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An examination of lower limb asymmetry in ankle isometric force control

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ABSTRACT

While asymmetries have been observed between the dominant and non-dominant legs, it is unclear whether they have different abilities in isometric force control (IFC). The purpose of this study was to compare ankle IFC between the legs. IFC is important for stabilization rather than object manipulation, and people typically use their non-dominant leg for stabilization tasks. Additionally, studies suggested that a limb can better acquire a motor task when the control mechanism of the task is related to what the limb is specialized for. We hypothesized that the non-dominant leg would better (1) control ankle IFC with speed and accuracy, and (2) acquire an ankle IFC skill through direct learning and transfer of learning. Two participant groups practiced an IFC task using either their dominant or non-dominant ankle. In a virtual environment, subjects moved a cursor to hit 24 targets in a maze by adjusting the direction and magnitude of ankle isometric force with speed (measured by the time required to hit all targets or movement time) and accuracy (number of collisions to a maze wall). Both groups demonstrated similar movement time and accuracy between the dominant and non-dominant limbs before practicing the task. After practice, both groups showed improvement in both variables on both the practiced and non-practiced sides ($p < .01$), but no between-group difference was detected in the degree of improvement on each side. The ability to control and acquire the IFC skill was similar between the legs, which did not support the brain is lateralized for ankle IFC.

1. Introduction

Limb dominance or laterality refers to the preferential use of one side of the body in voluntary movement (Sadeghi, Allard, Prince, & Labelle, 2000). Studying the underlying mechanism of limb dominance has been of great interest in the field of movement neuroscience. Historically, laterality research has focused more on the upper limb than the lower limb (Peters, 1988), although lower limb dominance is commonly observed in daily activities and sports (Carey et al., 2001; Grouios, Hatzitaki, Kollias, & Koidou, 2009; King & Wang, 2017; Wang & Newell, 2013). One study reported that approximately 80% of the soccer players in the 1998 World Cup preferred to use their right leg to kick, pass, and dribble the ball (Carey et al., 2001). The term "dominant leg" has been used to describe a person's preferred leg for manipulating an object or leading out in activities such as jumping and climbing up and down the stairs (Peters, 1988; Sadeghi et al., 2000).

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A functional asymmetry hypothesis was proposed to explain laterality in the lower limbs (Grouios et al., 2009; Peters, 1988; Sadeghi, Allard, & Duhaime, 1997; Sadeghi et al., 2000; Seeley, Umberger, & Shapiro, 2008). The hypothesis states that the dominant leg is specialized for mobilization or manipulation while the non-dominant leg is specialized for stabilization. This hypothesis is aligned with the notion that the left and right hemispheres are specialized for different functions. There is compelling evidence in other contexts suggesting hemispheric specialization (Mutha, Haaland, & Sainburg, 2012; Mutha, Haaland, & Sainburg, 2013; Ocklenburg & Gunturkun, 2012). For example, the right hemisphere is more specialized for visuo-spatial processing (Vogel, Bowers, & Vogel, 2003), while the left hemisphere is more specialized for production and processing of language (Ocklenburg, Gunturkun, & Beste, 2011). In addition, the right hemisphere contributes to position control while the left hemisphere provides predictive control when people perform motor adaptation using the arms (Bagesteiro & Sainburg, 2003; Sainburg, 2002; Sainburg & Wang, 2002; Wang & Sainburg, 2003).

However, there is insufficient evidence to support the functional asymmetry hypothesis for the lower limbs. For example, postural stability was not found to improve when individuals performed a single leg stance on the non-dominant leg compared to the dominant leg (Kiyota & Fujiwara, 2014; Lin, Liu, Hsieh, & Lee, 2009). There was no significant difference in the vertical impulse (which quantified the stabilization function) and propulsive impulse (which quantified the mobilization function) between the legs during walking (Seeley et al., 2008). A potential limitation of using single leg stance or walking to assess the functional role of the non-dominant leg is that these tasks are not novel to the subjects, and daily practice of these tasks could mask functional asymmetry (Bacelar & Teixeira, 2015; Teixeira, de Oliveira, Romano, & Correa, 2011). An alternative consideration is that functional asymmetry is a function of task context (Chew-Bullock et al., 2012; Grouios et al., 2009; King & Wang, 2017; Wang & Newell, 2013). The functional asymmetry may not be exploited in all lower limb activities. For example, Wang and Newell (2013) showed that leg preference and leg functional differences became more obvious when the task demand for postural stability became greater. King and Wang (2017) found that functional asymmetry of the legs was more prominent in a novel goal-directed kicking task compared to a single-leg stance test.

A gap in the literature on lower limb asymmetry is whether asymmetry exists in the ability to control muscle force. Based on the context of the task, muscle force control could be divided into two categories. The first type of control is to adjust the force to move a limb for motion generation. This type of control can contribute to object manipulation using a foot (e.g., picking up a pebble or juggling a ball), which is what the dominant leg is specialized for according to the functional asymmetry hypothesis (Coren, 1993; Grouios et al., 2009). Through lifelong practice, the dominant leg may better control this type of force. The second type of control is to adjust the force when the joint is not moving (i.e., isometric force control). This type of control is needed more often in stabilization than in object manipulation that involves range of motion. For example, the line of gravity falls in front of the ankle joint in quiet standing, and the plantarflexors need to work isometrically to maintain postural stability (Loram, Kelly, & Lakie, 2001; Loram, Maganaris, & Lakie, 2009). Given that the non-dominant leg is specialized for stabilization, it may have better ability to control isometric force through lifelong practice.

The purpose of this study was to determine if people perform differently in ankle isometric force control between the dominant and non-dominant sides. We examined this issue from both motor control and motor learning perspectives. The motor learning asymmetry in the lower limbs has been shown in inter-limb transfer studies using tasks involving motion/object manipulation. In one study (Morris, Newby, Wininger, & Craelius, 2009), subjects learned to move a cursor toward a target using ankle motion. The results showed that inter-limb transfer occurred from the non-dominant to the dominant ankle but not vice versa. In another study (Haaland & Hoff, 2003), soccer players participating in technical training (e.g., dribbling) with their non-dominant leg demonstrated improved performance in their dominant leg as well. However, this transfer of learning was not seen in their non-dominant leg when training with their dominant leg. The exact reason for the observed asymmetry in transfer of learning is unclear. Our interpretation is that the dominant leg is specialized for object manipulation, and it may have greater ability than the non-dominant leg to acquire a task involving object manipulation. Following this logic, if the non-dominant leg is specialized for isometric force control, it should have a better ability to acquire a novel isometric force control skill than the dominant leg. In this study, we examined two types of learning: (1) direct learning using the non-dominant ankle and (2) transfer of learning from the dominant ankle.

Based on the above discussion, we hypothesized that: (1) the non-dominant side would have better ankle isometric force control in terms of speed and accuracy; (2) the non-dominant side would better improve speed and accuracy in ankle isometric force control after multiple trials of practice; (3) the improvement in speed and accuracy of ankle isometric force control would better transfer to the non-dominant side from the dominant side, compared to the alternative.

2. Methods

2.1. Subjects

Twenty young, healthy subjects were recruited to practice a novel ankle isometric force control task. Subjects were included if they were aged between 18 and 45 years old and were generally in good health. Exclusion criteria included any current musculoskeletal or neuromuscular disorders affecting the legs. Subjects were randomly assigned to one of two groups. The "dominant practice group" (age: 24 $\pm$ 4.4 years old; 6 females and 4 males) practiced an ankle isometric task with the dominant leg, while the "non-dominant practice group" (age: 22.2 $\pm$ 0.4 years old; 7 females and 3 males) practiced the same task with the non-dominant leg. Before participation, all subjects were required to sign a consent form approved by the local Institutional Review Board.

Before data collection began, each subject's dominant leg was determined using the footedness questions in the Lateral Preference Inventory (Coren, 1993). These questions included: (1) With which foot would you kick a ball to hit a target? (2) If you wanted to