outfield player. As there is limited space during AS, the positional differences could disappear because of the high density of players.

Conclusions

The present data revealed limited positional differences across variables between the first and second half. Although defenders did exhibit decrements in total distance covered during match-play, the most pronounced declines for almost all test measures after the match. It is difficult to explain these findings considering the lack of AS studies in this specific area (motion analysis), and more integrated research is warranted that merges physical, technical, and tactical data. The knowledge of muscular endurance and power responses after matches is important as players compete in tournaments where more than one game is played per day.

References

Akenhead, R., & Nassis, G.P. (2016). Training load and player monitoring in high-level football: Current practice and perceptions. *International Journal of Sports Physiology and Performance, 11*(5), 587–593. PubMed doi:10.1123/ijspp.2015-0331

Barnes, C., Archer, D.T., Hogg, B., Bush, M., & Bradley, P.S. (2014). The evolution of physical and technical performance parameters in the English Premier League. *International Journal of Sports Medicine, 35*(13), 1095–1100. PubMed doi:10.1055/s-0034-1375695

Barros, R.M.L., Misuta, M.S., Menezes, R.P., Figueroa, P.J., Moura, F.A., Cunha, S.A., . . . Leite, N.J. (2007). Analysis of the distances covered by first division Brazilian soccer players obtained with an automatic tracking method. *Journal of Sports Science & Medicine, 6*, 233–241. PubMed doi:10.1111/j.1600-0838.1996.tb00097.x

Bradley, P.S., Carling, C., Archer, D., Roberts, J., Dodds, A., Di Mascio, M., . . . Krustrup, P. (2011). The effect of playing formation on high-intensity running and technical profiles in English FA Premier League soccer matches. *Journal of Sports Science, 29*(8), 821–830. PubMed doi:10.1080/02640414.2011.561868

Bradley, P.S., & Noakes, T.D. (2013). Match running performance fluctuations in elite soccer: Indicative of fatigue, pacing or situational influences? *Journal of Sports Science, 31*(15), 1627–1638. PubMed doi:10.1080/02640414.2013.796062

Bradley, P.S., Sheldon, W., Wooster, B., Olsen, P., Boanas, P., & Krustrup, P. (2009). High-intensity running in English FA Premier League soccer matches. *Journal Sports Science, 27*, 159–168. PubMed doi:10.1080/02640410802512775

Carling, C., & Dupont, G. (2011). Are declines in physical performance associated with a reduction in skill-related performance during professional soccer match-play? *Journal of Sports Science, 29*(1), 63–71. PubMed doi:10.1080/02640414.2010.521945

Casartelli, N., Müller, R., & Maffiuletti, N.A. (2010). Validity and reliability of the Myotest accelerometric system for the assessment of vertical jump height. *Journal of Strength and Conditioning Research, 24*(11), 3186–3193. PubMed doi:10.1519/JSC.0b013e3181d8595c

Castellano, J., Alvarez-Pastor, D., & Bradley, P.S. (2014). Evaluation of research using computerised tracking systems (Amisco and Prozone) to analyse physical performance in elite soccer: A systematic review. *Sports Medicine, 44*(5), 701–712. PubMed doi:10.1007/s40279-014-0144-3

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Lawrence Erlbaum.

Detrembleur, C., Vanmarsenille, J.M., De Cuyper, F., & Dierick, F. (2005). Relationship between energy cost, gait speed, vertical displacement of centre of body mass and efficiency of pendulum-like mechanism in unilateral amputee gait. *Gait & Posture, 21*(3), 333–340. PubMed doi:10.1016/j.gaitpost.2004.04.005

Di Mascio, M., & Bradley, P.S. (2013). Evaluation of the most intense high-intensity running period in English FA premier league soccer matches. *Journal of Strength and Conditioning Research, 27*(4), 909–915. PubMed doi:10.1519/JSC.0b013e31825ff099

Di Salvo, V., Gregson, W., Atkinson, G., Tordoff, P., & Drust, B. (2009). Analysis of high intensity activity in Premier League soccer. *International Journal of Sports Medicine, 30*(3), 205–212. PubMed doi:10.1055/s-0028-1105950

Dunst, C.J., Hamby, D.W., & Trivette, C.M. (2004). Guidelines for calculating effect sizes for practice-based research syntheses. *Centerscope, 3*(1), 1–10.

Gregson, W., Drust, B., Atkinson, G., & Salvo, V.D. (2010). Match-to-match variability of high-speed activities in Premier League soccer. *International Journal of Sports Medicine, 31*(4), 237–242. PubMed doi:10.1055/s-0030-1247546

Helgerud, J., Rodas, G., Kemi, O.J., & Hoff, J. (2011). Strength and endurance in elite football players. *International Journal of Sports Medicine, 32*(9), 677–682. PubMed doi:10.1055/s-0031-1275742

Innocencio da Silva Gomes, A., Gonçalves Ribeiro, B., & de Abreu Soares, E. (2006). Nutritional profile of the Brazilian amputee soccer team during the precompetition period for the world championship. *Nutrition, 22*(10), 989–995. PubMed doi:10.1016/j.nut.2006.05.019

Kegel, B., & Malchow, D. (1994). Incidence of injury in amputee playing soccer. *Palaestra, 10*(2), 50–54.

Krustrup, P., Mohr, M., Steensberg, A., Bencke, J., Kjær, M., & Bangsbo, J. (2006). Muscle and blood metabolites during a soccer game: Implications for sprint performance. *Medicine & Science in Sports & Exercise, 38*(6), 1165–1174. PubMed doi:10.1249/01.mss.0000222845.89262.cd

Krustrup, P., Zebis, M., Jensen, J.M., & Mohr, M. (2010). Game-induced fatigue patterns in elite female soccer. *Journal of Strength and Conditioning Research, 24*(2), 437–441. PubMed doi:10.1519/JSC.0b013e3181c09b79

Kunz, M. (2007, July). 265 million playing football. *FIFA Magazine,* 10–15. https://www.fifa.com/mm/document/fifafacts/bcoffsurv/emaga_9384_10704.pdf

Lago, C. (2009). The influence of match location, quality of opposition, and match status on possession strategies in professional association football. *Journal of Sports Science, 27* (13), 1463–1469. doi:10.1080/02640410903131681

Lowther, J., Lane, A., & Lane, H. (2002). Self-efficacy and psychological skills during the amputee soccer world cup. *Athletic Insight, 4*(2), 23–34.

Mohanty, R.K., Lenka, P., Equebal, A., & Kumar, R. (2012). Comparison of energy cost in transtibial amputees using “prosthesis” and “crutches without prosthesis” for walking activities. *Annals of Physical and Rehabilitation Medicine, 55*, 252–262. PubMed doi:10.1016/j.rehab.2012.02.006

Mohr, M., Krustrup, P., & Bangsbo, J. (2005). Fatigue in soccer: A brief review. *Journal of Sports Sciences, 23*(6), 593–599. PubMed doi:10.1080/02640410400021286

Mohr, M., Mujika, I., Santisteban, J., Randers, M.B., Bischoff, R., Solano, R., . . . Krustrup, P. (2010). Examination of fatigue development in elite soccer in a hot environment: A multi-experimental approach. *Scandinavian Journal of Medicine & Science in Sports, 20*(Suppl. 3), 125–132. doi:10.1111/j.1600-0838.2010.01217.x

Moreira, A., Costa, E.C., Lodo, L., Freitas, C.G., Arruda, A.F.S., & Aoki, M.S. (2013). Validity and reliability of GPS receivers in relation to the distance covered. *Revista Andaluza de Medicina del Deporte, 6*(4), 146–150. doi:10.1016/S1888-7546(13)70050-9

Özkan, A., Kayıhan, G., Köklü, Y., Ergun, N., Koz, M., Ersöz, G., & Dellal, A. (2012). The relationship between body composition, anaerobic performance and sprint ability of amputee soccer players. *Journal of Human Kinetics, 35*, 141–146. PubMed

Paul, D.J., Bradley, P.S., & Nassis, G.P. (2015). Factors affecting match running performance of elite soccer players: Shedding some light on the complexity. *International Journal of Sports Physiology and Performance, 10*(4), 516–519. PubMed doi:10.1123/ijspp.2015-0029

Rhodes, J.M., Mason, B.S., Malone, L.A., & Goosey-Tolfrey, V.L. (2015). Effect of team rank and player classification on activity profiles of elite wheelchair rugby players. *Journal of Sports Sciences, 27*, 1–9.

Simim, M.A., Bradley, P.S., da Silva, B.V., Mendes, E.L., de Mello, M.T., Marocolo, M., & da Mota, G.R. (2017, March). The quantification of game-induced muscle fatigue in amputee soccer players. *Journal of Sports Medicine and Physical Fitness, 57*, 766–772. PubMed doi:10.23736/S0022-4707.16.06299-X

Simim, M.A., Silva, B.V., Marocolo Junior, M., Mendes, E.L., Mello, M.T., & da Mota, G.R. (2013). Anthropometric profile and physical performance characteristic of the Brazilian amputee football (soccer) team. *Motriz, 19*(3), 641–648.

Stølen, T., Chamari, K., Castagna, C., & Wisløff, U. (2005). Physiology of soccer: An update. *Sports Medicine, 35*(6), 501–536. PubMed doi:10.2165/00007256-200535060-00004