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Generalization of Motor Adaptation Skills from Bimanual-Grasp to Individual Limbs

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***Abstract* —We reported previously that the skills transferred from practicing using a bimanual grasp to skills in right hand are small but significant. In this study on healthy right-handed people we compared how well skills learned while training using a bimanual grasp transferred to the left and right hands performance individually. As before, the task was to make target-directed reaching movements while grasping a planar robotic device that systematically disturbed movements at the handle. Results showed that skills learned while practicing with a bimanual grasp generalized (transferred) to both the dominant and the non-dominant arm equally well, with the right limb benefiting the most because it began with less error.**

I. Introduction

In many instances of daily life such as opening a jar or transporting an object, we use both our hands cooperatively to accomplish the task. As a consequence many of the things we do with on hand we can do easily with the other, and when both hands work together the outcome can be better than if a single limb is used by itself.

This concept becomes especially important to consider in the rehabilitation of individuals with hemiparesis secondary to stroke, where the less impaired limb might help in the recovery of the impaired limb. Bimanual steering tasks provided an environment that required both hands to participate and led to more appropriate forces from the hemiplegic hand [1]. Cortical activity in stroke patients is highest when both hands are involved [2]. Bimanual tasks are extremely challenging to individuals with hemiparesis because both hands must uniquely participate -- the unimpaired limb cannot simply replace the impaired limb.

What is not entirely clear, however, is whether the underlying neural machinery allows for beneficial transfer of skills from shared bimanual tasks to a single limb – even in the healthy nervous system. Others have demonstrated that interlimb transfer (e.g., right-to-left) can be observed, although only a mild percentage of what was learned [3-5]. However, little is known about transferring skills gained with a dual (bimanual) grasp to a single limb. We have reported previously that the skills transferred from practicing using a bimanual grasp to skills in right hand are similarly minimal [6]. However, we did not establish if those results would be different in the non-dominant left hand

The follow-up study presented here further investigates the ability to transfer skills from bimanual grasp training, and compares the differences on such training on both the left and right hands. As before, the task was to make target-directed reaching movements while grasping a planar robotic device that systematically disturbed movements at the handle. Results suggest no difference in unimanual performance. These results should guide future research in robot assisted training and rehabilitation.

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II. Procedures

A. Apparatus

All subjects used the two-degree-of-freedom planar manipulandum described elsewhere [7]. Two brushed DC torque motors (PMI model JR24M4CH, Kolmorgen Motion Technologies, Commack, NY, USA) control the forces at the handle at the end of the links. Angular position is measured by rotational digital encoders (model 25/054-NB17-TA-PPA-QAR1S, Teledyne-Gurley, Troy, NY, USA). A six degree of freedom load cell (Gamma 30/100 ATI, Garner, NC, USA) fixed to the handle records interface kinematics. Data was collected at 100 Hz. Rotational encoders recorded these hand positions while a 6DF load cell recorded hand forces (100 Hz).

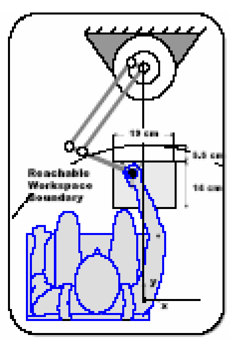

Figure 1: Subject seated at robotic apparatus. A subject's arm is obscured by a platform placed above the workspace of the robot.

B. Protocol

Our goal with this experiment was to address whether the motor system could adapt to a force field while holding the handle with both hands, and then transfer the skill to the right and to single hand performance (both left and right). Similar to our previous experiment, these targeted-reaching movements were performed with constant exposure to the "curl" force field, governed by:

$$\mathbf{F} = \begin{bmatrix} 0 & \lambda \\ -\lambda & 0 \end{bmatrix} \dot{\mathbf{x}}$$

where **F** is the vector of forces, $\dot{\mathbf{x}}$ is the vector of instantaneous velocity, and λ is the gain, set to a value of 20 N•s/m for this experiment. Essentially, the amount of force a subject would experience depended linearly on hand speed. Throughout the experiment, the subjects made 10 cm targeted reaching movements while grasping the handle of two-joint, robotic manipulator within this field. Each subject was instructed to make this movement from a starting target to an ending target in one half second. A "good" movement was one that lasted in between 0.45s and 0.55s. Qualitative feedback was provided to the subject about each movement's duration through various auditory tones. A horizontal screen was placed over the subjects' hands so that the workspace of the robot and targets were only visible as a projection on the screen. A small dot projected on the screen corresponded to the position of the handle.

Eight right-handed subjects with no known neuromuscular disorders participated in this experiment after giving informed consent in accordance with the Institutional Review Board standards of Northwestern University. Subjects briefly attempted the force field (initial exposure, 5 trials in each direction) with separate hands before beginning prolonged training in the presence of the force field with a bimanual grasp (training phase, 510 movements randomly distributed amongst the three movement directions). They then made the same reaching movements in presence of the force field with both the left and right hands separately (test phase, 5 trails in each of the 3 directions).

C. Data Analysis:

A subject's motor performance was accessed through a simple kinematics evaluation assuming that the subjects intended to make straight line movements. Quantitative evaluations of movement error compared a subject's initial movement direction with a straight line path from the starting target to the ending target. This initial direction error was calculated using the point at which the subject reached 30% of the distance to the target. We used five trials in each of the three movement directions at the beginning and end of each phase to compile our statistics on how much each subject's performance changed as a consequence of training. A t-test with an alpha-level of 0.05 was conducted to determine the statistical significance of the results between left and right performance after bimanual practice.

III. Results

We were interested in determining if skills could transfer equally to the right or left hands. Nearly all subjects significantly adapted, indicated by a significant reduction in error during training (Fig 1A; $p<0.001$). A brief exposure to the field on the left and the right hand displays the subject's unfamiliarity with the field (Fig. 1B and 1C, left columns).

Learning generalized for both left and right limbs (Fig. 1B and C; $p<0.001$ for both). However, regarding the difference in the ability to transfer skills to either the left or right hand, we failed to detect any difference -- the similarity in transfer for both was strikingly similar. However, the right limb, while showing similar amount of change, began and ended transferring with less error, so that the final errors were not significantly different than zero ($p>0.05$). In contrast, the left arm began with more error and ended with significant error ($p<0.005$).

IV. Discussion

This study on healthy right-handed people provides evidence that skills learned while practicing with a bimanual grasp generalize (or transfer) to both the dominant and the non-dominant arm equally well, with the right limb benefiting the most because it began with less error. We have shown that bimanual training of reaching movements produced transfer to the dominant hand that was no better than transfer to the dominant hand after nondominant training.

These results also support other studies [4, 6] by showing that the nervous system generalizes tasks using an extrinsic (i.e., Cartesian) coordinate system rather than an intrinsic (i.e., joint) system. Since trajectories on the right and the left hands both showed a similar orientation, knowledge of the field transferred in an extrinsic manner. This also bodes well for rehabilitation techniques that want to leverage one limb to help the recovery of function in the other, since this assumes that the system possesses a representation that is invariant to the limb.

Here we show that hand dominance plays only a minor role in transfer of a learned motor skill. Perhaps the limbs visit the same states & experience the same forces creating a combined learning effect. These results show that the left arm learns in a similar way to the right arm and that each receives a similar benefit after bimanual training.

Other studies have suggested that the functional form of internal models contains a mapping between intrinsic coordinates (i.e., joint angles) and the intrinsic forces (i.e., joint torques) [8]. However, because there is some motor control benefit to both contralateral and bimanual training, the nervous system must also establish and exploit a relationship between extrinsic endpoint coordinates and forces. This is clearly indicated in by the extrinsic transfer of skills observed here and in other studies. We suggest that there may be multiple representations in the nervous system.

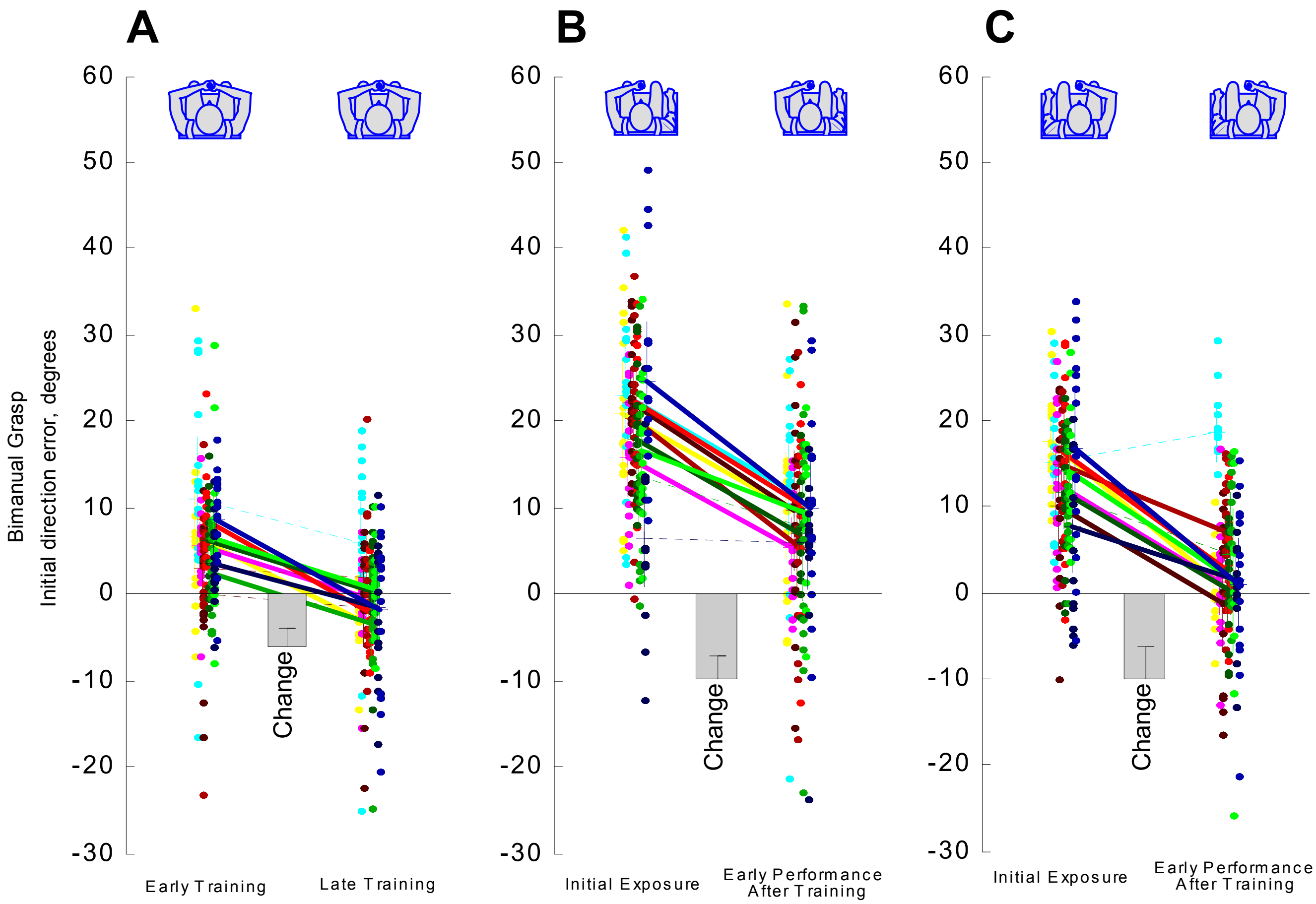

Fig2. Initial direction error for bimanual performance in the field for follow-up group. Each dot represents a trial's error, and each color indicates a different subject. Vertical whiskers using the same colors indicate the 95% confidence interval for a subject. Diagonal lines connecting pre- and post-learning are shown for each subject using the same colors, and if they are solid, they represent a significant change ($p < 0.05$, by a t-test) due to training for that individual. A) Learning for bimanual training in the presence of the force field. B) and C) represent the performance in the presence of the field of the left and right hands, respectively before and after bimanual training.

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