MULTIPLE JOINT PROPRIOCEPTION IN
MOVEMENT DISCRIMINATION

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ABSTRACT

To produce precise and coordinated movements, the human brain processes proprioceptive information concurrently from multiple joints around the body. However, few studies have investigated proprioception across multiple joints independently or simultaneously in the one testing session, and the understanding of proprioceptive mechanisms that underlie functional movement control is limited. The aim of this thesis was to explore proprioceptive ability across multiple joints, using an active movement extent discrimination task involving movements that are similar to normal joint function in sports and daily activities. A series of seven studies was conducted that began with developing an active movement extent discrimination apparatus (AMEDA) for assessing the multiple joints involved in finger pinch proprioception. The studies utilized this and another four versions of the AMEDA to enable systematic investigation of proprioceptive acuity at five sites around the body – the ankle, knee, spine, shoulder and fingers – in both athletes and non-athletic healthy young adults.

The first study (presented in Chapter 3) involved the development of a novel device for the measurement of functional finger pinch movement discrimination, and the chapter presents details of its construction, reliability and potential applications. The active finger movement extent apparatus (AFMEDA) was designed to be simple in construction and light in weight, and to fulfill the ecological validity criteria for assessing active movement function – using active movements, at normal speed and without physical constraints. The complete test included 15 familiarization trials and 50 testing trials, taking only 10 minutes. Reliability testing showed that the AFMEDA had a good reliability (ICC = 0.85) for assessing proprioceptive ability during functional pinch movements. The mid-range Area Under the Curve (AUC) discrimination scores (0.7 - 0.8) found with healthy young adults mean that factors thought to diminish discrimination acuity (e.g., hand injury) or improve it (e.g., having expert finger skills) could be examined with the device. The ease of use and portability of the novel device facilitate its use for assessing functional hand proprioception as part of clinical and epidemiological studies.
In Study 2 (Chapter 4), the effect of elastic resistance on proprioceptive acuity at the fingers was investigated. Sensitivity of pinch movement discrimination between the thumb and index finger was tested in sixteen participants, with and without elastic resistance. Results showed that adding elastic resistance from a spring to the thumb-index finger pinch task did not affect accuracy of pinch discrimination when measured as either the AUC ($F_{1, 15} = 0.07, p = 0.80$), or as the just noticeable difference (JND) ($F_{1, 15} = 1.78, p = 0.20$). The finding that elastic resistance did not affect finger pinch discrimination suggested that return tension on equipment lever arms has a practical but not perceptual function. The active finger pinch movement discrimination task, with or without elastic resistance, could be used for hand proprioceptive training, and as a screening tool to identify those with aptitude or decrements in fine finger movement control.

In the third study (Chapter 5), the AFMEDA and another four versions of AMEDA were used together to test proprioceptive ability at the fingers, shoulder, knee and ankle on the dominant side of body, and a further test was conducted at the spine. Movement discrimination scores were obtained from forty right-handed healthy young adults. Pearson correlation analysis showed that there was no significant correlation between the discrimination scores from the five sites (all $r \leq .21$, all $p \geq .20$). This finding extended a previous report of non-significantly correlated proprioception test scores at two lower limb sites, and the findings taken together suggest that rather than proprioception being a global, general-body ability, the proprioceptive ability that underlies movement control is site-specific.

Study 4 (Chapter 6) expanded the proprioception testing at multiple joints to testing both sides of the body. After selecting twelve participants with strong right arm and right leg preference, active movement proprioception at four pairs of upper and lower limb joints – the fingers, shoulders, knees and ankles – were tested using the AMEDAs. Consistent with the finding from Study 3 that there are no significant correlation between different body sites, results from this study showed that only correlations between the proprioceptive accuracy scores for the right and left sides at the same joint were large and significant (ankles 0.93, knees 0.89, shoulders 0.87, fingers 0.91, $p \leq 0.001$; with all other values of $r \leq 0.40$, $p \geq 0.20$). In addition, proprioceptive performance on the non-preferred left side of the body was found to be significantly better than the preferred right side at all four joints tested (overall $F_{1, 11} = 36.36, p < 0.001$, partial $\eta^2 = 0.77$).
The results point to both a side-general effect and a site-specific effect in the integration of proprioceptive information during active movement tasks, whereby the non-preferred limb/hemisphere system is specialized in the utilization of the best proprioceptive sources available at each specific joint, but the combination of sources employed differs between body sites.

In Study 5 (Chapter 7), a proprioceptive task was designed to be performed simultaneously by two hands, in order to examine individuals’ ability to process bimanual, simultaneous proprioceptive information. Both right- and left-handed young adults, ten for each handedness group, were investigated using duplicate AFMEDAs, with one at each hand. In line with previous findings from other laboratories, a non-preferred limb/hemisphere superiority effect was observed, where the non-preferred hands of right- and left-handed individuals performed overall significantly better than their preferred hands. For all participants, bimanual movement discrimination scores were significantly lower than scores obtained in the unimanual task. However, the magnitude of the performance reduction from the unimanual to the bimanual task was significantly greater for left-handed individuals. The effect whereby bimanual proprioception was disproportionately affected in left-handed individuals can be attributed to enhanced neural communication between hemispheres in left-handed individuals leading to less distinctive separation in the cerebral cortex with respect to information obtained from the two hands.

The last two studies (Chapters 8 and 9) focused on athletes’ proprioceptive ability at multiple joints, across a variety of sports. Study 6 (Chapter 8) was the preliminary study, in which ankle inversion movement discrimination scores were obtained from twenty non-athletic controls and one hundred athletes, competing at three different levels in football, swimming, badminton, sports dancing and aerobic gymnastics. Athletes showed better ankle movement discrimination scores than non-athletic controls ($p < 0.005$) but there was no significant difference between sports groups. When all sports groups combined, 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.

Study 7 (in Chapter 9) included data from another four AMEDA tests at the knee, spine, shoulder and fingers with the same athlete groups as before. Step-wise multiple regression analysis was conducted, with competition level as the dependent variable and AUC proprioception sensitivity scores at the ankle, knee, shoulder, spine, and finger, and years of sport-specific training, entered as independent variables. Results showed that 30% of the variance in the sport competition level an athlete had achieved could be accounted for by an equation that included, sequentially, ankle movement discrimination score, years of sport-specific training, and shoulder and spinal movement discrimination scores (p < 0.001). The 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. Although years of sport-specific training correlated with an athlete’s sport competition level achieved (r = 0.29, p = 0.004), years of sport-specific training was not correlated with proprioceptive acuity either averaged or considered singly from any joint tested (all r ≤ 0.13, p ≥ 0.217), suggesting that the amount of improvement in proprioceptive acuity due to training may therefore be constrained by biologically-determined factors.
PUBLICATIONS AND PRESENTATIONS

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Conference presentations

1. *Australian Conference of Science and Medicine in Sport, Fremantle, Perth, AUS*
   Han J, Waddington G, Anson J, Adams R (2011) Position discrimination of the fingertips during dynamic movement varies with the task undertaken. (Poster presentation)

2. *American College of Sports Medicine Annual Meeting, San Francisco, California, USA*
   Han J, Waddington G, Anson J, Adams R (2012) Ankle movement discrimination is correlated with sports performance levels. (Poster presentation)

3. *International Convention on Science, Education and Medicine in Sport (ICSEMIS) Conference, Glasgow, Scotland, UK*

4. *Canberra Health Annual Research Meeting, Canberra, ACT, AUS*
   Han J, Waddington G, Adams R, Anson J (2012) Ability to discriminate movements at multiple joints around the body: global or site-specific. (Poster presentation)

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