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Sport Attainment and Proprioception

by

**Jia Han, Judith Anson,
Gordon Waddington and Roger Adams**

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Sport Attainment and Proprioception

Jia Han[1, 2], Judith Anson[2], Gordon Waddington[2] and Roger Adams[3]
[1]Key Laboratory of Exercise and Health Sciences of Ministry of Education, Shanghai University of Sport, Shanghai, China
399 Changhai Road, Yangpu District, Shanghai, 200438, China
E-mail: Jia.Han@canberra.edu.au, or ari.jiahan@gmail.com
[2]University of Canberra, ACT, Australia
[3]University of Sydney, NSW, Australia

ABSTRACT
Proprioceptive ability specific to the movement challenges of a sport was hypothesised to relate to both years of sport-specific training and the competition level that a sport performer has reached. To test this hypothesis, proprioceptive sensitivity on an ankle movement discrimination test was obtained for one hundred athletes at different competition levels, and twenty non-sport-specific, healthy controls. All athletes were without significant injuries during the prior 6 months, preferred to use their right foot, had a minimum of two years sport-specific training (mean 8.7 years), and were actively competing in football, swimming, badminton, sports dancing and aerobic gymnastics. Test scores were higher for athletes than controls ($p < 0.005$) but not significantly different between sports groups. Within combined sports groups, ankle proprioception scores were significantly correlated with sport competition level attained ($rho = 0.45$, $p < 0.001$), but not with years of sport-specific training. Logistic regression analysis demonstrated that ankle proprioception score ($p = 0.001$) and years of training ($p = 0.009$) were the two significant predictors in an equation that could successfully classify 80% of the athletes as top-level or lower, highlighting the importance of good ankle proprioception in athlete success. Ankle movement proprioception testing may be useful in talent identification, particularly in sports with a higher level of lower limb demand, and may assist in the identification of athletes who require specifically targeted training to improve their ankle proprioceptive abilities to values associated with the highest-level competitors.

Key words: Ankle Proprioception, Sport-Specific Training, Talent Identification

Reviewer: David Mann (VU University, Netherlands)

INTRODUCTION

Proprioception, an important component of the sensorimotor system, is responsible for precise, smooth and coordinated movement control in sports and daily functional activities [1, p. 253; 2, 3]; and an understanding of the role of the sensorimotor system is essential for continued enhancement of athletic performance [4]. In jumping, landing or balancing, ankle proprioception plays a crucial role in control of the fundamental movements required. If having good ankle proprioception underpins good sports performance, individuals systematically involved in sports activities should demonstrate better ankle proprioception than normal controls [5-7]. Some sports require more ankle control than others. Thus there are sport-specific ankle movement skills – for example, controlling the ball when playing football, kicking when swimming, balancing and spinning when dancing, and showing aesthetic foot movement when executing gymnastic routines. Therefore, it can be hypothesised that due to sport-specific requirements for the control of ankle movements, athletes playing different sports should show differences in ankle proprioceptive ability [7]. Consistent with this hypothesis, a number of studies have reported that posture and balance ability, considered to be closely related to ankle proprioception [7-9], differ across athletes in different sports (see [10] for review).

Further, this evidence implies that greater ankle proprioceptive ability is related to sports training experiences. If a higher competition level is a result of years of sport-specific training, then it would be expected that the competition level achieved by an individual performer would be related to their quality of ankle proprioception. Specifically, if enhanced proprioceptive ability at the ankle was a facilitating or promoting attribute for success, it might be expected that ankle proprioception, years of sport-specific training and competition level attained would all be correlated. However, Ashton-Miller et al. [11] have questioned whether proprioception can be trained, suggesting that there would be no relationship between training time and proprioceptive ability.

The current research was designed to examine ankle movement discrimination within athletes of different competition levels playing a range of sports, in order to determine the relationship of ankle joint proprioception with years of sport-specific training, and with competition level attained in different sports.

METHOD

PARTICIPANTS

One hundred right-footed, healthy young athletes (mean 20.5 years, SD ±1.0, range 18-25) from five different sports and 20 right-footed, healthy controls (mean 20.6 years, SD ± 0.6, range 20-22) were recruited (Table 1). The athletes had a minimum two years of sport-specific training (mean 8.7 years, SD ± 3.8, range 2-16) and were all actively competing at different levels of competition. The controls were a group of healthy undergraduate students studying sports journalism or sports management at the Shanghai University of Sport, without specialised training experiences specific to any particular sport.

An individual's sport competition level was determined by their best performance grade within the past year (from lowest to highest level: Level 1 = Chinese national top 32 or regional top 3; Level 2 = Chinese national top 16; and, Level 3 = Chinese national top 6 and competing internationally). Athletes' mean competition level was 1.8, SD ± 0.7, range 1-3. The classification given to an athlete to be at a particular level is *a priori* because it is the classification applied to athletes in all sports associations in China, where athlete classification is officially managed by the General Administration of Sport. Swimming is an example of the stringency of these criteria. For the long course, 50 meters free style swim,

Table 1. Participant Information and Ankle Movement Discrimination

Group	Age (years)		Height (cm)		Body Mass (kg)		Competition level (n)					Sport-specific training (years)		Ankle movement discrimination scores (AUC)	
	Mean	±SD	Mean	±SD	Mean	±SD	L3	L2	L1	Mean	±SD	Mean	±SD	Mean	±SD
Sports combined (50 F, 50 M)	20.5	(1.0)	172.7	(7.8)	63.1	(10.1)	18	43	39	1.8	(0.7)	8.7	(3.8)	0.74**	(0.05)
Football (7 F, 13 M)	20.9	(0.7)	174.4	(8.0)	66.8	(10.5)	2	4	14	1.4	(0.7)	9.7	(2.1)	0.75**	(0.05)
Swimming (10 F, 10 M)	20.3	(0.9)	176.9	(6.9)	69.5	(9.6)	5	11	4	2.1	(0.7)	13.7	(1.5)	0.73**	(0.05)
Badminton (8 F, 12 M)	20.4	(1.1)	177.0	(6.3)	65.6	(6.0)	2	11	7	1.8	(0.6)	9.1	(2.0)	0.72**	(0.06)
Sports dancing (13 F, 7 M)	20.1	(0.9)	166.9	(6.3)	53.1	(7.2)	3	7	10	1.7	(0.7)	5.2	(3.5)	0.73**	(0.04)
Aerobic gymnastics (12 F, 8 M)	20.8	(1.3)	168.6	(6.0)	60.4	(8.0)	6	10	4	2.1	(0.7)	6.1	(2.3)	0.75**	(0.04)
Control group (10 F, 10 M)	20.6	(0.6)	170.9	(5.2)	60.5	(8.3)	-	-	-	-	-	-	-	0.67	(0.03)

where the 2012 London Olympics gold medal times were 21.77" and 24.51" for men and women, Chinese male swimmers classified as Level 3, 2 or 1 must achieve times of at least 22.54", 23.50" and 24.50", respectively; and female swimmers must achieve times of 25.52", 26.45" and 27.20", respectively. The time that is recorded by a swimmer must be obtained in an officially held competition that is at least a regional event.

Footedness was determined by the Edinburgh Handedness Inventory [12], as footedness has been reported to follow handedness in right-handers [13]. All potential participants were screened with a health questionnaire prior to inclusion to rule out the presence of lower limb injuries within the past 6 months or a diagnosis of chronic disease (e.g., multiple sclerosis, stroke, Parkinson's disease, rheumatoid arthritis, type 2 diabetes).

The project was approved by the University of Canberra Committee for Ethics in Human Research and informed consent was obtained from participants before the experimental session commenced.

APPARATUS

A purpose-built ankle Active Movement Extent Discrimination Apparatus (AMEDA) was employed [14, 15] to provide ankle movement discrimination scores that represent participants' sensitivity to small differences in extent of active ankle inversion. The AMEDA fulfils the validity criteria for assessing lower limb active movement function when weight bearing, namely: by using functional movement velocities and using sufficient trials to accurately determine ability to discriminate the extent of movement [14, 15]. The apparatus has been validated and displays sensitivity to a variety of interventions and conditions that might be expected to affect one's active ankle movement proprioception [14-21].

PROCEDURE

The AMEDA device consists of a stable wooden platform housing a skidproof square plate which rotates about a central metal axle, aligned to the long axis of the foot being tested (Figure 1). During the test, participants were instructed to stand astride the apparatus in bare feet, with the left foot on the stable platform and the right foot centred over the axis of the swinging plate. While distributing weight evenly on both feet, with eyes looking forward at a point on the wall opposite, the participants made an active inversion movement at a steady pace, until the outer side rim of the moveable plate contacted an adjustable metal stop. After returning the plate to the horizontal fixed position at the same pace, they gave a verbal judgment as to the extent of inversion.

The psychophysical method employed required participants to make an absolute judgement of ankle inversion movements, where there were five possible responses (position 1, 2, 3, 4, and 5) to the five possible stimuli (10, 11, 12, 13 and 14 degrees of inversion). After each inversion, participants used a number, from 1 to 5, to identify the degree of inversion that they had just experienced. Each participant was given a familiarisation session before data collection commenced. The participant experienced the five inversion depths, in order from smallest (position 1, i.e., 10 degrees) to largest (position 5, i.e., 14 degrees), three times: 15 inversion movements in total. Participants then undertook 50 trials, 10 for each of the 5 different inversion displacements, presented at random to the right ankle, without feedback being given as to the correctness of the judgment made for each trial. Purpose-programmed software was used to set the randomly predetermined position (error < 0.02 degrees), with the same experimenter entering the participant's response to the movement extent of each trial into a database.

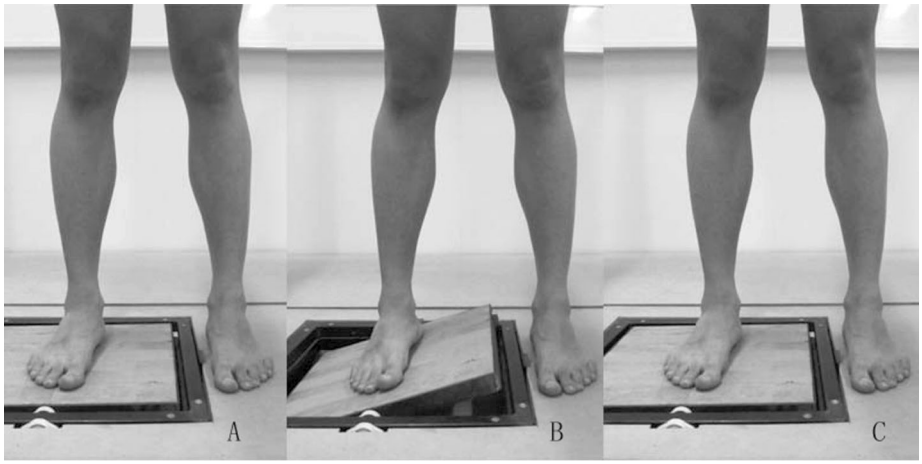


Figure 1. A) Participant Standing on the Ankle Active Movement Extent Discrimination Apparatus (AMEDA) Platform
B) Participant Making an Active Inversion Movement Which Rotates the Plate Until the Outer Side Rim of the Moveable Plate Contacted an Adjustable Metal Stop
C) Participant Returning the Plate to the Horizontal Fixed Position Before Indicating the Extent of Inversion Experienced

DATA ANALYSIS

To obtain movement discrimination scores, raw data were first cast into a 5 × 5 matrix representing the frequency with which each response was made for each stimulus. Non-parametric signal detection analysis was applied to the stimulus rows pair-wise, to produce Receiver Operating Characteristic (ROC) curves [22]. Thereafter, the mean Area Under the Curve (AUC) was calculated using SPSS software V.18 to give each participant an ankle movement discrimination score. AUC values range from 0.5, which is equivalent to chance responding, to 1.0, representing a perfect ability to discriminate the 5 different movement displacements.

To determine if there were any between-group differences, a one-way ANOVA was employed. Where a one-way ANOVA showed significant difference, a paired, two-sample t-test was used to determine the significance between the groups. Spearman's correlations, with statistical significance at $p < 0.05$, were calculated to assess the relationship between ankle movement discrimination scores and competition levels, years of sport-specific training, age, height and body mass. The number of athletes ($n = 100$) fulfilled the required minimum sample size requirements for logistic regression: $n \geq 50 + 8 \times m$ ($m = 5$ independent variables – ankle movement discrimination, years of sport-specific training, age, height and body mass) [23, p. 123]. This allowed the determination of significant predictors for a binary form of the dependent variable competition level, wherein the two classes were the Level 3 international athletes, and a class combining the regional and national, Level 1 and Level 2, athletes.

RESULTS

One-way, between-groups ANOVAs indicated significant differences in body mass ($F_{5, 119} = 9.8$, $p < 0.001$) and height ($F_{5, 119} = 8.8$, $p < 0.001$) but not age ($F_{5, 119} = 1.9$, $p = 0.11$). Mean

AUC discrimination score analysis revealed overall significance between groups ($F_{5, 119}$ = 6.5, $p < 0.001$), and post-hoc tests showed that this was due to the mean AUC discrimination score for the healthy control group (M = 0.67, SD ± 0.03) being significantly worse than any sport group (all $p < 0.005$), while there were no significant differences between any of the sport groups, with all $p > 0.35$ (Table 1).

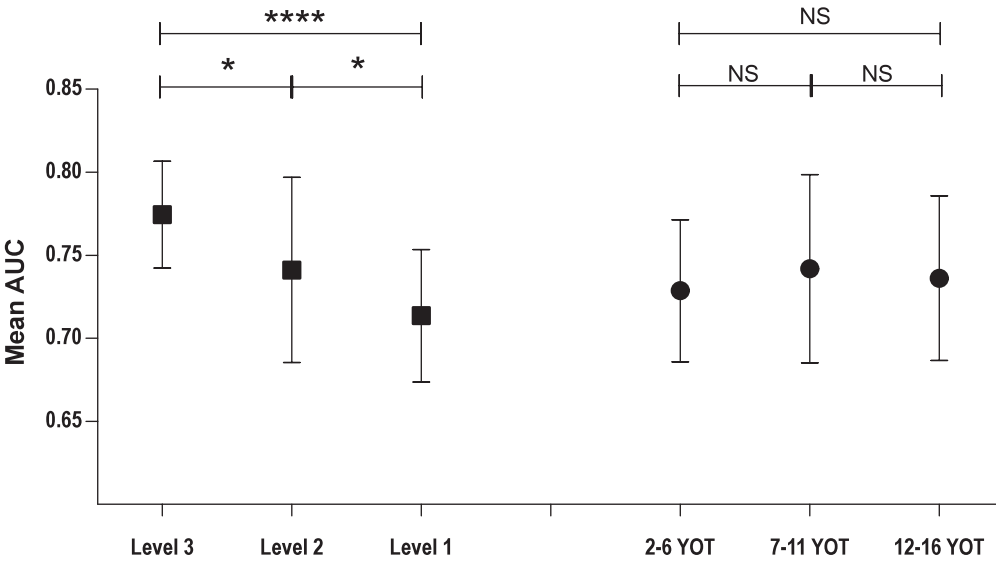


Figure 2 Comparisons of Mean Ankle Movement Discrimination Scores with Standard Deviations (all sports combined) Between Different Competition Levels and Between Different Years of Sport-Specific Training (YOT) Conditions
Data analysis showed that each competition level was significantly different from each other (* $p < 0.05$, **** $p < 0.0001$), but there was no significant difference between any two YOT conditions (NS, $p > 0.05$).

Mean ankle AUC discrimination scores for all sports combined were 0.77 ± 0.03, 0.74 ± 0.06 and 0.71 ± 0.04 at competition levels 3, 2 and 1 respectively (Figure 2). A one-way ANOVA analysis produced overall significance ($F_{2,97} = 10.98$, $p < 0.001$), and post-hoc tests showed that each of the three competition levels was significantly different from each other (all $p < 0.05$) indicating that ankle movement discrimination acuity was significantly better at higher competition levels. Conversely, mean AUC discrimination scores for all athletes who had trained for 2-6, 7-11, and 12-16 years were 0.73 ± 0.04, 0.74 ± 0.06 and 0.74 ± 0.05, respectively, and there was neither overall significance ($F_{2, 97} = 0.62$, $p = 0.54$) nor any significant pair-wise difference between groups with different years of sport-specific training experience (all $p > 0.05$), indicating that athletes who had been training in their sport longer did not have better ankle movement discrimination acuity (Figure 2).

Spearman's correlations between the mean ankle movement discrimination scores and competition level, years of sport-specific training, age, body mass and height were determined and are reported in Table 2. These data showed that ankle movement discrimination was significantly and positively correlated with attained competition level

Table 2 Spearman's Correlations Between Ankle Movement Discrimination AUC Scores and Competition Level, Years of Sport-Specific Training, Age, Height and Body Mass, for the Different Sports Groups and the Control Group

Group		Competition Level & AUC	Years of Sport-Specific Training & AUC	Age & AUC	Height & AUC	Body Mass & AUC
Sports combined (n = 100)	rho	0.45***	0.05	0.13	- 0.11	- 0.03
	p	(< 0.001)	(0.60)	(0.16)	(0.29)	(0.80)
Football (n = 20)	rho	0.56*	0.01	0.18	- 0.04	0.21
	p	(0.01)	(0.96)	(0.45)	(0.89)	(0.39)
Swimming (n = 20)	rho	0.37	0.07	- 0.05	0.01	0.20
	p	(0.11)	(0.78)	(0.84)	(0.99)	(0.39)
Badminton (n = 20)	rho	0.33	- 0.08	0.24	- 0.12	- 0.07
	p	(0.16)	(0.75)	(0.31)	(0.63)	(0.78)
Sports dancing (n = 20)	rho	0.74***	0.44	0.20	0.21	0.32
	p	(< 0.001)	(0.05)	(0.39)	(0.37)	(0.17)
Aerobic gymnastics (n = 20)	rho	0.45*	0.12	0.08	0.14	0.16
	p	(0.04)	(0.60)	(0.73)	(0.56)	(0.51)
Control group (n = 20)	rho	-	-	0.10	- 0.09	- 0.23
	p	-	-	(0.67)	(0.71)	(0.34)

* Correlation is significant at the 0.05 level. *** Correlation is significant at the 0.001 level.

(overall rho = 0.45, $p < 0.001$), but not with years of sport-specific training, age, height, or body mass. The degree of correlation between ankle movement discrimination and competition level varied with different sports (Table 2), with the highest correlations being in those sports with the highest demand for ankle control: sports dancing, football (soccer), and aerobic gymnastics. Spearman's correlations between competition level, years of sport-specific training and ankle proprioceptive acuity showed that ankle movement discrimination score was significantly related to competition level attained (rho = 0.45, $p < 0.001$) as was years of sport-specific training (rho = 0.27, $p = 0.007$), but ankle movement discrimination score and years of sport-specific training were not significantly correlated with each other (rho = 0.05, $p = 0.60$).

Lastly, logistic regression analysis was conducted with the binary form of competition level achieved as the dependent variable, using age, height, body mass, years of sport-specific training, and ankle movement discrimination scores as the predictor variables. A significant prediction equation was found ($\chi^2_{5df} = 23.06$, $p < 0.001$, Nagelkerke R Square = 0.34), where the two significant predictors were ankle proprioception AUC ($p = 0.001$) and years of sport-specific training ($p = 0.009$), and the equation accurately classified 80% of the athletes as being at international Level 3 or at a lower level.

DISCUSSION

There are four main findings in the present study. Firstly, ankle proprioceptive ability is significantly correlated with competition level, but there is no significant relationship between ankle proprioception and years of sport-specific training for the five sports tested here. Secondly, while ankle movement discrimination ability differs significantly between athletes at different competition levels, and is similar between athletes with differing years of sport-specific training experience, athletes had significantly better ankle movement discrimination scores than healthy controls. Thirdly, ankle movement discrimination ability and years of sport-specific training are both significant predictors of attained competition level. Lastly, the ability to discriminate between different ankle inversion movements was not related to individual anthropometrics, as athletes with differing anthropometrics across different sports performed similarly in terms of ankle movement discrimination.

In the current study, years of sport-specific training was not significantly correlated to ankle movement proprioceptive discrimination ability, a result consistent with the lack of significant correlation with years of football training found for knee rotation proprioceptive acuity reported by Muaidi et al [24]. Thus both years of sport-specific training and ankle movement discrimination score were significantly related to competition level attained, but not to each other. An implication of this is that the skills that underpin achieving a high sport competitive level are built over years of sport-specific training, whereas ankle movement discrimination ability may be more genetically determined, and may not be related to the number of years of sport activity. In this sense, the present findings support Ashton-Miller's proposition that proprioception is not a result of training [11], as higher-level athletes may initially have better ankle movement discrimination ability prior to commencing their sports training careers.

It could be argued that superior initial ankle movement discrimination ability enables athletes to devote more time and attention to other aspects of their performance, thereby enhancing sports outcomes. Provins [25] argues that a beginner performing a motor task must spend time consciously mastering the movements using a closed-loop system of control, whereas highly skilled performers only occasionally use sensory checking for successful execution of relevant movement actions [25]. Ankle-associated lower limb

movement skills are intensively used in several sports. Thus, potential elite athletes with good inherent ankle movement control may have an advantage in sports such as football, since elite footballers may be able to devote more attention to other tasks, such as localising team mates and opponents, and determining the best opportunity to pass or shoot, rather than having to allocate as much central capacity to movement control [26]. Consistent with this view, the ankle movement discrimination data here show stronger correlations with the competition level attained in more lower-limb-involved sports, such as football and sports dancing. If better inherent proprioception is important for high level success, then in more upper-limb-involved sports, such as swimming and badminton, a similar correlation would be expected if a shoulder or wrist movement discrimination test were used.

The observed relationship between ankle proprioception and competition level reflects the important role that proprioception plays in coordinated motor skills and control generally [27]. A recent study explored the relationship between a variety of performance characteristics and performance in competition two years later in young female gymnasts [28]. None of the initial measurements, including anthropometric and physical characteristics and expert coaches' judgements correlated with the competition results of sub-elite athletes. However, a motor coordination test battery did produce scores that significantly correlated with competition results for elite athletes [28]. As a consequence, the authors suggested that a motor coordination test might be considered for talent identification in gymnasts. The data from the current study were collected from athletes across a range of sports requiring different body movement patterns, suggesting that the component of ankle proprioceptive ability measured through movement discrimination testing differs with the movement demands found in different sports. Prospective studies across a wide range of sports with high ankle control demand would determine the value of the ankle proprioception inclusion in a multiple battery of talent identification tests [29, 30].

Although there is a lack of significant correlation between ankle proprioception and years of sport-specific training in the present study, the role of training in proprioceptive performance cannot be overlooked. Ericsson and Lehmann noted that some attributes underpinning high level performance, such as range of hip turnout in ballet dancers and shoulder external rotation range in throwers, which are developed through early activity and maintained by practice, revert towards population values when intensive training ceases [31]. If this is the case, it is clear that more work is needed to investigate the role of sport-specific training in maintaining a high level of ankle proprioceptive ability. Further, previous studies showed that specifically designed proprioceptive training can improve ankle proprioception [15, 19, 32], so prospective studies would be useful to determine whether specifically designed ankle proprioceptive training would lead to a higher competition level. Irrespective of whether an athlete's ankle movement discrimination acuity is primarily biologically-determined or practice-determined, however, the ankle movement discrimination score emerged as a predictor of competition level achieved, in the current analysis.

The current finding, that mean ankle movement discrimination ability is similar between athletes from different sports is, however, contrary to a number of studies comparing posture and balance ability between sports, where posture and balance ability has been found to differ between athletes playing different sports. A recent review suggests that gymnasts tended to have the highest level of posture and balance ability followed by soccer players, swimmers, active controls, and then basketball players [10]. Two possible explanations could account for the apparent inconsistency in the order of these sports based on their ankle use reported by Hrysomallis [10] and our data.

Results of the present work showed that athletes of a higher competition level have better

ankle proprioceptive ability. Thus, if posture and balance control is closely related to ankle proprioception [7-9], the posture and balance control study findings may be an artefact of different competition levels, rather than a type-of-sport effect. An implication of this is that validated comparisons of ankle proprioception or posture and balance control between different sports should take competition level into account. Alternatively, however, other findings suggest that ankle proprioception is not closely related to posture and balance control [10, 33-36]. It is likely that, rather than ankle proprioception, anthropometric variables may play a more significant role in determining athletes' posture and balance measurements. In the present study, although the sports varied from football to aerobic gymnastics, with significant anthropometric differences between the athlete groups, the effects of possible confounders such as body mass and height were minimised due to the nature of the ankle movement proprioception test. The lack of any significant correlation between ankle movement discrimination scores and participant height here is consistent with previous studies [17, 18]. In addition, while researchers have reported no correlation between ankle proprioception and body mass index (BMI) [37], body mass (weight) alone was not correlated with ankle movement discrimination. By this account, posture and balance ability and ankle proprioceptive ability may be separate, independent attributes.

CONCLUSION

Ankle proprioception scores are significantly predictive of attained competition level, highlighting the importance of ankle proprioception in sporting success. Prospective studies are needed to determine if greater ankle movement discrimination ability is an inherent characteristic of athletes performing at higher levels, as proposed here, as this has implications for both talent identification and coaching for sport attainment. Although a lack of correlation between ankle proprioception and years of sport-specific training was observed in the current study, longitudinal investigations would be informative to determine the role of sport-specific training in maintaining a greater ankle proprioceptive ability and the role of specifically-designed proprioceptive training in enhancing ankle proprioception ability.

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