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Virtual Reality Based Training to resolve Visio-motor Conflicts in Surgical Environments

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Abstract *–An issue that complicates movement training, specifically in minimally invasive surgery, is that often there is no one to one correlation between the visual feedback provided on a screen and the movement required to perform the given task. This paper presents a simulator that specifically addresses the intermodal conflict between motor actuation and visual feedback. We developed a virtual reality visio-haptic simulator to assist surgical residents in training to resolve visio-motor conflict. The developed simulator offers individuals the flexibility to train in various scenarios with different levels of visio-motor conflicts. The levels of conflict were simulated by creating a linear functional relation between movement in the real environment and the virtual environment. The haptic rendering was consistent with the visual feedback. Experiments were conducted with expert pediatric surgeons and general surgery residents. Baseline data on performance in conditions of visio-motor conflict were assimilated from expert surgeons. Residents were divided into experimental group that was exposed to visio-motor conflict and the control group which wasn't exposed to visio-motor conflict training. When the performance was compared on a standard surgical suturing task, the residents with inter-modal conflict training performed better than the control group suggesting the construct validity of the training and that visio-motor training can accelerate learning.*

Keywords *– Virtual Reality, Medical Simulation, Haptic User Interfaces, Surgical Simulation*

I. INTRODUCTION

Minimally invasive surgery (MIS) poses several problems for training surgical residents. One of the significant challenges lies in training residents to conduct sophisticated skill based procedures in a small workspace. The keyhole effect produced by the insertion of surgical tools through a keyhole port in the human body further limits possible movement. The second factor lies in the limited visual access to the interior of the human body on a monitor. The current surgical environment requires surgeons to view the interior of human body through the monitor generally placed at eye level. These conditions further exacerbate the ergonomic issues in performing surgery with high accuracy that is critical to increasing patient safety (See Figure 1).

In the past few years, virtual reality based simulators have emerged at the forefront of surgical education [1]. Virtual reality simulators have the advantage of simulating dynamic environments with controllable variations to operating parameters. This advantage can be leveraged to offer training to surgical resident that is based on cognitive learning principles. One particular type of learning theory, learning a new concept is dependent on the type of example stimuli that are presented during learning phase [2]. The theory suggests that exposing subjects to divergent examples of certain stimuli that represent a concept leads to faster learning. This learning theory can be converted into an educational strategy wherein students are exposed to controlled variation of a certain parameter in order to gain expertise in handling the parameter. This paper deals with the design, development and evaluation of a simulator for enabling surgical residents to handle visio-motor conflict introduced due to the ergonomic conditions of the MIS working environment. Visio-motor conflict is a type of intermodal conflict [3].

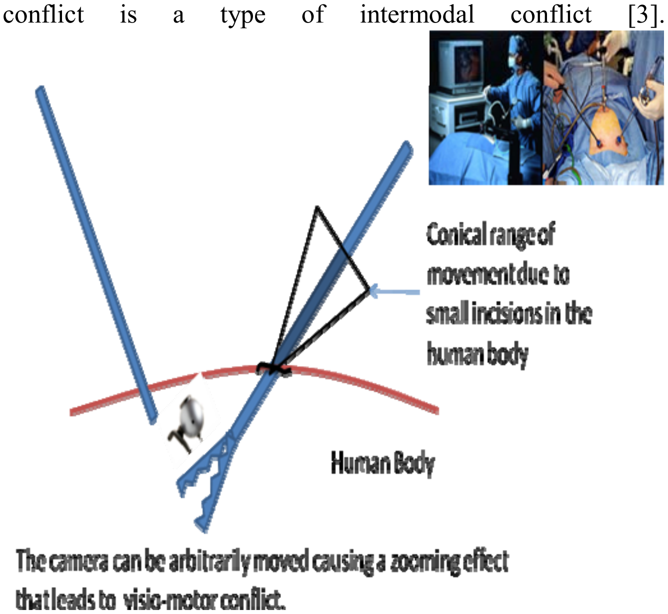

Fig 1. The minimally invasive surgery environment that creates visio-motor conflict.

An intermodal conflict occurs when there is a perceptual conflict between two or more sensory modalities. In the case of MIS environments this conflict occurs between the visual feedback provided to the surgeon and the motor actuation required to correlate tool movement in the video. This conflict occurs due to variations in camera viewpoint and occlusion. The surgeon, however, is also often faced with situations when the correlation between the visual feedback and motor actuation changes during the course of the surgery. This is due to unstable camera operation. In [4] Ballantyne states that inexperienced or bored camera holders tend to move the camera frequently, sometimes rotating it away from the horizon. This causes problems for the operating surgeon who needs to adapt immediately to resolve the new visio-motor conflict. Existing simulators do not provide for this kind of training.

The simulator presented in this paper provides for training of fine motor skills through modules that present different visio-motor conflicts. The basic hypothesis tested in here is that training in scenarios with greater visio-motor conflict will improve performance of surgeons in conditions of visio-motor conflict. We present the design, development and evaluation results of the simulator in the following sections.

The design of this simulator draws inspiration from pediatric MIS procedures. Researchers [5-7] have shown that in treating specific conditions like pyloric stenosis and appendicitis pediatric surgeons perform better than general surgeons (in terms of reduced hospital stay and fewer postoperative complications). However, there are no studies that examine if specifically skills acquired by pediatric surgeons are significantly different from skills acquired by general surgeons. Surgeons performing pediatric MIS perform the surgery in an even more constrained workspace than adult MIS procedures. The degree of visio-motor conflict is much higher in pediatric MIS than in adult MIS. Therefore it can be hypothesized that the key differentiation between adult and pediatric MIS is a difference in the degree of visio-motor conflict. This correlates with the goal to build a simulator with two modes of varying degrees of visio-motor conflict thereby providing an ideal application platform to build this simulator.

II. CONCEPTUAL DESIGN

The simulator for suturing is presented in this paper. The following subsections elucidate design decisions.

A. Visio-motor conflict simulation

The developed simulator has two modes of operation – normal mode and pediatric mode. Visual feedback is kept constant in both modes. The haptic workspace however is significantly smaller in the pediatric mode thereby creating the illusion of greater visio-motor conflict. We created a linear relation between the motion between actual environment and the motion between virtual environment. The scaling factor was programmable in our developed simulation. The simulation allowed for both positive scaling and negative scaling although for our simulation we were interested in positive scaling that makes virtual motion more pronounced than the real motion.

B. Suturing application simulation

The simulated surgical application is suturing. Suturing is one of the basic skills required for surgery and has a steep learning curve. In order to isolate difficulty due to resolution of visio-motor conflict from procedural difficulty, suturing was modeled as the simple task of controlling piercing through a deformable surface. The task focuses on piercing through tissue while keeping penetration depth (maximum distance travelled after piercing through the surface) as low as possible. This creates an ideal environment to test whether training on the pediatric mode improves performance in the normal mode of training.

III. IMPLEMENTATION

Figure 2 shows the basic interface of the simulator. The primary object in the simulator is the particle-system based deformable surface. An off-the-shelf particle system solver was used to for the simulation. The simulation allowed for varying the compressibility of the surface through the number of mass spring units attached to the surface and the friction and drag associated with the interaction.

The simulator was designed to provide each subject with 10 trials. Each trial contains 1 green target and 1 red target. The target that needs to be pierced is highlighted in green. A trial is divided into 2 phases. In the first half the participant used the needle to pierce the required target from the top of the surface. When this occurs the needle falls below the surface. In order to prevent occlusion, the surface is made translucent (Figure 3). This is the second phase of a trial. Here the participant is required to pierce the required target from below the surface. Upon completion of phase two a trial is also complete.

Figure 2 also shows the two different modes of operation – normal mode and the pediatric mode. The different levels of conflict are achieved by rendering different haptic workspaces while keeping visual feedback a constant. The similarity in visual feedback, and the appropriate scaling of the tool (needle) and targets, as shown in Figure 2, help complete the illusion of higher visio-motor conflict. We chose 200% as the scaling factor for simulation pediatrics mode and 100% for the normal mode. The movement in the virtual environment m_v is related to movement in the real environment m_r by the following relation

$$m_v = \text{scaling factor} * m_r \quad (1)$$

The scaling factor could be changed in the simulation dynamically through user input or pre-programmed camera movements.

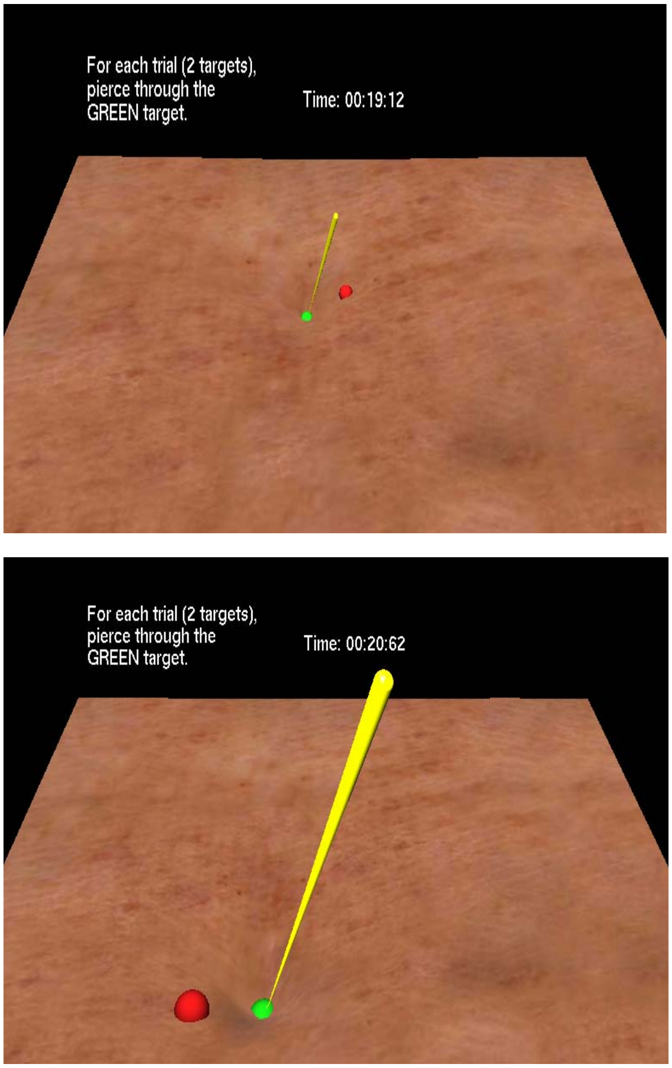

Fig. 2. Suturing simulation scenario. The figure shows a simple deformable surface with targets. [Above] The haptic workspace of normal mode of training [Below] The haptic workspace of pediatric mode of training. Visual feedback is kept constant in both.

Fig. 3. Suturing simulation scenario. The figure shows phase 2 of a trial when the participant is required to pierce through the target from below the translucent surface.

The simulator also tracks three parameters for performance evaluation – time taken to complete a trial (in seconds), error (defined as distance between point of piercing and the target), and penetration depth (maximum distance travelled after piercing through the surface). These metrics can be used to provide immediate feedback to the user regarding their performance. All these metrics have clinical relevance. Time taken to complete a trial is an effective indicator of skill of subjects. However care must be taken to interpret the results as often expert surgeons can take more time than novice while incurring lesser errors. Error as defined in the simulation has high significance in the clinical arena as a placement error can lead to medical complications and in some cases fatalities. Penetration depth is a measure of the control of the subject in being able to accomplish fine motor movements in a constrained environment without excessive force. In theory each of the variable hold an inverse relation with expertise since with increasing expertise, each of the three variables should show a decline. Each of the three variables is normalized to a range of 0-1. Our simulation also allows for measurement of hand movements through the use of Cybergloves®. However, those were not included in this simulation.

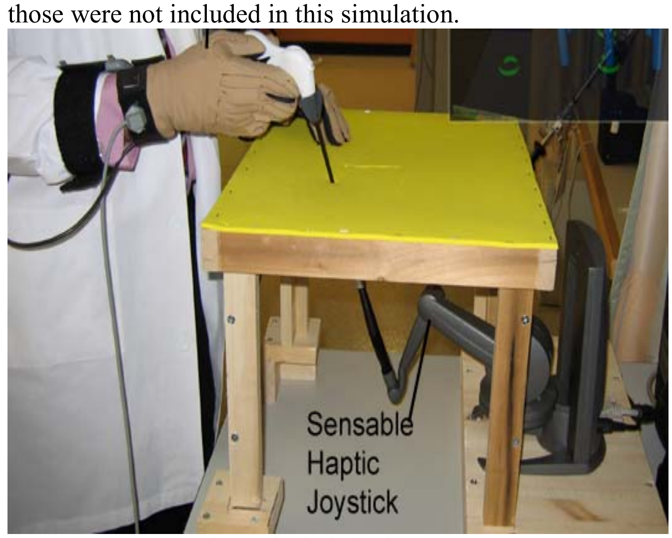

Fig. 4. Physical Simulator Setup

A 3.2GHz processor with a NVDIA Quadro FX550 graphics card was used for the simulation. Sensable Phantom Desktop^{TM} joystick is used to provide haptic feedback. OpenGL interfaced with the OpenHL library was used to build the interface. Figure 4 shows the physical set up of the simulator that mimics the operating conditions of surgical environment. Sensable joystick is connected to surgical probes which penetrate a constraining surface. This model mimics the keyhole movement that is obtained in real minimally invasive surgery.

IV. EXPERIMENTAL METHODOLOGY

The primary goal of this experiment is to test if training on the pediatric mode increases participant performance in the normal mode of training. The secondary aim is to use the expert data to validate the use of this simulator. The experiment was conducted with 3 expert pediatric surgeons and 10 residents. The participants performed 10 trials in the normal mode (Normal 1), 2 sets of 10 trials in the pediatrics mode (Pediatrics 1 and Pediatrics 2) followed by another 10 trials of the normal mode of training (Normal 2). The experts in our group included pediatric surgeons. We expected that the experts would perform better at the pediatric mode. Further we expected that the normal mode would also improve after further practice with the pediatrics mode.

The residents were divided into two groups. The experimental group of residents (3 males, 2 females first year general surgery residents) performed a set of 10 trials in the normal mode (Normal 1), 2 sets of 10 trials in the pediatrics mode (Pediatrics 1 and Pediatrics 2) followed by another 10 trials of the normal mode of training (Normal 2). This was analogous to the trial pattern of expert surgeons. The control group (4 males, 1 female first year general surgery residents) participated in four sets of normal training only. The performance in each of the four trials was recorded and plotted as a line graph.

In the final level of analysis, experimental group and control group were exposed to a condition with varying levels of visio-motor conflict ranging between 200% to 350%. Their performance on ten trials of suturing was recorded and compared using ANOVA. A $p<0.05$ was accepted as statistically significant difference.

V. RESULTS

Figure 5,6,7 shows a comparison of the performance of the various groups. Figure 5 shows the mean time taken to complete the task in each of the trials. Figure 6 shows the mean errors made per trial and Figure 7 shows the mean penetration depth made per trial.

The results show some clear trends. First it is clear that the experts perform significantly better than residents in terms of errors made and penetration depth. Time taken to complete the task showed that although the experts initially took longer to complete the trials, over time they improved their time taken to complete the task considerably. The longer duration to complete trial 1 can be attributed to familiarization phase for the experts. Experts tend to spend a significant time in familiarizing themselves with the task at hand. On the other hand, residents begin the simulation with significantly lower mean time durations to complete the task. This suggests a difference in motivations of experts and novices. It is clear that expert surgeons pay more attention to reducing errors and penetration depth rather than complete the given task within time constraints. This attention to accuracy is also seen in the increase in mean time during second pediatrics trial session. On the other hand, residents in general are more concerned about time to completion as being a primary variable of interest. This however can be extremely dangerous for patient safety.

The second level of analysis deals with studying the effect of visio-motor conflict training on resident's performance. We are concerned here with comparing performance of control group and experimental group. The results show an interesting trend. Initially both the groups begin with comparable time required for completion, errors and penetration depth. In the second set where pediatrics training is introduced for the experimental group, experimental group shows a sharp increase in time required for completion, errors and penetration depth. This can be attributed to the introduction of visio-motor conflict for the experimental group. Increased visio-motor conflict can significantly increase the difficulty of the task thereby showing an increase. On the other hand, the control group shows a decrease in each of the three variables albeit with small decrement levels.

The third set of tasks show the experimental group increasing their proficiency considerably during the pediatrics mode, while the control group simply continues the downward trend due to learning but with small decrement. The fourth trial which is in normal mode for both the control group and experimental group shows that the experimental group performs much better than the control group. There is a statistically significant difference between the performance of both the groups during the fourth trial ($p<0.05$ on both errors and penetration depth). It is also worth noting that when the performance of the first trial is compared to the performance on the fourth trial, the experimental group shows a statistically significant improvement ($p<0.05$ 37% improvement in errors and 39% improvement in penetration depth) while the control group shows only marginal improvement in their errors and penetration depth ($p<0.65$ 11% improvement in errors and 7% improvement in penetration depth).

Figure 8 shows the results of the final experiment wherein the performance of the control group and experimental group was compared on a varying visio-motor conflict simulation. The experimental group performed significantly better than the control group on the task ($p<0.05$). This shows that on a new task with varying levels of intermodal conflict, experimental group exposed to visio-motor conflict training can learn to compensate for conflict and perform better than the control group which is exposed only to conventional training. This figure also shows that the experimental group exposed to visio-motor conflict training can indeed transfer their learnt skills to different environments but the control group does not show such transfer.

VI. CONCLUSION AND DISCUSSION

In this paper, a surgical simulator is presented that provides different levels of visio-motor conflicts for training of surgeons. It has been shown that difficulty of a simulator

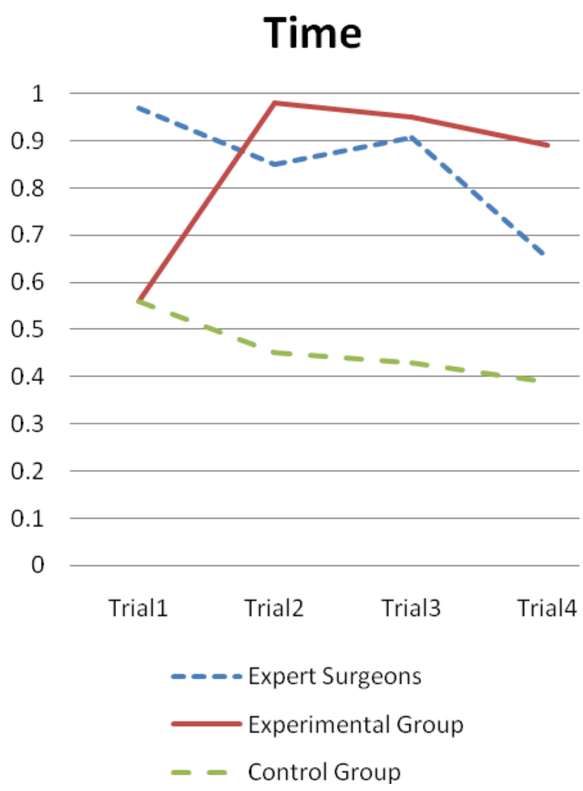

Fig. 5. Time Elapsed

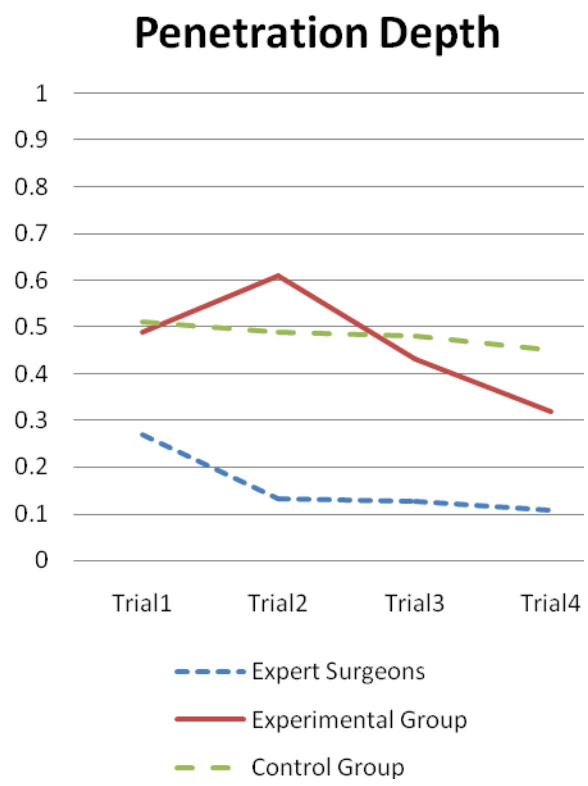

Fig. 7. Penetration Depth

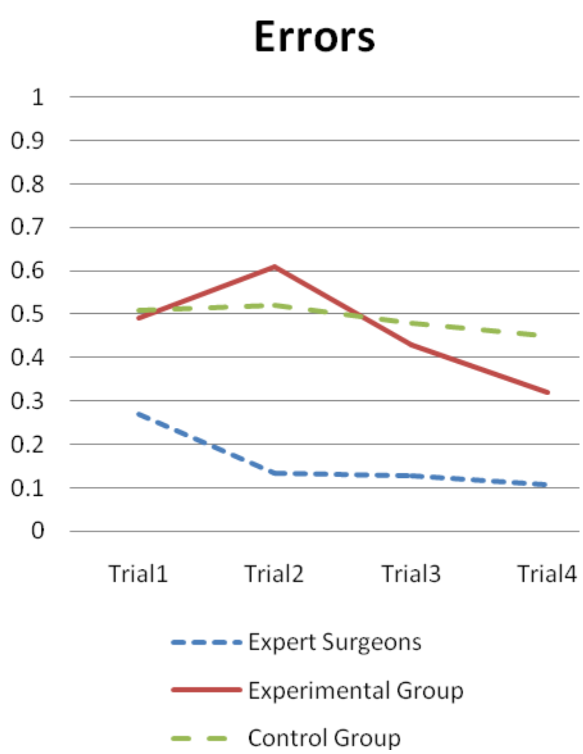

Fig. 6. Errors

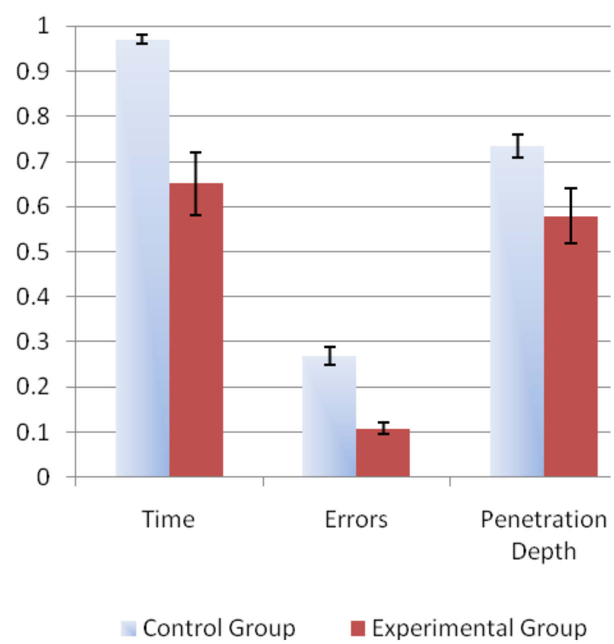

Fig. 8. Difference in performance of the control group and experimental group on the varying intermodal conflict task

need not necessarily be attributed to procedural difficulty alone. It can also be related to difficulty in resolving various visio-motor conflicts, a problem that potentially could cause issues in the operating room (OR). It has been shown that it is beneficial to train surgeons in modes that require fine motor control. This concept therefore can be incorporated in many simulators to create new levels of training based on the suggestion that introducing visio-motor conflict training accelerates learning in residents.

This paper also demonstrates that performance difference in resolution of visio-motor conflicts can be used to differentiate between pediatric surgeons and general surgeons. This pediatric mode can therefore be incorporated into most simulators, thereby providing more complex modules of training for the residents and specific specialty related training for pediatric surgeons.

From a psychological point of view, the results are consistent with reported literature in intermodal conflict domain which have shown that humans can learn to compensate for such conflict [1, 4, 8-10]. An intriguing direction of research lies in understanding the bounds of level of intermodal conflict that promote learning. It is possible that under very high levels of conflict, learning is impeded. This factor needs to be studied further for theoretical results on the employment of conflict for training.

Future work in this domain would focus on further isolating the effect of visio-motor conflict in surgical environment. We will incorporate the visio-motor conflict mode in different types of surgical tasks including complete procedures. Further we will apply the mode of intermodal conflict to different applications such as rehabilitation of patients with traumatic brain injury or stroke. Intermodal conflict resolution requires a significant effort from subjects and it is plausible that such activities can cause recovery in patients. We will test this hypothesis with a simpler set of tasks to be accomplished under conditions of visio-motor conflict.

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