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Bimanual proprioceptive performance differs for right- and left-handed individuals

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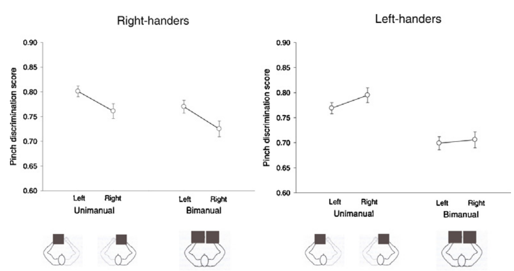
HIGHLIGHTS

- Proprioceptive asymmetry is mirrored for left- and right-handed individuals.
- Bimanual proprioceptive task performance is significantly worse than unimanual.
- The bimanual task performance reduction is significantly greater in left-handers.

GRAPHICAL ABSTRACT



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ABSTRACT

It has been proposed that asymmetry between the upper limbs in the utilization of proprioceptive feedback arises from functional differences in the roles of the preferred and non-preferred hands during bimanual tasks. The present study investigated unimanual and bimanual proprioceptive performance in right- and left-handed young adults with an active finger pinch movement discrimination task. With visual information removed, participants were required to make absolute judgments about the extent of pinch movements made to physical stops, either by one hand, or by both hands concurrently, with the sequence of presented movement extents varied randomly. Discrimination accuracy scores were derived from participants' responses using non-parametric signal detection analysis. Consistent with previous findings, a non-dominant hand/hemisphere superiority effect was observed, where the non-dominant hands of right- and left-handed individuals performed overall significantly better than their dominant 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 could be due to enhanced neural communication between hemispheres in left-handed individuals leading to less distinctive separation of information obtained from the two hands in the cerebral cortex.

1. Introduction

Using movement detection [33], movement discrimination [19], movement or position matching [3,16] methods, upper limb proprioception has been extensively investigated at the fingers [26,48], wrists [1,2], elbows [3,13–15] and shoulders [4,25]. Recent studies have revealed a non-dominant arm superiority in proprioceptive

Abbreviations: RH, right-handed; LH, left-handed.

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tasks [12–15]. The non-preferred arm/hemisphere specialization in the utilization of proprioceptive feedback has been attributed to functional differences between the roles of the preferred and non-preferred arms in bimanual tasks, where for both right- (RH) and left-handed (LH) individuals, the non-preferred limb positions and stabilizes, while the preferred limb executes controlled movements [15].

Many laboratory tasks, however, do not reflect a functional bimanual context, where the two hands perform two individual proprioceptive tasks concurrently. Rather, the proprioceptive performance of one limb/hemisphere system is generally assessed individually, although sometimes the contralateral arm is involved as the reference target [see 11 for a review]. In daily activities, however, bimanual movements are made more than twice as often as unimanual movements [30,40], and most bimanual movements involve different tasks, for example cutting a piece of paper while holding it with the other hand. In the conduct of bimanual movements, proprioceptive information from both hands must be processed simultaneously. At present, little is known about how bimanual concurrent proprioceptive information is processed in the brain, and whether the performance of each hand in bimanual proprioceptive tasks differs from the performance of the same hand in a unimanual proprioceptive task.

In general, when the two hands are required to perform different tasks concurrently, dual task interference appears and results in a decrement in performance of one or both hands [20,28,34]. If the dual task interference effect were evident in bimanual concurrent proprioceptive tasks, proprioceptive performance of one or both hands would be affected. However, different neural strategies could be used to process bimanual proprioceptive information, and then different results would be expected.

The hypothesis of functional differences between the roles of the two arms in bimanual tasks [15] predicts that upper limb asymmetries would be expected to remain evident in bimanual concurrent proprioceptive tasks, because a proprioceptive task favours the function of the non-dominant arm/hemisphere system – positioning – in bimanual tasks [15]. However, it has been argued that the hemisphere advantage observed in unimanual tasks does not extend to different bimanual tasks [20], suggesting that upper limb asymmetries may not be evident in a bimanual context.

The economy-in-energetics principle [36] predicts that bimanual proprioceptive performance would be lowered to the level of the lower performing hand. This observation has been reported in both lower and upper limb studies involving both injured and healthy individuals [41,42]. For example, a bimanual upper limb overhead movement discrimination study [41] found that when a single arm that performed well moved in conjunction with the other arm performing at a lower level, the result was lowered bimanual movement discrimination performance. Similarly, the sensory selection notion suggests that the brain tends to be biased towards one sensory input and will ignore or curtail other sources of related information [37]. For RH individuals, sensory selection or sensory gating has been found to be biased towards the right/dominant side [37]. Taken together, this evidence suggests that, when bimanual proprioceptive tasks are carried out concurrently, the consequence would either be to lower the normally superior performance of the non-dominant hand to the level of the dominant hand to save energy costs, or bias towards proprioceptive input from the dominant hand and ignore or curtail proprioceptive information from the non-dominant hand to save attention costs. Consequently, the non-dominant arm superiority observed in unimanual proprioceptive tasks would not be evident, i.e., there would be no upper limb proprioceptive asymmetry in bimanual proprioceptive tasks.

Recent studies have suggested that upper limb proprioceptive asymmetries are dependent on handedness [3,15] and gender [3]. Goble and colleagues [14,15] found these asymmetries to be mirrored between LH and RH individuals, while this mirror asymmetry was observed only in males in a study by Adamo et al. [3]. Other sensorimotor studies have found that LH individuals are simply less lateralized [17,29], or even identical to their RH counterparts [7]. What is unknown is the extent to which LH individuals might show different patterns than those predicted for RH individuals in bimanual concurrent proprioceptive tasks.

It has been argued that, in testing proprioceptive acuity, it is important that the tests maximize the similarity between the laboratory test and real life function, i.e., maximize ecological validity [10], so that individuals can integrate all normally available proprioceptive information from different receptors, such as cutaneous receptors, joint receptors and muscle spindles [9,46]. Accordingly, in the current study we employed an active finger movement extent discrimination apparatus (AFMEDA) that screens the target from vision, so that absolute judgments on finger movements must be based on proprioception [19]. The AFMEDA design is based on the principle of replicating functional movement [6,43], that is, active rather than passive movement, at a normal speed, without physical constraint of other body segments such as is involved in methods that use passive finger movement [e.g., 45], isolate a single finger joint [e.g., 39] or strap the testing finger [e.g., 48]. In addition, the nature of the AFMEDA task ensures that information about both finger movement extent and end position is available on every trial, and this combination allows for better performance than that which is seen with extent information alone [21]. By testing thumb-index finger pinch movement discrimination of the two hands between two groups specified for handedness, two genders and two conditions (unimanual and bimanual), we sought to compare proprioceptive performance differences.

2. Materials and methods

2.1. Participants

Ten RH individuals (5 males and 5 females, mean age = 21.6 years, SD ± 1.5) and ten LH individuals (6 males and 4 females, mean age = 21.1 years, SD ± 1.7) were recruited by an advertisement placed on a campus notice board. Participants demonstrated strong right or left hand preference, as evidenced by laterality quotients calculated from a ten-item version of the Edinburgh Handedness Inventory [27]. The scores for RH participants were mean ± SD laterality quotient, +83.0 ± 14.6, range from +65 to +100; and the scores for LH participants were mean ± SD laterality quotient, −78.0 ± 12.1, range from −65 to −100. Prior to inclusion, all participants completed a health questionnaire to exclude the presence of hand injuries within the past 6 months or a diagnosis of chronic diseases (e.g., multiple sclerosis, stroke, Parkinson's disease, rheumatoid arthritis, type 2 diabetes) [19].

The project was approved by the University of Canberra Committee for Ethics in Human Research (CEHR 10-110) and before commencing each participant provided informed consent.

2.2. Apparatus

The AFMEDA was used to generate the stimuli for the finger pinch movement discrimination task. The apparatus (Fig. 1) consists of two symmetrical coaxial aluminium alloy tubes with thimbles embedded at one end to stabilize the index finger and thumb and thereby enable participants to freely execute a pinching movement of the thumb and index finger. There were five possible pinch distances generated by five adjustable metal stops, which were screw heads of different diameters tapped into the central wheel, such that the smaller the screw head the greater the