# Bimanual Coupling and the Intermanual Speed Advantage

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## Abstract

This study investigated previously observed differences in speed when completing a two-handed task either bimanually (i.e., the normal, two-handed mode) or intermanually (i.e., when such tasks are performed with different peoples' hands). When comparing these two manual "coordination modes," a phenomena referred to as the internanual speed advantage has been observed. While various research domains have reported the internanual speed advantage (i.e., a "mode effect"), recent research suggests that the observed difference in performance may depend on fundamental bimanual limitations that are not observed when using the intermanual coordination mode. To investigate the intermanual speed advantage, a task was constructed to exploit a hypothesized bimanual limitation that may underlie this mode effect: bimanual coupling. Results showed a replication of the intermanual speed advantage and higher between-hand coupling during bimanual performance. Subsequent analyses suggest that speed during two-handed tasks may be facilitated by decoupled movement of the limbs, regardless of coordination mode.

## Introduction

Compared to completing the same manual task alone, some two-handed tasks are faster when working with a partner (Glynn & Henning, 2000; Gorman & Crites, 2013; Reed et al., 2006; Wegner & Zeaman, 1956; Zheng et al., 2005).

Participants were faster completing a tele-operation task with a partner than completing the same task alone (e.g., Gorman & Crites, 2013).

A two-handed laparoscopic cutting task with a partner was faster than completing the task alone (e.g., Zheng et al., 2005).

This study analyzed one of the potential aspects underlying such speed difference during two-handed tasks in the context of manual coordination modes:

- **Bimanual** – two-handed
- **Intermanual** – different people, each using one hand

*The two-handed tele-operated task of participants remotely navigating a rover around a track.*

**Bimanual**

Bimanual control of steering with the left hand and acceleration with the right hand across two joysticks

**Intermanual**

Intermanual control of one participant controlling steering with their left hand and another participant controlling acceleration with their right hand

**When comparing these coordination modes, intermanual has consistently outperformed bimanual as measured by speed (the so-called intermanual speed advantage).**
Importantly, this effect reverses or disappears if the task has been previously practiced bimanually (e.g., bimanual versus intermanual shoe-tying; Gorman & Crites, 2015).

**Specifically, what underlies the intermanual speed advantage?**
There is a lack of consistent understanding surrounding what facilitates speed during two-handed tasks (regardless of coordination mode).

**Some have suggested that shared mental models account for the mode effect of speed (Zheng et al., 2007).**
However, a simpler aspect of bimanual coordination may limit task performance in particular: ***Bimanual Coupling***.

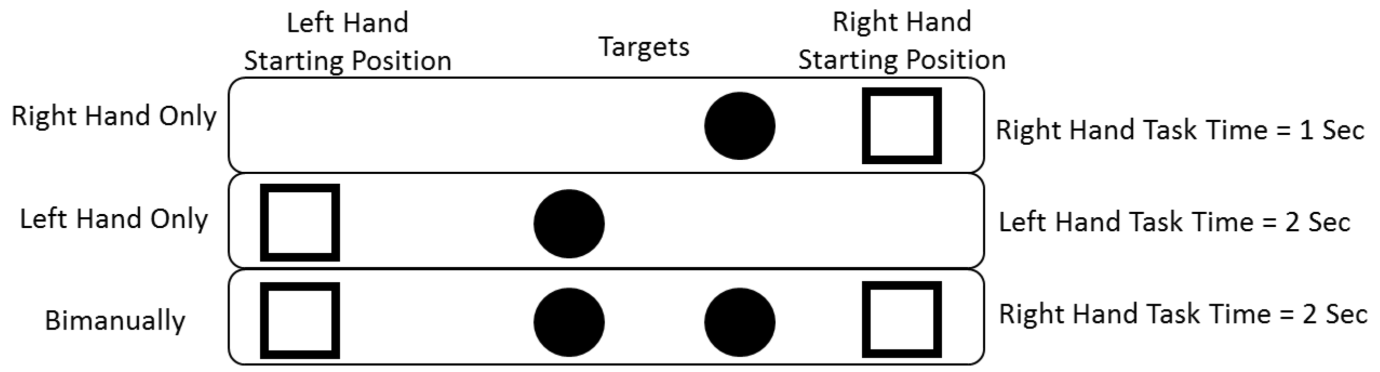
## Bimanual Coupling

**Bimanual coupling** refers to the lack of temporal and/or spatial independence of the hands when performing a two-handed task (Franz 1997; Kelso et al., 1979).

**When bimanual coupling takes place, two outcomes are typically observed:**

- People may isolate the movement of each limb so as to focus on the other limb (i.e., turn taking)
- The movement of one limb affects the movement of the other (i.e., each limb moves in a similar manner)

**Temporal coupling may occur when the two hands move together as a single motor unit and arrive at targets located at different distances at approximately the same time.**
The hand that is supposed to travel to the further target (e.g., left hand) constrains the movement of the hand that is supposed to travel to the closer target (e.g., the right hand (Kelso et al., 1979).




**In this case, completing a bimanual Fitts-law task with two separate targets at different distances, Fitts' Law can no longer predict task time for each limb (Fitts, 1954).**

**Spatial coupling may occur when simultaneous, incongruent movement during a bimanual task causes a higher degree of movement variability when compared to completing the task unimanually.**
Simultaneously drawing circles with one hand and a line with the other hand (Franz 1997).

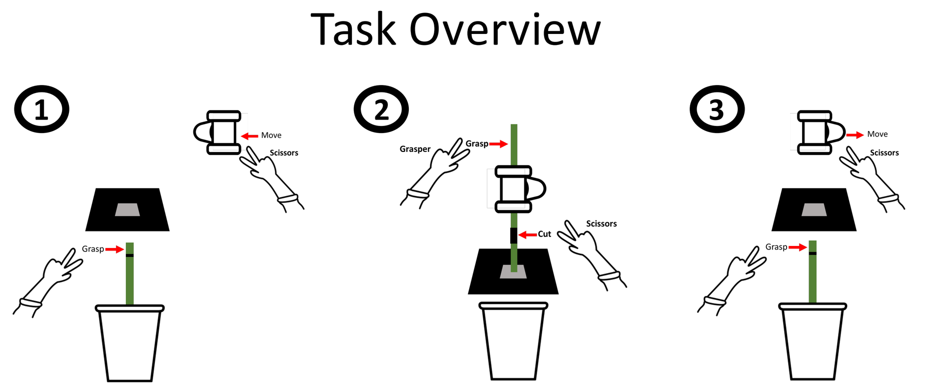
*Hypothetical circle trajectories from trials with a circle (left), a vertical line (middle), and a horizontal line (right) performed by the other hand.*

**Importantly, people are able to overcome both types of bimanual coupling with practice.**

## The Current Study

To investigate whether bimanual coupling negatively impacts bimanual performance as measured by speed, a task was constructed to exploit bimanual coupling during a two-handed simulated cutting task.

*Participants completed a two-handed simulated cutting task both individually (bimanually) and as a team (intermanually)*

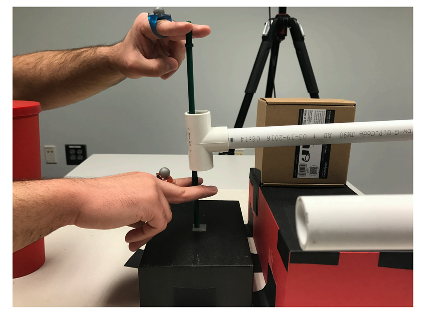



**Nearly all two-handed motions during this task were designed to exploit both temporal and spatial bimanual coupling.**

## Experimental Design

To address the question of a mode effect of speed, a within-subjects variable, Mode, was manipulated with two levels:

- **Bimanual (Bi)**
- **Intermanual (Inter)**

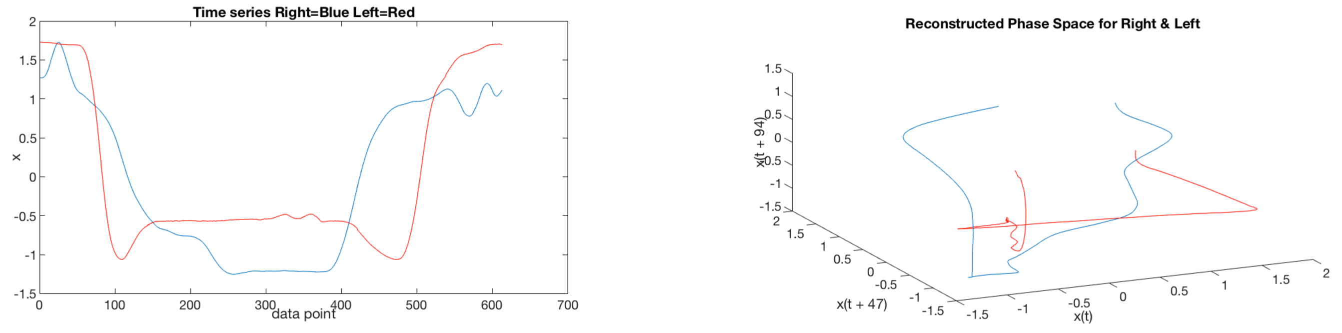


**During the Bi condition, participants individually completed the task using two hands (i.e., bimanually).**
**During the Inter condition, participants completed the task as a dyad (i.e., intermanually).**
Each participant used only one hand (one participant only used their left hand and the other participant only used their right hand).

## Cross Recurrence Quantification Analysis (CRQA)

**In addition to measuring *Speed* via TaskTime, CRQA was used to assess *Coupling*.**
CRQA is a method for assessing the coupling between any two dynamical systems (Shockley et al., 2002).

**Movement time series data for each hand was unpacked into its proper dynamical space using phase-space reconstruction (PSR; Abarbanel, 1996).**

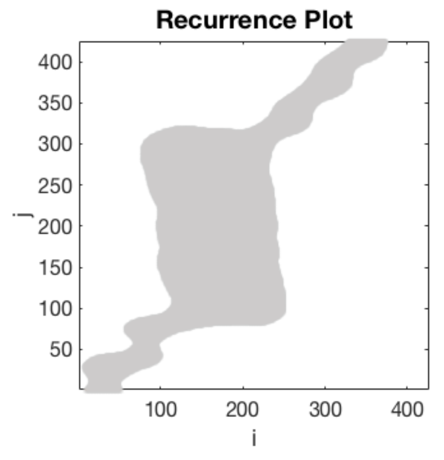



*Example of x-axis data from a participant completing the task during the bimanual condition.*

**CRQ analysis proceeds by constructing a Cross Recurrence Plot (CRP).**
A CRP is a graphical representation of the times at which the two dynamical systems are in the same state.

**A CRP is created by plotting a dot whenever those systems inhabit the same location of a shared dynamical space (for this study, the two dynamical systems are the hands).**

*Recurrence points were calculated using a radius of 30% of the maximum distance*




**The CRP is then used to obtain measures of the recurring, time-dependent dynamic patterns across participants' hands in the shared dynamical space.**
The CRQA measures coupling as "percent recurrence" (%REC) (Shockley, 2005).

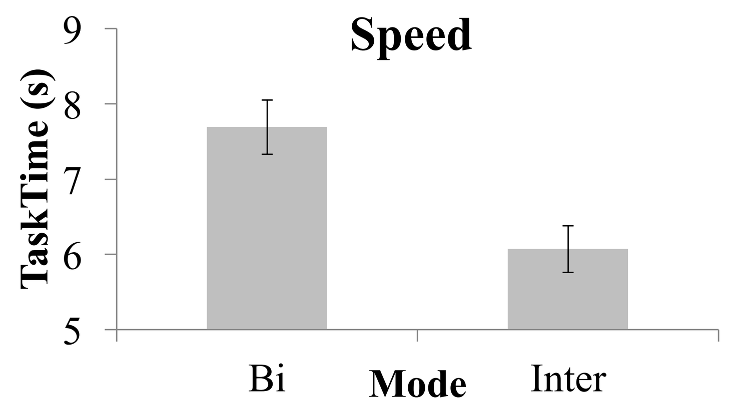
*Between-hand coupling was measured as %REC*

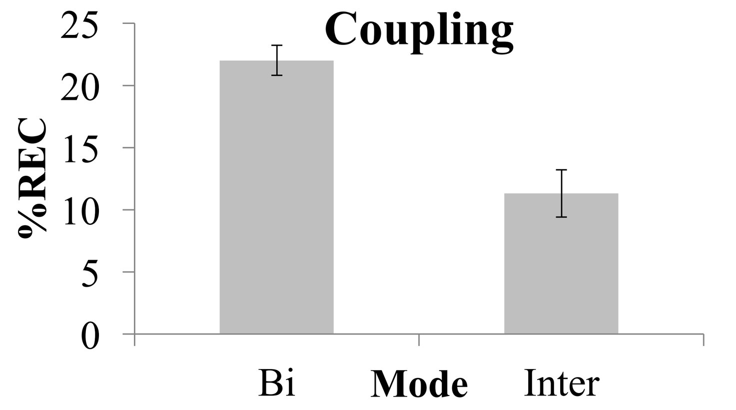
$$\%REC = \frac{\textit{Total \# Recurrent Points}}{\textit{Total \# Possible Recurrent Points}} * 100$$

## Results

***Speed.*** As predicted, the main effect of Mode was significant: participants were significantly slower when using the Bi Mode ($M = 7.70$; $SD = 1.14$) compared to the Inter Mode ($M = 6.07$; $SD = .98$).

***Coupling.*** As predicted, the main effect of Mode was significant: participants showed a higher degree of coupling when using the Bi Mode ($M = 22.02$; $SD = 3.82$) when compared to the Inter Mode ($M = 11.31$; $SD = 6.01$).




**Correlations between Speed and Bimanual Coupling were analyzed as a function of mode.**

Increased bimanual coupling is associated with longer task time (slower speed).

| | Bi | Inter |
|---|---|---|
| | %REC | %REC |
| **TaskTime** | 0.37* | 0.42* |

*$p < .01$

## Discussion

These results suggest that bimanual coupling greatly affects the bimanual mode but not the internanual mode leading to the internanual speed advantage.

In general, decoupling of the hands is associated with faster performance regardless of coordination mode (see also, Gorman & Crites, 2015)

Further research should address additional bimanual limitations contributing to the intermanual speed advantage, such as visuo-motor coupling, as well as the effect of previous bimanual practice observed during the Gorman and Crites (2015) study.

## Take-Home Points

- **Speed during two-handed tasks may be facilitated by decoupled movement of the limbs – regardless of coordination mode.**
- **Previously observed speed differences in two-handed tasks can be attributed to bimanual coupling.**
- **Application: Two-handed tasks, regardless of coordination mode, should be trained past the point of consequent inter-limb coupling to overcome the detrimental effects of bimanual coupling on performance.**

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