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SUPERIOR PREDICTIVE CONTROL OF INTERSEGMENTAL DYNAMICS IN DOMINANT ARM COORDINATION

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ABSTRACT

Previous research has supported a hypothesis of motor lateralization that attributes specialization for predictive coordination of interjoint coordination to the dominant hemisphere/limb system. This has been supported by reaching studies in healthy young participants (Mutha et al., 2013; Schaffer and Sainburg, 2017), and in stroke survivors with unilateral hemisphere lesions (Schaefer et al., 2009). While the studies in healthy subjects have shown differences in coordination between the arms, the nature of the reaching tasks leave open the possibility that the differences in coordination between the arms might be influenced by the perceptual and cognitive demands of targeted reaching movements, such as visually specified spatial precision. The purpose of this experiment was to find interlimb differences in interjoint coordination for a simple task that does not require either visual feedback nor precise spatial goals. Subjects performed slow and fast alternating unilateral wrist ulnar/radial deviation task, in which the wrist was free to move while the forearm rested in the neutral position. The task was to move the wrist throughout the range of motion using continuous rhythmic and alternating ulnar/radial deviation motions, reflecting a 'chopping' motion of the hand. Participants were instructed to prevent motion in the uninstructed degrees of freedom, flexion/extension or pronation/supination. They were instructed to move "slow" and "as fast as possible". Under the slow condition, all participants moved at a similar frequency (0.650 Hz) and were able to make fairly isolated radial-ulnar deviation motions. However, when participants moved "as fast as possible", the range of radial-ulnar deviation decreased, and the motion in uninstructed degrees of freedom increased. The non-dominant arm incorporated substantially more pronation/supination than did the dominant arm. We conclude that interjoint coordination, measured as the ability to prevent motion in uninstructed degrees of freedom, is substantially better coordinated in the dominant arm than the non-dominant arm. These results support our hypothesis that the dominant hemisphere/arm system is specialized for interjoint coordination, and that this is reflected in simple tasks that do not require a visually specified target.

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Chapter 1

Introduction

Brain lateralization describes the division of labor between the two hemispheres of the brain and plays a role in determining the central nervous system's contribution to a wide range of human behavior. In 2008 Dien integrated five different proposed models of laterality to develop the Janus Model of lateralization that proposes a predictive and planning role of the left hemisphere and a specialization of the right hemisphere for responding to changing environmental conditions (Dien 2008). A conceptually similar model was proposed by MacNeilage et. al., after integrating empirical findings across a large range of vertebrate species. According this this model, the left hemisphere is specialized for control of well-established patterns of behavior, while the right hemisphere is specialized for detecting and responding to unexpected environmental stimuli. Thus, two major models for hemispheric specialization have been proposed by integrating findings from a large range of studies in humans (Dien, 2008) and across vertebrate species (Mac Neilage et al., 2009). However, these models were based predominantly on perceptual, emotive, and cognitive processes, and did not address handedness, or motor lateralization, per se.

Handedness

Differences in coordination due to handedness were quantified by Woodworth as early as 1899. Woodworth's work noted the advantage of accuracy in the dominant hand during ballistic movements and suggested that the initial parts of these rapid movements were similar to projectile motion, suggesting that very rapid motions could not be altered in response to sensory feedback due to sensorimotor loop delays. However, Woodworth described a distinction between the initial 'ballistic' phase and a later visually guided phase, in which visual feedback is used to home-in on the target. The two phases were separated by the global peak in tangential hand velocity (Woodworth, 1899).

Flowers (1975) demonstrated symmetrical performance between the two hands when performing rapid movements of distal joints. The particular task Flowers tested was the rapid tapping of the index finger. Additionally, Annett et al. (1979) showed differences in performance between the two hands during peg-board performance, a complex task. Through videography, Annett quantified more positioning errors and error-corrections with the non-dominant than the dominant hand. However, no interlimb differences were seen in the overall time it took to place each peg in the pegboard. Annett et al. concluded that the dominant controller was superior in planning and executing a motor plan that did not require corrections, while the non-dominant controller is less able to plan movement, and better to exploit feedback mediated correction processes (Flowers, 1975; Annett et al., 1979).

Later, in 1986 Roy and Elliott ran a series of experiments in which they manipulated the visual feedback which subjects were given during reaching tasks. Additionally, in 1990 Carson et. al. also conducted experiments that manipulated visual feedback during dominant and non-dominant arm movements. Together, the results of these studies suggested that the difference in coordination between dominant and non-dominant hands is less dependent on visual feedback than on differences in motor planning processes. Roy and Elliott (1989) concluded that the dominant hemisphere is specialized for motor planning mechanisms while the non-dominant hemisphere is specialized for feedback-mediated motor correction mechanisms (Roy and Elliott, 1986; Roy and Elliott, 1989; Carson et al., 1990).

Dynamic Dominance

Based on studies that quantified interlimb differences in interjoint coordination, requiring predictive mechanisms that account for intersegmental dynamics, the inertial forces that are propagated between the segments of a moving limb, Sainburg (2002) introduced the Dynamic Dominance hypothesis. This hypothesis has been elaborated over the past 2 decades based on empirical studies in right and left handed participants without nervous system deficits (Sainburg and Kalakanis, 2000; Sainburg, 2002; Sainburg, 2014), and in right handed stroke patients with specific lesions in the right and left hemisphere (Wyke, 1967). In addition, Sainburg and colleagues (Sainburg, 2002; Yadav and Sainburg, 2014) have carried out control-theory based simulations to test the plausibility of this hypothesis. The current hypothesis proposes that each hemisphere contributes different control mechanisms to each arm: The dominant hemisphere is specialized for predicting inter and intra-segmental dynamics while the non-dominant hemisphere is specialized for impedance control that is robust to perturbations from within the body and in the environment. Dynamic dominance provides a detailed and control-theory based model of hemispheric specialization handedness that is consistent with the previously reviewed empirical findings.

Sainburg and colleagues have focused previous studies on targeted reaching tasks, in which visual targets were presented in the workspace, and participants reached toward these targets at a ‘go’ signal (Schaffer and Sainburg, 2017). While many of these studies used elbow and shoulder joint reaching movements that were supported in the horizontal plane by frictionless air-sled supports that eliminated the effects of gravity on the arm, studies of unsupported reaching movements performed in a gravitational field were done for vertical reaching movements (Tomlinson and Sainburg, 2012) and unsupported horizontal reaching movements (Schaffer and Sainburg, 2017). Regardless of the context of the reaching movements, the results were similar between studies demonstrating that dominant arm movements tend to be straighter and smoother, with lower energetic costs, while non-dominant arm movements tend to have more stable final positions, often with better accuracies. This led to the hypothesis that the non-dominant controller might reflect better control of impedance, a premise that was supported by studies indicating a non-dominant arm advantage in compensating unanticipated perturbations (Bagesteiro and Sainburg, 2002), and random environmental force fields (Yadav and Sainburg, 2014). However, the dominant arm advantage for intersegmental coordination has only been demonstrated during visually directed reaching studies incorporating the proximal, shoulder and elbow, joints of the arm. We now ask whether interlimb differences in interjoint coordination persist during a task that does not incorporate explicit spatial targets, visual feedback, and which is both simple and automatic, such that cognitive-perceptual processes play a smaller role than in targeted pointing movements. This task is a simple repetitive wrist deviation movement, with the forearm resting in the neutral position, such that the hand motion occurs predominantly in the sagittal plane. Participants were simply instructed to make smooth repetitive ‘chopping’ movements of their hands, such that they only moved the hand up and down, without twisting the forearm (pronation/supination) or moving the hand back and forth (flexion/extension). They were first asked to move slowly (no particular target frequency), then to move “as fast as possible”, with the same motion as their slow movements. We predicted that the dominant controller would show advantages for predictive control of intersegmental coordination, and that this would be reflected by reduced motion in non-instructed degrees of freedom during the rapid, ballistic-like, movements.

Hand Preference Depends on Task Complexity

There is a very rich line of research that has examined motor lateralization by quantifying conditions that elicit preferences in hand selection for different tasks. This line of research has employed questionnaires that ask participants to report which hand they prefer to use for a variety of tasks, as well as performance, in which participants are required to choose a hand reach toward an object, or perform a task. In general, the findings from many different studies over decades of research have suggested that hand-preference depends on the complexity or skill-requirement of a task (Brydan, 2015). For example, an individual will tend to reach for an object with the dominant hand more often if one intends to manipulate, rather than simply pick up the object. It has been suggested that this might reflect a dominant bias for more distal musculature (Liederman and Healey, 1986), but this idea was countered by a questionnaire based study by Steenhuis and Bryden (1989) that differentiated hand preference for distal tasks that required complex manipulation and skill (i.e. writing, throwing, sewing) vs distal tasks that do not require skill such as picking up small objects. This study differentiated the role of task complexity, regardless of distal requirements, indicating that the distal distinction cannot fully explain hand preferences. One of the problems with interpreting this line of research is the question of what factors define "skill" or "complex" behaviors. It is clear that complex tasks involve multiple steps (Brydan, 2016) and recruit greater cognitive resources. It should be noted that studies examining neural activation through imaging of the brain during motor behaviors (ie fMRI) have also supported the idea that activation patterns for dominant vs non-dominant arm movements are more asymmetric during performance of 'complex' vs 'simple' motor tasks. Taken together, this line of research suggests that handedness might be reflected by the complexity of the task and thus the requirement for cognitive resources.

The previous line of research is not incompatible with the idea that hand preference depends on task complexity because limb coordination and limb preference are not the same measure and might not predict one another. The research demonstrating coordination differences between the arms that have led to the dynamic dominance hypothesis was based on somewhat complex tasks, involving targeted reaching movements. Such movements, though seemingly simple, clearly have been shown to recruit substantial cognitive resources for planning (Rosenbaum et al., 1980).

We now ask whether interlimb differences in interjoint coordination persist during a task that does not incorporate explicit spatial targets, visual feedback, and which is both simple and automatic, such that cognitive-perceptual processes play a smaller role than in targeted pointing movements. This task is a simple repetitive wrist deviation movement, with the forearm resting in the neutral position, such that the hand motion occurs predominantly in the sagittal plane. Participants were simply instructed to make smooth repetitive 'chopping' movements of their hands, such that they only moved the hand up and down, without twisting the forearm (pronation/supination) or moving the hand back and forth (flexion/extension). They were first asked to move slowly (no particular target frequency), then to move “as fast as possible”, with the same motion as their slow movements. We predicted that the dominant controller would show advantages for predictive control of intersegmental coordination, and that this would be reflected by reduced motion in non-instructed degrees of freedom during the rapid, ballistic-like, movements.

Wrist Anatomy

Although motion of the wrist is complex, due to the gliding action of radius, ulna, and carpal bones, the motion of the wrist is often simplified as a two-axis system, with flexion/extension and radial/ulnar deviation axis. In addition, many muscles that cross the wrist also have moment arms in elbow (flexion/extension) and forearm (pronation/supination) degrees of freedom. Thus, the forearm/wrist musculoskeletal system is both redundant, but also coupled. That is that all muscles of the forearm and wrist have moment arms across multiple degrees of freedom (Ramsay et al., 2009). In our task, the elbow is stabilized by resting the forearm on a surface, while the other three degrees of freedom are unrestrained. The forearm/wrist muscles with moment arms in these degrees of freedom that are not primary elbow flexors or extensors include: pronator teres (PRO), supinator (SUP), extensor carpi radialis longus (ECRL), extensor carpi radialis brevis (ECRB), extensor carpi ulnaris (ECU), extensor digitorum communis (EDC), extensor digiti minimi (EDM), flexor carpi radialis (FCR), flexor carpi ulnaris (FCU), flexor digitorum superficialis (FDS), abductor pollicis longus (APL), and palmaris longus (PL). Because all of these muscles have significant actions in two or more of these degrees of freedom, coupling between these degrees of freedom is a natural consequence of activating any of these muscles (Ettema et al., 1998, Nichols et al., 2015, Gonzalez et al., 1997, Ramsay et al., 2009). The ability to constrain motion to one degree of freedom, thus requires a complex interaction between these muscles and is a form of interjoint (inter-degree of freedom) coordination. Figure 1 reproduced from Ramsay et al. (2009) demonstrates the coupling and redundancy of these wrist muscles. Redundancy is reflected in this plot by the vertical columns of arrows associated with each degree of freedom, while coupling is reflected by the horizontal rows of arrows, which associate more than one degree of freedom with a muscle. One more factor that complicates coordination at the wrist is the fact that the moment arm in a secondary degree of freedom tends to change with joint angle of the primary degree of freedom.

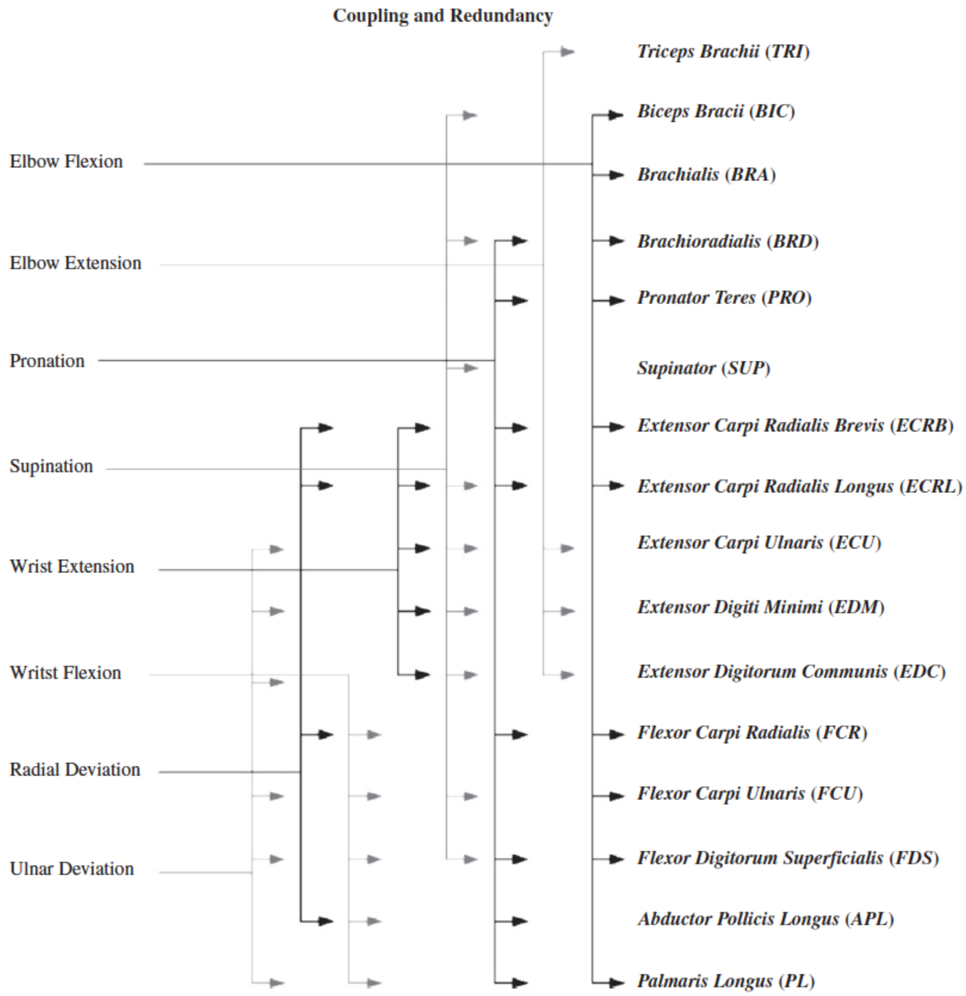

Fig. 2. *Coupling and redundancy*: (Agur and Dalley, 2005; Perkins, 2001). Anatomical origin and insertion sites were used to determine the actions of wrist muscles at the elbow. Muscle contribution to multiple motions demonstrates *coupling* and is shown with arrows aligned in rows next to the muscle name. Multiple muscles contributing to an individual motion demonstrates *redundancy* and is shown with arrows aligned in columns.

Figure 1. *Coupling and Redundancy in Wrist Muscles*

Purpose of Study

Previous research from Dr. Sainburg's laboratory (Sainburg, 2002; Sainburg and Duff, 2006; Sainburg et al., 2016) as well as other labs (Harris and Eng, 2006, Przybyla et al., 2013) have supported a hypothesis of motor lateralization, which attributes predictive coordination of limb dynamics, and thus interjoint coordination, to the dominant hemisphere/limb system. This has been supported by planar reaching studies in healthy young participants (Mutha et al., 2013), and in stroke survivors with unilateral hemisphere lesions. While these studies have clearly quantified differences in coordination between the arms, the nature of the reaching tasks leave open the possibility that these differences might arise from cognitive and perceptual factors associated with discrete targeted reaching movements. This project tests the hypothesis that dominant arm coordination is superior in predictive control of inter-degree of freedom coordination during simple, relatively automatic repetitive movements that do not target a spatial location and are not visually monitored. Eight healthy young adults (18-30 y/o) will perform a rapid alternating wrist ulnar/radial deviation task. The movements of the wrist and forearm (10 DOF) will be recorded using a magnetic tracking system (Trackstar, Northern Digital).

Chapter 2

Methods

Participants

Participants were 8 right-handed individuals (2 Male/6 Female) aged 21-25 years old. All 8 of the recruited subjects were right hand dominant. The handedness of each of the subjects was determined using the Handedness Quotient of the Edinburg Handedness Inventory. Informed consent was given prior to subject participation which was approved by The Pennsylvania State University's Institutional Review Board. Each subject received payment as compensation for his or her participation

Experimental Setup

Participants were seated in a chair with a movement restriction apparatus attached to the side. They were to be able to sit in the chair with either arm bent at a 90-degree angle at the elbow and in the neutral position with their thumb facing up. Figure 1 shows the experimental set-up. Each participant's wrist and forearm movements were tracked using 6 DOF magnetic sensors at 116 Hz (Ascension Trackstar) placed on the hand and upper arm. The forearm was supported in the neutral positon, but was unconstrained in all three degrees of freedom.

Figure 2. ***Experimental Setup.*** **Participants sat in a chair with either arm supported by the movement restriction apparatus shown**

Experimental Task

Participants were instructed to make smooth alternating 'chopping' movements of the hand, moving only in radial/ulnar deviation. They were instructed to move either "slow" for a 10 second interval, or "as fast as possible" for 10 seconds. Four of the participants performed a slow trial first and four of the participants performed a fast trial first. Each participant performed this sequence twice. The first sequence was a familiarity trial to orient individuals to the task. The second trial was the test sequenced, which was recorded and analyzed. We counterbalanced the order of each experimental factor between participants. Half of the participants performed the slow condition prior to the as fast as possible condition. Half of the participants performed with the right hand prior to the left hand.

Kinematic Analysis

Two 6-DOF magnetic trackers (Trackstar) were placed on the hand and upper arm segments, while the index finger, 2^{nd} MCP joint, medial and lateral wrist points, medial and lateral epicondyles of the humerus, and the lateral acomium process were digitized, and custom software was used to estimate joint centers, and calculate 10-DOF at the shoulder, elbow, forearm, and wrist. Because the forearm was supported, shoulder and elbow movements were restricted. From this data, we quantified the following angles: Forearm Pronation/Supination, Wrist Flexion/Extension, and Wrist Ulnar/Radial Deviation. Once recorded, trials were broken up into individual cycles, reflecting one full down and up motion of the hand. This was done using an automatic algorithm based on the hand tangential velocity profile, which was then confirmed or corrected through visual inspection.

Statistical Analysis

We employed a within-subjects repeated-measures ANOVA with 2 factors, hand (left, right), and speed condition (fast, slow). This 2 X 2 ANOVA tested for main effects of speed condition, main effects of hand, and whether an interaction occurred between these variables. Post-hoc analysis (T-test) was used to check for differences between individual levels of the factors. For each participant, mean values for each dependent variable was calculated under each level of each factor, and then subjected to ANOVA using a repeated measures model in JMP (SAS Software).

Chapter 3

Results

We first confirm that participants chose similar frequencies for their ‘slow’ and ‘as fast as possible’ instructed conditions. Then we will present data on hand motion, followed by individual joint motion under these two conditions by each hand. We used the forefinger tip point to calculate hand movement parameters.

Hand Motion

As shown in figure 3, the mean frequency of each cycle of hand movement was similar between participants and hands, but substantially different between conditions. When instructed to move as fast as possible, participants made movements under the fast conditions with a mean frequency of 4.0 Hz (± 1 SE), and under the slow condition, they moved with a frequency of 0.65 Hz. (± 1 SE) Our ANOVA showed a main effect of condition ($F(1,6.917) = 95.176$, $p<.0001$), but no main effect of hand nor interactions between factors. Thus, regardless of the open-ended instruction to move slow and fast, participants chose similar frequencies for each condition.

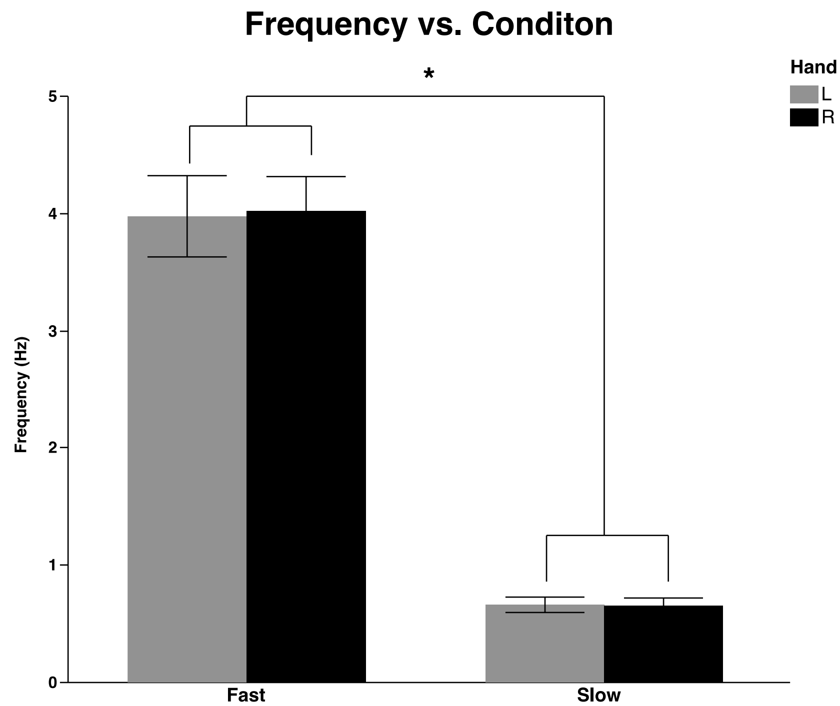

Figure 3. ***Frequency vs. Condition.*** **Participant's mean frequency of movement throughout a full cycle compared in fast and slow conditions with error bars representing SE. (*) signifies a significant difference between fast and slow conditions**

Figure 4 shows the mean ± 1 SE of the distance moved in each ½ cycle of motion (up or down movement). As expected, participants made smaller excursions under the fast than the slow condition. When asked to move as fast as possible, the mean distance was .149 meters (± 1 SE), while under the slow condition, excursion was .200 meters (± 1 SE). Our ANOVA showed a main effect of condition ($F(1,6.732) = 8.328$, $p=.0245$), but no main effect of hand or interaction between these factors.

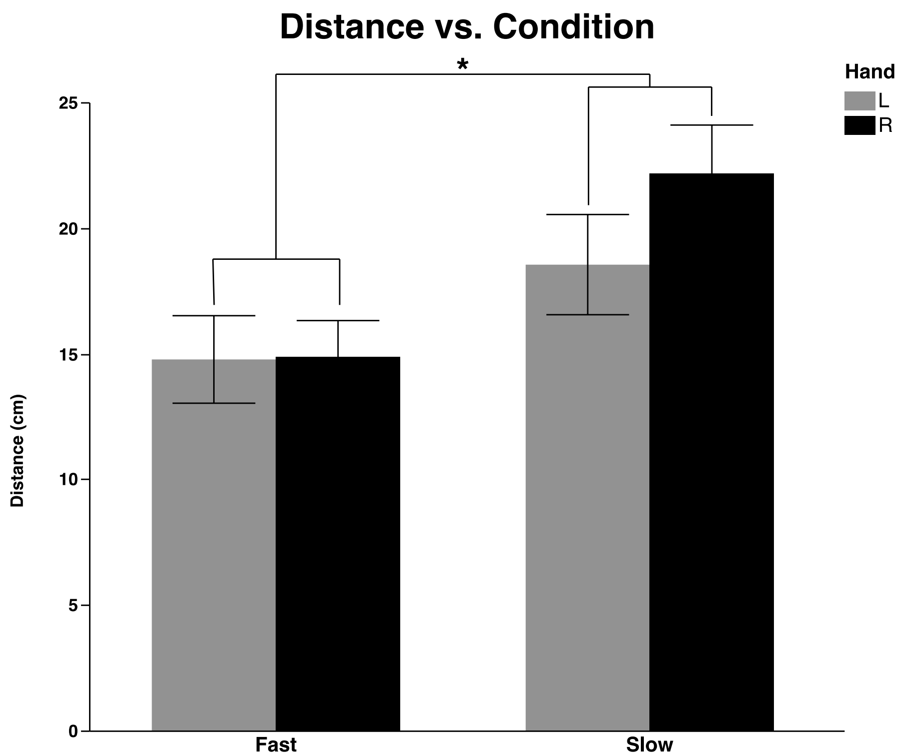

Figure 4. ***Distance vs. Condition.*** **Participant's mean distance of movement throughout a 1/2 cycle compared in fast and slow conditions with error bars representing SE. (*) signifies a significant difference between fast and slow conditions**

As expected, the speed of hand motion varied with speed condition, but not with hand (see figure 5). We found that participants made movements under the fast conditions with a mean peak velocity of .918 meters/ second (± 1 SE), and under the slow condition, they moved with a peak velocity of .302 meters/ second (± 1 SE). Our ANOVA showed a main effect of condition ($F(1,7.086) = 249.102$, $p<.0001$), but no main effect of hand nor interactions between factors.

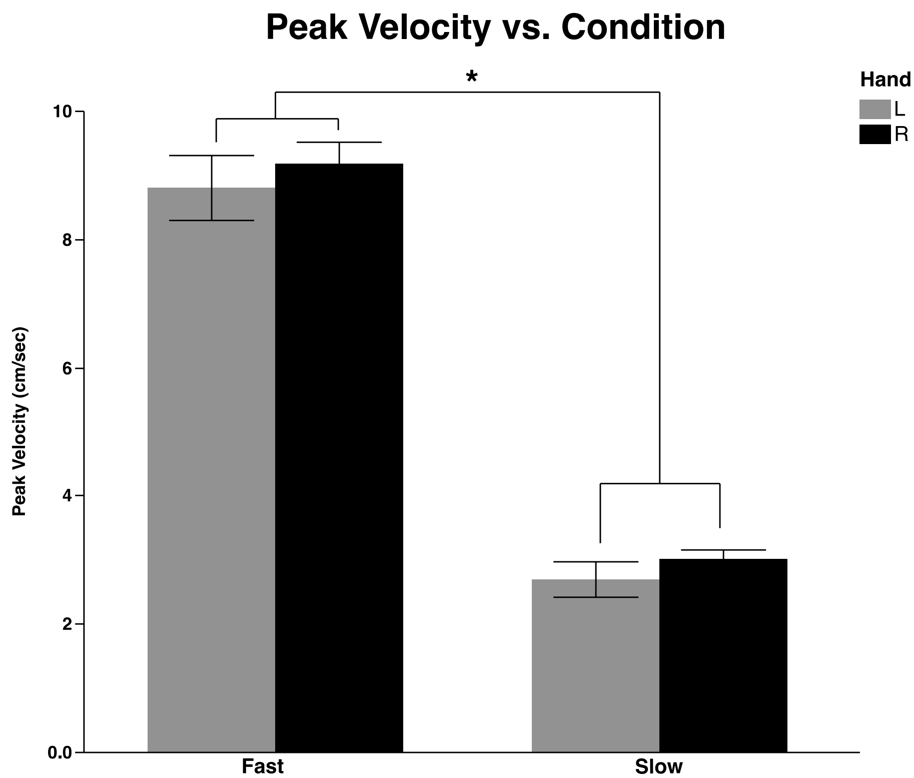

Figure 5. ***Peak Velocity vs. Condition.*** **Participant's mean peak velocity throughout a full cycle compared in fast and slow conditions with error bars representing SE. (*) signifies a significant difference between fast and slow conditions**

Motion in individual Degrees of Freedom

Our analysis of hand motions, as detailed above, demonstrates that all participants performed the task similarly with each hand. The only effects for our dependent variables for hand motion were for speed condition, but not for hand. We now assess how participants produced these hand motions at each degree of freedom at the wrist and forearm: At each degree of freedom, we quantified the change in angle for each full cycle of hand motion.

Wrist ulnar/radial deviation (RUD) was the instructed degree of freedom in this task. As shown in figure 6, we found that participants made movements under the fast conditions with a mean RUD angle of 25.2 degrees (± 1 SE), and under the slow condition, they moved with a RUD angle of 54 degrees (± 1 SE). There were no differences between the hands. Thus, our ANOVA showed a main effect of condition ($F(1,6.881) = 42.843$, $p<.0003$), but no main effect of hand nor interactions.

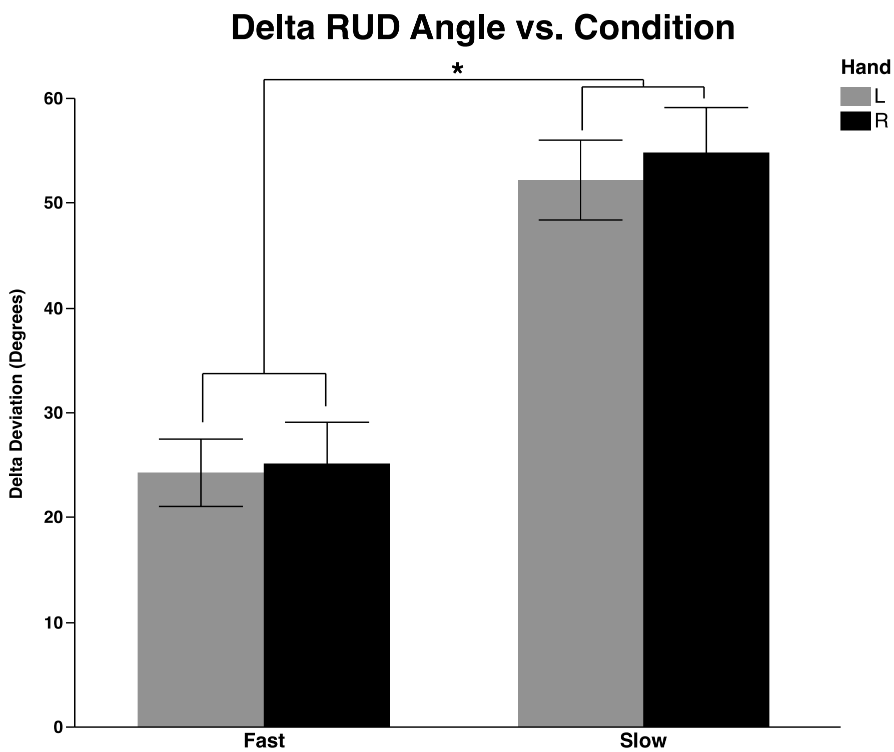

Figure 6. ***Change in Radial/ Ulnar Deviation Angle.*** **Participant's mean change in RUD throughout a full cycle compared in fast and slow conditions with error bars representing SE. (*) signifies a significant difference between fast and slow conditions**

Regardless of the instruction to isolate movements to radial/ulnar deviation, all subjects incorporated substantial flexion/extension (FE) at the wrist, but this degree of freedom did not vary with either hand, nor speed. As shown in figure 7, participants made movements under the fast conditions with a mean FE angle percentage of 122% (± 1 SE), and under the slow condition, they moved with a FE angle percentage of 40% (± SE). Our ANOVA showed a main effect of condition (F(1,7.228) = 35.0045, p=.0005). There was no effect for hand, or interaction between hand and condition. Thus, participants did show substantial coupling between degrees of freedom for this task.

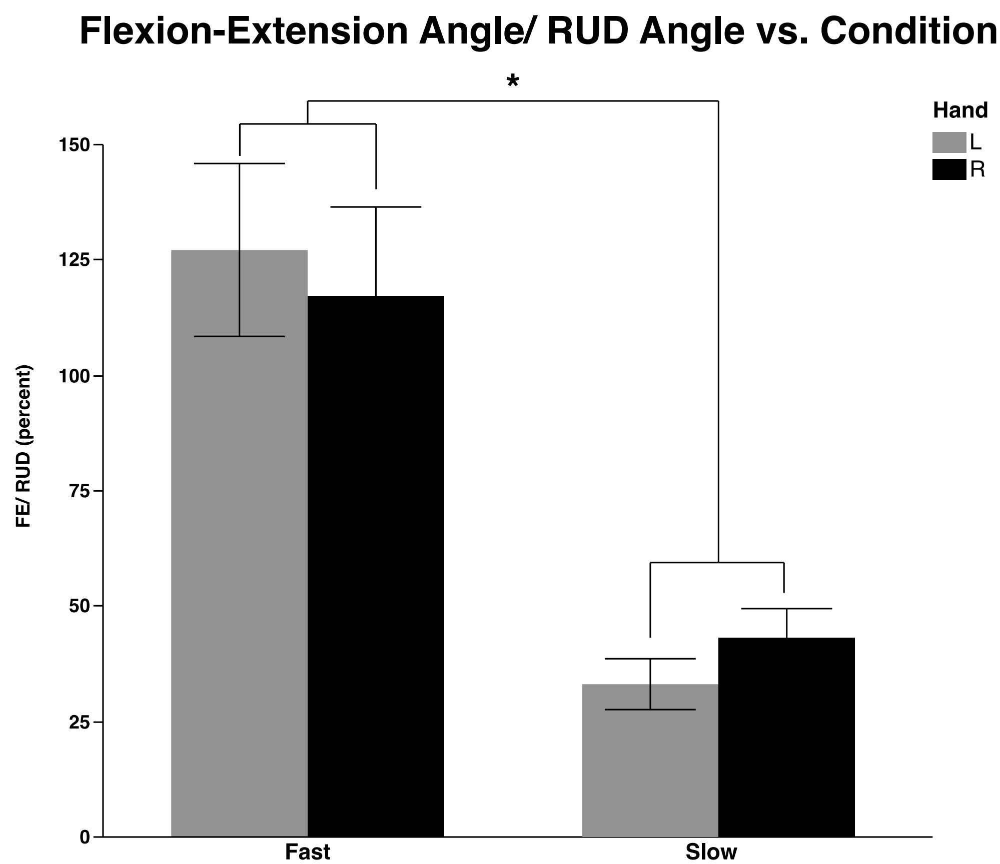

Figure 7. ***Normalized FE Angle/ RUD Angle.*** **Participant's mean change in flexion-extension angle divided by the change in RUD angle throughout a full cycle compared in fast and slow conditions with error bars representing SE. (*) signifies a significant difference between fast and slow conditions**

Figure 8 shows that participants demonstrated significant incorporation of pronation-supination, even though instructed to make only radial-ulnar deviation motions. Our ANOVA for pronation-supination/ RUD angle shows a hand by condition interaction (F(1,7.153) = 8.1274, p=.0241), with more pronation under the fast condition. We found that participants made movements under the fast conditions with a mean pronation angle percentage of 128% (± 1 SE) for the left hand and 65.4% (± 1 SE) for the right hand, and under the slow condition, they moved with a mean pronation angle percentage of 41%. The normalization of pronation-supination /RUD angle shows a main effect for condition, hand, and an interaction between hand and condition (see figure 8).

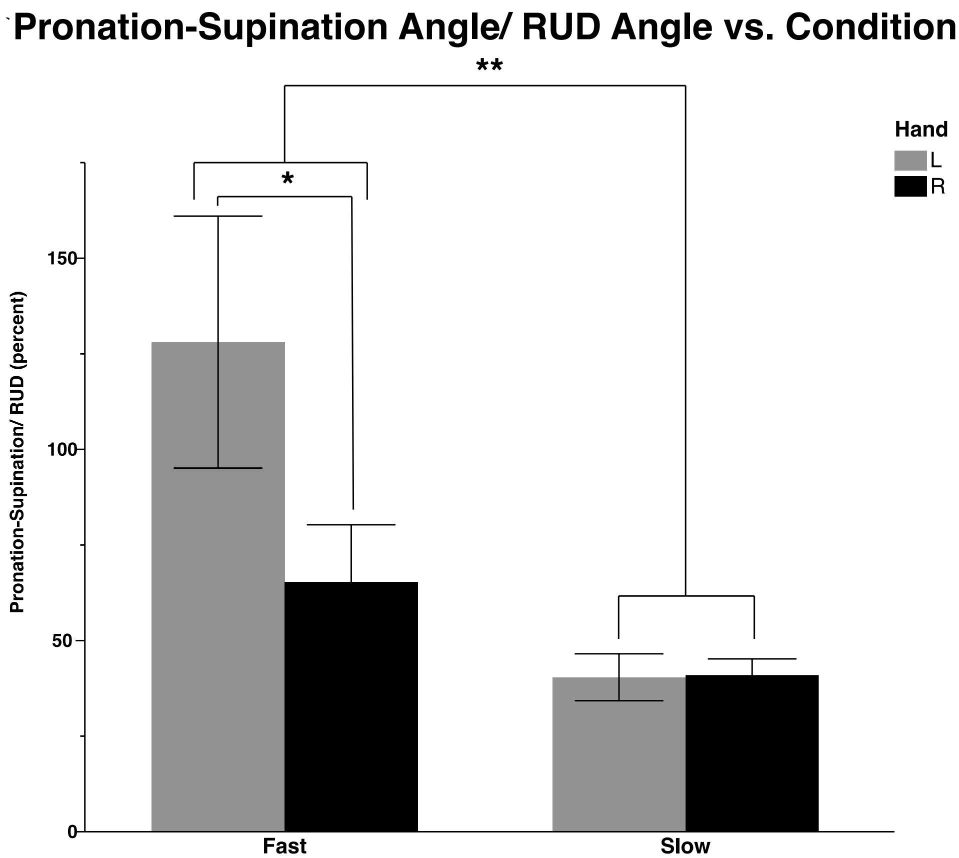

Figure 8. ***Normalized Pronation/ Supination Angle/ RUD Angle.*** **Participant's mean change in pronation-supination angle divided by the change in RUD angle throughout a full cycle compared in fast and slow conditions with error bars representing SE. (*) signifies a significant difference between the left and right hand during fast trials. (**) signifies a significant difference between fast and slow conditions.**

Chapter 4

Discussion/ Conclusions

The task was specifically designed to try and isolate radial and ulnar deviation of the wrist and minimize all other movements. Participants were asked to make repetitive 'chopping' movements with their wrists supported in mid-position, moving only in up and down directions (radial and ulnar deviation), and not rotating (pronation) the wrist, or moving it back and forth (flexion, extension). Participants were asked to do this slowly first. After three trials, each 10 seconds in length, they were then asked to do it again as fast as possible. All participants moved at frequencies that were not significantly different in slow conditions, and in fast conditions. All participants moved faster in fast conditions, but moved smaller distances that were not significantly different. All participants made similar deviation and extension movements that were different between conditions, but not participants. During the fast movements, all subjects incorporated more pronation into their left-arm movements than their right-arm movements. Thus, both absolute pronation, and more importantly, pronation as a function of deviation (instructed degree of freedom) were higher for left fast movement than right fast movements, but not different under the slow condition. We now go back to our earlier question and ask whether interlimb differences in interjoint coordination persist during a task that does not incorporate explicit spatial targets, visual feedback, and which is both simple and automatic, such that cognitive-perceptual processes play a smaller role than in targeted pointing movements. We predicted that the dominant controller would show advantages for predictive control of intersegmental coordination. During rapid oscillating wrist movements, the non-dominant arm of right-handers does not isolate coordination to one instructed degree of freedom to the extent that the dominant arm does. The dependence of speed is consistent with the hypothesis that the dominant controller is specialized for predictive control, while the non-dominant controller is not because rapid movement rely on feedforward processes to a greater extent than slower movements. 2) The simple repetitive movements studied here did not require visual feedback nor did they draw on declarative cognitive resources, yet the differences in coordination were substantial. This implies that the differences in coordination between dominant and non-dominant arms does not require complex tasks, as previously suggested by many studies. Instead, we propose that the differences reflect the degree to which motor coordination requires predictive mechanisms that account for biomechanical variations, such as movement dependent changes in muscle moment arms.

We conclude that interjoint coordination, measured as the ability to prevent motion in uninstructed degrees of freedom, is substantially better coordinated in the dominant arm than the non-dominant arm. These results support our hypothesis that the dominant hemisphere/arm system is specialized for interjoint coordination, and that this is reflected in simple tasks that do not require a visually specified target.

The Dynamic Dominance hypothesis has been elaborated over the past 2 decades based on empirical studies in right and left handed participants without nervous system deficits (Sainburg and Kalakanis, 2000; Sainburg, 2002; Sainburg, 2014), and in right handed stroke patients, in whom hemisphere-specific deficits were predicted in the non-paretic arm. (Mutha et al., 2013). Sainburg and colleagues (Sainburg, 2002; Yadav and Sainburg, 2014) have carried out control-theory based simulations to test the plausibility of this hypothesis. The current hypothesis proposes that each hemisphere contributes different control mechanisms to each arm: The dominant hemisphere is specialized for predicting inter and intra-segmental dynamics while the non-dominant hemisphere is specialized for impedance control that is robust to perturbations from within the body and in the environment. This led to the hypothesis that the non-dominant controller might reflect better control of limb impedance, which confers resistance to external forces (Bagesteiro and Sainburg, 2002; Yadav and Sainburg, 2014). However, having only been demonstrated during visually directed reaching studies, we asked whether interlimb differences in interjoint coordination persisted during a task that does not incorporate explicit spatial targets, visual feedback, and which is both simple and automatic, such that cognitive-perceptual processes play a smaller role than in targeted pointing movements and found that significant differences exist across the degrees of freedom that are not instructed by the task.

23 Annett et al. (1979) showed differences in performance between the two hands during peg-board

performance, a complex task. Through videography, Annett quantified more positioning errors and error-corrections with the non-dominant than the dominant hand. However, no interlimb differences were seen in the overall time it took to place each peg in the pegboard. Annett et al. concluded that the dominant controller was superior in planning and executing a motor plan that did not require corrections, while the non-dominant controller is less able to plan movement, and better to exploit feedback mediated correction processes (Annett et al., 1979). The results of these studies and ours suggest that the difference in coordination between dominant and non-dominant hands is less dependent on visual feedback than on differences in motor planning processes. (Roy and Elliott, 1986; Roy and Elliott, 1989; Carson et al., 1990).

One of problems associated with the interpretation of this line of research is the question of what factors might define a "skill" or a "complex" behavior. According to Brydan, (2016) complex tasks involve multiple steps (Brydan, 2016) and recruit greater cognitive resources. Consistent with this idea, the research supporting the dynamic dominance hypothesis was also based on somewhat complex tasks (targeted reaching movements.) Such movements, though seemingly simple, clearly have been shown to recruit substantial cognitive resources for planning (Rosenbaum et al., 1980).

In this study, we exploited the redundancy and coupling between the muscles that move the wrist. All muscles of the forearm and wrist have moment arms across multiple degrees of freedom (coupling) and each degree of freedom is acted upon by many muscles (redundancy) (Ramsay et al., 2008). In our task, participants are instructed to move the wrist along one degree of freedom, while the other three degrees of freedom are unrestrained. Nevertheless, we found that significant pronation displacement tends to be recruited during this task, and is substantially greater for a given displacement in wrist deviation, for the non-dominant arm. Thus, the dominant hemisphere/arm system appears to be more adapted for compensation for both redundant and coupled muscle actions at the wrist, even when the task is simple 24 and does not require visual targets, does not include visual feedback, and requires limited attentional and cognitive resources. We therefore conclude a specialization for inter-degree-of-freedom coordination is a fundamental feature of the dominant limb controller.

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ACADEMIC VITA

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Education

Major: Kinesiology (Movement Science)
Honors: Kinesiology
Thesis Title: Superior Predictive Control of Intersegmental Dynamics in Dominant Arm Coordination
Thesis Supervisor: Robert Sainburg, PhD

Professional/Observation Experience

O'Neill Physical Therapy, State College, PA
September 2016- November 2016

- Student
- 45 hours of physical therapy observation
- Outpatient experience in physical therapy setting
- Learned procedures for both evaluation and re-evaluation
- Observed how physical therapists prescribe exercises and follow through with plan
- Acquired knowledge of skills including e-stim and ultrasound therapy techniques

HCR Manorcare, Monroeville, PA
July- August 2016

- Student
- Completed 65 hours of physical therapy observation
- Assisted physical therapists in taking patients through prescribed exercises
- Witnessed initial evaluation of patients
- Provided assistance via. chair follows

UPMC Mercy Inpatient Rehabilitation, Pittsburgh, PA
March 2016

- Student
- Accumulated 14 hours of physical therapy/occupational therapy observation in two days

- Observed stroke rehab unit and spinal cord injury rehab unit
- Assisted both physical and occupational therapists with treatment
- Worked with speech pathologist for 2 hours separately

Certifications

American Red Cross
- CRP/AED
- First-Aid
- Lifeguarding

Job Experience

The Grand Residence, Upper St. Clair, PA
May 2017- present
- Personal Aide
- Direct geriatric patient care
- Cleaning, feeding, transport of patients
- Ambulation assistance

American Pool Management, Pittsburgh, PA
2015- present
- Lifeguard at various 1-2 guard pools
- Ensured safety of all patrons
- Properly maintained chemical balance of pool
- Tracked entrance of patrons via apartment pass

Citiparks, Pittsburgh, PA
2013-2015
- Lifeguard
- Taught children's "Learn to Swim" 2 separate summers
- Kept facilities clean and safe

Leadership Positions

HealthWorks, The Pennsylvania State University, University Park, PA
2015- present
- Peer/ health educator/ Team leader
- Team leader for Mission Nutrition (subgroup of HealthWorks)
- Facilitates workshops for various groups of students on campus
- Provides information at tabling events

- Offers wide variety of health resources to campus students through the University Health Services
- 250 hours of Health Education

Ayuda, The Pennsylvania State University, University Park, PA
March 2017- present

- Executive board member: Special Projects Chair

Women's Club Ice Hockey, The Pennsylvania State University, University Park, PA
April 2017- present

- Executive Board Member: Treasurer
- Team Captain