Physical Therapy in Sport 35 (2019) 36–41

Contents lists available at ScienceDirect

Physical Therapy in Sport

journal homepage: www.elsevier.com/ptsp

Original Research

Dynamic postural stability, is associated with competitive level, in youth league soccer players

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ARTICLE INFO

Article history:
Received 31 August 2018
Received in revised form
2 November 2018
Accepted 3 November 2018

Keywords:
Soccer
Static balance
Dynamic balance
Postural control
Dynamic postural stability index (DPSI)
Time to stabilization (TTS)

ABSTRACT

Objectives: To assess the effect of competitive level on dynamic postural stability in young elite and sub-elite soccer players.
Design: Cross-sectional study.
Setting: Laboratory.
Participants: Fifty-four male soccer players of Under 16 and Under 17 categories (mean age 15.9 ± 0.6), divided into two groups who regularly compete at national ($n = 28$) and regional ($n = 26$) levels.
Main outcome measures: Dynamic Postural Stability Index (DPSI) and vertical Time to Stabilization (vTTS) for a forward-jump landing. Static postural sway was calculated on the basis of center-of-pressure trajectories for a 20 s one-legged stance.
Results: Players at national level exhibit better dynamic postural control than those at regional level, as indicated by the significantly lower DPSI (0.327 vs. 0.373, $p < 0.001$) and vTTS (0.887 vs. 1.158 s, $p = 0.003$). In contrast, no differences between groups were found in any of the postural sway parameters for the static test.
Conclusions: Young soccer players at national level are characterized by better balance performance in terms of faster and more efficient stabilization after a forward jump, while one-leg static standing tests appear not challenging enough to reveal differences in balance abilities associated with the combination of superior technical and physical features.
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1. Introduction

In recent times, soccer players' postural control (i.e. the ability to maintain, achieve and restore a state of balance during any posture or activity, Pollock, Durward, Rowe, & Paul, 2000) has recently received considerable attention as a relevant number of game situations such as dribbling, sudden changes in direction, especially under acceleration/deceleration conditions, landing after jumps etc. are better performed in presence of well-developed body control (Schreiner, 2000). Moreover, postural control has been suggested as playing a role as co-factor in the onset of no-contact lower limb injuries (Dallinga, Benjaminse, & Lemmink, 2012; Hornbeck & Peterson, 2012; Murphy, Connolly, & Beynnon, 2003; Read, Oliver, De Ste Croix, Myer, & Lloyd, 2016; Romero-Franco et al., 2014).

In the last decade, balance of soccer players has often been quantitatively investigated using objective techniques such as postural sway analysis, on the basis of center-of-pressure (COP) time series obtained using a force/pressure platform under quiet standing conditions. Several studies have reported that postural sway is dependent on factors such as age (i.e. state of maturation of the postural control system, Steinberg et al., 2016), fatigue originated either by training session or actual matches (Brito et al., 2012; Gioftsidou, Malliou, Pafis, Beneka, & Godolias, 2011; Pau et al., 2014a 2016), level of expertise (Paillard & Noé, 2006; Pau et al., 2015) and playing position (Bizid & Paillard, 2006; Pau et al., 2014b) and can be enhanced with properly designed training programs (Cè et al., 2018; Gioftsidou et al., 2012). In this context, the existence of better postural control might be considered an indirect indicator of performance (Edis, Vural, & Vurgun, 2016) and

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https://doi.org/10.1016/j.ptsp.2018.11.002
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propensity to injuries.

Nevertheless, there is a certain lack of clarity about the way balance tests should be interpreted and the most suitable modalities for administering them. Recent studies appear to agree that static and dynamic postural control are scarcely related and thus reflect different abilities (Krkeljas, 2018; Pau et al., 2015; Ringhof & Stein, 2018). While most previous studies on soccer players have been performed under static conditions (either in uni- or bipedal standing), recent research tends to adopt more appropriate metrics such as Time to Stabilization (TTS, McKinley & Pedotti, 1992; Colby, Hintermeister, Torry, & Steadman, 1999) and Dynamic Postural Stability Index (DPSI, Wikstrom, Tillman, Smith, & Borsa, 2005) which are essentially associated with the ability of individuals to stabilize their bodies after a forward jump starting from a bipedal position and ending with a single leg landing. Although fundamentally laboratory-based, such measures are considered more adequate in describing abilities useful in actual game situations.

Considering that young elite players are characterized by superior technical and motor skills (Rebelo et al., 2013; Abdullah et al., 2017; Bekris, Gissis, Ispyrlidis, Mylonis, & Axeti, 2018), as well as physical fitness with respect to sub-elite players, it appears of interest to clarify whether competitive level is somehow associated with superior postural control system performances or not. Thus, the aim of the present study is to provide experimental data on static and dynamic postural control of young soccer players at national and regional levels, through analysis of single-leg static sway, TTS and DPSI. The hypothesis to verify is that one (or more) quantitative parameters that reflect balance abilities assume different values among elite and sub-elite level athletes.

2. Methods

2.1. Participants

In the period September–December 2017, 54 youth league players were recruited for the study on a voluntary basis. The participants belong to two teams, both located in Cagliari (Italy), which compete in the Under 16 and 17 championships respectively at national (Cagliari Calcio S.p.A.) and regional (San Francesco Quartu) levels. Their main anthropometric features are reported in Table 1. The dominant limb of each participant was defined by asking him his preference when kicking the ball. All the players regularly train either for 5 (national) or 4 (regional) 90-min sessions per week, plus a tournament match (all of them) during the competitive season, approximately from September–October to June, and were free from lower limb injuries in the six weeks prior to the test.

The study was carried out in compliance with the ethical principles for research involving human subjects expressed in the Declaration of Helsinki and was approved by the Departmental Review Board. Written informed consent was obtained from all participants and their parents after a detailed explanation of the purposes of the study and a description of the experimental methodology.

Table 1
Anthropometric features of participants. Values are expressed as means ± SD.

	National Level	Regional Level	p-value
Players (#)	28	26	–
Age (years)	16.1 ± 0.7	15.8 ± 0.6	0.067
Height (cm)	176.1 ± 6.8	170.5 ± 6.4	<0.001
Body Mass (kg)	65.0 ± 7.3	56.7 ± 6.9	<0.001
Body Mass Index (kg m^{-2})	20.9 ± 1.5	19.4 ± 1.8	<0.001
Dominant limb (R = right, L = left)	26 R, 2 L	22 R, 4 L	–

2.2. Data acquisition and post-processing

All experimental tests were performed using a force platform (BTS P6000, BTS Bioengineering S. p.A., Italy) set at 480 Hz frequency. Static balance was assessed by means of postural sway analysis performed on the basis of the COP time series acquired under unipedal stance conditions. The players were asked to perform three trials for each limb (e.g. dominant and non-dominant) in a random sequence, by standing barefoot on the plate, as still as possible for 20 s, with the supporting foot placed on the platform and the other leg raised in such a way as to have the suspended foot approximately at the supporting limb malleolus height while their arms were held crossed behind their backs. The COP time series were low-pass filtered (10 Hz cutoff; 4th-order Butterworth; bidirectional) and then post-processed with a custom-developed Matlab® routine to calculate the following sway parameters:

- sway area (95% confidence ellipse, expressed in mm^2)
- COP path length (i.e. the overall distance travelled by the COP during the trial, expressed in mm)
- COP maximum displacements (i.e. the difference between the maximum and minimum values of the selected coordinate recorded during the trial, expressed in mm) in the medio-lateral (ML) and antero-posterior (AP) directions.

Dynamic balance was assessed by means of vertical TTS (vTTS) and DPSI, as well as postural sway analysis performed during the post-landing stabilization phase. To this end, participants were required to jump forward over a hurdle 35 cm high from a starting line placed at a distance equal to 40% of their stature from the center of the platform (Sell, 2012; Williams et al., 2016) and land on a single limb being instructed to stabilize the body as quickly as possible (even with the help of their arms) and stand still in the arrival position for at least 10 s until they received a verbal signal marking the end of the trial (Fig. 1). Three valid trials per limb were acquired in this case as well.

Both GRF and COP time series were simultaneously collected. The first 3 s of the GRF curve from the initial contact (considering this as the time in which the GRF value exceeded 5% of body weight) were used to calculate the DPSI, according to the procedure described by Wikstrom et al. (2005), using the following relationship:

$$DPSI = \frac{\left(\frac{\sqrt{\sum(0-GRF_x)^2+\sum(0-GRF_y)^2+\sum(BW-GRF_z)^2}}{number\ of\ data\ points}\right)}{BW}$$

where BW is the individual's body weight, and GRFx, GRFy and GRFz are the three components of the GRF (in particular, x and y refer to the components lying in the plane of the force platform and z refers to the vertical component).

Instead, vTTS was computed as the time necessary for the sole vertical component of the GRF to reach and stay within ±5% of body weight after landing on the force platform (McKinley & Pedotti, 1992). The COP time series associated with the 10 s period elapsed from the initial contact on the platform were processed to obtain the post-landing sway parameters in a way similar to what was previously described for the static condition.

Participants were allowed to familiarize with the equipment and the posture/movements required to perform the tests prior to final data collection. The mean value of the three trials was calculated and considered representative of each condition investigated. All tests were carried out in a quiet dedicated room at the same

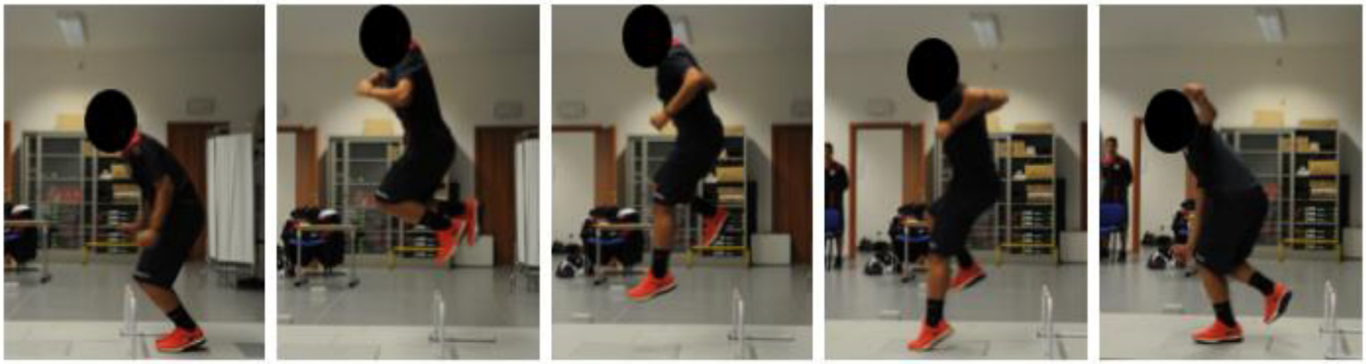

Fig. 1. Example of forward jump performed by the soccer players.

time in the morning with participants well-rested.

2.3. Statistical analysis

Two-way multivariate analyses of variance (MANOVA) were carried out on the three datasets obtained from the static (sway) and dynamic (DPSI/vTTS, sway) test experiments following verification of parametric model assumptions (e.g., normality, homogeneity, and presence of outliers). In all cases the independent variables were the level of competition (national/regional) and limb (dominant/non-dominant) while the dependent variables were 4 in the case of postural sway (sway area, COP path length, COP maximum displacements in AP and ML direction) and 2 (DPSI and vTTS) for the dynamic balance parameters. The level of significance was set at $p = 0.05$, and effect sizes were assessed using the eta-squared coefficient (η^2). Follow-up analyses were carried out using separate two-way ANOVAs for each dependent variable by reducing the level of significance after a Bonferroni adjustment for multiple comparisons.

3. Results

The results of static tests are reported in Table 2, while Table 3 summarizes the dynamic balance (vTTS and DPSI) and post-landing postural sway parameters.

Under static conditions, MANOVA detected no significant difference in postural sway parameters associated with either competition level [$F(4,101) = 0.20$, $p = 0.936$, Wilks $\lambda = 0.99$, $\eta^2 = 0.008$] or limb [$F(4,101) = 0.43$, $p = 0.784$, Wilks $\lambda = 0.98$, $\eta^2 = 0.017$]. Moreover, no significant group × limb interaction was found $F(4,101) = 0.705$, $p = 0.590$, Wilks $\lambda = 0.97$, $\eta^2 = 0.027$].

In contrast, a significant effect of group was detected for the tests performed under dynamic conditions [$F(4,101) = 7.24$ $p < 0.001$, Wilks $\lambda = 0.78$, $\eta^2 = 0.22$] while again no effect of limb [$F(4,101) = 0.85$ $p = 0.499$, Wilks $\lambda = 0.97$, $\eta^2 = 0.03$] or group × limb interaction [$F(4,101) = 7.24$ $p = 0.883$, Wilks $\lambda = 0.97$, $\eta^2 = 0.03$] were found. In particular, national-level players exhibited significantly smaller vTTS (average value of two limbs 0.887 vs. 1.158 s, $p = 0.003$) and DPSI (0.327 vs. 0.373, $p < 0.001$) in comparison with those at regional level. The analysis of post-landing postural sway revealed that elite players exhibit a COP path length 15% shorter (607.5 vs. 712.5 mm, $p = 0.008$).

4. Discussion

The purpose of the present study was to investigate the possible role played by competitive level on static and dynamic balance performance of young soccer players to understand if, similarly to what has previously been observed for physical fitness and technical skills (Rebelo et al., 2013), the constant exposure to superior challenging training and match conditions influences postural stability. Although our attention was mainly focused on dynamic balance abilities, which are likely to better reflect actual game conditions, we also tested players under static conditions to have a term of comparison with previous similar studies which, in most cases, analyzed only this aspect. The main findings derived from our analysis can be summarized as follows: players who compete at national level exhibit a significantly lower DPSI score and vTTS, thus indicating a superior capability to stabilize the body after a jump with unipedal landing. In contrast, players of both groups exhibited similar postural sway values in the case of single leg static standing. The results of the post-landing sway analysis describe a sort of intermediate condition as all values were found lower in national level players, but only for the length of the COP trajectory was statistical significance achieved.

The analysis of postural sway under static conditions (mostly in the case of bipedal but also unipedal standing) has been employed in the last twenty years to obtain information about the balance performance of athletes vs. untrained subjects or to classify the abilities associated with a specific discipline, with mixed results (Paillard, 2017). In fact, while there is a certain consensus that athletes sway less than untrained individuals (Kiers, Van Dieën,

Table 2
Postural sway parameters for single leg static standing. Values are expressed as means ± SD.

Static balance parameters	Dominant Limb		Non-dominant Limb		*Limb p-value*	*Team p-value*	*Limb x Team p-value*
	National Level	Regional Level	National Level	Regional Level			
Sway Area (mm^2)	697.75 ± 247.29	694.38 ± 227.24	735.38 ± 224.23	703.69 ± 185.33	0.585	0.896	0.862
COP Path Length (mm)	669.35 ± 136.92	689.58 ± 134.24	692.14 ± 173.23	668.92 ± 140.95	0.970	0.958	0.446
COP Max Disp ML (mm)	33.14 ± 5.06	33.43 ± 4.90	33.19 ± 5.47	33.15 ± 4.61	0.907	0.896	0.862
COP Max Disp AP (mm)	42.66 ± 7.52	43.38 ± 10.44	46.35 ± 11.27	43.24 ± 7.33	0.325	0.508	0.288

Table 3
Dynamic Postural Stability Index (DPSI), vertical Time to Stabilization (vTTS) and postural sway parameters calculated during the post-landing stabilization phase. Values are expressed as means ± SD.

Dynamic balance parameters	Dominant Limb		Non-dominant Limb		*Limb p-value*	*Team p-value*	*Limb x Team p-value*
	National Level	Regional Level	National Level	Regional Level			
DPSI 3s[a]	0.329 ± 0.048	0.365 ± 0.044	0.325 ± 0.048	0.383 ± 0.050	0.434	**<0.001***	0.250
vTTS (s)[b]	0.854 ± 0.345	1.197 ± 0.548	0.921 ± 0.305	1.119 ± 0.590	0.414	**0.003***	0.414
Sway Area (mm^2)	2808.30 ± 1644.03	3602.55 ± 2067.81	2987.31 ± 1643.43	3871.81 ± 2067.81	0.527	0.019	0.899
COP Path Length (mm)	594.88 ± 138.51	720.04 ± 238.80	621.21 ± 166.60	705.11 ± 243.37	0.883	**0.008***	0.594
COP Max Disp ML (mm)	126.34 ± 33.12	133.04 ± 32.90	120.78 ± 36.52	133.77 ± 31.83	0.752	0.117	0.588
COP Max Disp AP (mm)	54.83 ± 23.49	65.37 ± 32.55	59.54 ± 26.96	65.51 ± 37.27	0.680	0.161	0.697

The symbol * denotes a significant effect of the factor after Bonferroni correction (p = 0.008); [a,b] lower values denote a better performance.

Dekkers, Wittink, & Vanhees, 2013), in some cases the observed differences have been either limited to one or few parameters or restricted to specific testing conditions (i.e. absence of visual input, soft surfaces, etc.). Such a lack of differences has been explained by the fact that balance abilities specifically required to perform certain technical gestures cannot be straightforwardly transferred to a simple motor task such as quiet bipedal standing. In other words, quiet standing tests are rather insensitive in detecting subtle differences between groups (Kiers et al., 2013; Paillard, 2017). In this context, our results obtained under unipedal static conditions, which show that elite and regional level players are characterized by the same postural sway values in agreement with previous studies carried out on gymnasts, alpine skiers, judoists and samboists (Asseman, Caron, & Crémieux, 2008; Melnikov, Savin, Emelyanova, Nikolaev, & Vikulov, 2011; Noé & Paillard, 2005; Paillard et al., 2002, 2006). In all these cases the authors failed to detect a superior performance of the postural control system except under very specific conditions, often similar to those of actual competition. Only the study by Paillard and Noé (2006), who tested adult professional and amateur soccer players, revealed a significant lower sway area and COP velocity in the professional group, both in presence and absence of visual input. It may be that such an apparently contrasting result is due to relevant differences in the weekly training load. In fact, it is known that professional soccer players train 12–14 h/week, usually divided into 5–7 sessions (depending on season period) while in the case of amateur players at regional level such value drops to 6 h/week (Cloak, Nevill, & Wyon, 2016; Cometti, Maffiuletti, Pousson, Chatard, & Maffulli, 2001; Ricotti, Rigosa, Niosi, & Menciassi, 2013).

In contrast, we observed significant differences in terms of better dynamic stability in national level players as expressed by both DPSI and vTTS. The importance of adopting dynamic tests to assess balance of athletes was highlighted in the last decade by considering several main factors namely: 1) in most disciplines (except pistol/rifle shooting and archery) static standing is not a realistic condition encountered during the performance (Williams et al., 2016), 2) postural control under static and dynamic conditions are not correlated, as demonstrated in the general case of physically active adults (Sell, 2012; Fransz, Huurnink, Kingma, & van Dieën, 2014) and in the specific case of elite adult and young soccer players (Pau et al., 2015) and 3) dynamic tests based on landing from a jump are the most suitable for identifying athletes with ankle instability issues (Wikstrom, Tillman, Chmielewski, Cauraugh, & Borsa, 2007; Fransz, Huurnink, Kingma, Verhagen, & van Dieën, 2013). To date, DPSI has proven able to detect gender-related differences in dynamic stability (Dallinga, van der Does, Benjaminse, & Lemmink, 2016), identify individuals with functional ankle instability (Wikstrom et al., 2007), assess the effectiveness of home-based balance training and whole-body vibration protocols (Cloak et al., 2016; De Ridder, Willems, Vanrenterghem, & Roosen, 2015). However, to the author's knowledge, DPSI has never been used to characterize dynamic balance in young elite and sub-elite athletes, even though the study by Cloak et al. (2016) on the effect of vibration training previously mentioned tested two groups of adult professional and amateur soccer players. In that case, the authors detected that amateur players were characterized by poorer dynamic balance with respect to professional players (as indicated by a DPSI 15% higher) while no differences were found in the control group. Unfortunately, as this aspect was not the focus of the study, the authors did not discuss these results.

Our data suggest that even in the case of young players with limited experience the habit of training and competing with mates characterized by superior technical skills and physical characteristics develop better dynamic postural stability. The lack of previous similar studies makes a direct comparison with existing data difficult, but it is noteworthy that Butler, Southers, Gorman, Kiesel, and Plisky (2012) found better dynamic balance performance in professional soccer players with respect to high school and college athletes on the basis of the Lower Quarter Y Balance Test (a variation of the Star Excursion Balance Test) thus confirming that despite the difference in the measurement techniques competition level represent a key factor implicated in dynamic balance abilities. Moreover, a recent investigation performed by Williams et al. (2016) on active adults highlighted that dynamic postural stability is influenced by ankle flexibility and muscle strength at ankle and knee level. Although we performed no strength measurements, previous findings indicate that elite players are characterized by superior muscular strength of knee flexors and ankle dorsi-plantarflexors both as adults (Cometti et al., 2001; Maly, Zahalka, & Mala, 2014; Öberg, Moller, Gillquist, & Ekstrand, 1986) and youths (Gird & Coetzee, 2006; Gissis et al., 2006) with respect to non-elite athletes. It also appears that prolonged exposure to high-level competition environment enhances such differences (Fousekis, Tsepis, & Vagenas, 2010). It is thus reasonable to hypothesize that the combination of practicing and competing at high levels originates specific strength adaptations in the functioning of knee and ankle musculature (Fousekis et al., 2010), which results in improved dynamic postural stability. It is noteworthy that the DPSI values calculated in the present study are in good quantitative agreement with those reported in previous similar studies (De Ridder et al., 2015; Dallinga et al., 2016; Williams et al., 2016), thus confirming the robustness of this approach despite the unavoidable differences in terms of experimental conditions.

Finally, some considerations are in order regarding the choice of the most suitable parameter for quantitatively assessing dynamic stability. In this study we calculated both vTTS and DPSI, similar to what was carried out in previous investigations on soccer players (Cloak et al., 2016; Pau et al., 2016). The vTTS has the advantage that only the vertical component of the GRF is needed, and thus it can be measured using either a force or a pressure platform or even a lowcost device like the Nintendo Balance Board (Eguchi & Takahashi, 2018). In contrast, the DPSI also requires that the in-plane components of GRF be acquired. The findings of the present study suggest that both parameters are similarly sensitive to the difference in stabilization performance associated with different competition levels and thus, even when a force plate is not available, the sole vertical GRF data should provide sufficiently reliable information for classifying the dynamic balance abilities of players.

Some limitations of the study are to be acknowledged. Initially, we investigated the dynamic stability associated only with a forward jump landing. Although this is probably the most common case in actual matches, it is not the only one possible and thus, as also highlighted by Liu and Heise (2013), multiple jump-landing directions (i.e. lateral, medial and backward) should be tested to have a complete overview of athletes' dynamic stability. The second important limitation is represented by the fact that we tested only players of the Under 16 and Under 17 categories, and thus our results are not generalizable to all youth leagues. It would be of interest to understand whether the differences in dynamic balance abilities associated with competition level that we observed in the present study are present from the early stages of agonistic activity or if they rather emerge at some point of the player's maturation process. Finally the group of national-level players was characterized by significantly higher values of stature and body mass, a fact that was to be expected, considering that the selection of elite players is based, among other factors, also on their physical features (le Gall, Carling, Williams, & Reilly, 2010). Such differences were not taken into account in the analysis of balance parameters.

5. Conclusions

Young soccer players who compete at national level exhibit better dynamic postural stability than those at regional level, as indicated by lower values of DPSI and vTTS calculated for a forward-jump landing. In contrast, the postural sway calculated for one-leg static standing is similar in both groups. Such results suggest that although static balance tests might to some extent represent basic balance abilities and associate with a propension to lower limb injuries, dynamic postural control appears more suitable for describing the attitude of players to stabilize their bodies after an external perturbation and, as such, better related to performance under actual match conditions.

The differences observed here in dynamic balance parameters depending on competition level, which are likely due to a combination of superior habit of training and competing in more challenging environments and better physical features and motor skills, could be included in the overall assessment of players during their maturation to improve the selection process of more talented players.

Future developments of the study should include a detailed kinematic analysis, together with suitable lower limb muscle strength assessment, to verify the influence of such aspects on landing and stabilization strategies and thus support the design of better and more efficient strength and conditioning training routines.

Conflicts of interest

All authors have approved the submission of this manuscript. There are no conflicts of interest to declare.

Ethical statements

All participants provided informed consent, and study protocol was approved by the departmental review board.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Acknowledgments

The authors wish to thank all the athletes who participated in the study, their coaches and parents. In addition, we acknowledge the Cagliari Calcio S.p.A. Club (Cagliari, Italy) and the San Francesco Club (Quartu S. Elena, Italy) for the invaluable support provided during the organization of test sessions.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2018.11.002.

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