Tohoku J. Exp. Med., 2020, **251**, 31-37

# Differences in the Magnitude of Motor Skill Acquisition and Interlimb Transfer between Left- and Right-Handed Subjects after Short-Term Unilateral Motor Skill Practice

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Motor skill practice improves performance not only in the trained - but also in the untrained contralateral limb - a phenomenon called as interlimb transfer. Handedness affects motor skill acquisition and interlimb transfer, but it remains unknown whether handedness affects interlimb transfer when practicing with the dominant or non-dominant limb. We have hypothesized that interlimb transfer of skill acquisition differs between left- and right-handed participants, and that right- as compared with left-hand motor skill practice shows greater interlimb transfer, regardless of handedness. Strongly left-hand (n = 12, aged 27.3 ± 4.4 years; 3 female) and right-hand dominant (n = 12, 20.7 ± 3.8 years; 5 female) subjects with no history of neurological or orthopedic disorders performed the grooved pegboard test before and after 4 blocks of practice on the same apparatus. Subjects were timed on their speed of the task. Right-handed subjects failed to improve manual performance in their right hand after right- or left-hand motor practice. In contrast, they showed improvement on the left hand in each condition. These data suggest greater interlimb transfer after right-hand motor skill practice, but no interlimb transfer after left-hand practice. On the other hand, our results show consistent interlimb transfer effects in left-handed subjects, irrespective of whether the dominant left or the non-dominant right arm has been initially trained. In conclusion, our results add to the body of literature by detecting the differences in the magnitude of motor skill acquisition and interlimb transfer between left- and right-handed subjects after short-term unilateral motor skill practice.

**Keywords:** cross-education; grooved pegboard test; handedness; motor skill acquisition; side-dominance
Tohoku J. Exp. Med., 2020 May, **251** (1), 31-37.

## Introduction

Motor learning is defined as a set of experience-dependent improvements in performance that aims to refine new skills by practicing them. The essence of motor learning is about producing more effective movements through the process of acquiring new motor skills (Krakauer et al. 2019). Most of the goal-directed actions occur in a visual context, especially when performed by the hands. Although both brain hemispheres contribute to motor control of the human body, findings from visual perception and motor control studies suggest a functional interhemispheric asymmetry. While the left hemisphere has been associated with higher-order aspects of motor control and known to be involved in the temporal evaluation of visual stimuli (Corballis 1996; Nicholls et al. 2002), the right hemisphere is important for most visual perception dependent space discrimination (visuospatial) tasks by transforming the visual information to guide movements based on spatial recognition (Coull and Nobre 1998; Ng et al. 2000; Corballis 2003). Behavioral data suggest right-hemisphere lateralization of visuospatial process for purely visuoperceptual tasks (Gazzaniga et al. 1965), however, results are controversial regarding the interhemispheric differences in visuospatial processing during visually guided motor (visuomotor) tasks (Callaert et al. 2011; Begliomini et al. 2015; Floegel and Kell 2017).

In 1894, Edward Wheeler Scripture coined the term

Received February 13, 2020; revised and accepted April 30, 2020. Published online May 20, 2020; doi: 10.1620/tjem.251.31.
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"cross-education" describing the improvement in performance of not only the trained limb but also in the untrained contralateral limb (Scripture 1894) - a phenomenon called as interlimb transfer. Although many details have yet to be identified, it is well documented that interlimb transfer of strength and skill is due to changes within the nervous system at multiple levels including cortical, subcortical, and spinal reflex pathways (Hortobagyi 2005; Barss et al. 2016). Previous studies aimed to detect whether asymmetries in the interlimb transfer are present, but the results are controversial. While a number of studies have reported asymmetries in the interlimb transfer depending on whether the dominant or non-dominant arm is initially trained (Sainburg and Wang 2002; Chase and Seidler 2008; Lefumat et al. 2015), others failed to detect such an effect (Balitsky Thompson and Henriques 2010; Stockinger et al. 2015). Nevertheless, it was shown that asymmetry in the interlimb transfer of motor performance depends on hemispheric specialization (Sainburg et al. 2016).

Manual laterality (handedness) is a widely investigated area (Gurd et al. 2006; Cowell and Gurd 2018). Understanding the structure and function of neural systems that underlie differences between left- and right-handed people is fundamental to detect the human asymmetry. Although several studies provided evidence for differences in the asymmetry of the motor cortex and related pathways with respect to handedness (Witelson 1985; Habib et al. 1991; Jancke et al. 1997; Amunts et al. 2000), a previous study found no motor skill performance differences of left- and right-handers using a grooved pegboard test (Bryden and Roy 2005) for the evaluation of visuospatial motor skills. Nevertheless, handedness seems to affect motor skill acquisition. While right-handed people had significantly greater skill improvement for their dominant-right hand compared to their non-dominant left hand, left-handers demonstrated comparable learning effects in each hand (McGrath and Kantak 2016).

Although many previous studies aimed to detect the effects of handedness on motor skill acquisition, it remains unknown whether handedness may affect interlimb transfer when practicing with the dominant or non-dominant limb. Therefore, the aim of the study was to determine the effects of handedness on manual performance and interlimb transfer induced by a short-term unilateral left- or right-hand motor skill practice. Based on neuroanatomical studies showing differences in the asymmetry of the motor cortex and related pathways with respect to handedness, we have hypothesized that interlimb transfer of skill acquisition differs between left- and right-handed participants. To investigate this question, we examined the motor skill performance of subjects using the grooved pegboard test before and after a unilateral motor practice using the same pegboard apparatus. Because the right hemisphere is known to be important for transforming the visual information to guide movements in space (Coull and Nobre 1998; Ng et al. 2000; Corballis 2003), regardless of handedness, we have hypothesized greater improvements on the left compared to the right hand, but greater interlimb transfer after right- as compared with left-hand motor skill practice, regardless of handedness.

## Materials and Methods

*Participants*

Sample size calculation (G*Power 3.1.7 (Faul et al. 2007)) was based on a previous study (Bryden and Roy 2005) which determined the influences of sex and handedness on manual performance on the grooved pegboard test. Power analysis for repeated measures analysis of variance (rANOVA) indicated a total sample size of 24, assuming type I error of 0.05 and power of 0.80.

Based on the power analysis, 12-12 strongly left-handed (n = 12, age = 27.3 ± 4.4 years, range 20-34 years; 3 female) and right-handed (n = 12, age = 20.7 ± 3.8 years, range 18-22 years; 5 female) healthy adults were enrolled in the study. Handedness was determined using the Edinburgh Handedness Inventory (Oldfield 1971). Laterality index was calculated by summing the number of tasks performed with the right limb ($R$) and the number of tasks performed with the left limb ($L$) as follows: $(R - L)/(R + L)$. Laterality index for left- and right-hand dominant participants was –90.6 ± 9.1 and 98.3 ± 4.0, respectively, showing that participants were strongly left- or right-hand dominant, respectively. Participants were randomly assigned in equal numbers to one of the following groups: 1.) LHLP: left-handed participants performing left-hand motor skill practice, 2.) RHLP: right-handed participants performing left-hand motor skill practice, 3.) LHRP: left-handed participants performing right-hand motor skill practice, or 4.) RHRP: right-handed participants performing right-hand motor skill practice. Participants had no history of or presented with neurological or orthopedic disorders. After giving both verbal and written explanation of the experimental protocol, all participants gave written informed consent in accordance with the Declaration of Helsinki. The study was carried out in accordance with the recommendations of Tohoku University Medical Ethical Committee.

*Apparatus*

In line with previous studies (Bryden and Roy 2005; Causby et al. 2014; Kojima et al. 2019), the standard grooved pegboard apparatus was used (Lafayette instruments). Briefly, the apparatus consisted of a 10.1 cm × 10.1 cm metal surface, with a 5 × 5 matrix of keyhole-shaped holes in varying orientations. Each peg was 3 mm in diameter and had a small ridge running along its 2.5 mm length. A round receptacle for the pegs was located at the bottom of the pegboard.

*Experimental procedures*

The standard procedure for the grooved pegboard test was used. Participants were instructed to place all the 25

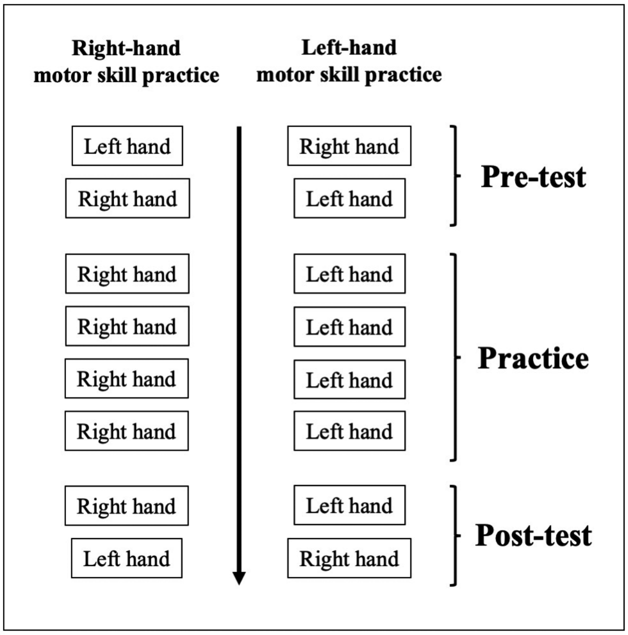


Fig. 1. Experimental design.
Left-handed and right-handed participants were randomly assigned in equal numbers to left- or right-hand motor skill practice groups (n = 6 in each group). Participants completed one trial of grooved pegboard test with each hand separately (pre-test). Participants were timed on their speed of the task. This was repeated for a second trial (post-test) after undergoing four blocks of unilateral hand motor skill practice with the assigned hand using the same apparatus.

pegs, one at a time, into the holes as quickly as possible. Each participant completed one trial of the place task with each hand separately (Fig. 1). Participants were timed on their speed of the task. This was repeated for a second trial (post-test) after undergoing four blocks of unilateral hand motor skill practice with the assigned hand using the same apparatus with 2 min rest between each block. Because the pegboard contains holes with randomly positioned slots and pegs which have a key along one side, and pegs must be rotated to match the hole before they can be inserted, rotating the backboard during the practice changed the directions of the keys, making the practice different from the testing trials. Therefore, during the practice, the pegboard was placed on the table in 4 different ways (Fig. 2) in a randomized order within and between subjects for the 4 blocks. Nevertheless, the pre-, and post-test were done under normal placement (Fig. 2A). Therefore, the task for the tests differed from the practice trials.

*Statistical analyses*

The analyses were performed using SPSS Statistics Package (version 22.0, SPSS Inc., Chicago, IL). Variables were normally distributed, measured by Shapiro-Wilk's test of normality and visual inspection of their histograms. To statistically investigate the effect of handedness and unilateral motor skill practice on manual performance and interlimb transfer, a group (LHLT, RHLT, LHRT, RHRT) × time (pre, post) × hand (trained, not-trained) exploratory rANOVA with repeated measures on the last 2 factors with planned post-hoc tests with Bonferroni correction for multiple comparisons was performed. Compound symmetry was evaluated with the Mauchly's test and Greenhouse-Geisser correction was used when data violated the assumption of sphericity so that when the Epsilon was less than 0.75 for Mauchley's Test of Sphericity, we used the Greenhouse-Geisser corrected value and the Huynh-Feldt corrected value for Epsilon greater than 0.75. Complementary post-hoc analyses (paired samples t-tests) were used when indicated. Cohen's effect size, d, was also computed as appropriate. Additionally, effect sizes of the independent variables were expressed using partial eta squared ($\eta_p^2$) (Peat et al. 2008). In order to determine if the magnitude of skill acquisition in each condition was associated with the magnitude of interlimb-transfer, Pearson's correlation was computed. Statistical significance was set at $p < 0.05$. Results were interpreted by 95% confidence intervals.

## Results

*rANOVA* with repeated measures on time, and hand revealed a main effect of time ($F_{1,20} = 125.4$, $p < 0.000$, $\eta_p^2 = 0.86$), and its interaction with hand ($F_{1,20} = 5.0$, $p = 0.037$, $\eta_p^2 = 0.20$). Post hoc-analysis showed smaller post-test values for time, suggesting a development in manual performance, irrespective of hand, and group. There were also a hand × group ($F_{3,20} = 10.8$, $p < 0.000$, $\eta_p^2 = 0.62$) and time × hand × group ($F_{3,20} = 3.2$, $p = 0.047$, $\eta_p^2 = 0.32$) interactions with the post-hoc analyses revealing that each participant performed the grooved pegboard test faster at post-test with their left hand, irrespective of handedness. However, right-handed participants failed to improve manual performance in their right hand neither after right- (p = 0.154, d = 0.89), nor after left-hand motor skill practice (p = 0.210, d = 0.43), whereas they showed improvement on the left hand in each condition (p = 0.012, d = 1.23; p = 0.005, d = 1.31, respectively) (Fig. 3). These data suggest hemispheric asymmetries in this particular test after short-term motor skill practice.

Pearson's correlation analysis revealed that the magnitude of skill acquisition and interlimb transfer was not associated in any of the conditions (LHLT: r = 0.308, p = 0.552; RHLT: r = 0.253, p = 0.628; LHRT: r = 0.379, p = 0.459; RHRT: r = –0.215, p = 0.682).

## Discussion

The aim of the present study was to determine if handedness would affect manual performance and interlimb transfer induced by a short-term unilateral motor skill practice. To the best of our knowledge, our study is the first comparing not only motor skill acquisition of left- and right-handers after left- or right-hand practice but also measuring the potential differences in interlimb transfer of the acquired motor skill. In line with our hypothesis, our

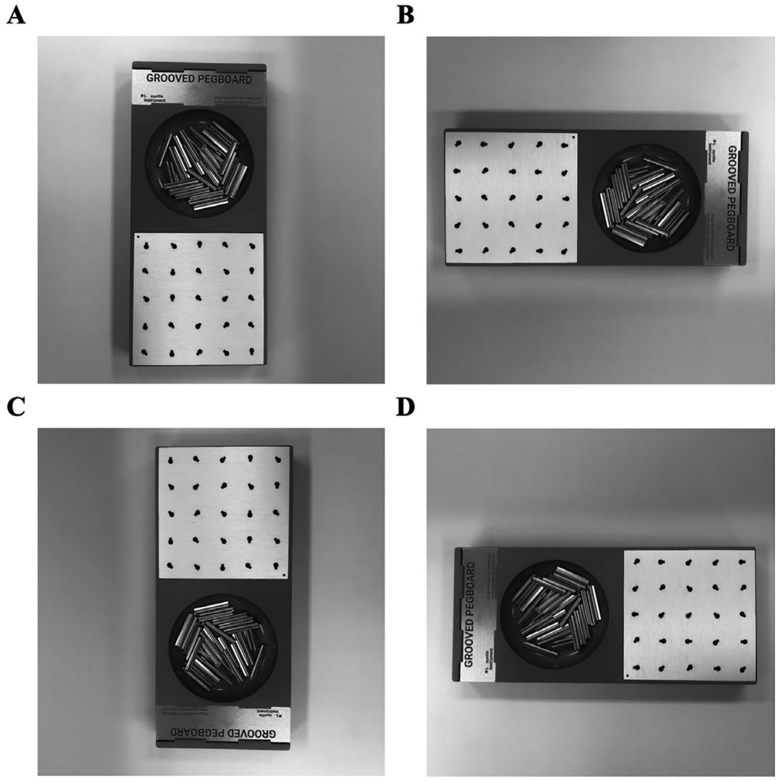


Fig. 2. Practice set up.
Illustration of pegboard placement during motor skill practice.

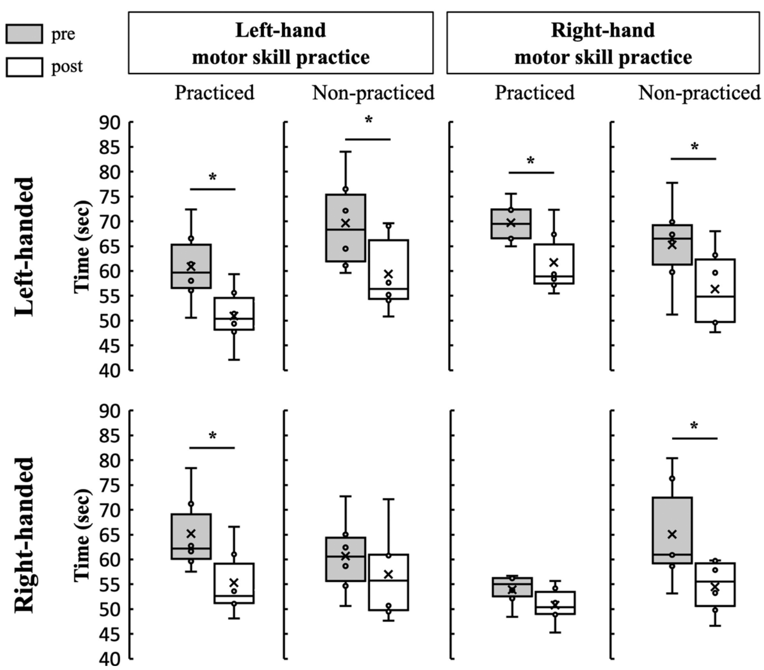


Fig. 3. Results from Grooved Pegboard Test in each group for the practiced (motor skill acquisition) and the non-practiced (interlimb transfer) limb.
Left-handed participants performed the grooved pegboard test faster at post-test (white boxes) compared to pre-test (grey boxes) not only with their trained but also with their non-trained hand, regardless of the practicing hand ($n = 6$ in each group). On the other hand, right-handed participants failed to improve manual performance in their right hand neither after right- nor after left-hand motor skill practice ($n = 6$ in each group). The boxplots show the median, the upper, and lower quartiles, and the min and max value of the groups. "×" within the boxplot represents the mean line.
*$p < 0.05$.

results indicate that interlimb transfer of skill acquisition differs between left- and right-handed participants so that while left-handed subjects' performance increased not only in the practiced but also in the non-practiced hand, irrespective of the practicing hand. Right-handed subjects failed to improve manual performance in their right hand neither after right- nor after left-hand motor skill practice. However, right-handers also showed improvements on the left hand in each condition. This is in line with our second hypothesis suggesting greater improvements on the left- compared to the right hand, but greater interlimb transfer after right- as compared with left-hand motor skill practice. Nevertheless, contrary to our hypothesis, this result was only present in right-handed subjects.

Our results are supported by previous neuroanatomical findings detecting hemispheric asymmetries during visuomotor processing (Frey et al. 2005; Culham et al. 2006; Begliomini et al. 2015). According to the double filtering by frequency (DFF) theory (Ivry and Robertson 1998), the right hemisphere acts as a low pass filter for visuospatial information which leads to the right lateralization of spatial processing during visuomotor planning (Floegel and Kell 2017). More specifically, the right hemisphere exhibits a processing preference for planning global spatial movement features whereas the left hemisphere preferentially times local features of visual movement trajectories and adjusts movement online.

Moreover, in line with a previous study, we did not find differences in the magnitude of motor skill acquisition between left- and right-handers using a grooved pegboard test (Bryden and Roy 2005), however, handedness affected motor skill acquisition. While a previous study found significantly greater skill improvement in right-handed people for their dominant-right hand compared to their non-dominant left hand (McGrath and Kantak 2016), our results show no improvement in right-hand performance neither after right- nor after left-hand motor skill practice. One possible explanation for this controversial data is the difference in experimental setup. The previous study used a kinematic-trajectory learning task that requires distinctly different motor demands than the grooved pegboard test. Another main difference between the two studies is the amount of practice given to the participants. In our study, participants practiced the pegboard test only 4 times, while participants in the other study practiced the kinematic task for 270 trials. In other words, it is possible that with extended practice, right arm may be also able to learn the motor skill and perform it even better than with the left hand. Nevertheless, both the previous and our study showed comparable learning effects in each hand for left-handed subjects.

Although previous studies have demonstrated mixed findings in left-handed individuals (Boulinguez et al. 2001; Sainburg 2005; Przybyla et al. 2012), some of them yielded similar performance improvements with both right and left hands (Wang and Sainburg 2006; McGrath and Kantak 2016) which is supported by our data, demonstrating reduced asymmetry in motor skill learning in left-handers (Przybyla et al. 2012). It is possible that left-handed individuals are more adept with both hands due to the fact that they must use their non-preferred hand more frequently, therefore they have better motor control of their non-dominant hand than right-handers (Annett and Kilshaw 1983; Kilshaw and Annett 1983). This idea is supported by scientific data showing reduced asymmetry in left-handers during several functional tasks, including reaching control (Przybyla et al. 2012), or daily activities (Borod et al. 1984). Potential underlying mechanisms involve differences in pronounced asymmetry of brain structure and function (Amunts et al. 1996) and also in motor cortex reorganization and plasticity (Schade et al. 2012) between right- and left-handed individuals. Furthermore, left-handed individuals have no significant differences in effective functional connectivity during movements of their left or right hand as compared to right-handers (Pool et al. 2014).

One of the main aims of our study was to determine whether handedness affects interlimb transfer of a motor skill. Although a number of studies aimed to detect asymmetries in interlimb transfer that depended on whether the dominant or non-dominant arm is initially trained (Sainburg and Wang 2002; Chase and Seidler 2008; Balitsky Thompson and Henriques 2010; Lefumat et al. 2015; Stockinger et al. 2015), to the best of our knowledge our study is the first examining such asymmetries in interlimb transfer in both left- and right-handed individuals. Interlimb transfer of skill learning has often been used as a paradigm to study functional specialization and hemispheric interactions in relation to handedness, however, results are contradictory in this area (Laszlo et al. 1970; Hicks 1974; Baizer et al. 1999). Although several studies showed that interlimb transfer can only be observed from the dominant to the non-dominant arm (Criscimagna-Hemminger et al. 2003; Galea et al. 2007), others presented bidirectional transfer effects (Wang and Sainburg 2004; Sarwary et al. 2015). Our results indicate consistent interlimb transfer effects in left-handed subjects, irrespective of whether the dominant left or the non-dominant right arm has been initially trained, however, right-handers showed interlimb transfer effect only from the dominant to the non-dominant hand without improved performance on the practicing dominant hand. This somewhat unexpected result might be due to the short term of practice. It is, therefore, possible that with extended practice, the right arm may be also able to learn the motor skill (McDonnell and Ridding 2006) and perform it even better than with the left hand (McGrath and Kantak 2016). Nevertheless, handedness seems to affect manual performance and interlimb transfer after a short-term unilateral motor skill practice.

One limitation of our study is the relatively low sample size. Although the pre-statistical power-analysis revealed that recruiting 24 subjects for the study is sufficient enough to detect changes in the observed variables, increasing the sample size would possibly increase the statistical power. Second, our study investigated only the performance development by timing subjects on their speed of the task. Future studies are required to understand the differences in neural mechanisms of motor skill acquisition and learning and interlimb transfer between left- and right-hand dominant individuals after practicing with the dominant or non-dominant limb using functional neuroanatomical imaging. Future studies also need to solve the inconsistencies between studies by detecting the effect of handedness on motor skill acquisition and interlimb transfer based on the amount of practice given to the participants.

In conclusion, we detected differences in manual performance and interlimb transfer after a short-term unilateral motor skill practice between left- and right-hand dominant individuals. Our data indicate that right-handed subjects failed to improve manual performance in their right hand neither after right-, nor after left-hand motor skill practice; however, they showed improvement on the left hand in each condition. These data suggest greater interlimb transfer after right-hand motor skill practice, but no interlimb transfer after left-hand practice. On the other hand, our results show consistent interlimb transfer effects in left-handed subjects, irrespective of whether the dominant left or the non-dominant right arm has been initially trained. Although our data extends the literature on the effects of handedness on motor skill acquisition and interlimb transfer, future studies need to detect the possible underlying neural mechanisms of such differences after practicing with the dominant or non-dominant limb for a longer period of time. Although the findings in our study cannot be directly applied to patients, they provide some significant information that may be also clinically meaningful and can serve as a basis for future studies in patients with neurological disorders, and may support the success of rehabilitation from a unilateral hand injury.

## Author Contributions

Y.F.W., J.Z., and J.N. designed the research. Y.F.W., J.Z. performed the research. J.N analyzed the results. R.N. directed the research. Each author contributed to writing the manuscript and all the authors have read and approved the final version.

## Conflict of Interest

The authors declare no conflict of interest.

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