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Level of competitive success achieved by elite athletes and multi-joint proprioceptive ability

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ABSTRACT

Objectives: Proprioceptive ability has been suggested to underpin elite sports performance. Accordingly, this study examined the relationship between an athlete's proprioceptive ability, competition level achieved, and years of sport-specific training.
Design: Cross-sectional study.
Methods: One hundred elite athletes, at competition levels ranging from regional to international, in aerobic gymnastics, swimming, sports dancing, badminton and soccer, were assessed for proprioceptive acuity at the ankle, knee, spine, shoulder, and finger joints. An active movement extent discrimination test was conducted at each joint, to measure ability to discriminate small differences in movements made to physical stops.
Results: Multiple regression analysis showed that 30% of the variance in the sport competition level an athlete achieved could be accounted for by an equation that included: ankle movement discrimination score, years of sport-specific training, and shoulder and spinal movement discrimination scores ($p < 0.001$). Mean proprioceptive acuity score over these three predictor joints was significantly correlated with sport competition level achieved ($r = 0.48$, $p < 0.001$), highlighting the importance of proprioceptive ability in underpinning elite sports performance. Years of sport-specific training correlated with an athlete's sport competition level achieved ($r = 0.29$, $p = 0.004$), however, proprioceptive acuity was not correlated with years of sport-specific training, whether averaged over joints or considered singly for each joint tested (all $r \leq 0.13$, $p \geq 0.217$).
Conclusions: Proprioceptive acuity is significantly associated with the performance level achieved by sports elites. The amount of improvement in proprioceptive acuity associated with sport-specific training may be constrained by biologically determined factors.

1. Introduction

Proprioceptive sensitivity is the ability to integrate sensory information from mechanoreceptors and thereby determine body position and movements in space.[1,2] Having good proprioceptive ability is more important for tasks with high skill demand than it is for normal activities,[3–5] suggesting that it may underlie elite athletic performance. However, there is presently little evidence to support this hypothesis.

Although some research has shown athletes to have superior proprioceptive ability compared to non-athletic controls,[3–5] the tests have been conducted at one joint, and in one sport. As a consequence, it has not been determined whether proprioceptive ability determined over multiple body joints, for athletes in different sports, is related to how good an athlete is, as reflected in the competition level they have achieved.

Superior proprioceptive ability in athletes has been attributed to prolonged periods of athletic training.[3,4,6] Because few studies have examined the relationship between proprioceptive ability and years of sport-specific training, it is not known whether this superior proprioceptive ability in athletes is inherently determined and selected for by competitive success, or whether it arises from extensive training. Recently, Daneshjoo et al.[7] reported that knee proprioception at 45 and 60° was significantly improved by eight weeks of specifically designed warm up program, suggesting that proprioception may be enhanced by sport-specific training. If enhanced proprioceptive ability is an outcome of years of sport-specific training, proprioceptive sensitivity and years of sport-specific training should be significantly correlated. Conversely, it has been argued that proprioception cannot be trained,[8] suggesting that no correlation would be apparent.

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Table 1
Participant information.

	Elite competition level (*n*)			Sport-specific training (years)		Body mass (kg)		Height (m)		Age (years)	
	i	ii	iii	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Aerobic gymnastics (8 M, 12 F)	4	10	6	6	3–13	60	48–75	1.69	1.58–1.78	21	18–23
Swimming (10 M, 10 F)	4	11	5	14	6–15	70	56–92	1.77	1.66–1.92	20	19–22
Sports dancing (7 M, 13 F)	10	7	3	5	2–16	53	45–75	1.67	1.56–1.80	20	18–23
Badminton (12 M, 8 F)	7	11	2	9	4–12	66	57–76	1.77	1.64–1.86	20	18–22
Football (Soccer) (13 M, 7 F)	14	4	2	10	6–13	67	52–85	1.74	1.61–1.90	21	20–22
Control group (10 M, 10 F)	–	–	–	–	–	61	51–83	1.71	1.63–1.82	21	20–22

For elite competition level, i represents Chinese national top 32 or regional top 3; ii represents Chinese national top 16; and iii represents Chinese national top 6 and competing internationally.

The aim of the current study was to examine the relationship between proprioceptive ability, competition level achieved, and years of sport-specific training. Elite athletes from 5 sports – aerobic gymnastics, swimming, sports dancing, badminton, and soccer – all actively competing at regional, national or international level, were recruited, and proprioception tests conducted on 5 body sites: the ankle, knee, spine, shoulder and fingers.

In the present study, a set of tests, each using a form of the active movement extent discrimination apparatus (AMEDA), was employed to assess proprioceptive ability. The AMEDAs were developed based on the principle of replicating functional movement,[9] i.e., using active rather than passive movement, testing in normal weight-bearing conditions, moving at a steady pace, and without physical constraints to non-tested limbs, in order to maximize the ecological validity of proprioception testing. The AMEDA method for assessing proprioceptive acuity has been validated by being able to: identify subjects with ankle ligament laxity,[10] evaluate the effect of training on knee proprioception,[11] show different patterns of spine flexion discrimination in subjects with spinal disc replacement,[12] reveal a correlation between shoulder proprioception with humeral torsion in adolescent baseball players[13] and show superiority for the non-dominant hand/hemisphere system in the utilization of pinch movement proprioception.[14,15]

2. Methods

The project was approved by the University of Canberra Committee for Ethics in Human Research (approval number: CEHR 11-47) and written informed consent was obtained from participants before testing sessions commenced. The organizations that provided funding for this project had no role in recruitment, data collection, analysis, interpretation, or approval for submission for publication.

Participant information is presented in Table 1. Recruitment was from sports where there were sufficient elite athletes available at the time of testing. One hundred right-handed athletes competing at high levels in five different sports and twenty right-handed, non-athletic controls were recruited from advertisements posted throughout the Shanghai University of Sport. The athletes who volunteered had a minimum of two years of sport-specific training, and all were actively competing in their chosen sport. An athlete's sport competition level was determined as their best level achieved within the prior year, at three elite levels. These were, from lowest to highest: (i) Chinese national top 32 or regional top 3; (ii) Chinese national top 16; and (iii) Chinese national top 6 and competing internationally. Given the selection pool for athletes in China, all individuals reaching these levels can be regarded as elites.[16] A group of healthy university students without any history of specialized training experience specific to a particular sport was recruited as non-athletic controls. As all students participated in the weekly 90 min physical education classes held at the Shanghai University of Sport, they were physically able to undertake the proprioception tests. All participants were asked to adhere to their normal routine of training, sleeping, eating and hydration prior to doing the AMEDA tests.

The Edinburgh Handedness Inventory[17] was used to determine right-handedness. When questioned regarding footedness, all participants responded that they would also use their right foot to kick a ball. A health questionnaire was used to rule out the presence of significant injuries within the past 6 months or a diagnosis of neurological disease, specifically Parkinson's disease, brain damage, chronic pain, Down's syndrome or diabetic neuropathy.[3]

A purpose-built AMEDA was employed for the proprioception tests at each body site (Fig. 1). The apparatus employed here has been described previously for the ankle,[10] the knee,[11] the spine,[12] the shoulder[13] and the fingers.[18] Reliability of the scores (Interclass Correlation Coefficient) generated by the AMEDA tests has been determined as ranging from 0.82 to 0.96.[14,18,19] The series of AMEDAs were used to generate a set of 5 end positions at each joint tested. The 5 predetermined displacements from smallest to largest were: ankle inversion = 10, 11, 12, 13 and 14°, knee flexion = 37, 38, 39, 40 and 41°, spine flexion = 20.9, 21.5, 22.1, 22.6 and 23.2°, shoulder flexion = 170.6, 171.2, 171.7, 172.3 and 172.9°, and thumb-index finger pinch extent = 5.5, 8.0, 10.5, 13.0 and 15.5 mm. A position number (1, 2, 3, 4 or 5) was assigned to each movement displacement in order, so that participants were able to use the assigned position numbers to make their responses during the test.

The protocol for testing at each joint consists of a standardized familiarization session and a data collection session. During the familiarization session before data collection, each participant was informed that they would experience the five movement distances in order, from the smallest (moving to position 1) to the largest (moving to position 5), three times in succession, to ensure participants were focused on the relevant dimension. After the 15-trial familiarization, participants then undertook 50-trials of testing, in which all five positions were presented 10 times, in a random order. During testing, participants were asked to make a judgment as to the position number (1, 2, 3, 4 or 5) of each movement as soon as they returned the testing joint to the start position, without feedback being given regarding the correctness to the judgment they made for each trial. That is, the participants used their memory of the 5 movement displacements from the familiarization trials to enable them to evaluate the current stimulus and thus make a numerical judgment about each stimulus as it was presented. This task was thus a single stimulus, or absolute judgment task, wherein a single stimulus was presented and single response was made on each trial. The psychophysical method employed in the current study fulfills the validity criteria for assessing active movement function, with sufficient trials to determine participants' ability to use proprioceptive information when they discriminate a set of movements.[20,21]

The procedure for spine flexion discrimination is described here as an example. Participants wore a loose shirt, short pants and were