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Effect of visual feedback on learning of a 2:1 isometric bimanual coordination pattern

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Effect of visual feedback on learning of a 2:1 isometric bimanual coordination pattern

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Report

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Abstract

Effect of visual feedback on learning of a 2:1 isometric bimanual coordination pattern

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Abstract: The primary purpose of this study was to examine if the coupling effect could be overcome in a bimanual isometric tracking task, using methods similar to those of the Kovacs et al. team in previous bimanual kinematic research. Thirty right-handed participants, with a mean age 22.5 (SD 3.5) years, free from any neurological disorder or physical ailment, were randomly assigned to one of three groups that differed in percent of feedback provided during the practice trials (100%, 50% or 0%). The participants then performed a bimanual isometric manipulation tracking task that was a 2:1 rhythm (backwards C shape) scaled to 30% maximum voluntary contraction (MVC). Participants performed five blocks of five trials with the feedback schedule assigned to their group, rested for 30 minutes, then performed a retention task. Significant differences ($p<.05$) in Root Mean Square Error (RMSE) occurred between the 100% group and both the 50% and 0% groups during the practice blocks. Significant differences ($p<.05$) also occurred between the 50% group and the 100% and 0% group for the first four practice blocks. Though differences occurred between the groups during

the practice trials, no differences occurred between the groups during the retention block. These findings support the position that the coupling effect in bimanual isometric manipulation tasks is very strong and cannot be as easily overcome as it is in kinematic bimanual task. This may be due to the feedback systems used in isometric conditions versus kinematic tasks (i.e. force and pressure sensation vs. position and motion proprioception).

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

Skilled actions usually require the coordination of both hands. Tasks such as tying one's shoes or peeling an orange require the two hands to perform different activities at the same time. Other tasks such as catching a football or swimming the breaststroke require identical activities of the two hands. Skilled bimanual activities, like these, are vital to living a normal day to day life. Many people rely on the ability to perform tasks with differing force levels in each hand to make a living as well as to being able to take care of themselves.

It has been shown that there are two preferred coordination patterns in bimanual actions; in-phase (symmetric, relative phase of 0°) coordination or a positive correlation between limbs, and anti-phase coordination (asymmetric, relative phase of 180°) or negative correlation between limbs (Kelso, 1984). This has been shown to be primarily due to neural coupling, which can arise from bilateral connections within the neuromuscular system (Heuer, 1993). This coupling, present in bimanual coordination, has been primarily studied using gross motor tasks such as elbow flexion/extension and, in some cases, has been overcome using specific practice strategies (Kovacs et al., 2009ab; Kovacs et al., 2010; Kovacs et al., 2011; Salter et al., 2004). By being able to overcome this coupling effect, participants have been able to learn more complex bimanual rhythms in a relatively short time. The ability to overcome the coupling effect may represent an enhancement of the neural pathways that are responsible for bimanual coordination, possibly leading to faster recovery times for people who are unable to perform everyday bimanual tasks. In bimanual isometric force production, it has also been demonstrated that coupling between the limbs occurs and that both hands tend to produce similar force levels, or show a positive correlation, even when the task goal was to produce different forces in each hand (Rinkenauer et al., 2001). However, there are no reports of efforts to overcome this isometric coupling effect as there are for actual movements, such as elbow flexion. This is a major void in the current bimanual coordination literature. The ability to overcome the isometric bimanual coupling effect could possibly enable patients with neurological deficits, especially stroke patients, to once again live a normal life and avoid depending upon others to perform simple, everyday tasks for them--such as tying their shoes or peeling an orange.

Bimanual coordination has been studied vigorously over the past fifty years. Many studies have involved finger tapping, drawing circles with both hands and bimanual reaching tasks. From each of these studies, the primary finding has been that in-phase and anti-phase patterns are the more stable patterns and easiest to perform without extended practice. This has primarily been illustrated in experiments where participants performed a 1:1 rhythmic movement of the fingers, wrists or arms with the use of an auditory or visual metronome (Tuller & Kelso, 1989; Yamanishi, Kawato, & Suzuki, 1980). Relative phase patterns that are not 0° or 180° generally have been found to be inherently unstable without days of practice.

Recent research performed by Peper et al. (2005) further demonstrates the difficulty of successfully performing non 0° or 180° relative phase patterns. Participants performed elbow flexion with both arms in the transverse plane with the use of an auditory metronome and a goal of performing a relative phase pattern of 30°. As previously illustrated, initially participants tended to perform the task with a relative phase pattern of 0° or 180° (Peper et al., 2005; Tuller and Kelso, 1989; Yamanishi, Kawato, & Suzuki, 1980). Only after three days of practice was the goal of bimanual elbow flexion with a relative phase pattern of 30° achieved (Peper et al., 2008). In this case the coupling effect present in bimanual coordination was overcome with the use of an auditory metronome and several days of practice.

In a further effort to overcome the coupling effect in bimanual coordination, Kovacs et al. (2009a) employed the use of Lissajous visual feedback in the learning of a 1:1 relative 90° pattern with elbow flexion in the transverse plane. This 1:1 relative 90° pattern has consistently been shown to be initially unstable (Zanone & Kelso, 1992; Fontaine et al., 1997) and can only be produced with relatively small variability after several days of practice (Hurley & Lee, 2006; Lee et al., 1995; Peper et al., 2005; Swinnen et al., 1998; Swinnen et al., 1997a,b). Lissajous feedback involves a two-dimensional plot which represents the actions of the arms in space together over time as a single cursor trajectory on a computer screen. In a typical example, vertical movement of the cursor results from flexion and extension of the left arm and horizontal movement of the cursor from flexion and extension of the right arm. Flexion and extension of both arms together can move the cursor in any direction on the screen, much like a child's etch-a-sketch does. In Kovacs' study, a circle was projected on the screen to represent the 1:1 relative 90° pattern and the participant's task was to trace the circle with the cursor as fast and accurately as possible. The strategy of only using Lissajous feedback, when compared to the use of Lissajous feedback and an auditory metronome, resulted in participants being able to perform the desired task with much less error and with only five minutes of practice (Kovacs et al., 2009a).

Kovacs et al. (2009b) continued the use of Lissajous feedback in the learning of multiple relative phase patterns by using the Lissajous feedback system compared to the use of a visual metronome with the participants' arms covered. The Lissajous feedback system used elbow flexion and extension in the same way as Kovacs et al. (2009a). Participants in this study performed a relative 1:1 phase pattern, with the relative phase beginning at 0° and increased by 30° until 180° was reached. Participants who only used the Lissajous feedback were able to master the task within three minutes of practice. In contrast, participants using a visual metronome with no Lissajous feedback were only able to successfully perform the 0° and 180° relative phase patterns after three minutes of practice (Kovacs et al., 2009b). These results demonstrate that by covering the participant's arms and representing the actions of the two arms as a single position on the computer screen, the visual attention of the participant can be reduced to a single augmented feedback system. These findings indicate that with Lissajous feedback a variety of relative phase tasks that had traditionally been shown to be unstable can be performed with minimal practice and with very little error. This finding is attributed to the Lissajous feedback minimizing the perceptual and attentional distraction, which in this study, was the attention to proprioception of the participants' arms and the vision of each arm moving independently (Kovacs et al., 2009b).

While the initial findings of Kovacs et al. (2009a,b) are instructive in understanding how to break the coupling effect that takes place during bimanual coordination tasks, it wasn't until a later report, (Kovacs et al., 2010a) that it was completely understood how dominant the Lissajous feedback can be in bimanual learning. In this experiment, participants were able to perform a variety of elbow flexion, multi-frequency bimanual rhythms (2:1, 3:2) without vision of their arms and using only Lissajous feedback. While 2:1 and 3:2 rhythms are relatively easy to learn and perform in bimanual tapping tasks (Peper, Beek, & van Wieringen, 1995a, 1995b; Summers, Todd, & Kim, 1993; Walter, Corcos, and Swinnen, 1998), producing similar ratios involving wrist and elbow flexion have been shown to be extremely difficult types of bimanual rhythms to perform without a vast amount of practice (Byblow & Goodman, 1994; Sternad, Turvey, & Saltzman, 1999a, 1999b; Treffner & Turvey, 1993; Swinnen, Dounskaia, Walter, & Serrien, 1997a, 1997b).

After only five minutes of practice, participants using Lissajous feedback with their arms shielded from view were able to perform the 2:1 and 3:2 rhythms with very minimal error. These results, once again, showed that by reducing the participant's visual and attention to proprioceptive feedback, they were able to focus solely on the Lissajous feedback and perform extremely difficult bimanual tasks (Kovacs et al., 2010b). This was once thought to be impossible without extensive practice by the participants.

The Kovacs et al. studies, to this point, have shown the ability to overcome the coupling effect that is present during bimanual coordination tasks with the use of Lissajous feedback. While the benefits of participants being able to perform different relative 1:1 phase patterns and multi-frequency bimanual rhythms (2:1, 3:2) with little practice can be inferred, the ability to transfer this skill into performing other non-practiced rhythms can be seen as more relevant to the field. The next Kovacs et al. (2010b) study, demonstrated how the quick learning of a different and equally difficult polyrhythm using the Lissajous feedback could result in excellent performance, with very little error. Participants in this study, performing under identical conditions as used in Kovacs et al. 2010a, were able to master a difficult 5:3 bimanual coordination pattern and, without additional practice, perform an equally difficult 4:3 coordination pattern with no additional practice. The participants performed the 4:3 coordination pattern with as little error as the 5:3 pattern they had practice and mastered. These findings suggest that much of the difficulty connected with bimanual tasks should be viewed in terms of perceptual limitations in relation to the surroundings (Kovacs et al., 2010b).

It is easy to see the importance of Lissajous feedback in the learning of difficult bimanual tasks. A problem with the use of Lissajous feedback in the Kovacs et al. experiments has been that participants have only been able to perform difficult polyrhythms and relative phase patterns with the continued use of the Lissajous feedback. As soon as the researchers removed the Lissajous feedback, the participants were no longer able to perform the difficult bimanual tasks (Kovacs et al., 2009a,b; Kovacs et al., 2010a,b). This finding has led other researchers to believe that participants are not, in fact, learning how to perform these difficult patterns and developing an internally driven ability to perform these patterns. Rather, they were only relying on the feedback of the Lissajous plot to externally drive their performance (Kovacs et al., 2011). This is a viable claim and it led the Kovacs et al. research team to develop a study designed to determine what is really happening, i.e. was the Lissajous feedback teaching the participants how to perform the tasks? Or, are adjustments to the practice schedule with the frequency of Lissajous feedback needed?

A method shown to reduce the dependency on external feedback, (such as the Lissajous plot in the Kovacs et al. experiments) and develop an internal representation of the task is to reduce the frequency of feedback or knowledge of results (KR) given to the participant (Lee, White, & Carnahan, 1990; Sparrow & Summers, 1992). This method of reducing feedback frequency was developed based on the guidance hypothesis, which states that participants who receive feedback or KR for every trial become reliant on the feedback and are not processing intrinsic information during trials. A test of this would be to provide practice trials with decreasing amounts of feedback, thus requiring participants to attend to intrinsic information to see if they can develop an internal representation of the task that allows them to perform the task when the feedback is withdrawn.

The Kovacs research team implemented such a test of the guidance hypothesis approach in their next experiment (Kovacs et al., 2011) to determine whether participants could actually develop an internal representation of the task and perform it once the Lissajous feedback was removed. This was done with participants performing a continuous circle representing a 1:1 pattern with a relative phase of 90°. The same task was performed as in Kovacs et al. 2009a., except that one group would perform the task with 100% Lissajous feedback on practice trials, one group received Lissajous feedback on 50% of the trials on a fading schedule and one group received no Lissajous feedback (0% of the trials). After 20 minutes of practice, the fading 50% feedback group was performing the 1:1 pattern with a relative phase of 90° with no Lissajous feedback. This group performed with no significant difference in error from the 100% feedback group, which was still performing the task using the Lissajous feedback. This performance leap was maintained after a 24 hour retention test performed with the same task. This finding supported the hypothesis that the fading 50% Lissajous feedback group had developed an internal representation of the task that allowed them to perform the task just as well as the group that was still using the Lissajous feedback (Kovacs et al., 2011).

A similar finding with isometric bimanual force production was reported by Hu et al. (2010). The researchers instructed participants to hold a specific percentage of their maximum voluntary contraction force, indicated by a line on a monitor. The participants were to hold a cursor representing the isometric force they were producing at the level of the line. One group of participants received this visual feedback of their force production in the form of a cursor throughout the whole experiment, while a different group slowly had the feedback taken away. By the end of the practice trials, no difference could be seen in the steadiness of force production between the two groups (Hu et al., 2010). The partial feedback group was able to hold the desired force level just as consistently as the 100% feedback group, even in the absence of the visual feedback. This demonstrates that the partial feedback group had developed an internally driven method of producing the desired force.

While the ability to overcome the coupling effect and develop an internally driven method of performing the task with dynamic gross motor tasks is important to the field, this ability has yet to be applied to the field of isometric force manipulation. Bimanual coordination research with varying isometric force tasks may benefit clinical populations such as stroke patients, who are not yet able to undergo rehabilitation using dynamic motor tasks. It has been shown that stroke patients have greater difficult overcoming the coupling effect in isometric force control following their stroke and could benefit from this type of training task (Lodha et al., 2011, Malkounet et al., 2011).

The intent of this study was to examine if the coupling effect could be overcome in a bimanual isometric tracking task, using methods similar to those of the Kovacs et al. team in previous bimanual kinematic research. This study examined the effect of visual feedback on learning a 2:1 bimanual isometric force manipulation pattern by comparing three groups performing the same task with differing visual feedback (100%, 50% and 0% visual feedback). Root mean square error (RMSE) values from the three groups were examined to determine how accurately they performed the pattern during their specific group's training trials and during the retention task that all groups performed. To determine the participants' variability while performing the task, coefficient of variation of error (CVE) was used to establish the within participant variability of the groups as they performed the task under the different visual feedback conditions. On the basis of the findings of previous studies, it was hypothesized that there would be no significant difference in performance between the 100% visual feedback group and the 50% visual feedback group during the five practice blocks. Additionally, it was hypothesized that the 50% visual feedback group would perform, with significantly fewer errors during the retention block of trials compared to the 100% and 0% visual feedback groups.

Chapter 2: Methods

2.1 Participants

Thirty right-handed healthy volunteer participants between the ages of 18 and 30 with mean age 22.5 (SD 3.5) years were recruited from the Austin area. All participants gave written consent prior to experiment participation and reported no history of neurological disorders, upper limb malfunction, or pain during activities of daily living. The participants were randomly assigned to one of three groups: the 100%, 50% or 0% knowledge of results (visual feedback) group.

2.2 Tasks and Procedures

A force transducer system with two sensor pads measured force produced by isometric flexion contractions of the index finger of each hand. The Manual Force Quantification System (MFQS) was used to record all force data. The participants' arms were positioned so that the upper arms were in the sagittal plane and elbows positioned at 70-80 degrees from anatomical position. Participants rested their forearms on a small pad on the ulnar side of their forearms and grasped a hard foam cube, sized to fit them, with all but their index fingers. The participants then had an elastic wrap wrapped around their hands with the foam cube between their hands. This isolated the index fingers and did not allow for the use of the elbows or wrists. Once the participants were in position, the force transducers were adjusted in both height and position so that the index fingers of both hands rested against the transducer pads. The participant's index fingers were placed so the palmar side was in contact with the force sensors (Figure 1). The participant's left index finger controlled the horizontal motion of a cursor on a computer screen in front of the participant and the right index finger controlled the vertical motion of the cursor. The combination of bimanual forces moved the cursor on the monitor.

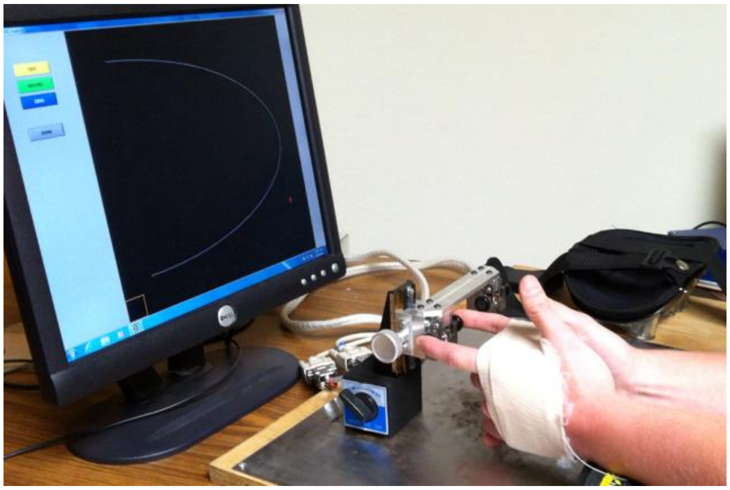

Figure 1- The manual force quantification system (MFQS) apparatus, including the monitor with target template and force transducers.

Once the participant understood how the MFQS system worked, three maximum voluntary contractions (MVC) of index finger flexion were performed and recorded using 20-pound maximum transducers. The participant pressed (flexion) as hard as possible at the same time with both index fingers for 3-4 seconds and then released. The average maximum forces from three trials were used to determine the maximal force each digit could produce, which was used as the reference for calculating 27% of maximum force of each participant, the upper boundary of the force range for each trial. The screen for the task was scaled to 30% MVC but the task did not use the whole screen, resulting in the 27% maximum force for the task. Once the MVC trials were finished, the transducers were switched to 10-pound maximum force transducers and participants were given a familiarity trial. During this trial, participants were instructed to move the cursor in the following sequence: to the bottom right corner of the screen, to the top right corner, bottom left corner, top left corner, bottom right corner, then finally return it to the resting position. This was done on a blank monitor and controlled how each participant became accustomed to the equipment and cursor movement controlled by their two index fingers.

After the familiarity trial, participants were randomly assigned to one of three groups that differed in percent of feedback provided during the practice trials (100%, 50% or 0%) and began the first of 5 practice blocks of 5 trials (25 total practice trials). During the practice trials, feedback was present and participants were instructed to follow the track ball moving along the shape on the screen with their cursor. When the feedback was not present, the participant still saw the desired template (trajectory) and the track ball they were to follow, but not the cursor they controlled. The curved line (Figure 2) required the participant to produce 27% of MVC in the left finger and to produce approximately 13% of MVC in the right finger to reach the half way point in the curve. Then, the participant decreased force in the left finger to 3% while continuing to increase the force in the right finger to 27% to reach the top of the line. The process was reversed to travel back down the line.

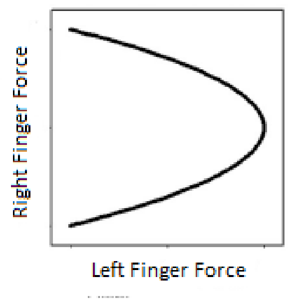

Figure 2- The graphical representation of the 2:1 rhythm (backwards C). To successfully move the cursor along the initial part of the pattern, the left finger must apply force causing the cursor to move right on the screen while the right finger applies force causing the cursor to move up on the screen.

Within each trial, the participant completed 4 repetitions of the 2:1 rhythmic pattern (backwards C shape). The pattern was performed in two directions in each trial. The forward direction was moving away from the start point, and the backward direction was moving back toward the start point. Each trial had two repetitions of each direction and took 35 seconds to complete. After all trials, a 15 second rest period was given to control for physical fatigue and 1 minute of rest was given between each block to minimize the possibility of physical and mental fatigue.

The 100% feedback group was provided feedback throughout all the practice trials while the 0% feedback group received no extrinsic feedback during the practice trials. The 0% feedback group was only given the template as shown in figure 2 and the track ball to attempt to mimic, but was not able to see the cursor controlled by their bimanual force production. For the 50% feedback group, feedback was presented in a fading schedule. This schedule was based on the guidance hypothesis. For the first block of five trials, the participants were given feedback for the first 88.5% of each trial and had to perform the last 12.5% of each trial with no feedback. The amount of feedback then continued to decrease for the trials for every block. Therefore, block 1 had feedback for the first 88.5% of each trial, block 2 had feedback for the first 75% of each trial, block 3 had feedback for the first 50% of each trial, block 4 had feedback for the first 25% of each trial and block 5 only had feedback for the first 12.5% of each trial. This schedule provided the participant an average of 50% feedback over all the trials.

After completing the 5 practice blocks, all participants were provided a break for 30 minutes and were instructed to play a labyrinth game on an IPod and advance to the furthest level possible during the 30 minute period. This task focused the participant's attention on something besides the experimental task and controlled the rest period by having the participants use their hands in a similar way and with similar low levels of force during the break period. They then completed a block of 5 trials as a retention test. Within each retention trial each participant completed 4 repetitions of the same backwards C shape as in the practice trials but visual feedback was only given for the first 12.5% of each trial (the first half of the first backwards C shape).

Once the participants finished the retention task, 3 MVC trials were performed as previously described. The average of these three trials was recorded to determine whether fatigue that may have developed during testing.

2.3 Data acquisition

All data collection was performed in the Motor Behavior Laboratory in Bellmont Hall (BEL 848) using the MFQS apparatus. The MFQS apparatus included a Dell computer, custom-designed LabVIEW software, and A/D sampling of force records from a pair of force transducers. All data collection was controlled by a LabVIEW software application, which displayed instructions and task performance, sampled data, and stored the data for offline analysis. The index finger forces were recorded by two pairs of strain-gauge sensors. Root mean square error (RMSE) with respect to the template line and coefficient variation of error (CVE) were calculated using the force data collected. MVC force was measured using sensors that were calibrated up to 20 lb of force. Experimental trial data were collected using sensors that were calibrated up to 10 lb of force. All force data were sampled at 1000 Hz with LabVIEW.

2.4 Data analysis

The template traced in each repetition was comprised of 2 segments, repeated four times, for a total of 8 segments per trial. The data collected from each trial through the MFQS system were analyzed with MATLAB and Excel programs to determine total RMSE and CVE for each trial for each participant. Each repetition of the rhythm was collapsed across all participants within each group. RMSE and CVE data were averaged into blocks for each participant and compared across groups.

SPSS software was used to run a 3x6 multivariate analysis of variance (MANOVA) to determine the main effects of practice and feedback schedule. Significance was set at $p < 0.05$ for all statistical analyses. Post-hoc tests were used to examine significance of differences among groups and contributions to any significant interactions.

2.5 Research Protocol

The following testing procedures were employed with each participant:

1) Provide overview of general task and procedures,
2) Complete consent form,
3) Position participant's elbows and hands
4) Explain and demonstrate MVC testing
5) Collect 3 MVC's
6) Provide familiarization with apparatus through familiarity task
7) Explain tracking task and feedback schedule
8) Collect data during 25 practice trials (with fifteen seconds of rest between each trial and one minute of rest between each block of five trials)
9) Provide a 30 minute break (the participants will play a labyrinth game during this time)
10) collect data during 5 retention test trials (with fifteen seconds of rest between each trial)
11) collect 3 MVC's to control for fatigue

Each participant spent approximately 90 minutes in Bellmont 848.

Chapter 3 Results

Table 1 and Figure 3 show that RMSE values differed during practice blocks among the three groups. To test the statistical significance of these differences, a one way MANOVA was performed for a GROUP (100%, 50% and 0% feedback groups) effect on Block RMSE values for all practice and retention files. This test revealed an overall significant effect of GROUP [Wilks' λ=.022, F(12,44)=21.307, p<.001, partial eta squared=.853, power to detect the effect was .998] on Block RMSE. Given the significance of the overall test, the univariate main effects were examined. The univariate GROUP effect was also significantly different (p < .025) on all the practice blocks (Blocks 1, 2, 3, 4 & 5). No significant differences occurred during the retention block (p=0.188).

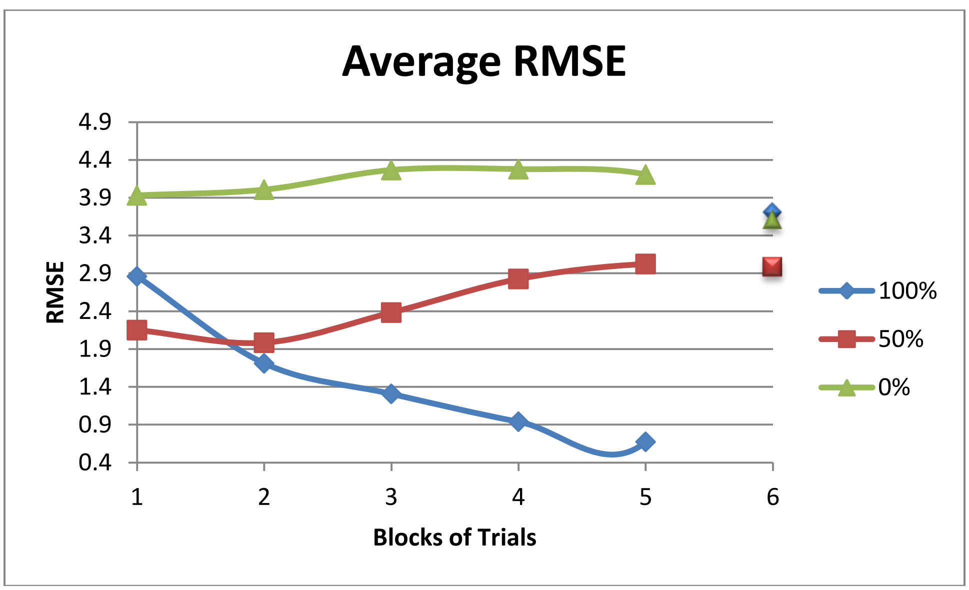

Figure 3- Average Root Mean Square Error (RMSE) values for all participants, for all blocks (5 trials per block). 100%= feedback for all practice trials, 50%= fading 50% feedback schedule for practice trials, 0%= no feedback for any practice trials

Table 1- Average Block RMSE values for each group

	Group	Mean	Std. Deviation
Block1 RMSE	100% group	2.86	1.12
	50% group	2.15	1.04
	0% group	3.93	0.60
Block2 RMSE	100% group	1.71	0.76
	50% group	1.98	0.87
	0% group	4.01	0.67
Block3 RMSE	100% group	1.31	0.60
	50% group	2.38	0.86
	0% group	4.27	0.78
Block4 RMSE	100% group	0.94	0.37
	50% group	2.83	1.08
	0% group	4.28	0.86
Block5 RMSE	100% group	0.67	0.21
	50% group	3.02	1.08
	0% group	4.21	0.79
Retention RMSE	100% group	3.70	0.92
	50% group	2.99	0.97
	0% group	3.61	0.89

In order to investigate the significant findings further, Bonferroni post-hoc tests were examined. These tests showed a significant difference ($p<.05$) between the 100% group and the 50% group RMSE values for blocks 3, 4 and 5. A significant difference ($p<0.05$) occurred between the 0% feedback group and the 100% and 50% feedback groups for all practice trials. No statistically significant differences ($p<0.05$) occurred between the groups for the retention block.

To test the statistical significance of the differences seen between groups' CVE (Table 2 & Figure 4), a separate one way MANOVA was performed for GROUP (100%, 50% and 0% feedback groups) effect on Block CVE values for the practice and retention blocks. This test revealed an overall significant effect of GROUP [Wilks' λ=.017, F(12,44)=24.332, p<.001, partial eta squared=.869, power to detect the effect was .997] on Block CVE values. Given the significance of the overall test, the univariate main effects were examined. The univariate main effects were that GROUP had a significant effect (p < .025) on all the practice blocks CVE values (Blocks 1, 2, 3, 4 & 5) but not the retention block (p=0.616). To investigate these significant finding further, Bonferroni post-hoc tests were examined. These results show that in block 1 a statistically significant difference (p<0.001) occurred between the 100% feedback group (CVE=0.52, SD=0.13) and the 50% feedback group (CVE=0.80, SD=0.07). This significant difference continued through blocks 2, 3 and 4 but in block 5 were not different (p=0.913) between the 100% feedback group (CVE=0.58, SD=0.02) and the 50% feedback group (CVE=0.60, SD=0.04). A significant difference (p<0.05) for all practice blocks occurred between the 0% feedback group and the 100% and 50% feedback groups.

The link between the 50% groups increasing RMSE and decreasing CVE during practice blocks suggests that the 50% feedback group performed the task more similarly to the 0% feedback group and displayed the same high error but constant pattern as feedback was taken away. This finding, along with the significant differences in RMSE that occurred between the 100% and 50% feedback groups during practice did not support our first hypothesis that there would be no significant differences in performance between the 100% visual feedback group and the 50% visual feedback group.

Table 2- Average Block CVE values for each group

	Group	Mean	Std. Deviation
Block1 CVE	100% group	0.52	0.13
	50% group	0.80	0.07
	0% group	0.53	0.04
Block2 CVE	100% group	0.57	0.07
	50% group	1.00	0.07
	0% group	0.55	0.05
Block3 CVE	100% group	0.60	0.05
	50% group	0.88	0.07
	0% group	0.52	0.02
Block4 CVE	100% group	0.57	0.03
	50% group	0.71	0.03
	0% group	0.52	0.04
Block5 CVE	100% group	0.58	0.02
	50% group	0.60	0.04
	0% group	0.51	0.02
Retention CVE	100% group	0.64	0.02
	50% group	0.62	0.06
	0% group	0.63	0.02

To examine the second hypothesis, that the 50% visual feedback group would perform with significantly fewer errors during the retention block of trials compared to the 100% and 0% visual feedback groups, RMSE and CVE values for the retention block were examined. As previously reported, GROUP had no significant effect on RMSE ($p=0.188$) or CVE ($p=0.616$) between any of the groups during the retention block. These findings did not support our second hypothesis.

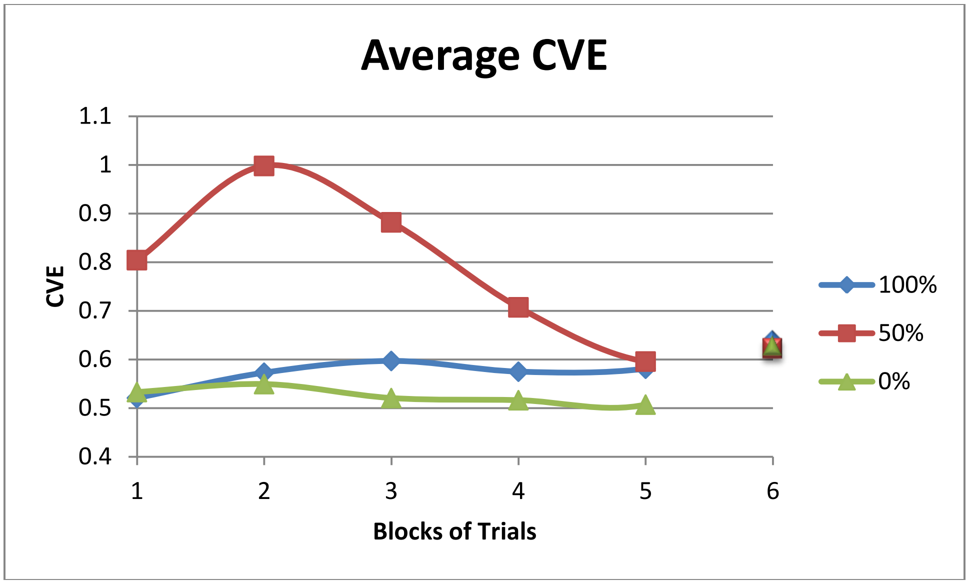

Figure 4- Average coefficient of variation of error (CVE) values averaged for all participants, for all blocks (5 trials per block). 100%= feedback for all practice trials, 50%= fading 50% feedback schedule for practice trials, 0%= no feedback for any practice trials

Chapter 4 Discussion

The present study was designed to examine whether the bilateral coupling effect could be overcome in a bimanual isometric task, using methods similar to those of the Kovacs team in previous bimanual kinematic research. In our results section, we reported a significant difference in the 100% group's average RMSE values for blocks 3, 4 and 5 (1.31, SD=.239; 0.940, SD=.261; 0.674, SD=.248) and the 50% group's average RMSE values for blocks 3, 4 and 5 (2.38, SD=.239; 2.83, SD=.261; 3.03, SD=.248). This significant difference between RMSE values for the 100% feedback group and 50% feedback group and no significance between the 50% feedback group and 0% feedback group suggests that over the practice trials, the 50% feedback group was unable to learn how to perform the 2:1 bimanual task to the level of the 100% feedback group.

Additionally, since the results for the retention block showed no significant differences for RMSE or CVE values for the 100% (RMSE=3.70,SD=0.92;CVE=.64 ,SD=.02), 50% (RMSE=2.99 ,SD=0.97;CVE=.62 ,SD=.06) or 0% feedback groups (RMSE=3.61,SD=0.89;CVE=.63,SD=.02), it appears no group was able to truly learn how to perform the 2:1 pattern and overcome the coupling effect without feedback.

This finding is not consistent with those of previous bimanual kinematic research (Kovacs et al., 2009a,b; Kovacs et al., 2010a,b: Kovacs et al., 2011). In those bimanual kinematic studies, no significant differences were observed between the 50% feedback group and the 100% feedback groups during the fifth block of trials. The lack of a difference during practice trials in these studies shows that the 50% feedback group processed intrinsic feedback during the trials with no visual feedback and developed an internal representation of the task (Kovacs et al., 2011). This was additionally supported by the 50% feedback group performing statistically more accurately on a retention task than the 100% or 0% feedback groups. This result supported the claim that the 50% feedback group learned the movement and overcame the coupling effect (Kovacs et al., 2011). The failure in this study to corroborate previous findings leads us to believe that the coupling effect in bimanual isometric manipulation tasks is very strong and cannot be as easily overcome as it is in the kinematic bimanual tasks (Morrison et al., 2012). This could be due primarily to the feedback systems used in isometric conditions versus kinematic tasks (i.e force and pressure sensation vs. position and motion proprioception).

In the kinematic studies, the single augmented feedback system, Lissajous feedback, was used to decrease the participant's attention from the individual movement generated proprioceptive feedback from both arms and visual feedback of both arms moving independently to a single point on a computer screen, allowing participants to learn complex bimanual patterns in a very short period of time (Kovacs et al., 2009a,b). This allowed the participants in the 50% feedback schedule to develop an internally driven method and overcome the coupling effect. In the current study, the single augmented feedback system was used to decrease the participant's attention from individual subcutaneous pressure receptors in both fingers to a single cursor on the computer screen. This use of the single augmented feedback system did not allow for the 50% feedback group to overcome the coupling effect in an isometric condition. These different individual feedback systems for either arm or hand may explain the differences in learning the pattern and ability to overcome the couple effect. It also suggests that the additional movement-generated proprioceptive feedback available in positioned control of levers may be a major reason why positioning tasks are accompanied by less error, than isometrically controlled tasks (Choi, 1995).

The 100% feedback group's performance on the task (Figure 5) follows the general pattern of previous research findings (Kovacs et al., 2009a,b; Lee, White, & Carnahan, 1990; Sparrow & Summers, 1992) and demonstrates the guidance hypothesis perfectly. Throughout the practice trials the group increased their accuracy (decreased RMSE) and held a constant variability (CVE). However, during the retention block when visual feedback was taken away the group's accuracy decreased and variability increased, demonstrating that they had become dependent on the guidance of the visual feedback and did not actually learn the pattern (Kovacs et al., 2009a,b; Lee, White, & Carnahan, 1990; Sparrow & Summers, 1992).

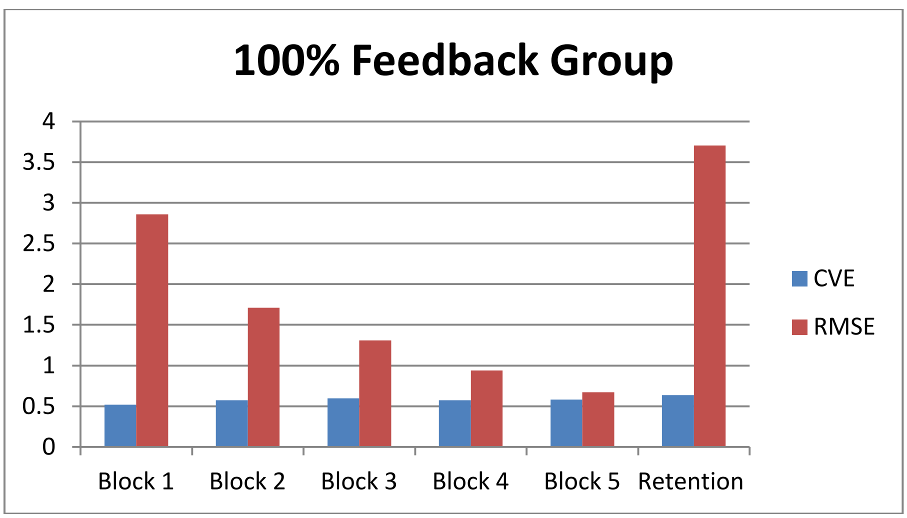

Figure 5- Average Participant RMSE and CVE for 100% feedback group

The changes for the RMSE and CVE values for the 50% feedback group can be seen in figure 6 below. The overall decrease in accuracy (increase in RMSE) and decrease in variability (decrease in CVE) can be explained by the participants' inability to process the intrinsic feedback that they experienced during trials with less feedback (i.e. Blocks 3, 4 & 5). This would cause the 50% feedback groups RMSE and CVE values to be more similar to that of the 0% feedback group, as seen this in study, instead of being more like that of the 100% feedback group, as seen in the Kovacs et al. studies.

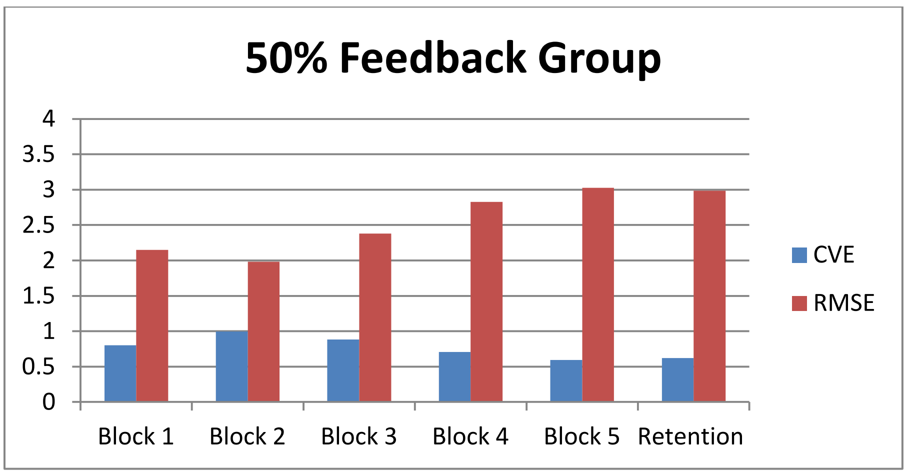

Figure 6- Average RMSE and CVE for 50% feedback group

Figure 7 illustrates that the 0% visual feedback group had approximately the same accuracy (RMSE) and variability (CVE) throughout all the practice trials. These results confirm previous research and suggest that the participants in the 0% feedback group performed the same general motor program throughout all the practice trials (Schmidt, 1975). With no feedback available to guide adjustments in their performance, participants in this group continued to perform the task in about the same way every trial. No change in the group's RMSE was seen until the retention trials and this probably was due to the participants receiving feedback for the first 12.5% of the trial, allowing them some feedback to slightly adjust the motor program they were using. However, this adjustment caused a slight increase in the participant's CVE. This increase was caused by the participant's processing the extrinsic feedback and trying to make changes to the motor program they had been and were continuing to use (Schmidt, 1975), which suggests that the participants started to make changes to the motor program they were using during the retention trials.

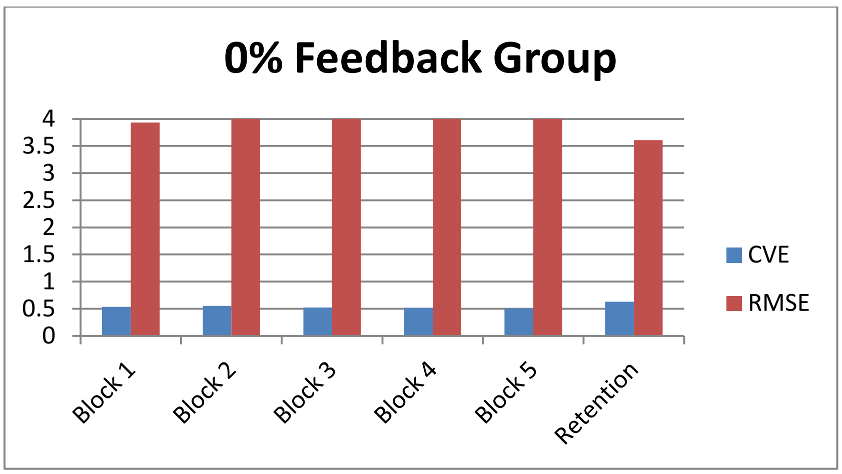

Figure 7- Average RMSE and CVE for 0% feedback group

One limitation of this study was that the task was performed with relatively low levels of force (5-27% MVC) and only with index finger action. This makes the comparison between this fine motor isometric study and the Kovacs et al. studies, which used dynamic movements of the arms, incomplete. Although the findings of this study certainly can be compared to the Kovacs et al. findings, a direct comparison of dynamic finger or elbow flexion and isometric finger or elbow flexion should be studied in future research. This would provide the best comparison between isometric and dynamic conditions.

Other limitations of the study are that individual participants may have not held a uniform arm and hand geometry throughout all trials. All participants were instructed to perform the task with a given arm and hand orientation, using was a uniform description for all participants and aided by the participants hands being wrapped with a block between their hands. However, some small adjustments of arm angle and hand orientation did occur between trials. This possibility of a shift in arm or hand orientations may have created a change in the interaction between the index fingers and the force transducers during the trials. However, this limitation was present in all three groups, and there were no apparent anomalous irregularities between adjacent blocks, so it shouldn't have affected the overall group differences.

Future studies could investigate the effect of changing the feedback schedule from a fading schedule as used in this study, to a random feedback schedule, in which the amount of feedback would differ from trial to trial in a random order. This type of feedback may increase the ability of the participants to process intrinsic feedback and develop an internally driven method of performing the task. Additionally, investigating if this type of training can transfer to increase in function for stroke patients could be beneficial.

Delimitations of this study are that the results may apply only to healthy right-handed young adults between the ages of 18-35 performing a bimanual isometric at 30%

MVC, and other individual differences such as handedness, injury or disease might be expected to alter the findings of this study.

Chapter 5: Conclusion

The differing visual feedback schedules did show an overall practice effect on a 2:1 bimanual isometric force pattern during the practice trials. The 100% feedback group did have significantly lower RMSE values by the end of the practice blocks, with no differences occurring between the three groups during the retention block. These results indicate that the feedback schedule did make a difference during the performance of the 2:1 bimanual isometric force pattern but this difference did not carry over to the retention task. Indicating that the coupling effect is very strong in isometric conditions and cannot be overcome using methods similar to those used by as the Kovacs' teams in their bimanual kinematic research.

Appendix (Univariate Test Results)

	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Block1	16.077	2	8.038	9.021	.001	.401
Block2	31.472	2	15.736	26.437	.000	.662
Block3	44.847	2	22.424	39.264	.000	.744
Block4	56.001	2	28.001	41.111	.000	.753
Block5	64.676	2	32.338	52.620	.000	.796
Retention	3.052	2	1.526	1.779	.188	.116

Appendix A. Univariate main effects for GROUP effect on CVE values

	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Block1	.514	2	.257	34.136	.000	.717
Block2	1.275	2	.637	155.239	.000	.920
Block3	.725	2	.363	152.728	.000	.919
Block4	.191	2	.096	75.827	.000	.849
Block5	.045	2	.022	22.510	.000	.625
Retention	.001	2	.001	.493	.616	.035

Appendix B. Univariate main effects for GROUP effect on CVE values

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