

PROPRIOCEPTIVE TRAINING AND INJURY PREVENTION IN A PROFESSIONAL MEN'S BASKETBALL TEAM: A SIX-YEAR PROSPECTIVE STUDY

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ABSTRACT

Riva, D, Bianchi, R, Rocca, F, and Mamo, C. Proprioceptive training and injury prevention in a professional men's basketball team: A six-year prospective study. *J Strength Cond Res* 30(2): 461–475, 2016—Single limb stance instability is a risk factor for lower extremity injuries. Therefore, the development of proprioception may play an important role in injury prevention. This investigation considered a professional basketball team for 6 years, integrating systematic proprioceptive activity in the training routine. The purpose was to assess the effectiveness of proprioceptive training programs based on quantifiable instability, to reduce ankle sprains, knee sprains, and low back pain through developing refined and long-lasting proprioceptive control. Fifty-five subjects were studied. In the first biennium (2004–2006), the preventive program consisted of classic proprioceptive exercises. In the second biennium (2006–2008), the proprioceptive training became quantifiable and interactive by means of electronic proprioceptive stations. In the third biennium (2008–2010), the intensity and the training volume increased while the session duration became shorter. Analysis of variance was used to analyze the differences in proprioceptive control between groups, years, and bienniums. Injury rates and rate ratios of injury during practices and games were estimated. The results showed a statistically significant reduction in the occurrence of ankle sprains by 81% from the first to the third biennium ($p < 0.001$). Low back pain showed similar results with a reduction of 77.8% ($p < 0.005$). The reduction in knee sprains was 64.5% (not significant). Com-

paring the third biennium with the level of all new entry players, proprioceptive control improved significantly by 72.2% ($p < 0.001$). These findings indicate that improvements in proprioceptive control in single stance may be a key factor for an effective reduction in ankle sprains, knee sprains, and low back pain.

KEY WORDS balance training, neuromuscular training, ankle sprains, knee sprains, injury rates, low back pain

INTRODUCTION

An injury occurs when the stress applied to a tissue is greater than its ability to “absorb” the stress acutely or chronically (25). Among contact sports, the contemporary game of basketball emphasizes the speed and power of its competitors. Both frequency and intensity of the competition expose these athletes to potentially injurious forces (43). An analysis of 16 years (1988–2004) of National Collegiate Athletic Association (NCAA) injury surveillance data (9) found that ankle sprains were the most common injury overall and knee internal derangements were the most common injury causing athletes to miss more than 10 days of participation. In sports such as basketball, football, and volleyball, ankle sprains can present reinjury rates as high as 70–80% (32), leading to chronic ankle instability in 20–50% of these cases (48). A 17-year overview (1988–2005) of the National Basketball Association (NBA) showed that the most frequent game-related injuries were ankle sprains, occurring at a rate of 3.4 per 1000 athlete exposures (AEs). The next most frequent injuries were lumbar sprain or strain followed by knee sprains, occurring, respectively, at a rate of 1.1 and 0.8 per 1000 AEs (11).

Common interventions for preventing ankle sprains include tape, ankle braces, evolver muscle strengthening, and proprioceptive training (48). Although some studies have controversial results (21), most authors and several reviews and meta-analyses have proven that proprioceptive training is effective in decreasing ankle sprain recurrences significantly (30–50%) (2,5,12,27,30,41,49).

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Studies on training programs for knee sprain prevention mainly focused on anterior cruciate ligament (ACL) injuries. Most of these studies included multiple preventive training proposals and showed that they were generally effective in reducing this injury risk, whereas the role of the proprioceptive training remains controversial (14,24,39,44,45,46).

Studies to prevent low back pain (LBP) based solely on proprioceptive training have not been found. A recent review (18 studies) on the effectiveness of multifaceted training programs for LBP rehabilitation concluded that the benefit of adding proprioceptive training is unclear (26). Some authors found that subjects with LBP showed impaired single stance stability and longer trunk muscle response latencies to perturbation than healthy controls (23,29,33,35). Another study reported that single stance instability is a risk factor for recurrent LBP and lower extremity injury (42). These findings would support the hypothesis of a relationship between lower limb injuries and LBP.

Proprioception plays an important role in joint stability and injury prevention. According to Hootman et al. (16), although most studies aim to minimize injury to particular joints (e.g., ankles), research should be directed to define proprioceptive programs that are able to simultaneously prevent more than 1 type of injury.

Proprioceptive inputs are conveyed to different levels of the nervous system (36), but most remain unconscious, and only a very few reach the conscious level (37). The joint position sense and the joint movement sense are the expressions of the conscious component, whereas postural control is mainly based on the unconscious component (36). Proprioceptive control is the expression of the effectiveness of the stabilizing reflexes in controlling vertical stability (38). Single stance stability should be based on proprioceptive control (minimizing the visual and vestibular contribution) to guarantee the safety of basic movements such as walking, running, jumping, and performing refined motor skills while keeping the fluency of movements. In fact, world and Olympic champions of ground sports have very refined proprioceptive control in single stance (38).

Proprioceptive Misunderstanding

Despite the above considerations, in the literature, a specific definition of proprioceptive exercises (also called balance or neuromuscular training) does not exist (4,26). A broad typology of exercises is proposed as proprioceptive (12,27,32,41,49), but which characteristics should an exercise have to be classified as proprioceptive? Generally, the so-called proprioceptive exercises require the management of instability. The problem is that every movement and every posture could be defined as proprioceptive because each of them generates a proprioceptive flow. So, what is the threshold for calling an exercise “proprioceptive” and how can we assess different levels of proprioceptive involvement and effectiveness? In our opinion, an exercise should be classified by characterizing the mechanical typology of the instability,

the presence of an enhancer of the instability frequency, the tasks assigned to the subject, and the expected quantifiable outcomes. In this study, the requested outcome was a significant improvement in single stance stability by refining proprioceptive control (38).

The purpose of the study was to assess the effectiveness of single stance proprioceptive training programs based on high-frequency instability, to reduce ankle sprains, knee sprains, and LBP. We hypothesized that refined and enduring proprioceptive control in single stance would minimize the injurious forces and improve the capability of absorbing them, allowing better interaction with the ground.

METHODS

Experimental Approach to the Problem

This study attempted to determine whether quantifiable proprioceptive training proposals, based on single stance, can reduce the injury rates. Over the 6-year period from 2004 through 2010, the athletes of an Italian professional basketball team were monitored by measuring single stance stability and by collecting the data on injuries and exposures that occurred in organized practices and competitions. The injuries considered in this study were ankle sprains, knee sprains, and LBP.

The 6-year period was divided into three 2-year periods (each biennium consisted of 2 preseasons and 2 regular seasons), each characterized by different proprioceptive training programs.

In the first biennium (2004–2006), the preventive training program was based on classic proprioceptive exercises using rocking boards and unstable surfaces. In the second biennium (2006–2008), the proprioceptive training program became quantifiable and interactive by means of electronic postural proprioceptive stations. Single stance stability and proprioceptive control were periodically measured. In the third biennium (2008–2010), the intensity (density) of the proprioceptive training sessions was increased: the repetitions became progressively longer, and the recovery time between repetitions was minimized. Compared with the previous 2 bienniums, the actual training time increased, whereas the session duration became shorter.

Subjects

The subjects studied were 55 basketball players over a 6-year period participating in the First League Championship of the Italian Basketball Federation. The study was approved by the local ethical committee, and all subjects (ranging in age from 18 to 45) signed written informed consent before participation. The characteristics of the 55 athletes are summarized in Table 1. After the first year, the percentage of new entries each year varied from 66.7 to 75%. No significant differences were found when considering age, height, and body weight in the different years (or bienniums). Because a history of previous sprain has consistently been shown to be the most common predisposing

TABLE 1. Participant characteristics.*

Characteristics	2004–05	2005–06	2006–07	2007–08	2008–09	2009–10
No. subjects	12	12	12	12	12	12
Age (y)	27.8 ± 6.8	30.9 ± 6.4	27.9 ± 5.3	24.9 ± 3.7	26.0 ± 3.7	27.1 ± 5.3
Height (cm)	196.3 ± 12.4	195.4 ± 9.4	196.8 ± 9.9	196.7 ± 9.9	196.0 ± 10.1	196.4 ± 9.4
Body weight (kg)	95.0 ± 12.9	96.8 ± 13.3	96.3 ± 13.5	92.8 ± 12.2	95.3 ± 12.4	92.4 ± 13.1
New entries (%)	12 of 12 (100)	9 of 12 (75.0)	9 of 12 (75.0)	9 of 12 (75.0)	8 of 12 (66.7)	8 of 12 (66.7)

*Values are mean ± SD.

factor in an athlete who sustains an ankle sprain (3), the occurrence of previous ankle sprain was investigated. More than 85% of the athletes stated a history of at least 1 ankle sprain and 74% of them reported recurrent sprains to 1 ankle. This occurrence is consistent with previous reports on elite basketball players (22,32).

Procedures

The same strength and conditioning coach managed the proprioceptive training protocols over the 6 years of the study.

Instruments. The stability tests and the training were performed by means of electronic postural proprioceptive stations (DPPS; Delos, Turin, Italy) (6). Each station, con-

nected to a personal computer with specific software (DPPS 5.0), included an electronic rocking board, an electronic postural reader, an infrared sensor bar, and a display. In case of risk of falling, the subject could touch the bar placed in front of him to regain vertical control rapidly. The bar was equipped with an infrared sensor that is able to indicate when the subject touched it for support. None of the subjects needed to use the support of the sensor bar. The electronic postural reader (Delos Vertical Controller), applied to the sternum, measured the trunk inclination in the frontal (x) and sagittal plane (y) by means of a 2-dimensional accelerometer unit. The electronic rocking board (Delos Equilibrium Board) had a single degree of freedom on the frontal plane (range of motion: ±15°) and measured the inclination of its moving plate. Table 2 shows the characteristics of the rocking board (40).

Algorithms. The data from the postural reader and the rocking board are a stream of acceleration samples taken by converting into the digital domain the sensor outputs, at a rate of 100 Hz. These raw data were initially averaged with a 4-tap sliding window, so the 3 dB bandwidth was narrowed to approximately 11 Hz. A scaling with the calibration data of the instruments was then performed to convert the raw data into angles. For the rocking board,

$$\varphi(i) = \left(\frac{dt(i) - dt_{-15}}{dt_{+15} - dt_{-15}} - 0.5 \right) \cdot 30, \quad (1)$$

where φ is the angle of inclination of the plate of the board, $dt(i)$, $dx(i)$, and $dy(i)$ are the generic elements of the raw data stream, whereas those with the numerical indexes are calibration data taken at the mechanical limits of the instrument. The rocking error (RE) indicates the average inclination of the board in relation to the horizontal plane,

$$RE = \frac{1}{n} \sum_{i=1}^n |\varphi(i)|. \quad (2)$$

The equations involved in the management of the data coming from the postural reader have been described in a previous article (37). The postural assessment was based on

TABLE 2. The characteristics of the rocking board.*

Board characteristics	
Typology of instability	Rocking
Rolling structure	Section of a cylinder
Radius of the rolling structure	55 mm
Distance of the plantar surface from the ground	50 mm
Degrees of freedom	1 (single axis)
Range of motion	
Mobile roll axis (x)	
Inclination	±15°
Rolling	≈ 30 mm
Mobile pitch axis (y)	
Inclination	0°
Rolling	0°
Yaw axis (z)	
Rotation	0°
Frequency enhancer	Feedback and feedforward

*The rocking motion is a complex movement that includes the rolling of a cylindrical surface and the consequent inclination of the moving plate.

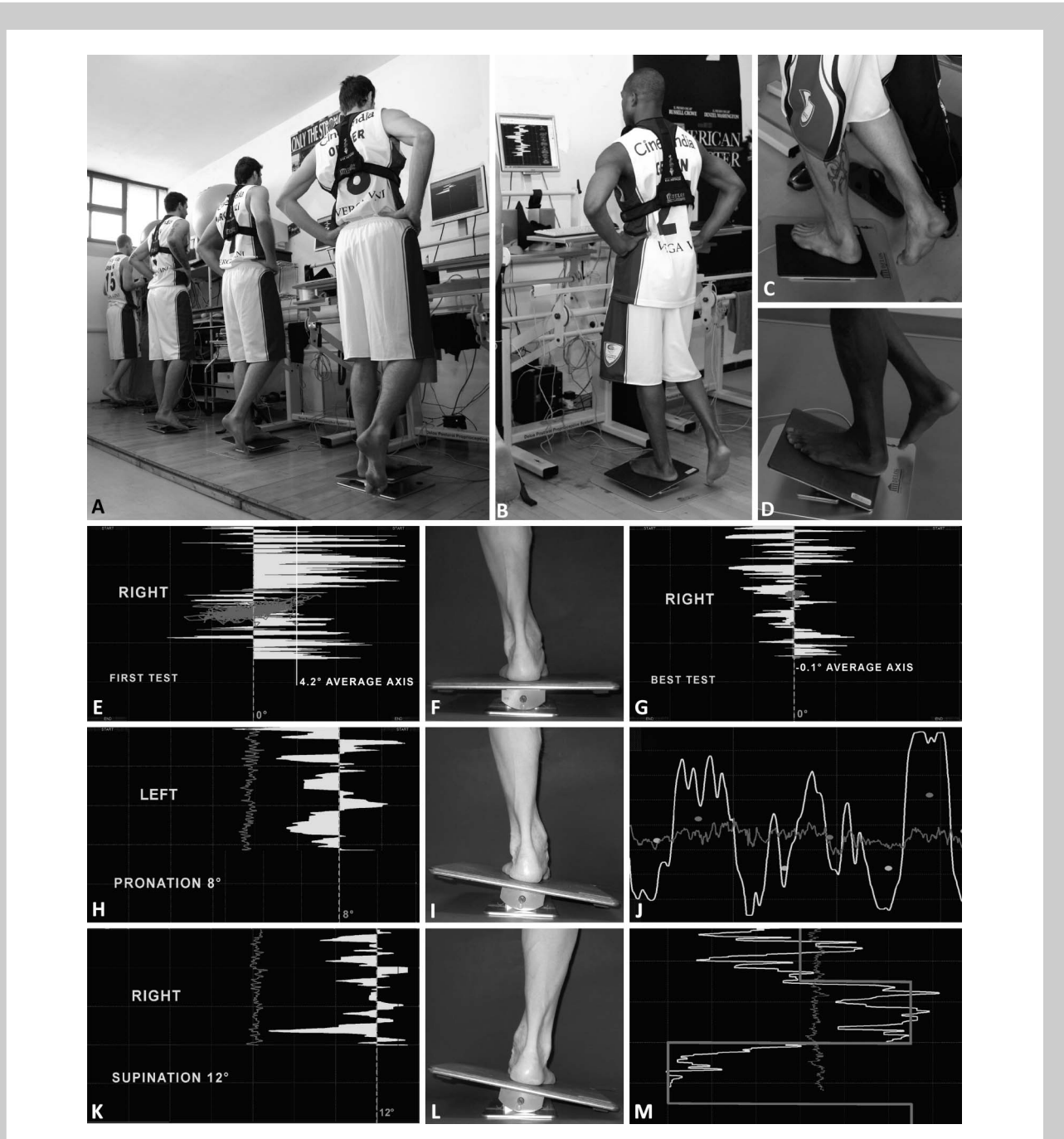


Figure 1. A and B, A proprioceptive training session. C, Orientation of the rocking base at -45° to affect different ranges of motion. D, Maintaining vertical stability with the weight-bearing ankle in maximum dorsiflexion. E, The real-time trace (yellow bars) of the rocking base (F) and the trace of the postural reader (blue line). Note the hypersupination in the first test of the season vs. the best test (G). H and I, Dynamic exploration of the ankle range: attempting to maintain 8° of inclination (pronation, eversion). K and L, Attempting to maintain 12° of inclination (supination, inversion). In both cases, the players were asked to minimize postural instability (blue line). J, Performing slalom by moving the rocking base on the sagittal plane (anterior and posterior). M, After the target line by moving the rocking base (yellow line) side-to-side (alternating supination and pronation).

the measure of the postural instability (PI), which derives from the average instability in the frontal and sagittal planes. PI_{xy} (expressed in degrees) is an indicator of the average amplitude of the postural cone of instability.

Single Stance Stability Assessment. Single stance stability was assessed with a static single stance test (ST) and a dynamic single stance test (DyT). Static test was performed with eyes open (EO) and closed (EC). The subject, barefooted, was

asked to minimize PI_{xy} (amplitude of the postural cone) while staying in single stance on a stable wooden surface. The subject was looking at a display that showed the count-down before each trial, the eye condition requested, and which foot was to be used as support. No feedback on postural stability was given during the tests. The sequence proceeded automatically. Each trial lasted 20 seconds followed by a pause of 15 seconds. Static single stance test consisted of 6 trials (2 with EO and 4 with EC), in an alternate sequence of the left and the right limb. The average of the 2 limbs for all variables was considered.

During DyT, the subject was asked to minimize postural instability while staying in single stance on the electronic rocking board with 1 degree of freedom, maintaining the board as close as possible to the horizontal plane. The subject was looking at the display that showed in real time the inclination of the rocking board with respect to the horizontal plane. The athlete, barefooted, adopted the prescribed single limb stance as in ST. Each trial lasted 30 seconds. Four trials were performed on each leg in an alternate sequence of the left and the right limb. PI_{xy} and RE were assessed. The sum of PI_{xy} and RE represents the entropy (EN) of the system and is expressed in degrees. The term entropy derives from thermodynamics and is used, in its broad meaning, as a measure of the disorder of a system and consequently of its efficiency. Very low entropy in postural control is

indispensable to perform refined motor skills (38). The best trial out of 2 for each leg was considered. The parameters to classify trials were in order of priority: EN, PI_{xy} , and RE.

The postural reader was metrologically characterized through a calibration for comparison with a reference triaxial microelectro-mechanical systems accelerometer used as reference standard. This standard was calibrated at INRIM, the National Metrology Institute (NMI) of Italy, with a procedure that was validated through a comparison with other NMIs. From the calibration results, it was evaluated that the expanded uncertainty (with a confidence level of 95%) of the postural reader is 0.1° within the operative and calibration ranges (40).

Proprioceptive Training Protocols. In the first biennium (2004–2006), the preventive training program consisted in classic proprioceptive exercises using rocking boards and unstable surfaces. From the beginning of the second biennium (2006–2008), the proprioceptive training was based on the active management of high-frequency rocking instability (rolling + inclination) of the board (Figures 1A,B,F). The real-time visual trace on the monitor (it is the feedback of the rocking movements of the base and acts as feedforward) tracks the subject and notably increases the frequency of corrections (inversions) of the rocking platform inclination (Figures 1B, E,G). On the same rocking base, without visual feedforward, the same subject would experience instability only at low

TABLE 3. Proprioceptive training characteristics and goals of the 6-year period using a classic proprioceptive proposal (first biennium), high-frequency instability (second biennium), and coupling hyperfrequency and high-density proprioceptive training (third biennium).*†

	Unit	First biennium	Second biennium		Third biennium	
		2004–2005	2006	2007	2008	2009
Proprioceptive training characteristics		2005–2006	2007	2008	2009	2010
Proprioceptive control		No	±	+		+
Proprioceptive endurance		No		No		+
Structural remodeling		No		No		+
Frequency of instability		Low		High		Very high
Proprioceptive stations (n)		–	●● (2)	●●●● (5)		●●●● (5)
Single session duration	min	20 ± 5	15 ± 5	25 ± 5	15-20-25	12-18-24
Weekly session number		2–3		2–4		2–4
Weekly PT time	min	50 ± 10	35 ± 10	60 ± 10	50 ± 5	10-5
Intertrial recovery time	s	NA		20		10-5
Weekly actual PT time	min	NA	17 ± 5	35 ± 5		45 ± 5
Density	%	NA		Low (<50)		High (>85)
PT time‡	h	20–30	10–20	15–30		15–30
Actual PT time‡	h	NA	5–10	7–15		13–26
Coach commitment‡	h	66–72	60–70	90–110		90–110
Rocking inversions‡		NA	65,000	150,000	200,000	250,000
			150,000	300,000	450,000	550,000

*PT = proprioceptive training; NA = not applicable.
 †Density = actual PT time per session duration.
 ‡9-month period.

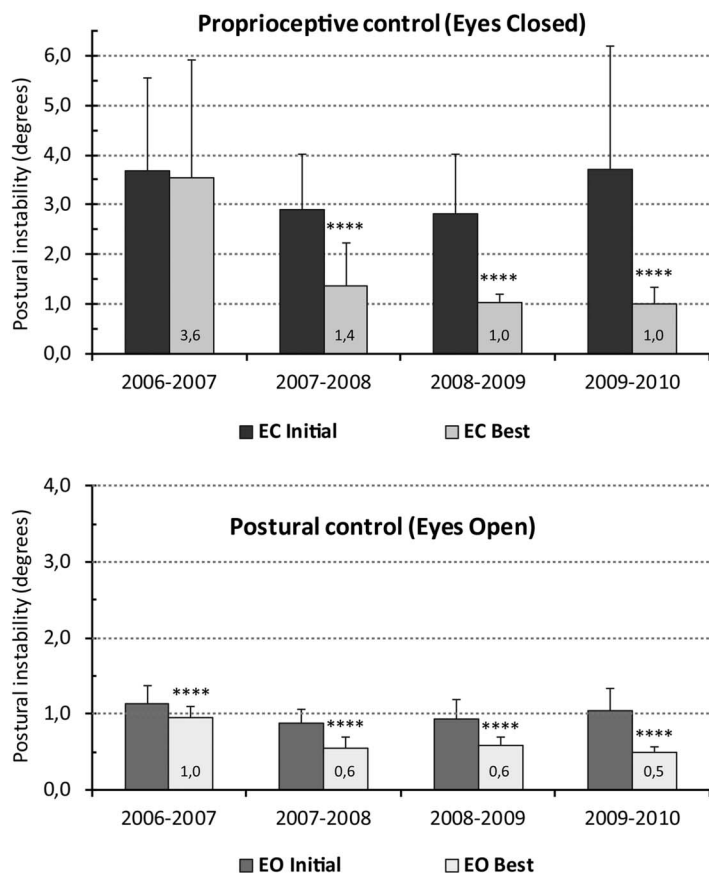


Figure 2. Static single stance test (ST). Annual variations in proprioceptive control and postural control in the second (2006–2008) and third bienniums (2008–2010). EO = eyes open; EC = eyes closed. Mean ± SD; *****p* < 0.001.

frequencies. The postural reactions change from macroamplitude at low frequency to microamplitude at high frequency (Figures 1E,G). The instability of the rocking base and the resulting postural instability of the subject were recorded. In summary, the second biennium was characterized by the use of electronic proprioceptive stations that introduced 3 new key concepts:

- high-frequency instability of the rocking base (the athlete’s interaction with the visual feedforward increases the frequency of correction of board inclination and rolling, creating many more situations to be managed);
- feedback of the vertical control;
- assignment of specific tasks concerning board control and postural control (Figures 1E–Q).

The exercises with the rocking base were performed in various orientations of the support surface to affect different ranges of motion of the ankle (Figures 1B,C). The sessions consisted of a sequence of repetitions lasting 30 seconds, alternating the left and right limbs. The recovery period between repetitions was 15 seconds.

The third biennium (2008–2010) introduced some quantifiable changes in exercise intensity, session duration, task assignments, and visual feedforward, whereas surfaces and exercise typology remained the same. The additional features were:

- Progressively longer repetitions (which reached a maximum duration of 60 seconds) and minimized recovery time. These changes increased the “training density” (actual training time per session duration) from 45 to over 85%. With respect to the previous 2 bienniums, the actual training time increased while the sessions became shorter.
- Tasks for exploring the ankle range of motion dynamically: the visual information allowed for the assignment of specific tasks, such as maintaining the rocking base at an inclination corresponding to a certain level of pronation (4°–8°, Figures 1H,L) or supination (4°–12°, Figures 1N,P) or passing from one inclination to another (Figure 1Q).

- Hyperfrequency instability: more details of the rocking movement were shown by zooming the trace on the display. The greater number of details led the subject to further increase the frequency of correction.

The proprioceptive training sessions of the third biennium consisted of a sequence of trials lasting 30–60 seconds, alternating the left and right limbs. The recovery period between repetitions decreased progressively from 15 to 5 seconds. The athletes mainly performed 3 types of proprioceptive training sessions characterized by the following goals, durations, and intensity:

- proprioceptive control: 18 ± 5 minutes (density <50–80%),
- enduring proprioceptive control and structural resilience: 25 ± 5 minutes (density ≥85%),
- proprioceptive activation (pre-match and pre-training): 8–12 minutes (density 70–80%).

In the 3 bienniums, the overall compliance of all players to the program was 100%.

The characteristics and goals of the proprioceptive training program over the 6-year period are shown in Table 3.

Indicators of Proprioceptive Control in Static Test. The PI_{xy} (postural instability or cone amplitude) of EO trials was taken as an indicator of postural control (all sensory channels open), whereas the PI_{xy} of EC trials was considered an indicator of proprioceptive control. Low values of postural instability in EC trials correspond to refined proprioceptive control (narrow cones) because they are the expression of effective proprioceptive reflexes that are able to stabilize the subject rapidly before the vestibular responses can be activated (37). Higher values of PI_{xy} (wider cones) in EC trials may include the intervention of the vestibular system, but they are in any case the expression of rougher proprioceptive control. In fact, as the vestibular system has a higher threshold of intervention and takes longer before becoming active, it can intervene only if proprioceptive control is not refined and, therefore, permits a longer period for activation (37).

Injury Data. All injuries were recorded, but those considered in this study were ankle sprains, knee sprains, and LBP occurring from the first day of preseason to the end of the regular season. These injuries are the most frequent game-related injuries in professional basketball players (11,43) and all are related to single stance instability (23,29,33,35,42). Each subject was free of injuries at the start of the season. Data regarding the number of practices and games missed and the support devices worn were also collected. A reportable injury, according to the injury surveillance system, was defined as one that occurred in an organized practice or competition and required medical attention by an athletic trainer or physician and resulted in a game or practice being missed (11,43). A reportable AE was defined as 1 athlete participating in 1 practice or competition, regardless of the time associated with that participation. Only athletes with actual playing time in a competition were counted as having game exposures. Only the competitions of the regular season were classified as games. The injury rate was expressed per 1000 AEs (9,20). Because AEs do not take into account the length of time an athlete is actually participating, an additional method was used to calculate game-related injury rate. Considering that each game represents 200 total minutes of competition (5 players on the court for 40 minutes), 10,000 competition minutes (CMs) would then represent 5 players competing in 50 games. Incidence rates for CMs were calculated using the formula: number of injuries (group)/total game minutes played (group) * 10,000 (43).

Statistical Analyses

The means and the standard deviations of every test were measured, stratifying by season. Analysis of variance (ANOVA) was used to analyze the differences between group means, between years and between bienniums. When comparing the results of the same athletes (initial test results vs. best test of the season), the repeated-measures ANOVA

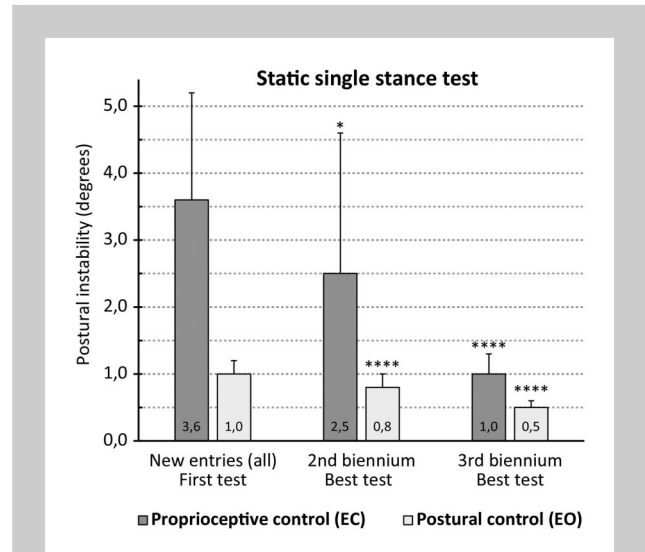


Figure 3. Static single stance test (ST). Significant improvements in proprioceptive control (EC) and postural control (EO) in the second and third bienniums vs. the initial test of all new entry players (all years). EO = eyes open; EC = eyes closed. Mean \pm SD; **** $p < 0.001$; * $p \leq 0.05$.

was used. The value of $p \leq 0.05$ was considered to indicate statistical significance. For each biennium, injury rate was expressed as the number of injuries (by category and anatomic site) per 1000 AEs (or 10,000 CMs) (9,20) and compared with rate ratio (RR) and 95% confidence interval (CI). Rate ratios were computed by dividing the injury rate in the second or third biennium by the injury rate in the first biennium (taken as comparison group).

Linear regression was used to analyze the trend of injuries over the 6-year period. The equation of the regression line was also calculated. How well this equation describes the

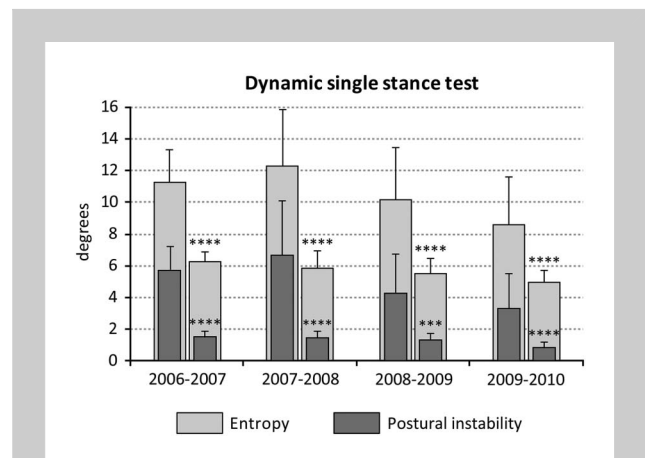


Figure 4. Dynamic single stance test. Annual variations in entropy (disorder of the system) and in one of its components: Postural instability (PI_{xy}) in the second and third bienniums. Each pair of columns represents the initial test (left) and the best test of the season (right). Mean \pm SD; **** $p < 0.001$; *** $p < 0.005$.

TABLE 4. The occurrence of ankle sprains in the three bienniums.*

Period	n	Ankle sprains										RR	95% CI
		Game-related				Practice-related				Overall			
		Rate x 1000 AEs	%†	Rate x 10,000 CMs	%†	n	Rate x 1000 AEs	%†	N	Rate x 1000 AEs	%†		
2004-2006	5	8.0	–	3.7	–	23	2.9	–	28	3.3	–	1	–
2006-2008	2	3.1	–61.6	1.5	–60.0	10	1.2	–57.7	12	1.4	–58.3	0.42	0.21–0.82
2008-2010	1	1.9	–76.8	0.9	–76.6	5	0.6	–81.0	6	0.6	–81.0	0.19	0.08–0.46

*AEs = athlete exposures; CMs = competition minutes; RR = rate ratio; CI = confidence interval.
 †Percentage of decrease vs. first biennium.

data is expressed as a coefficient R^2 (R-squared): the closer R^2 is to 1.00, the better the line fits the data (LabWrite, NC State University, 2004). All analyses were performed using Analyse-it for MS Excel Method Validation Edition (version 3.90.5), 2014 (Analyse-it Software, Ltd., Leeds, UK).

RESULTS

Considering the duration of the study and the complexity of applying long-term training protocols to a professional team, we will present not only the variations in stability between the bienniums but also the annual variations, to better understand how the methodology becomes progressively more effective.

Static Single Stance Test

Considering the 6 trials of a test, PI_{xy} was calculated for EO (indicator of postural control) and for EC (indicator of

proprioceptive control) from the following combinations of trials: the average between the 2 limbs of EO trials and the average between the 2 limbs of the better EC trial for each limb (37). The variations in proprioceptive control and postural control are shown in Figure 2. Comparing the first test with the best test of the season, postural control improved significantly ($p < 0.001$) in each of the 4 seasons with the proprioceptive training proposals based on quantifiable high-frequency instability. Instead, the improvement in proprioceptive control was not significant in the first season (2006–2007) but became significant in each of the following 3 seasons.

Comparing the first test of all new entries of the last 4 years with the best test of the second biennium (Figure 3), both proprioceptive control and postural control improved significantly ($p < 0.005$ and $p < 0.001$, respectively). In the third biennium, there was a further improvement with respect to the second biennium. The increase became highly significant for both proprioceptive and postural controls ($p < 0.001$). In the third biennium, proprioceptive control improved by 72.2% and postural control by 50% with respect to the level of all new entries of the last 4 years (both $p < 0.001$).

New Entries vs. Veterans

Proprioceptive control did not show significant differences when comparing the initial stability tests of the new entry athletes of the last 4 years. Proprioceptive control showed

TABLE 5. The occurrence of knee sprains in the three bienniums.*

Period	n	Knee sprains			
		Overall			
		Rate x 1000 AEs	%†	RR	95% CI
2004-2006	5	0.59	–	1	–
2006-2008	4	0.46	–22.2	0.78	0.21–2.90
2008-2010	2	0.21	–64.5	0.36	0.07–1.83

*AEs = athlete exposures; RR = rate ratio; CI = confidence interval.
 †Percentage of decrease vs. first biennium.

TABLE 6. The occurrence of back pain in the three bienniums.*

Period	Low back pain				
	Overall				
	<i>n</i>	Rate x 1000 AEs	%†	RR	95% CI
2004	20	2.4	–	1	–
2006	9	1.0	–56.2	0.44	0.20–0.96
2008	5	0.5	–77.8	0.22	0.08–0.59
2010					

*AEs = athlete exposures; RR = rate ratio; CI = confidence interval.
 †Percentage of decrease vs. first biennium.

practice-related injury, occurring in the first biennium (2004–2006) at a rate of 8.0 per 1000 AEs in games and 2.9 per 1000 AEs in practices. In the second biennium, the rate of the game-related and practice-related ankle sprains decreased to 3.1 (–61.6%) and 1.2 (–57.7%), respectively. In the third biennium, a further decrease was observed, which is more evident for the practice-related rate (0.6 per 1000 AEs, –55.2% vs. 1.9 per 1000 AEs, –39.5%). Comparing the first and third bienniums, the cumulative decrease

was –76.8% for the game-related ankle sprains and –81.0% for those practice-related. These results were confirmed when considering the CMs to calculate the incidence rate of game-related ankle sprains. Considering together the game-related and practice-related ankle sprains, the risk of sustaining an ankle injury was reduced, from the first to the third biennium, by 81% (RR = 0.19; 95% CI: 0.08–0.46; *p* < 0.001).

Dynamic Single Stance Test

The average of the 2 limbs was calculated considering the best trials of each limb. The variations in entropy, postural instability, and RE are shown in Figure 4. Entropy and PI_{xy} decreased significantly in each of the last 4 seasons, whereas the changes in RE were not significant. Comparing the second with the third biennium, the decrease in entropy (indicator of visual-proprioceptive control) and postural instability was highly significant (*p* < 0.01 and *p* < 0.005, respectively). In the third biennium, entropy decreased by 54.8% and postural instability by 80.7% with respect to the level of all new entries of the last 4 years (both *p* < 0.001).

Injury Occurrence

The occurrence of ankle sprains is shown in Table 4. Ankle sprains were the most frequent game-related and

practice-related ankle sprains, occurring in the first biennium (2004–2006) at a rate of 8.0 per 1000 AEs in games and 2.9 per 1000 AEs in practices. In the second biennium, the rate of the game-related and practice-related ankle sprains decreased to 3.1 (–61.6%) and 1.2 (–57.7%), respectively. In the third biennium, a further decrease was observed, which is more evident for the practice-related rate (0.6 per 1000 AEs, –55.2% vs. 1.9 per 1000 AEs, –39.5%). Comparing the first and third bienniums, the cumulative decrease

was –76.8% for the game-related ankle sprains and –81.0% for those practice-related. These results were confirmed when considering the CMs to calculate the incidence rate of game-related ankle sprains. Considering together the game-related and practice-related ankle sprains, the risk of sustaining an ankle injury was reduced, from the first to the third biennium, by 81% (RR = 0.19; 95% CI: 0.08–0.46; *p* < 0.001).

The small number of game-related knee sprains suggested considering the overall trend. The occurrence of knee sprains (Table 5) showed a rate of 0.59 per 1000 AEs in the first biennium, decreasing to a rate of 0.46 per 1000 AEs (–22.2%) in the second period, and presenting a further decrease in the third biennium to a rate of 0.21 per 1000 AEs (–54.3%). The risk of sustaining a knee sprain was reduced from the first to the third biennium by 64.5% (RR = 0.36; 95% CI: 0.07–1.83; *p* = 0.22).

There was no correlation between rate of injury and age, height, and weight.

TABLE 7. Games and practices missed in the three bienniums.

Period	Ankle + knee sprains						Low back pain		Overall	
	Games missed		Practices missed		Games + practices missed		Games + practices missed		Games + practices missed	
	<i>n</i>	%*	<i>n</i>	%*	<i>n</i>	%*	<i>n</i>	%*	<i>n</i>	%*
2004	16	–	222	–	238	–	56	–	294	–
2006	4	–75.0	67	–69.8	71	–70.2	22	–60.7	93	–68.4
2008	4	–75.0	62	–72.1	66	–72.3	6	–89.3	72	–75.5
2010										

*Percentage of decrease vs. first biennium.

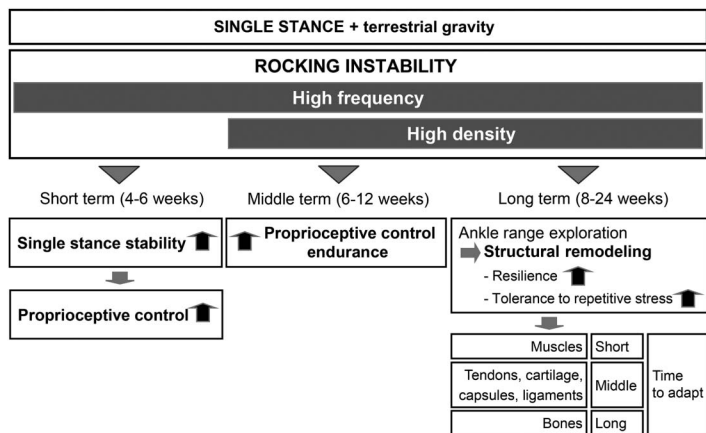


Figure 5. Coupling single stance in terrestrial gravity and high-frequency rocking instability induces vertical control reprogramming in a short time. Proprioceptive control endurance (middle-term effect) and structural remodeling (long-term effect) additionally require cumulative and high-density volume of solicitations.

Observing that very often, the onset of LBP is not instantaneous but progressive, we considered the overall occurrence without differentiating its relationship with games or practices (Table 6). In the first biennium, LBP occurred at a rate of 2.4 per 1000 AEs, decreasing to 1.0 per 1000 AEs (-56.2%) in the second biennium (RR = 0.44; 95% CI: 0.20-0.96; $p \leq 0.05$), and to 0.5 (-49.2%) in the third biennium. The risk of suffering from LBP was reduced from the first to the third biennium by 77.8% (RR = 0.22; 95% CI: 0.08-0.59; $p < 0.005$). The R-squared values ($R^2 = 0.95$ for ankle sprains; $R^2 = 0.97$ for knee sprains; $R^2 = 0.94$ for LBP) confirm the linear trend of the injury rates.

Missed Games and Practices

Ankle and knee sprains were considered together in causing missed games or practices (Table 7). From the first to the second biennium, games missed decreased from 16 to 4 (-75%), stabilizing this occurrence in the third biennium. Practices missed had a slightly smaller decrease passing from 222 training sessions missed to 67 (-69.8%) in the second period and to 62 (-7.5%) in the third period with an overall decrease of 72.1%. Low back pain caused only 1 missed game in 6 years. Games and practices missed because of LBP decreased from 56 to 22 (-60.7%) in the second biennium, showing a further decrease to 6 (-26.8%) in the third biennium with a cumulative decrement of 89.3%.

DISCUSSION

This investigation is the first study that monitors a professional basketball team for 6 years and integrates systematic proprioceptive activity in the training routine. The purpose was to assess the effectiveness of proprioceptive

training programs based on quantifiable instability, to reduce ankle sprains, knee sprains, and LBP through developing refined and long-lasting proprioceptive control.

The players of the first biennium worked as a control group by undergoing a classic proprioceptive training proposal based on instability boards with the same mechanical characteristics as the electronic boards of the following 2 bienniums. The proprioceptive training programs of the second and third biennium (Figure 1), based on high-frequency instability exercises, led to improvements in proprioceptive and postural control and were effective in reducing the incidence of ankle

sprains, knee sprains, and LBP. The lack of significance in the reduction of knee sprains was probably due to the small number of knee injuries.

These findings would indicate that the improvement in proprioceptive control may be a key factor for an effective reduction in lower limb injuries and LBP.

The training proposal of the third biennium, which differs from the second in that it is based on shorter sessions but with higher frequency and higher intensity instability exercises, seems to be the most effective.

It must be underlined that all 33 studies taken into account by recent review articles compared the effectiveness of proprioceptive training programs vs. control groups not including proprioceptive exercises and in most cases without planning any preventive intervention (18,21,27,32,41,46). In this study, the control group underwent a classic proprioceptive program with a training time similar to those of the following 2 bienniums (Table 3).

The absence of correlation between injury rate and age, height, and weight was expected. These findings were consistent with previous studies on the NBA (11,43).

New Entries vs. Veterans

The new entry players of the second and third biennium did not show significant differences in proprioceptive control at the initial test. This absence of significant differences, even if the athletes came from different teams, and the high percentage of previous ankle sprains in most players suggest that common procedures of prevention are unable to guarantee an adequate level of single stance stability and are ineffective in preventing injuries. These results are consistent with a previous study (17) that found that there were no significant differences in balance ability at the start

and during the competitive season and concluded that sports participation and regular training did not influence balance control. Data about other 6 teams of the Italian First League collected in the same period confirmed that the game-related injury rate for ankle and knee sprains was similar to that reported in the first biennium of this study (G, Annino, R, Colombini, S, Malafrente, C, Mazzaufò, F, Pileri, L, Talamanca, unpublished data, 2008). On these bases, we can reasonably assume that the initial and final levels of stability of the athletes in the first biennium are similar to the level of stability of the new entry athletes of the following years.

Injury Decrease

Two synergic mechanisms would explain the significant decrease in ankle sprain, knee sprain, and LBP rates (Figure 5). The first is based on improved proprioceptive control that permits better movement control (38) and adequate management of jumping and landing trajectories, minimizing mechanical stress on lower limbs and spine. The repetitive reflex contraction of the stabilizing muscles (in particular, the extrinsic and intrinsic muscles of the foot) during the high-frequency exercises increases their strength and endurance, shortening their mechanical latency. These effects make these reflexes more efficient in counteracting the expected and unexpected situations that lead to ankle and knee sprains. The increased strength of the peroneal muscles allows a less supinated attitude of the feet during flight (Figures 1E–G and P), improving their protective potential against inversion (wider space of braking). The importance of this aspect is underlined by the findings of a recent review confirming that a previous ankle sprain results in moderate-to-strong peroneal reflex time deficits (15). Another study showed that subjects with pronated or supinated foot structures had slower peroneus longus reaction times than subjects with neutral feet (7). Assigning tasks of controlling different degrees of inclination of the rocking base (Figures 1H,L,N,P), also near the limits of the ankle range of motion (12° of supination and 8° of pronation), would contribute to making the stabilizing proprioceptive reflexes more effective. The second mechanism is based on the cumulative effect of the traction forces applied thousands of times to passive structures such as ligaments and capsules that would increase their resilience to impulsive stress (10,19,47), enhancing their protective action when the muscle protection is overcome. This plasticity of tendons and ligaments would depend on their capacity of adapting to variations in mechanical loading by adjusting their size and material properties (50). The significant decrease in LBP would depend on the same mechanisms. Refined and enduring proprioceptive control would minimize shear and compressive forces. Higher functional stability of the spine would be consequent to the increased strength of the stabilizing muscles and better resilience of ligaments and passive structures. The increase in proprioceptive control and the reduction in ankle sprains, knee sprains, and LBP would confirm the findings of

previous studies that hypothesized a relationship between impaired single stance stability, lower limb injuries, and LBP (23,29,33,35,42).

Missed Games and Practices

The decrease in the 3 typologies of injuries was confirmed by a similar decrease in the related games and practices missed (overall decrease 75.5%). However, the proprioceptive training program did not affect the severity of the sprains. Specifically, it did not reduce the mean number of days lost. This finding is consistent with previous studies (27,49). Proprioceptive training may raise the threshold of protection, allowing for the absorption of potentially injurious forces, but when the threshold is overcome, the damage is typical and requires the usual recovery time.

In the third biennium, shorter sessions with higher density further reduced the incidence of injury. Considering the games and practices missed for LBP, the third biennium showed a different trend with respect to ankle and knee sprains. The decrease in games and practices missed was greater than in the second biennium. A possible explanation could be the complexity of the spine system that would have a longer time but a greater potential of adaptation. The expression of this potential would require the cumulative effect of a greater number of stimuli and higher intensity.

The results for injury reduction in this study would seem to be better than those in the literature. For example, Hübsher et al. (18) reported, in a review of 7 studies, that balance training was effective in reducing the risk of ankle sprain injuries by 36% (RR = 0.64, 95% CI = 0.46–0.9, $p < 0.01$) among young adult athletes during ball sports. Balance training resulted in a nonsignificant risk reduction for injuries overall (RR = 0.49, 95% CI = 0.13–1.8, $p = 0.28$). A systematic review of 8 studies conducted by Postle et al. (32) to assess the effectiveness of proprioceptive exercises after ankle ligament injury did not find statistically significant differences in the occurrence of recurrent injury with respect to the control groups ($p = 0.68$). The addition of proprioceptive training demonstrated a significant reduction in subjective instability and functional outcomes ($p < 0.05$). Schiffan et al. (41) in a recent review investigated whether proprioceptive training as sole intervention is effective in reducing the incidence or recurrence rate of ankle sprains among sporting populations with or without a history of ankle sprains. Results of the meta-analysis, irrespective of ankle injury history status, revealed a significant reduction in ankle sprain incidence when proprioceptive training was performed, compared with a range of control interventions (RR = 0.65, 95% CI 0.55–0.77). The effectiveness for participants without a history of ankle sprain was found to be inconclusive. There was no measurement of proprioceptive control. Taylor et al. (46) evaluated in a systematic review the effectiveness of each component in the training program for ACL injury prevention. The results of the meta-analysis showed a significant reduction in all ACL injuries (pooled

odds ratio = 0.612, 95% CI 0.44 to 0.85; $p = 0.004$). Moreover, these results revealed that a greater duration of balance training was associated with a higher risk of ACL injury ($p = 0.04$). Most authors have investigated the effect of balance training during 1 season without any follow-up in the next season (5). Only Bahr and Bahr (2) reported on a 3-year cohort study that evaluated a proprioceptive prevention program including other preventive elements. They found that the incidence of ankle sprains was reduced by 47% from the first to the third year, but they could not determine to what degree each of the program's elements contributed to the overall results. McKeon and Hertel (28), in a systematic review, found that balance training was not consistently associated with improvements in instrumented measures of postural control derived from testing on a stable force plate. According to the authors, these instrumented measures may lack the sensitivity to detect improvements from balance and coordination training. Arnold et al. (1), reviewing 23 articles, found that functional ankle instability was associated with poorer balance. What remains unclear is whether these differences preexisted or were the result of injury. In summary, from the literature, the effectiveness of proprioceptive training to prevent injuries is accepted for ankle sprains, controversial for knee sprains, and little studied for LBP. Ankle sprains, knee sprains, and LBP are all associated with single stance instability.

All reviewers noted a wide variety of proprioceptive (also called neuromuscular or balance) training programs. Frequency, duration, and intensity varied across studies and sometimes were not specified (28). The only common element of all proprioceptive training proposals was the creation of a certain level of instability. In all exercises, it was impossible to identify common and quantifiable biomechanical or physiological characteristics that could lead to specific adaptations. In this investigation, those elements were defined and quantifiable: mechanical instability, presence of the visual feedforward to enhance the frequency of instability (high-frequency and hyperfrequency), dynamic ankle range exploration, training volume, and training density with the related concepts of proprioceptive endurance and structural remodeling.

NBA vs. Italian League

The injury rate for ankle sprains in the NBA (3.4 per 1000 AEs) (11) and NCAA (2.3 per 1000 AEs) (36), reported in previous studies, seems to be lower than that of the first biennium of this study (8.0 per 1000 AEs). When comparing injury rate in the Italian first league with that of the NBA, it is important to consider the difference between the 2 leagues. The first difference is a rule titled "defensive 3 seconds," which exists in the NBA. This rule prohibits any defensive player to remain in the area nearest the basket for more than 3 consecutive seconds. Thus, a player jumping and landing near the basket in an NBA game has a lower chance of dangerous impacts because of a less crowded area. A second

difference depends on the smaller number of games in the Italian league vs. the NBA (34 vs. 82) and the presence of 2–3 relegations. These differences increase the value of each game result and enhance the pressure on the athletes. Finally, a recent study on the NBA suggested that a smaller roster dimension, like those in the Italian league, could increase the number of injuries (31). In fact, the study showed that after the roster expansion (from 12 to 15 players) in 2006, injuries and games missed decreased significantly. All these characteristics could contribute to explain the higher injury rate in the first biennium of this study.

Compliance

The high compliance of the athletes would be due not only to the effectiveness in injury prevention but also to the perception of improvements in stability, technical skills, and movement control. In our experience, this awareness and consequent high adherence to the preventive program are common to all athletes using this methodology in different sports.

Tape and Braces

It is of interest to note that in the first biennium, most players (more than 90%) were used to taping their ankles or wearing braces. During the second biennium of the study, and even more in the third biennium, the percentage decreased progressively and spontaneously to less than 30%. Asked about the motivation for this change, all players reported that it was due to the awareness of improved stability and better movement control on the court. These considerations are consistent with a recent review investigating whether taping and braces can improve the conscious components of proprioception in athletes with ankle instability or recurrent ankle sprains. This review reported that the use of taping or braces did not significantly affect the joint position sense or the sense of movement (34). Another study provides preliminary evidence that wearing high-top shoes can induce a delayed preactivation timing before landing and decreased amplitude of evtor muscle activity with a potentially detrimental effect on the ankle joint stability (13). These findings are consistent with the hypothesis that an external stabilization of the ankle could lead to functional instability.

Limitations of the Study

A first limitation was present because, for the small number of healthy players, we could not differentiate the results according to the presence or absence of a history of ankle sprains. This situation may lead to overestimation of reduction in injury rates. However, it must be considered that this low percentage of healthy players reflects the actual situation in professional basketball teams (22,32).

A second limitation concerned the integration of the systematic activity of prevention in the training routine of a professional team. This process entailed some limits to the study: it was not possible to randomize the treatments or have a control group. In fact, these options would not have

been acceptable for professional athletes who always expect to receive the best treatment. On these bases, we took the athletes of the first biennium as the reference group and we assume that the initial and final levels of stability of the athletes in the first biennium would not differ significantly from the initial level of stability of all new entry athletes of the 4 following years for the following reasons: (a) the percentage of annual new entries was always in the range $70 \pm 5\%$; (b) there were no significant differences in stability among the new entries in the second and third bienniums; (c) according to the literature (17), single stance stability would remain stable during the season. Therefore, the means of the first tests of all new entries were considered as the initial reference level.

PRACTICAL APPLICATIONS

The findings of this investigation indicate that significant improvements in proprioceptive control in single stance may be a key factor for an effective reduction in ankle sprains, knee sprains, and LBP (from 50 events during the 2004–2006 biennium to 13 events in 2008–2010; overall decrease: 75.5%). The clinical meaningfulness was reinforced by the same decrease in the related games and practices missed (from 294 to 72; overall decrease: 75.5%). Among the benefits, besides injury reduction, the athletes reported a perception of improvements in stability, technical skills, and movement control. Moreover, it must be highlighted that all studies taken into account compared the effectiveness of proprioceptive training programs vs. control groups not including proprioceptive exercises. In this study, the control group underwent a classic proprioceptive program with a training time similar to those of the following 2 bienniums.

The functional aim of the study was to refine proprioceptive control to guarantee adequate and long-lasting proprioceptive-based single stance stability. Furthermore, the cumulative effect of the traction forces applied thousands of times to ligaments and capsules would increase their resilience to impulsive forces, improving their capability of absorbing them, without damage, when the active muscle protection is overcome.

Even if this method allows for maximal proprioceptive activation, no overuse or other negative effects, consequent to proprioceptive training, were observed in the 3 bienniums.

In this study, unlike most proposals in the literature, the biomechanical and physiological characteristics of the proprioceptive training were quantifiable and modifiable. Acting on these elements, it was possible to increase the effectiveness of the program and to reach a high level of protection. The most important element was the visual feedforward that shows in real time the movements of the rocking base. Its characteristics were critical for enhancing the frequency of instability (high frequency and hyperfrequency). The other quantifiable and modifiable elements were the radius of instability of the rocking base, the feedback of the vertical control (postural feedback), the tasks for exploring the ankle

range of motion dynamically, the training volume, and the training density. For instance, progressively longer repetitions and minimized recovery time allowed for shorter sessions and higher density (that changed from 45 to over 85%). The data of the first biennium and the comparison with the studies available in the literature suggest that this high level of injury protection is unreachable without specific instrumental interaction able to induce high-frequency instability and to quantify proprioceptive control.

Based on the results of this study, the static single stance test is a reliable functional assessment for basketball players. It can be used by the strength and conditioning coach and the athletic trainer to investigate the level of proprioceptive control. The dynamic single stance test contributes to defining the stability profile of the athlete and his capability in managing vertical control in more difficult situations. The mean values of all new entries can be used as a reference level for professional players to rank their first test. The athletes should be prepared to expect poor test results and informed that the worse the test, the greater the opportunity for raising their threshold of protection against injuries and automatically improving their technical gestures and fluency of movement. In addition, it is indispensable to consider the test results to personalize and maximize the effectiveness of the proprioceptive program. The mean values of the best tests in the third biennium can be considered an adequate target for a player performing this proprioceptive program for the first season. These results are attainable in 3–4 months with a high frequency and high-density proprioceptive training time of 50 ± 5 minutes per week in 2 or 3 sessions (Table 3).

The results of the study suggest the introduction of this methodology in the evidence-based practice applied to injury prevention. The system portability (rocking base, postural reader, laptop) allows the athletes to perform the proprioceptive program not only in their training facility but also on road trips (in hotels, locker rooms, airports). The possibility of performing this proprioceptive program practically anywhere makes it easy to reach adequate training volume and density even for teams with a large number of athletes. Since 2014, 3 NBA teams have included this method in their training routine with results in injury prevention consistent with those expected.

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