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**A CODING SYSTEM TO QUANTIFY POWERFUL ACTIONS IN SOCCER
MATCH PLAY: A PILOT STUDY**

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Keywords: Locomotion, pediatric exercise, movement components, biomechanics.

Abstract

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Purpose: The powerful activity profile of elite soccer match play has not been documented appropriately to inform specific maximal power assessment and development criteria. The aims of the current study were to develop a soccer specific powerful action (SSPA) notational analysis coding system that could be used to compare frequency and durations of powerful actions during elite youth soccer match play. **Methods:** Sixteen elite male English Premier League (EPL) Academy players (19±1 yrs) were recorded by an individual camera during sixteen competitive EPL U18 and U21 games. Video footage was analyzed using performance analysis software and SSPAs were coded according to the following categories: initial acceleration, leading acceleration, sprint, unilateral jump and bilateral jump. **Results:** The SSPA coding system demonstrated very good inter- and intra-rater objectivity (kappa coefficients ≥ 0.827). Elite youth EPL soccer players undertook significantly more initial (31±9) and leading (37±12) accelerations than sprints (8±3; $p=0.014$, $d=1.7$, and $p<0.001$, $d=1.7$, respectively) and jumps (6±5; $p=0.002$, $d=1.7$ and $p<0.001$, $d=1.7$, respectively). Players performed a significantly greater number of initial and leading accelerations with action durations below 1.5s compared to above 1.5s ($p=0.001$, $d=1.6$, and $p=0.002$, $d=1.4$), respectively. **Conclusions:** Our SSPA coding system provides an objective observational instrument for quantifying the frequency and duration of powerful actions performed during elite soccer match play. In our sample of elite youth soccer players, horizontal accelerations of short duration (<1.5s) from different starting speeds appear the most dominant powerful action in elite youth soccer match play.

25 **Keywords:** Locomotion, pediatric exercise, movement components,
26 biomechanics.

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28 An analysis of movement is important for understanding the physiological
29 demands of a sport (Carling, Bloomfield, Nelsen, & Reilly, 2008). Evaluating the
30 specific movements provides the basis for categorizing the types of actions that may be
31 important for performance. Sport specific actions can be described as powerful when
32 the athlete attempts to generate the greatest possible velocity at take-off, release or
33 impact (Cormie, McGuigan, & Newton, 2011). Understanding the specific nature of
34 the powerful actions performed during elite soccer match play can help inform
35 assessments of muscular power and training strategies in this domain (Issurin, 2013;
36 Maulder & Cronin, 2005).

37 Much of the available data on the performance of powerful actions within soccer
38 come from studies that have used automated time motion analysis systems, which have
39 classified maximal accelerations (Bradley, Di Mascio, Peart, Olsen, & Sheldon, 2010;
40 Varley & Aughey, 2013) and sprint (Di Salvo et al., 2010) efforts as actions that require
41 the player to complete both accelerations and running velocities over pre-determined
42 thresholds [i.e. maximal acceleration threshold: $>2.78 \text{ m}\cdot\text{s}^{-2}$ (Varley & Aughey, 2013);
43 Sprint threshold: $>25.2 \text{ km}\cdot\text{hr}^{-1}$ (Di Salvo et al., 2010)]. However, during linear speed
44 testing protocols (Stolen, Chamari, Castagna, & Wisloff, 2005) and competitive games
45 (Bradley et al., 2009), elite soccer players present a range of individual capabilities in
46 terms of accelerations and maximal running speeds. As a consequence, the
47 classification of accelerations and sprints as maximal could be misleading as these
48 arbitrary speed thresholds may incorrectly classify movements that are not truly
49 indicative of a maximal action for a specific individual player (Dogramac, Watsford, &

50 Murphy, 2011). The accuracy and objectivity of time motion analyses systems are
51 frequently compromised at such higher speed ranges, and in actions that require both
52 greater rates of acceleration and during efforts involving a change of direction
53 (Akenhead, French, Thompson, & Hayes, 2014; Jennings, Cormack, Coutts, Boyd, &
54 Aughey, 2010). Automated time motion analyses systems also often fail to report the
55 vertical jump demands of soccer. Subsequently, considering these limitations, studies
56 using automated time motion analysis systems may not characterize the powerful
57 activity in elite soccer match play in sufficient detail to inform the specificity of soccer-
58 associated muscular power assessment and development protocols.

59 Notational analysis systems have been proven as reliable and valid method of
60 tracking player movements where short distances, frequent changes in direction
61 (Dogramac et al., 2011) and vertical jumps (Faude, Koch, & Meyer, 2012; Mohr,
62 Krustup, & Bangsbo, 2003) are observed. Unlike automated time motion analyses
63 systems, this method offers more flexibility for the identification of powerful actions
64 based on the circumstances, during which the action is performed (i.e. during a situation
65 when two players from opposite teams are accelerating in a race to get to an area of the
66 pitch, or to a free soccer ball, this would suggest that the acceleration is performed as
67 rapidly as possible, and can therefore be described as a powerful action). Notational
68 analysis may therefore provide a more accurate description of the frequency and
69 duration of the complex powerful actions performed by individual players during
70 soccer match play (Dogramac et al., 2011).

71 To date, previous soccer notational systems coded sprints but not accelerations
72 (Bloomfield, Polman, & O'Donoghue, 2007; Faude et al., 2012), failed to report action
73 duration (Faude et al., 2012), and only reported the frequency of powerful actions
74 preceding goals (Faude et al., 2012) and during isolated random fifteen-minute periods

75 of games (Bloomfield et al., 2007). No study has provided a comprehensive description
76 of the powerful actions performed over the duration of a competitive soccer match.
77 Consequently, there is currently limited information available to inform the specific
78 detail of soccer-associated power assessment and training intervention protocols.

79 The primary aim of our study was to develop an objective soccer specific
80 powerful action (SSPA) notational analysis coding system that could assess and
81 compare the frequency and durations of various powerful actions during elite youth
82 soccer match play. We also aimed to use this SSPA notational analysis coding system
83 to describe the powerful activity profile of a sample of elite soccer players during youth
84 English Premier League (EPL) soccer match play.

85

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Method

87

88 Participants

89 Sixteen elite male soccer players registered to an EPL football academy provided
90 consent to participate in the study. The study was approved by the (deleted for
91 reviewing purposes) and complied with the Declaration of Helsinki (Ethics protocol
92 number: P13/SPS/033; approved 31/10/13). Soccer players were considered elite if
93 they had competed regularly (played over 12 competitive games in the previous 6
94 months) for one of the highest ranked (Category One) soccer academies in England,
95 according to the Elite Player Performance Plan (Premier-League, 2011) audit criteria
96 (only 24 out of 86 English soccer academies were awarded Category One status). Our
97 entire sample of elite soccer players competed regularly in Division One of the
98 Premier League 2 (the league for U23 Category One English academies).
99 Furthermore, 12 of the participants were also members of their respective youth

100 national teams, while three players had previously represented their senior national
101 team. Players' age, height, body mass, sum of seven skinfold sites (taken at the
102 biceps, triceps, subscapular, supraspinale, abdominal, mid-thigh, and calf) and
103 estimated % body fat were (mean \pm SD) 18.5 ± 1.0 years, 1.81 ± 0.07 m, 74.9 ± 8.6
104 kg, 44.3 ± 7.1 mm and 7.9 ± 1.2 %. The sample of players included three central
105 defenders, three full backs, three central midfielders, three wide midfielders and four
106 center forwards. Three of the players were substituted at various time-points during
107 the second half. Therefore, their first-half performance data were reported but
108 removed from the statistical analyses.

109

110 **Equipment and Software**

111 Individual player footage was filmed using digital video camera (Canon XM2,
112 Amstelveen, Netherlands) mounted on a stationary tripod (Libec, Arizona, USA).
113 Video footage was transferred to a desktop computer (Apple iMac, California, USA)
114 and then analyzed using performance analysis software (Sportscode Gamebreaker Plus,
115 Sportscode, NSW, Australia), operating at a frequency of 25 Hz. Speed testing (10 m
116 and 30 m sprint) was performed using a photocell timing system (Brower Timing
117 System, Salt Lake City, UT, USA). Seven of the players wore 10 Hz global position
118 system (GPS) technology (STATSports, Newry, Northern Ireland) for complete 90 min
119 matches.

120

121 **Experimental Design**

122 Firstly, a SSPA coding system was developed. Once the contents validity
123 evidence, intra-observer and inter-observer objectivity of the SSPA coding system were
124 established, sixteen players were filmed with an individual camera and the SSPA

125 coding system was used to analyze the powerful activity profile performed by each
126 player.

127

128 **Soccer Specific Powerful Action Coding System**

129 A video based player tracking notational analysis SSPA coding system was
130 developed during five sequential stages (Brewer & Jones, 2002). Considering the
131 limitations of previous soccer coding systems, it seemed appropriate initially to clearly
132 define what actions can be considered powerful and hence could be incorporated into a
133 notation system. A powerful action was defined as an effort that was performed as (or
134 nearly as) explosively as possible. The identification of powerful actions was therefore
135 based on the researcher recognizing circumstances in which the player performed an
136 explosive effort. For example, accelerations and sprints were considered powerful
137 actions in situations when the player was perceived to be aiming to travel to a specific
138 area of the pitch as quickly as possible. Such actions were generally performed under
139 circumstances which required the player to advance towards the ball before an
140 oncoming opponent, move away from an advancing opponent, or travel to a specific
141 area of the pitch in an attempt to gain possession of the ball from an opponent. Vertical
142 jumps were considered powerful actions when it was assumed that the player was
143 attempting to meet the ball at its highest point and therefore, jumping as high as
144 possible.

145 The researcher initially filmed pilot video footage of four different players and
146 observed this pilot video footage in real time, and in slow motion, and developed a
147 broad categorisation of SSPAs by identifying discrete movements that were perceived
148 as being performed as (or nearly as) explosively as possible. The SSPA coding system
149 is detailed in Tables 1 and 2. As acceleration (10 m linear speed assessment time) and

150 sprint (30 m linear speed assessment time) capabilities are independent attributes in
151 soccer players (Little & Williams, 2005), it was thought to be important to ensure that
152 the SSPA coding system included specific criteria to allow the frequency of both of
153 these types of powerful actions to be coded. The average 10 m linear speed assessment
154 times for the elite youth academy players recruited for the current study was $1.72 \pm$
155 0.07 s. As these 10 m sprint times were similar to those previously reported in sample
156 of Premier League footballers that also included international players (1.69 ± 0.08 s;
157 this cohort included 14 players with 6 internationals; Cotte & Chatard, 2011), we
158 believed it was an accurate representation of the acceleration capabilities within this
159 cohort. Therefore, when the player had accelerated as (or nearly as) explosively as
160 possible for more than 1.72 s, it can be assumed that they have progressed through the
161 acceleration phase and now transitioned into performing a sprint action.

162

163 xxxxxxxxxxxx Table 1 and 2 near here xxxxxxxxxxxx

164

165 The contents validity of the SSPA coding system was established via
166 interactions with an expert panel (n=5) that included one experienced applied football
167 researcher, practitioner and university professor, one video analyst and two sport
168 scientists, all currently employed by English Premier League Clubs. These specialists
169 were invited to review and validate the coding system. This process consisted of the
170 author explaining and demonstrating the coding classification system and receiving
171 verbal feedback on it during a series of meetings. Following these discussions, all the
172 specialists agreed with the SSPA coding system categories and rules. As a consequence,
173 the SSPA coding system was deemed a valid measuring tool for recording the most
174 frequent and important powerful actions performed during soccer match play.

175 Having established contents validity evidence for the SSPA coding system, the
176 intra-observer objectivity was then investigated to establish if the test-retest objectivity
177 for the principle researcher using the system was acceptable. Similarly, inter-observer
178 objectivity was investigated to establish whether the author, and an inexperienced
179 observer who had no previous experience of notational analysis methods, could record
180 the same movements, at the same time points, during the same game. The process for
181 investigating the intra- and inter-observer objectivity of the SSPA coding system is
182 illustrated in Figure 1.

183 To investigate the intra-observer objectivity, the researcher initially viewed the
184 individual player video footage of a single full competitive game and coded the
185 powerful actions based on the criteria of the SSPA coding system being assessed.
186 Twelve days later, the same researcher then repeated this analysis process again, coding
187 the powerful actions during the same individual player video footage. Game codes were
188 extrapolated to timelines with a recording scale of 0.5 s (with the exception of vertical
189 jump actions, removing actions <0.5 s duration). The two timelines were matched.

190 During the inter-observer objectivity procedure, an in-experienced observer was
191 required to view the same individual player video footage of a full competitive game
192 and code the powerful actions based on the criteria of the SSPA coding system being
193 assessed. The game codes were extrapolated and the observer timeline (recording scale
194 0.5) was matched with the corresponding timeline from the same individual player
195 video footage coded by the researcher during the intra- objectivity analysis.

196 The level of agreement between matched timelines was analyzed for intra- and
197 inter-observer objectivity using kappa statistics (Figure 1). During the development of
198 the SSPA coding system the intra- and inter-observer objectivity assessments were
199 completed on three and two occasions, respectively (Figure 1).

200

201 xxxxxxxxxxxxxx Figure 1 near here xxxxxxxxxxxxxx

202

203 The comprehensive development of the SSPA coding system indicated that the
204 tool was an objective observational instrument for the coding of SSPAs. Following this
205 evaluation, the data collection procedures commenced in conjunction with GPS-
206 derived acceleration data, which were collected simultaneously with our SSPA data.
207 This enabled us to compare our SSPA system with technology that is commonly used
208 to quantify powerful actions in the applied field. The GPS-derived accelerations were
209 recorded using wearable 10 Hz global position system (GPS) technology (STATSports,
210 Newry, Northern Ireland). Seven players wore the trunk-mounted GPS unit, positioned
211 in the mid scapula region as per manufacturer guidelines in a STATSports vest (Newry,
212 Northern Ireland), for complete 90 min matches (the same as coded using our SSPA
213 system). An acceleration was registered when the change in GPS speed increased for
214 at least half a second, with a maximal acceleration of over 3 ms⁻². We compared the
215 total number of accelerations throughout the game measured using GPS technology
216 with the total number of powerful accelerations (initial and leading accelerations) coded
217 using our SSPA coding system.

218

219 **Procedure**

220 Filming was conducted during sixteen competitive EPL Academy Youth
221 League soccer matches (thirteen U21 and three U18 League Games) in the 2013-2014,
222 and 2014-2015 season. All games were played on a grass surface and filmed using a
223 digital video camera (Canon XM2, Amstelveen, Netherlands) mounted on a stationary
224 tripod (Libec, Arizona, USA). Individual players were recorded and tracked by an

225 individual camera, which was zoomed to provide clear, unobstructed and close images
226 of the specific player in question from an elevated position.

227 The video footage of each game was transferred to a desktop computer (Apple
228 iMac, California, USA) and then analyzed using performance analysis software
229 (Sportscodex Gamebreaker Plus, Sportscodex, NSW, Australia), operating at a frequency
230 of 25 Hz. Only actions when the circumstances would suggest that the player had to
231 perform an effort as (or nearly as) explosively as possible were coded according to the
232 categorisation criteria detailed in Table 1. The start and end points of powerful actions
233 were coded to provide frequency counts and action duration outcomes. The video
234 footage could be played back frame-by-frame, or in slow motion, to allow specific start
235 and end points to be identified. Specific criteria used to identify these time points are
236 illustrated in Table 2.

237

238 **Data Analysis**

239 Due to the relatively low number of observations for both unilateral and bilateral
240 jumps, these actions were grouped together as one category (vertical jumps) for
241 analyzing differences within and between powerful actions. The whole dataset was
242 checked for normality and the frequency data for vertical jumps were not normally
243 distributed. Therefore, a Friedman's test was used to determine if there were
244 differences between the total frequencies of different powerful actions performed
245 during the whole game (initial accelerations, leading accelerations, sprints, vertical
246 jumps). Pairwise comparisons were performed with a Bonferroni correction to
247 determine specific differences between the different powerful actions. Wilcoxon
248 signed ranked tests were used to detect differences between the same powerful actions
249 performed during the first half compared to the second half. Wilcoxon signed ranked

250 tests were also used to detect differences between the number of powerful actions
251 performed in the two duration categories (0.5 - 1.49 s and ≥ 1.5 s; these categories
252 were chosen as 1.49 s is below 1.72 s, which is the average 10 m maximal sprint time
253 for this group of players. This gives the practitioner a reference for the number of
254 maximal accelerations performed over a distance of less than 10 m) and the number
255 of unilateral compared to bilateral vertical jumps performed during the whole game.
256 Simple effect size, estimated from the ratio of the mean difference to the pooled SD,
257 was also calculated. Effect size ranges of <0.20 , $0.21-0.60$, and $0.61-1.20$, $1.21-2.00$,
258 and >2.00 were considered to represent trivial, small, moderate large, and very large
259 differences, respectively. To assess the level of agreement between SSPA and GPS
260 methods regarding frequency of (maximal/near maximal) accelerations for the seven
261 players, who wore the GPS unit for complete 90 min matches, we performed a
262 Student's paired T-test and also calculated the coefficient of variation, a two-way
263 random effect with absolute agreement intra-class correlation coefficient, and ratio
264 limits of agreement (Nevill & Atkinson, 1997). All statistical analyses were
265 completed using SPSS version 21 (SPSS Inc., Chicago, IL), and statistical
266 significance was set at $p < 0.05$. All data are expressed as mean \pm SD.

267

268

Results

269

270 Comparing The Frequencies of Powerful Actions

271 During a competitive soccer match, elite youth soccer players performed a total
272 of 81 ± 18 powerful actions. There were significant differences between the frequency
273 of actions performed during the match ($\chi^2(4) = 48.043$, $p < 0.001$). Pairwise
274 comparisons revealed that players performed a significantly greater number of initial

275 accelerations and leading accelerations than vertical jumps during the whole game ($p =$
276 0.002 and $p < 0.001$, respectively; Table 3), with these differences associated with large
277 effect sizes ($d = 1.7$ and $d = 1.7$, respectively). Similarly, a significantly greater number
278 of initial accelerations and leading accelerations were performed compared to sprints
279 during the whole game ($p = 0.014$ and $p < 0.001$, respectively; Table 3), with these
280 differences associated with large effect sizes ($d = 1.7$ and $d = 1.7$, respectively). There
281 was no difference in the number of vertical jumps performed compared to sprints during
282 the entire match ($p = 1.000$; Table 3), which was also associated with a small effect size
283 ($d = 0.4$). Likewise, players performed a similar number of initial and leading
284 accelerations during the whole game ($p = 1.000$; Table 3), which was also associated
285 with a small effect size ($d = 0.6$).

286

287 **Temporal Pattern of Maximal Actions**

288 A significantly higher total number of powerful actions were performed during
289 the first compared to the second half of matches (45 ± 10 vs. 37 ± 10 ; $Z = -2.944$, $p =$
290 0.003), with this difference associated with a moderate effect size ($d = 0.7$). More
291 specifically, players performed a significantly greater number of initial accelerations in
292 the first half ($Z = -1.959$; $p = 0.050$; Table 3), with this difference associated with only
293 a small effect size ($d = 0.6$). A higher number of leading accelerations ($Z = -1.889$; $p =$
294 0.059 ; Table 3) was observed during the first, compared to the second half of the
295 matches though this difference was not significant, and this differences was associated
296 with a small effect size ($d = 0.5$). There was no difference between the numbers of
297 sprints ($Z = -0.158$, $p = 0.874$; Table 3) or vertical jumps ($Z = -1.437$, $p = 0.151$; Table
298 3) performed during either half, with such comparisons also associated with trivial (d
299 $= 0.1$) and small effect sizes ($d = 0.4$), respectively.

300

301 Duration of Powerful Actions

302 There were significantly greater number of initial accelerations ($Z = -3.189$, p
303 $= 0.001$; Table 3), leading accelerations ($Z = -3.115$, $p = 0.002$; Table 3), and sprints (Z
304 $= -2.325$, $p = 0.020$; Table 3), performed that lasted for durations between 0.5-1.49 s
305 compared to the number of these activities performed for more than 1.5 s. These
306 differences in the number of initial accelerations, leading accelerations, and sprints,
307 were associated with large ($d = 1.6$), large ($d = 1.4$) and moderate ($d = 0.7$) effect sizes,
308 respectively.

309

310 Jump Type Frequency

311 There was no difference in the total number of unilateral compared to bilateral
312 jumps performed during the matches (3 ± 3 vs. 3 ± 3 ; $Z = -3.180$, $p = 0.437$). The range
313 of total vertical jumps performed, however, was large (Total vertical jumps: 2 – 18).

314

315 xxxxxxxxxxxxxx Table 3 near here xxxxxxxxxxxxxx

316

317 Comparing frequency of accelerations measured with SSPA and GPS methods

318 The frequency of “maximal” accelerations determined via GPS (49.6 ± 25.0)
319 was lower than the number of total accelerations determined by SSPA (68.3 ± 19.7 , t_6
320 $= -3.45$, $p = 0.014$). The intraclass correlation coefficient between the two methods was
321 0.755 (95% CI: 0.111 – 0.969; $p = 0.009$), and the coefficient of variation was 27.5%.
322 The ratio limits of agreement were 1.478 ($*/ \div 1.838$). The bias ratio (1.478) implies
323 that SSPA coded the frequency of maximal (or near maximal) accelerations on average
324 47.8% higher than those quantified using GPS, while the agreement ratio ($*/ \div 1.838$)

325 indicates that 95% of the agreement ratios lay within 83.8% above or below the mean
326 bias ratio. Thus, we can state that the agreement between the two methods for
327 quantifying frequency of maximal (or near maximal) accelerations was poor.

328

329

Discussion

330 Our study aimed to develop a notational analysis coding system that could
331 characterize the powerful activity profiles of elite youth soccer players in sufficient
332 detail to inform the detail of maximal power assessment and development protocols.
333 The main finding was that our SSPA coding system provides a highly objective
334 observational instrument for quantifying the frequency and duration of powerful
335 actions performed during elite soccer match play. In the sample of elite youth soccer
336 players subsequently analyzed using the SSPA coding system, we show that over the
337 course of a competitive game, EPL youth players performed a significantly greater
338 (associated with a large effect size) number of initial and leading accelerations
339 compared to both sprints and vertical jumps. Action duration data showed that the
340 majority of initial accelerations (large effect size), leading accelerations (large effect
341 size) and sprints (moderate effect size) performed over the course of a game lasted less
342 than 1.5 seconds. Our findings suggest that accelerations of short duration (<1.5
343 seconds), from different starting speeds that are oriented in the horizontal direction, are
344 the most dominant powerful action in elite youth soccer match play. This information
345 suggests that soccer-associated maximal power assessment and development protocols
346 could specifically focus on evaluating and enhancing the ability to perform horizontal,
347 rather than vertical, powerful actions.

348 If a video based player tracking notational analysis coding system is to be used
349 to provide information to inform the prescription of assessment and training strategies

350 for elite soccer players, it is imperative that the coding system has been validated and
351 shown to be objective for observers using the instrument. By consulting a range of
352 experts in the field in series of meetings we have also provided very good content
353 validity evidence that the SSPA coding system is representative of the powerful actions
354 performed during soccer match play. The large kappa coefficients (≥ 0.827) calculated
355 in the intra- and inter-observer objectivity analyses procedures demonstrates that the
356 SSPA coding system is objective for both the researcher, and an inexperienced
357 observer. Our findings therefore show that the SSPA coding system developed can be
358 used with a high level of objectivity by other researchers in future studies to quantify
359 the frequency and duration of powerful actions performed during soccer match play.
360 As such detailed information is lacking in the current body of literature, we believe the
361 SSPA coding system can serve as a platform for innovative future research that could
362 provide the applied practitioner with detailed information to inform maximal power
363 assessment and development processes in a soccer specific context.

364 Considering automated time motion analysis systems, utilizing GPS
365 technology, have been commonly used to quantify “high intensity” aspects of a soccer
366 match, we decided to compare the frequency of “maximal” accelerations identified via
367 our SSPA method with that identified via GPS. Although the intraclass correlation
368 coefficient was moderate, the large confidence intervals, the extremely wide ratio limits
369 of agreement and high coefficient of variation showed there was poor agreement
370 between the SSPA and GPS derived maximal (or near maximal) accelerations. Given
371 that the objectivity and validity of 10 Hz GPS for measuring accelerations is
372 compromised for those over 4 ms^{-2} (Akenhead et al., 2014), it is clear that the 10 Hz
373 wearable GPS units are not suitable for accurately assessing the number of soccer-
374 specific high intensity activities. Moreover, the speed and acceleration capabilities of

375 our elite youth soccer players varied (range in 10 m sprint performance substantially:
376 1.53 – 1.75 s; range in 20 m sprint performance: 2.72 – 3.02 s), thus implying that some
377 players surpassed the generic maximal acceleration threshold when eliciting only
378 submaximal efforts, whereas other players may not have surpassed this generic
379 threshold even when performing maximal/or near maximal accelerations. Considering
380 these two factors, it is therefore not surprising that we found a discrepancy in the
381 number of powerful accelerations when comparing the results from an automated time
382 motion analysis system (with compromised validity and objectivity), with our SSPA
383 coding system, which has been shown to have very good intra- and inter-observer
384 objectivity. Our work further illustrates the limitations of using automated time motion
385 analysis systems for describing the powerful activity profile in elite soccer. The
386 discrepancy in results signifies the importance of our study for providing an accurate
387 and objective representation of the powerful activity demands of youth soccer.

388 Unlike previous notational analysis coding systems (Bloomfield et al., 2007;
389 Faude et al., 2012), our SSPA coding system documented the number and type (initial
390 or leading) of powerful accelerations performed throughout the duration of a whole
391 game [as opposed to just before goals scored (Faude et al., 2012), or during isolated 15-
392 minute periods (Bloomfield et al., 2007)]. Moreover, unlike previous notational
393 analysis coding systems (Bloomfield et al., 2007; Faude et al., 2012), we also included
394 the action duration, which gives valuable information for the practitioner that may
395 inform the rep duration of speed/agility or conditioning drills, and the specificity power
396 development protocols. By also being the first study to include the type of jump action
397 (unilateral or bilateral), we provide innovative information that may be used to inform
398 soccer specific power assessment and development protocols. We believe the
399 information provided in our study provides the most objective and comprehensive

400 available description of the detail of powerful actions performed over the duration of a
401 competitive soccer match.

402 Using the SSPA coding system to analyse a sample of elite youth soccer players
403 during youth EPL match play, we show that these players undertook 8~fold more
404 horizontal accelerations than sprints (~68 vs. 8, respectively), thus suggesting
405 horizontal acceleration is a more dominant action (Table 3). We also show that elite
406 EPL youth soccer players performed 11~fold more horizontal accelerations (initial and
407 leading accelerations combined) than vertical jumps (~68 vs. 6, respectively) during a
408 competitive match. Subsequently, our data suggests that powerful efforts oriented in
409 the anterior-posterior and mediolateral directions are performed more frequently during
410 elite EPL youth soccer match play than efforts oriented the vertical direction.
411 Considering it has been previously documented that unilateral jump capabilities in
412 different directions are independent qualities that require different muscle activation
413 profiles (Murtagh et al., 2017) and should be assessed and developed separately
414 (Meylan, Nosaka, Green, & Cronin, 2010), our data in this sample of EPL players
415 suggests that future soccer specific power assessment and development protocols
416 should prioritize anterior-posterior and mediolateral power production. More
417 specifically, our findings suggest that horizontal jump assessments (rather than vertical
418 jumps which are the most common assessment employed currently at elite soccer
419 clubs), should be prioritized in elite soccer assessment protocols. However, the range
420 in vertical jump frequency in the current study (2-18) may also suggest that this capacity
421 is more important for some positions than others, or perhaps dependent on the type of
422 game and opposition. Our innovative data therefore makes the soccer practitioner aware
423 that certain EPL youth players may be required to jump in the vertical direction more

424 frequently. Subsequently, vertical power training may be prescribed on an individual
425 basis depending on how often the player is required to jump vertical in a game.

426 To optimize muscular power assessment and development programmes for
427 soccer players, knowledge of the detail of these actions is important. The majority of
428 horizontal accelerations and sprints were performed for durations of less than 1.5 s
429 (Table 3). This information suggests that short duration explosive horizontal efforts are
430 the most dominant powerful action during elite youth EPL soccer match play. These
431 findings are in agreement with Cometti and Colleagues (2001) and, as acceleration
432 performance has been associated with horizontal-forward jump performance (Dobbs,
433 Gill, Smart, & McGuigan, 2015), these findings may further support the inclusion of
434 this assessment in elite soccer talent identification protocols. In addition, this data from
435 our sample of EPL players also suggests that the most frequent action included in soccer
436 specific speed, and soccer speed endurance development drills, should be explosive
437 short duration maximal accelerations (<1.5 s).

438 Our study is the first to categorize accelerations as initial or leading, based on
439 the inertia that the player is required to overcome before initiating the acceleration. As
440 there was no difference (and small effect size) in the number of initial and leading
441 accelerations completed by EPL youth soccer players (Table 3), our results show that
442 both of these actions are should be developed simultaneously during soccer training
443 interventions.

444 Analyzing the effect of time on the frequency of powerful actions may also
445 provide useful information for the prescription of soccer conditioning programmes.
446 Elite EPL youth soccer players performed fewer maximal actions in the second half in
447 comparison to the first half. More specifically, significantly fewer initial accelerations,
448 and a tendency for fewer leading accelerations, were performed in the second half, thus

449 suggesting that powerful horizontal actions were reduced as a function of time.
450 However, these differences between halves for initial and leading accelerations were
451 associated with small effect sizes. Due to the complexity of factors that could influence
452 the reduction in running performance during soccer match play (Paul, Bradley, &
453 Nassis, 2015), the significance of these findings is not yet known from a practical or
454 theoretical perspective. Nevertheless, our data may suggest that soccer practitioners
455 could aim to apply specific conditioning interventions to help players perform initial
456 accelerations more frequently during the second half of competitive matches. Such
457 interventions could include high intensity conditioning drills that include the
458 performance of maximal accelerations, from static or walking starts, in the latter stages
459 of the session when a certain level of fatigue has been accumulated.

460 Although our cohort included 12 international standard players from six
461 different countries, a limitation of our study was that all 16 elite youth players, who
462 participated in this study, represented the same English Premier League Academy at
463 U18/U21 level. Thus, our results may not be indicative of soccer powerful activity
464 profiles in other age groups or in teams competing in other leagues in different
465 countries. Moreover, as we only included 16 elite youth players, our study should be
466 repeated with a larger sample size to confirm our findings are representative of EPL
467 youth soccer match play. Future research could therefore recruit larger cohorts and
468 focus on using our SSPA coding system to compare the powerful action demands at
469 different age groups and in elite soccer clubs playing in different countries

470 In conclusion, the current study developed a video-based player tracking
471 notational analysis coding system that could be used to provide a highly objective
472 account of the powerful actions performed during elite soccer match play. In our sample
473 of elite EPL youth soccer players analysed, vertical jumps and sprints were performed

474 less frequently than both initial and leading horizontal accelerations. The results
475 showed that initial and leading horizontal accelerations of short duration (< 1.5 s) are
476 the most frequently performed powerful actions during elite youth soccer match play.
477 In comparison to the first half, EPL youth soccer players performed significantly fewer
478 initial accelerations during the second half.

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What Does This Article Add?

481 Our study provides evidence that a notational analysis coding system can be
482 used to provide soccer practitioners with an insight into the powerful action demands
483 of EPL youth soccer match play. The detail that the SSPA coding system describes such
484 powerful actions may be used to inform the specificity of soccer specific physical
485 assessment and development protocols. As the most dominant action performed by the
486 sample of elite youth EPL soccer players in our study were horizontal accelerations
487 from different starting speeds, our data suggests the assessment and development of the
488 ability to produce horizontal impulse from static or walking speeds, but also from
489 moving speeds, should be prioritized within the athletic development protocols applied
490 at elite youth soccer clubs. We also show that elite youth soccer players are required to
491 perform powerful vertical jump and sprint actions, and whilst these capabilities may
492 also be important to assess and develop, they should not be prioritized over the ability
493 to perform short duration horizontal accelerations. The vertical jump requirements of
494 EPL youth soccer match play were varied (range between 2-18) and therefore, the
495 ability to produce vertical power may be more important for specific players. Analyzing
496 the temporal patterns of powerful actions shows that the specific action that was
497 performed less frequently during the second half was the initial acceleration.

498 Practitioners may aim to improve the ability to perform this action in conditioning
499 programmes tailored towards improving second half physical performance.

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Table 1. Soccer specific powerful action (SSPA) coding system categories and definitions.

Category	Definition
Initial acceleration	Very high-intensity horizontal acceleration where the player propels their body in the forward or sideways direction whilst initiating the first propulsion when either static, walking, or after changing direction.
Leading acceleration	Very high-intensity horizontal acceleration where the player propels their body in the forward or sideways direction whilst initiating the first propulsion when performing a movement that cannot be defined as static, walking or changing direction.
Sprint	If the player is perceived to continue to perform the very high intensity acceleration effort for over 1.72 s, the acceleration now turns into a sprint action. At this time point the acceleration terminates and a sprint action will begin.
Bilateral jump	Very high-intensity propulsion of body off two legs in a primary vertical direction with only partial horizontal direction. This must have a clear identifiable take off and flight phase.
Unilateral jump	Very high-intensity propulsion of body off one leg in a primary vertical direction with only partial horizontal direction. This must have a clear identifiable take off and flight phase. This category can include actions such as jumping to control the ball and does not necessarily have to be a jump for a header.

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584

Table 2. Criteria for defining start and end point of all powerful actions.*Start point of powerful actions:*

- The beginning of all powerful actions was defined as the moment that the players' foot first made contact with the ground immediately before initiation of the first explosive propulsion of the movement.
- On the rare occasion that the player initiated the powerful action from a static stance with both feet in contact with the ground, the action began at the instance (time frame before) marked by the first noticeable extension of ankle, knee or hip.

End point of powerful actions

- All powerful actions ended one-time frame before the first ground contact of the deceleration or landing phase.
- The deceleration phase of horizontal actions began when the player's stride pattern changed and his landing foot contacted the ground in front of his center of mass acting to slow him down.
- This was often marked by a heel strike when the foot initially made ground contact.

Table 3. Absolute frequencies of powerful actions during elite youth soccer match play (n=16); mean \pm SD.

	Initial acceleration	Leading acceleration	Sprint	Vertical jump
Total	31 \pm 9 ^{cd}	37 \pm 12 ^{cd}	8 \pm 3 ^{ab}	6 \pm 5 ^{ab}
1 st Half	17 \pm 5 [#]	20 \pm 7	4 \pm 2	3 \pm 3
2 nd half	14 \pm 5	16 \pm 6	4 \pm 3	3 \pm 2
Action duration 0.50-1.49 s	22 \pm 6 ^{&}	25 \pm 9 ^{&}	5 \pm 2 ^{&}	N/A
Action duration > 1.50 s	9 \pm 4	12 \pm 4	3 \pm 2	N/A

Post hoc tests: ^a Significantly different to the frequency of initial accelerations, ^b Significantly different to the frequency of leading accelerations, ^c Significantly different to the frequency of sprints, ^d Significantly different to the frequency of vertical jumps; [#] Significantly different to the frequency of the same powerful action performed in the 2nd half; [&] Significantly different to the frequency of the same powerful action performed for a duration > 1.50 s ($p < 0.05$).

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586

587 Figure 1

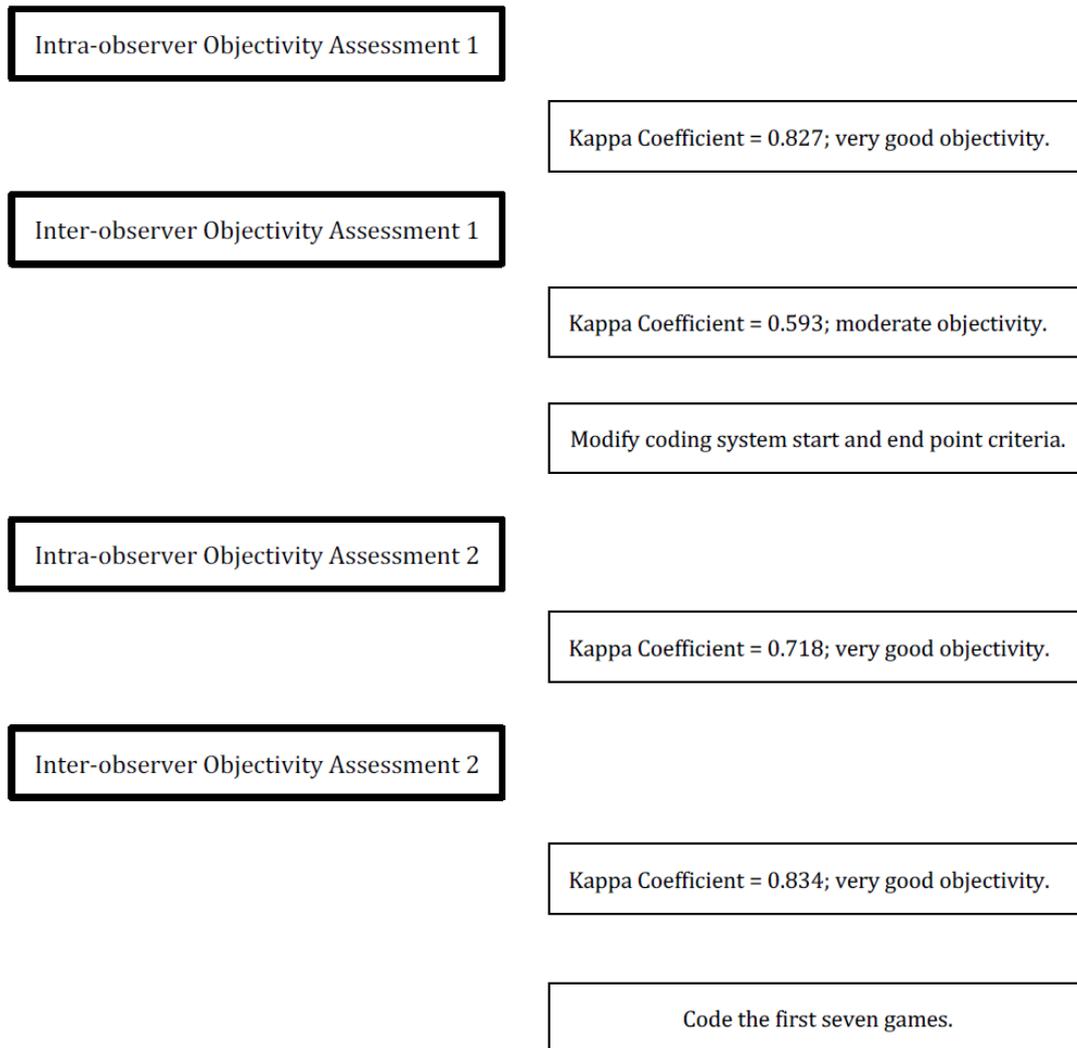


Figure. 1 An illustration of the intra- and inter- observer reliability (objectivity) process.