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The Effect of Task Complexity Influencing Bilateral Transfer

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ABSTRACT

International Journal of Exercise Science 10(8): 1174-1183, 2017. Bilateral transfer is a well-known phenomenon whereby training one limb results in improvement in the untrained homologous limb. However, despite evidence across a range of motor skill paradigms, the influence of motor skill complexity on the magnitude of bilateral transfer has not yet been fully explored. The aim of this preliminary study was to compare bilateral transfer effects between three dexterity tasks with the hypothesis that the complexity of the task, the volume of time training, and the amount of improvement in the trained hand would positively influence bilateral transfer. Using a randomized cross-over design, 14 young healthy participants (mean age of 22.6 ± 6.6 years; eight female) completed three finger dexterity tasks (O'Connor dexterity, Purdue pegboard, and Mirror Purdue pegboard tasks) with one week rest between each task. Each task required training with the participant's dominant hand with pre and post testing in both the dominant and non-dominant hands. The Mirrored Purdue pegboard task showed the greatest rate of improvement in the dominant hand. Similarly, the greatest bilateral transfer effect was found in the Mirrored Purdue task. Interestingly, the amount of time training was not a factor associated with bilateral transfer. In conclusion, this study has demonstrated that the value of task complexity, but not the volume of practice, correlated with the magnitude of bilateral transfer to the non-dominant hand.

KEY WORDS: Cross-transfer, cross education, finger dexterity, motor control

INTRODUCTION

In 1894 Scripture and colleagues (32) were the first to show that practicing motor tasks with one limb can enhance performance in the trained, but also the untrained contralateral homologous limb. This phenomenon has been termed bilateral transfer of motor skills (16), but has also been termed inter-limb, cross-transfer or cross-education (2, 5). Bilateral transfer has been shown to occur across a range of tasks including multi-finger tapping sequences (26), visuomotor rotation (31) ballistic motor skill training (9, 28), and more recently following unilateral (2-6 weeks) strength training (8, 13, 17). Similarly, bilateral transfer has been also used in rehabilitation models demonstrating maintenance of strength and muscle morphology in an immobilized limb with unilateral training of the contralateral limb (7, 24).

There are three well-described theories, involving both cognitive and motor explanation, to explain the mechanisms of bilateral transfer. One focuses on the cognitive explanation surmising that with novice task learning involving cognitive elements; for example understanding the goal of the skill and cognitively formulating the techniques for optimization of successful movement. The second centers on a motor control explanation incorporating a general motor program (GMP) for a movement skill that fall into the same response class. Muscles are seen as a parameter of the GMP; therefore the GMP does not develop as a muscle-specific to control motor skill performance. Based upon this characteristic of the GMP (19), once the skill has been learnt with one limb, the GMP that controls it also has been learned and is now available for use to produce the skill with the other limb (26). A third explanation, involving motor output, involving neurophysiological mechanisms, suggests that whilst corticospinal projections to the muscles are mostly contralateral, there are also ipsilateral projections contributing towards improvement in skill acquisition or more recently in strength training of the non-trained limb (14). Further, studies have suggested that bilateral transfer is mediated by interhemispheric connection creating bilateral activation of homologous regions of the motor cortex. For example using transcranial magnetic stimulation to explore the excitability of the corticospinal pathway, Perez and Cohen (27) demonstrated, with evoked potentials (EPs) from transcranial magnetic stimulation (TMS), bilateral motor cortical activity during a unilateral wrist flexion task increased EPs from both contralateral but also the ipsilateral corticospinal pathway with increasing force output from the task. For greater depth regarding these theories, the reader is directed to Magill (19) and Rose and Christina (29).

Studies continue to investigate the question regarding the degree of cross transfer from the trained to untrained limb. For example, Parlow and Kinsbourne (23) posit that the amount of cross-transfer to the contralateral untrained limb is proportional to the improvement of the trained limb. Similarly, it has been suggested that the duration of movement training is important in determining the extent of bilateral transfer with motor skill acquisition (15). Further, it has been also suggested that the direction and strength of transfer is dependent upon the parameters of the specificity of the task during the learning process of the motor skill (12).

Whilst the majority of research has shown that bilateral transfer occurs from the dominant to the non-dominant limb (6, 34), more recent studies have shown bilateral transfer from non-dominant to dominant limb (3). Several studies, albeit in older adults, have shown a reduction (22) or even absence in bilateral transfer following simple motor tasks, such as finger abduction (10). This suggests that the novelty and complexity of the motor task might be of greater importance (11). Interestingly, studies that showed a reduction of bilateral transfer of simple tasks did report bilateral transfer of more complex tasks in older adults (10, 22).

Critically, the degree of bilateral transfer of motor skills therefore depends on several factors, including how skilled, or complex a task is, and theoretically how novel it is to those performing it (11, 30). Thus, motor skill training that encompasses a component of task complexity (e.g., performing precision tasks with and without a mirror), conceptually could result in greater bilateral transfer effects to the untrained limb. However, there appears to be limited data concerning the complexity of the skill in younger adults determining the magnitude of the bilateral transfer effect to the contralateral untrained limb.

One way in which the complexity of motor skills can be developed is via action observation. Action observation is a type of motor learning whereby observing the actions performed by others activates the same neural structures responsible for the actual execution of those same motor actions. In this regard, action observation generates an internal duplication of that action within the observers' motor pathways without causing any motor actions. Viewing a motor action in a mirror also activates the same neural elements that are involved actual movement execution, but, very little research has focused on the effects of performing a motor task, with only mirror feedback (29). Based upon our understanding of action observation, using a mirror as feedback to learn a motor task, should engage all the neural elements that would facilitate motor learning of a trained and untrained task.

The aim of this preliminary study was to compare the effect of bilateral transfer between three dexterity tasks, performed by the trained arm only. Given that both strength training studies and visuomotor adaptation training studies have reported bilateral transfer effects (3, 13, 14, & 21), to the best of our knowledge there have been no studies that have examined the impact of task complexity on the magnitude of bilateral transfer. Therefore, it was hypothesized that: 1) more challenging motor tasks would lead to greater bilateral transfer effects; 2) the volume of motor training would lead to greater bilateral transfer effects, and 3) the magnitude of bilateral transfer would be proportional to the amount of motor learning improvement.

METHODS

Participants

Fourteen participants (mean age of 22.6 ± 6.6 years; eight female, six male) were recruited from the University population. Participants were required to be free from any neurological condition and to be free from any musculoskeletal injury. Twelve of the participants were right handed and two participants were left handed (20). The sample size calculations were performed via an *a-priori* analysis using one-way repeated measures ANOVA. We estimated that 10 participants in each motor learning condition would provide at least 80% power (95% confidence interval) in order to detect a 10% difference in mean time to complete each motor learning task assuming a standard deviation of 7-12% between conditions at $P < 0.05$ (two-tailed). All participants provided written informed consent prior to taking part in the study, with all study protocols approved by the University Human Research Ethics committee, complying with the principles set out by the Declaration of Helsinki.

Protocol

Using a randomized crossover repeated-measures design, all participants completed the three finger dexterity tasks using only their dominant hand in a randomized order, with a one-week washout period between each task to avoid serial order or learning effects (Figure 1).

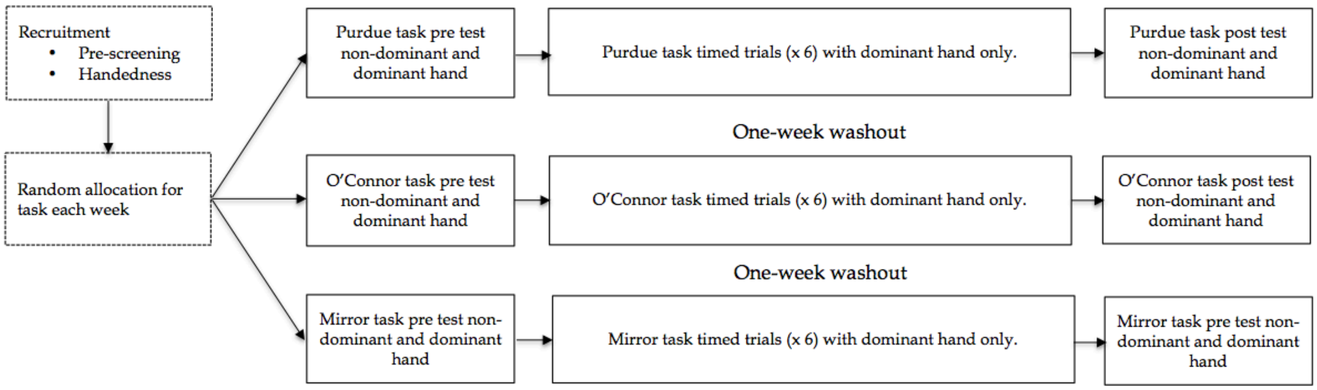

Figure 1. Schematic of the study protocol. Each task was completed in randomized order and one week break taken between tasks to avoid potential serial or learning effects.

The three tasks comprised of two well described finger dexterity assessments, the modified O'Connor dexterity (1, 4) and Purdue pegboard (33), and a modification of the Purdue pegboard. We considered the mirror Purdue task as the most complex. Conversely, the orthodox Purdue pegboard task was considered the least complex. The O'Connor requires the placement of three small pins into each hole using the participant's dominant hand. We used a modified form of this task by measuring the time it takes to place three pins into one hole across three rows (ten holes in each row) of the board (30 holes in total) (1, 25). The Purdue pegboard consists of two parallel columns of 25 holes organized vertically. Participants were instructed to place one pin in each hole rapidly, and the time taken to complete 50 pins (33). The modification of the Purdue Pegboard (33) involved the use of a mirror. The pegboard was placed inside a mirror box with the participant only able to place the pegs in the holes using the mirror to locate where the grooves were (Figure 2). Participants were instructed to place one pin in each hole rapidly, and timed for the placement of 50 pins. (33).

The design (Figure 1) followed established bilateral transfer experimental protocols to quantify bilateral transfer to the non-trained hand following training of the dominant hand. (19, 29). Rose and Christina (29) state that the protocol would demonstrate that the trained hand would show expected improvement, as a result of practice. However, as the non-preferred hand received no training, there would be no expectation of improved performance unless training with the preferred hand transferred to cause improvement (29).

One motor learning task was performed each week, with a one week wash-out period (Figure 1). The protocol involved time to completion of each motor learning tasks with both the participant's dominant and non-dominant hands. The participant then completed six self-directed timed trials using their dominant hand only. A one-minute break between each practice trial was allocated. Once the six timed trials were completed, testing of both hands was again undertaken (Figure 1). All testing conducted, followed the established protocol by Magill (19), and Rose and Christina (29). All motor tasks were assessed using a stopwatch and recorded on a form and entered into SPSS (V24, IBM SPSS, Chicago, IL).

Statistical Analysis
Statistical methods should be described in enough detail to allow a knowledgeable reader with access the original data to verify the reported results. Include the computer software used, and the alpha-level used for the determination of significance.

RESULTS

Due to the disparity in task completion times, improvement in training times were normalised to trial 1 result and are illustrated in Figure 2. One way repeated measures ANOVA revealed a significant time by condition interaction $F_{7,136}$=5.63; p<0.001 (Figure 3). Post hoc analysis revealed that motor learning improvement in the dominant hand was significantly greater in the Mirror Purdue task compared to the O'Connor (p=0.006) and Purdue tasks (p =0.013).

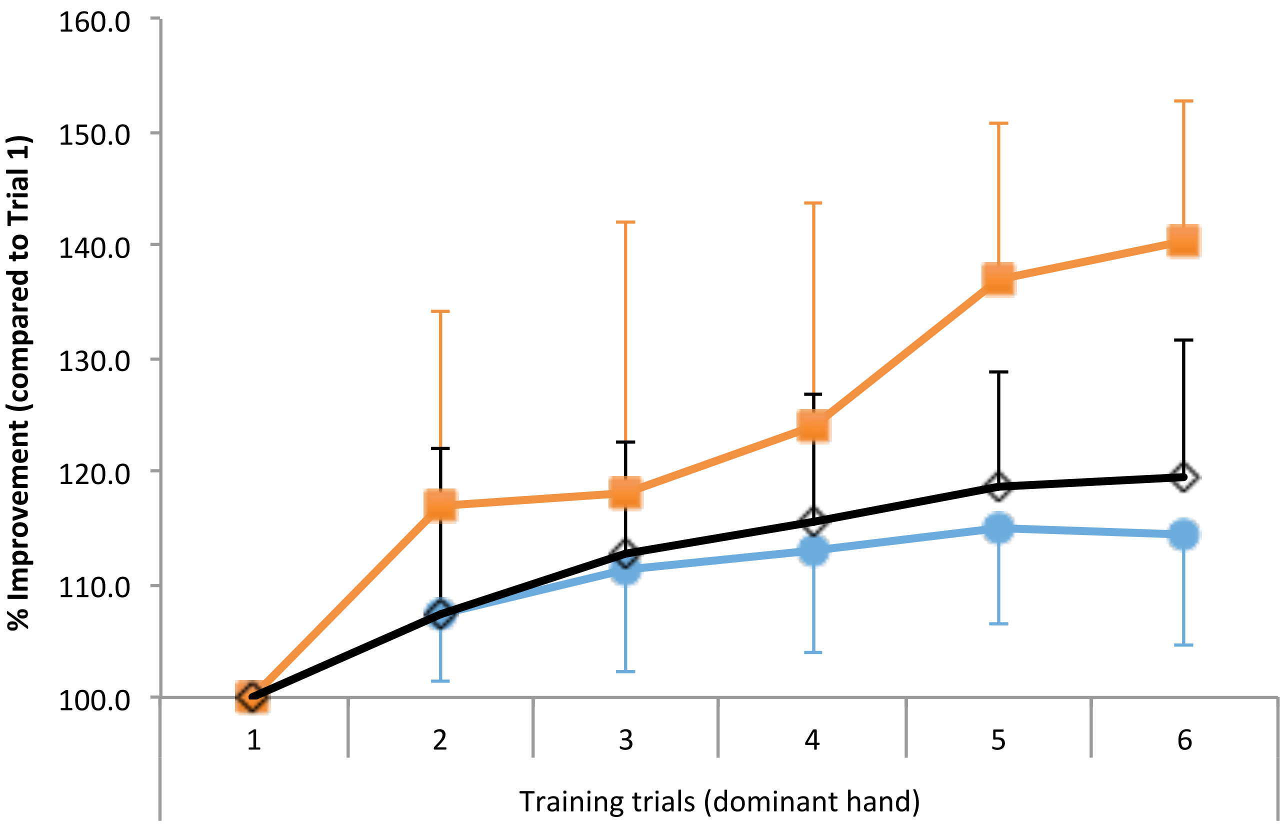

Figure 2. Group mean (±SD) percentage improvement (compared to trial 1) in completion time following each practice trial, compared to Trial 1, for O'Connor (blue), Purdue (black), and Mirrored Purdue (Orange) tasks. Each task was separated by one week.

Figure 3 illustrates the difference in time taken to complete each task with the non-dominant hand. One way ANOVA showed a significant difference between groups $F_{2,39}$=8.26; p=0.001 with post hoc pairwise comparisons showing a significant improvement in the non-dominant hand following the Mirror Purdue task compared to both the O'Connor (p=0.045) and Purdue (p=0.001). Effect size analyses showed large performance improvements in both the O'Connor and Mirror Purdue tests (d=1.5 and 1.63 respectively), and medium improvement in the traditional Purdue (d=0.72).

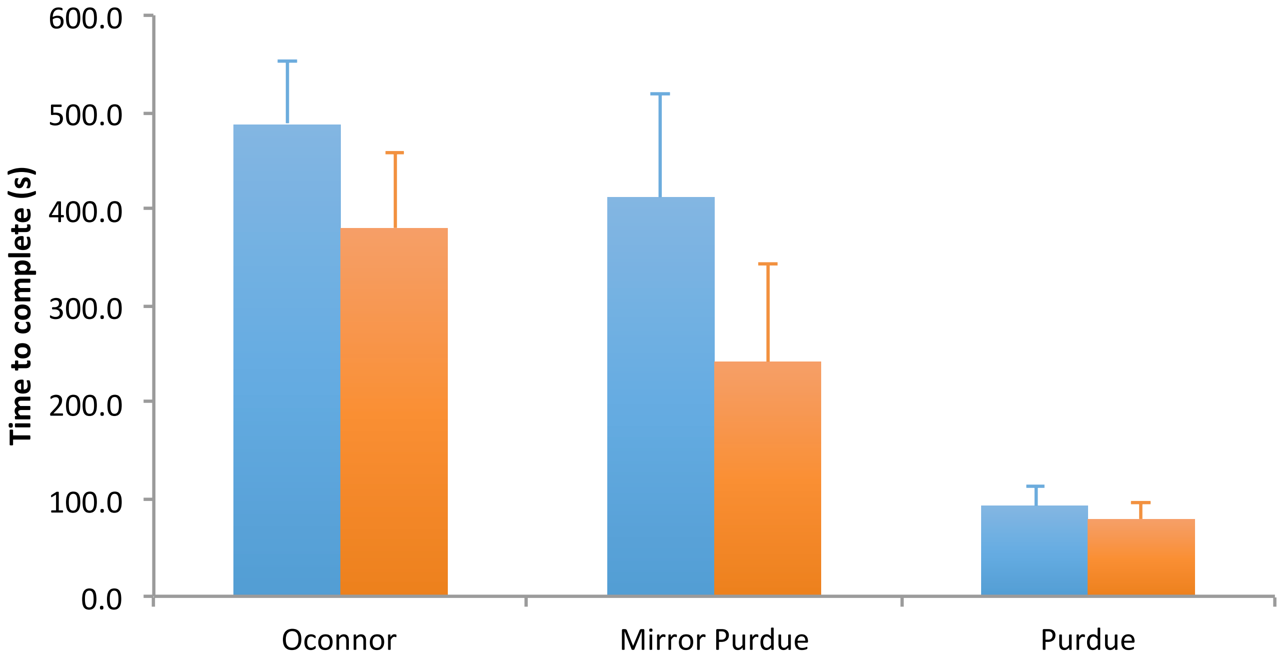

Figure 3. Group mean (±SD) comparison of pre-training (blue) and post-training (orange) performance of each task in the non-dominant hand.

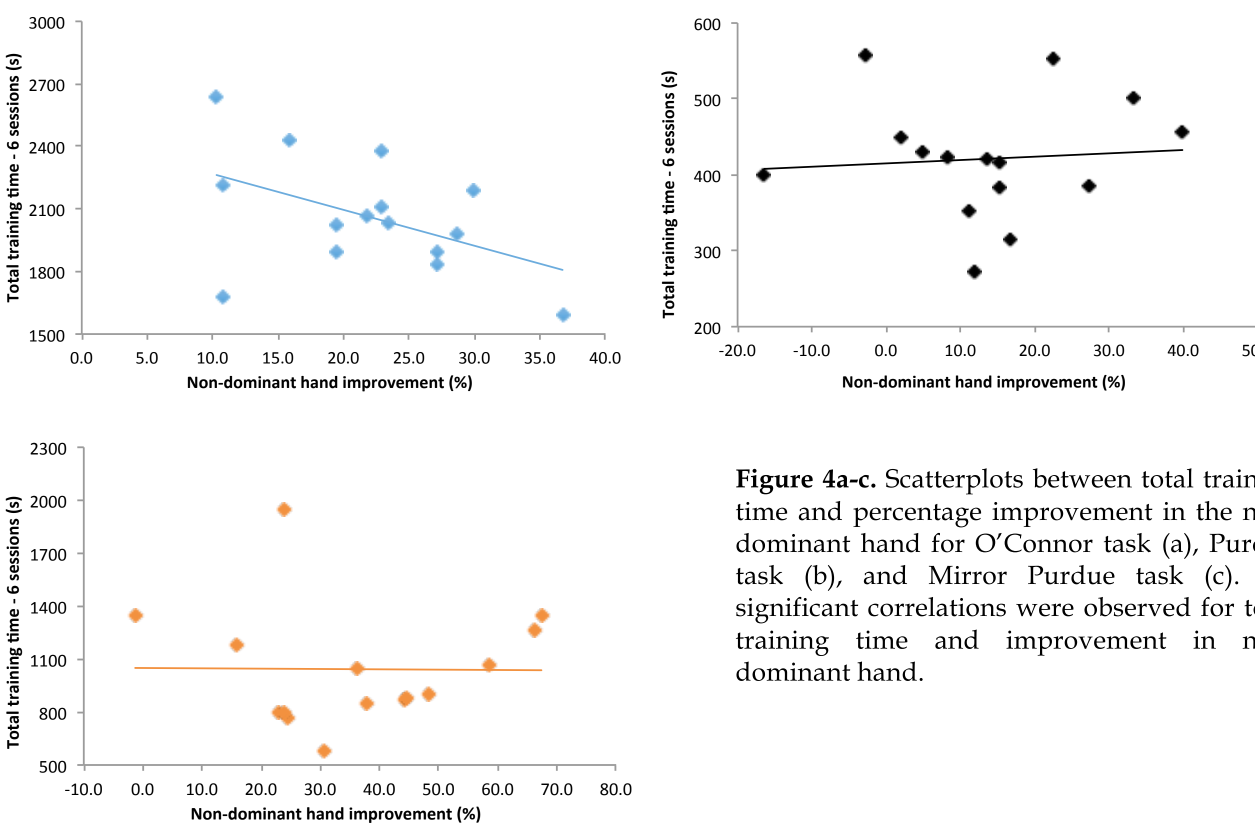

Figure 4a-c. Scatterplots between total training time and percentage improvement in the non-dominant hand for O'Connor task (a), Purdue task (b), and Mirror Purdue task (c). No significant correlations were observed for total training time and improvement in non-dominant hand.

Correlations between total training times of the dominant hand to non-dominant hand improvement (figures 4a-c) revealed no significant correlations (O'Connor: r=-0.47, p=0.09; mirror Purdue: r=-0.01 p=0.97; Purdue: r=0.08, p=0.79). Whilst no correlations between improvements of dominant hand to non-dominant hand (figure 5a-c) were observed in the O'Connor (r=-0.35 p=0.22) or Purdue (r=0.40 p=0.16), a significant correlation was found in the Mirror Purdue (r=0.59 p=0.03).

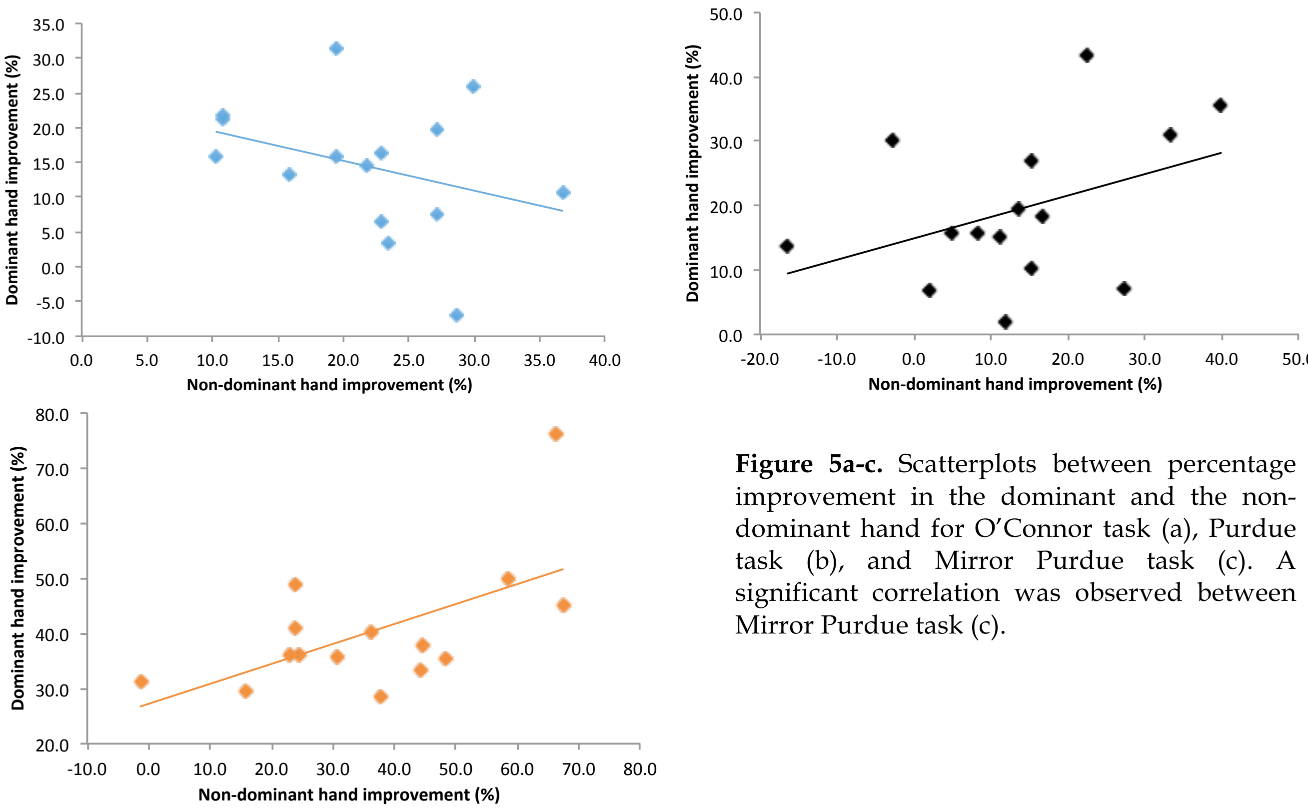

Figure 5a-c. Scatterplots between percentage improvement in the dominant and the non-dominant hand for O'Connor task (a), Purdue task (b), and Mirror Purdue task (c). A significant correlation was observed between Mirror Purdue task (c).

DISCUSSION

This preliminary study compared bilateral transfer effects across three dexterity tasks. We hypothesized that the complexity of the task, amount of improvement in the trained hand, and the volume of total training time would positively influence bilateral transfer. Our data showed that the modified Purdue training task was the most complex and this lead to the greatest amount of bilateral transfer. Interestingly, task complexity was strongly correlated to the magnitude of bilateral transfer, which supports our original hypothesis. Consistent with previous bilateral transfer literature, the magnitude of improvement (i.e. time to complete the motor task) in the trained hand was associated with the magnitude of improvement in the non-trained hand. However, we found no association between the total amount of motor training time (i.e. total time spent training the dominant hand) and the improvement in motor learning of the untrained (non-dominant) hand.

Whilst it has been suggested that bilateral transfer is the result of both cognitive and motor factors (19, 29), previous studies in both motor skill and strength training have demonstrated that the magnitude of bilateral transfer is proportional to the improvement experienced in the trained limb (14, 23). Further, recent research has shown that the demands of the task, as well as the type of task, play an important role in the degree of bilateral transfer (18). We have shown that differences in the amount of bilateral transfer of different motor skills of varying difficulty are associated with increasing complexity. The modified Purdue task was considered the most complex of the three motor learning task and interestingly it resulted in the largest bilateral transfer. Certainly, factors such as how complex a task is and how novel the motor task is to those performing it, affect the magnitude of bilateral transfer. Therefore, whilst all three tasks could be considered 'novel' or unfamiliar to the participants undertaking the activity, the Mirror Purdue motor task encompassed a greater complexity to the other tasks. On this basis, the complexity of the task has yielded a greater bilateral transfer effect.

While we have shown the behavioral effects of task complexity on bilateral transfer, the mechanisms encoding these adaptations are unclear. Previous research suggests that motor learning tasks, such as the Mirror Purdue likely involve a distributed network of visual and motor regions within the brain that undergo plastic changes. However, in light of this, it is not clear how bilateral transfer obtained from increased task complexity relates to motor learning in other contexts, such as limb immobilization and unilateral injury. Further research is required to answer these questions for application to exercise rehabilitation.

In conclusion, this study has demonstrated the value of task complexity on bilateral transfer effects. Further research is required to investigate specifically the direction of transfer (i.e., if this effect is observed in reverse in left-hand dominant individuals). Additional studies should also investigate if the effects are as strong in an older population compared to a younger aged group used in this study. By expanding this study to a wider age group, the findings can be translated towards rehabilitation particularly when motor control following unilateral injury.

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