Classroom Assignments and Exercises

Monograph Matters
Supplement to Brakke & Pacheco (2019)

Includes 4 modules:
Module 1. Form and Function of Bimanual Hand Coordination
Module 2. Development of Bimanual Coordination in Infants
Module 3. Practicing In-phase and Anti-phase Behavior
Module 4. Bimanual Coordination as a Clinical Tool

Introduction to the Activities:

Bimanual coordination, or skilled complementary use of the hands, is important to typical human functioning and the development of material culture. Bimanual coordination also serves as a model motor system in research on motor control and learning. For these reasons, understanding how we use our hands together, and how we learn to do so, can be a worthwhile educational goal. We present here a series of modules that allow learners to investigate different aspects of bimanual coordination.

The activities within each module are written at the advanced undergraduate level but may be adapted for coursework at other levels at the instructor's discretion. Student learning outcomes corresponding to the activities in each module are listed; these SLO's may also be adapted as activities are selected or modified. Accompanying PowerPoint slides can be found on the *Monograph Matters* website.

These materials may also be used by individuals as a supplement to reading the Monograph, particularly by readers who are not experts in motor control. The activities introduce the reader to general characteristics and development of bimanual actions well as some basic principles of Dynamical Systems Theory and the kinds of coordinated cyclic actions that are discussed in the monograph.

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Form and Function of Bimanual Hand Coordination

Learning Objectives:
- Describe the different dimensions of bimanual coordination
- Explain how a Dynamical Systems Theory approach applies to bimanual coordination
- Discuss how bimanual coordination supports development and use of human material culture

Part I. The Characteristics of Bimanual Actions

Bimanual activities can differ along several dimensions:

Synchrony -- the degree to which the hands move at the same time.

Differentiation – the degree to which the actions or roles (motor movements) of the hands are distinct from each other when performing a bimanual action. Lack of differentiation corresponds closely to symmetry of movement.

Dexterity -- the degree to which the action requires precise fine motor movements of one or both hands.

Complementarity -- the degree to which the hands must act together to achieve the desired goal. The motor movements and timing may differ, but the two hands must work in concert.

Continuity -- the degree to which the action consists of sustained movement over time. If the action repeats periodically, it can be considered rhythmic as well as continuous.

Activity: Bimanual Actions in Everyday Life. List 5 bimanual actions that you perform, and characterize them as 'high' or 'low' along each of the dimensions:

Action	Synchrony	Differentiation	Dexterity	Complementarity	Continuity

Part II. The Organization of Bimanual Activity: Dynamical Systems Theory

One of the theories that explains how different behaviors emerge is Dynamical Systems Theory. Some of the principles of this theory relevant to the current assignment are:

- Behavior is thought of as a complex system of components.
- Development is understood as the interaction of all levels of the system, from the molecular to the cultural, as it undergoes change over time.
- Development is understood as incorporating nested processes that unfold over many timescales, from milliseconds to years.
- The pattern and order of behaviors emerge from the interactions of the components of a complex system without explicit instruction. This is known as ‘self-organization’ of the system.
- Both biological and environmental components of an organism’s system serve to support and constrain the emergence of a particular behavior.
- Once all of the underlying components required to perform a behavior fall into place, the behavior emerges as a result of the system’s self-organization.
- To the extent that the supporting and constraining components tend to be similar across individuals, similar behavioral forms will emerge.
- The tendency of some behaviors to fall into particular patterns that are very similar across all individuals is called ‘canalization’.
- The behavioral forms that are most commonly and easily performed by an individual are known as ‘attractor states’.

Activity: Applying Dynamical Systems Theory to a Specific Action

1. Select one of the behaviors that you listed above, and think about how that behavior is organized. What are the different biological subsystems and environmental factors that have to be in place to support the emergence of the behavior?

2. Now think about how the behavior functions in interaction with the environment. How do the features of the environment and the organism constrain, or limit, how the action is expressed?

3. 'Canalization' occurs when behaviors become channeled into particular forms (or attractor states) given the different supports and constraints that are present. For example, walking tends to self-organize into a particular pattern of alternating leg swings that is supported by the presence of level horizontal surfaces, gravity, the musculoskeletal structure of our bodies, our perceptual systems, and so on. Think about how different people perform the bimanual behavior you've selected. Is this behavior highly canalized, or does it take different forms in different people and under different circumstances?

Part III. Bimanual Coordination and Human Material Culture

The term "material culture" refers to all of the artifacts or physical objects that humans have created or modified throughout time.

Activity: Bimanual coordination and Culture. How do the flexibility and variety of human bimanual actions support the development of human material culture? How do you think our lives might be different if we were not able to coordinate the use of our two hands with the degree of dexterity, complementarity, and differentiation that most of us automatically experience?

Development of Bimanual Coordination in Infants

Learning Objectives:

- Characterize how infants of different ages engage with objects
- Explain the role of motor coupling in infants' use of bimanual activity
- Describe role-differentiated bimanual manipulation and explain why it is important to human development
- (advanced) Design an experiment that addresses a research question involving the development of bimanual manipulation in infants.

Bimanual coordination, or the skilled use of the two hands together, has played an important role in human evolution and cultural history. It is also an important component of early childhood development. Although infants sometimes engage in spontaneous bimanual movements even at very early ages, they must learn how to control their two limbs so that their hands can work together to achieve different goals.

One of the main things infant researchers look at is whether infants' arm or hand movements are coupled, or linked together in their movement. Typically, bimanual coupling is expressed when the same muscle groups of the two arms move simultaneously, producing mirror-image movement (or close to it). For example, at some ages infants may reach for a small toy with two hands even though using just one would be more efficient. At other times, infants rely on just one hand to reach for objects. In fact, it may be difficult for an infant under one year of age to hold two objects (one in each hand) at the same time!

Toward the end of their first year, infants start to use their two hands together in different ways, allowing them to perform more complex kinds of object manipulation than they could earlier. When the two hands work together to act on objects but each performs a different role, the behavior is known as 'role-differentiated bimanual manipulation'. An example of this would be holding a jar with one hand while lifting its lid with the other.

Different kinds of bimanual actions emerge at different ages. For example, behaviors that require the hands to simultaneously perform different movements for a sustained period of time – such as playing a musical instrument – are quite complex and do not usually emerge until well after infancy. A relatively simple version of this continuous bimanual activity involves rhythmic movement, such as using drumsticks to beat a drum. This behavior seems to typically emerge during the second year of life.

Part I. Reaching and Grasping in Young Infants

Activity**: **Observing Reaching & Grasping Behavior. Observe an infant (live or on video) between 4 and 8 months of age reaching for small objects placed in front of it.

- Provide a brief description of your observation:

- Does the infant primarily use one hand or both hands when reaching for the objects?

- Is the form of reaching consistent or does it vary between different attempts at reaching?

- Is the infant usually successful at grasping the object securely?

- Does the infant appear to adjust its movements appropriately when reaching for different types or sizes of objects?

Part II. Object manipulation in older infants and toddlers

Activity: Observing Early Bimanual Manipulation. Observe an infant or toddler (live or on video) between the ages of 12 and 24 months of age playing with toys or interacting with other objects.

- Briefly describe the bimanual actions that you observe.

- Do you notice any hand-dominance in the child's actions? Does one hand seem to be more active or skilled than the other?

- Do you see any role-differentiated bimanual manipulation or rhythmic bimanual activity? If so, briefly describe how the infant organizes the actions of the two hands so that they work together.

- Why might role-differentiated bimanual manipulation be considered an important milestone in human development?

Part III. Try Your Own Experiment: Interacting with Infants (advanced activity)

Activity*: *Research Design. Design an experiment (or quasi-experiment) to address one of the following research questions. If you have access to infants of the appropriate ages, try to conduct your experiment and answer the question!

Can infants at different ages hold two objects at once?

Does holding objects affect whether or how an infant performs a bimanual behavior such as clapping or drumming?

Does imitation of an adult model help infants perform bimanual actions?

Practicing In-phase and Anti-phase Behavior

Learning Objectives:

- Apply Dynamical Systems Theory to behavior involving bimanual coordination
- Explain the concept of phase relationships
- Demonstrate behaviors that illustrate phase relationships

Dynamical Systems Theory (DST) provides the theoretical foundation for much of the current research in bimanual motor learning and control. Some of the tenets of DST are as follows:

- Behavior is thought of as a complex system of components.
- Development is understood as the interaction of all levels of the system, from the molecular to the cultural, as it undergoes change over time.
- Development is understood as incorporating nested processes that unfold over many timescales, from milliseconds to years.
- The pattern and order of behaviors emerge from the interactions of the components of a complex system without explicit instruction. This is known as 'self-organization' of the system.
- Both biological and environmental components of an organism's system serve to support and constrain the emergence of a particular behavior.
- Once all of the underlying components required to perform a behavior fall into place, the behavior emerges as a result of the system's self-organization.
- To the extent that the supporting and constraining components tend to be similar across individuals, similar behavioral forms will emerge.
- The tendency of some behaviors to fall into particular patterns that are very similar across all individuals is called 'canalization'.
- The behavioral forms that are most commonly and easily performed by an individual are known as 'attractor states'.

One of the ways in which researchers have applied DST to motor learning and control is through the study of bimanual coordination. In particular, cyclic bimanual activity such as finger-tapping or pendulum-swinging has been used as a foundational class of behaviors to examine the variety of factors that contribute to the performance and stability of coordinated movement. With these behaviors, one of the main variables of interest is the phase relationship between the moving segments of the two hands or arms. The term 'phase relationship' refers to the symmetry of the two limbs' movements. In finger-tapping, for example, if the right and left index fingers move up and down together, they are said to be "in phase" with each other. If one finger moves up as the other moves down, however, the movement is said to be 'anti-phase' because the fingers move in opposite directions. Borrowing from physics, we can also think of the fingers' movement as representing two oscillators, and express the relationship between their movement in terms of degrees along circular coordinates. In-phase coordination occurs at a phase relationship of 0^o and anti-phase coordination at 180^o.

Although both in-phase and anti-phase coordination patterns often serve as attractor states, in-phase actions tend to be more stable because they take advantage of our intrinsic tendencies to easily perform simultaneous, symmetrical movements with muscle groups on both sides of the body. Teenagers and adults are well-practiced with many anti-phase actions, such as swinging the arms, finger-tapping, or drumming. However, even adults can experience the stronger in-phase attractor state when engaging in new behavior patterns that have not been practiced, or when trying to perform the patterns under new conditions.

Activities: Stability of In-phase and Anti-phase Coordination Patterns

Activity 1**: **Air-Circles. Hold your hands in front of you with your index fingers pointing forward from your fists. Move both hands simultaneously so that each draws a large (6" – 10" diameter) circle in the air in front of you. Try the two different phase relationships:

In-phase: Start with both hands at the top of the circle and move them in simultaneous mirror-image to one another, so that one is moving clockwise and the other counterclockwise. Your hands should move at the same pace so that they reach the top and bottom of their respective circles together.

Anti-phase: The movements of each hand are identical to those performed in the in-phase condition above, but with one important difference in the relation between the two hands. Rather than starting both hands at the top of the circle, start one hand at the top and the other at the bottom. Again moving one hand in the clockwise direction and the other counter-clockwise. Move the hands at the same rate, so that one reaches the bottom of the circle just as the other reaches the top.

Observe your performance of in-phase versus anti-phase movement. Which one is easier for you to keep stable? Try increasing the speed of movement in each condition. As you go faster, what happens in each condition – does one stay more stable than the other? Next, try to keep moving consistently while turning your attention to something else (e.g., talk with someone, count backward, etc.). After 15-20 seconds, observe how your hands are moving. Have there been any changes?

Activity 2**: **Finger-tapping. Even with familiar behaviors, the anti-phase pattern can break down if the parameters change. For this activity, you will need a metronome beat to pace your movements. If you don't have a physical metronome, you can find a beat generator online by searching for 'metronome'.

For this activity, we will use a finger-tapping task in which you tap your index fingers in time to a metronome beat. You will tap in in-phase and anti-phase coordination patterns.

First, set the metronome to a comfortable tapping pace, for example 100-120 bpm. Tap your index fingers in an in-phase pattern in time with the beat of the metronome for 30 seconds. Then switch to an anti-phase pattern for 30 seconds, making sure to maintain the same speed of movement with each hand. One index finger (e.g., right) will touch the surface with each metronome beat, while the other (e.g., left) will reach the highest point of the cycle at the sound of each beat. Under this condition, both in-phase and anti-phase patterns should be stable over the entire 30 seconds.

Next, increase the metronome beat to a faster pace, for example 180-200 bpm, and repeat the coordination patterns that you performed with the slower pace described above. Observe the stability of the in-phase and anti-phase patterns over time. Is one more difficult to maintain than the other? Does one pattern lose its stability more than the other?

Bimanual Coordination as a Clinical Tool

Learning Objectives:

- Identify brain areas and functions involved in the expression of bimanual coordination behavior
- Identify disorders that disrupt bimanual coordination
- Develop a test of bimanual coordination that might be used for clinical assessment

Part I. Neural Underpinnings of Bimanual Activity

Although behaviors emerge from the dynamic interaction of multiple environmental and biological systems, many people are especially interested in the neurological underpinnings of/contributions to the system. Knowing how the brain supports skilled bimanual action can help medical professionals such as doctors and therapists diagnose and treat disorders or injuries that impair bimanual functioning.

The human brain is an incredibly complex organ with countless complicated networks of activity that support different types of behaviors. We can identify, however, some structures of the brain that appear to be especially important to skilled bimanual performance. Listed below are some of the brain structures that are believed to support coordinated bimanual movement.

Corpus Callosum (CC): The corpus callosum consists of bands of tissue that connect the left and right hemispheres of the brain. Along with the anterior commissure, the corpus collosum is essential for information transfer, or communication, between the two cortical hemispheres.

Supplemental Motor Area (SMA): The supplementary motor area is a part of the cerebral cortex known as the motor cortex. Its specific functions are unknown, but research suggests that it has an important function for bimanual coordination in particular.

Cerebellum: The cerebellum plays a key role in regulating and coordinating voluntary movement through motor timing and balance. It receives sensory signals from around the body and helps coordinate muscle movements so that action is performed smoothly. The cerebellum also plays a role in motor learning.

Cingulate Motor Cortex (CMC): The cingulate cortex appears to have many functions, several of which are related to emotion. Much about the multiple functions of this area is still unknown. The anterior part of the cingulate cortex appears to have a role in selecting and initiating motor movements, so is known as the 'cingulate motor cortex'.

Perceptual and attentional cortical systems: Perception and attention are important to successful performance of skilled bimanual action.

Activity: Mapping Motor Control in the Brain

1. Consult an online brain atlas or map and label (as precisely as possible) the following brain structures or regions on the diagram:

   a. Corpus callosum (CC)

   b. Supplementary Motor Area (SMA)

   c. Cerebellum

   d. Cingulate Motor Cortex (CMC)

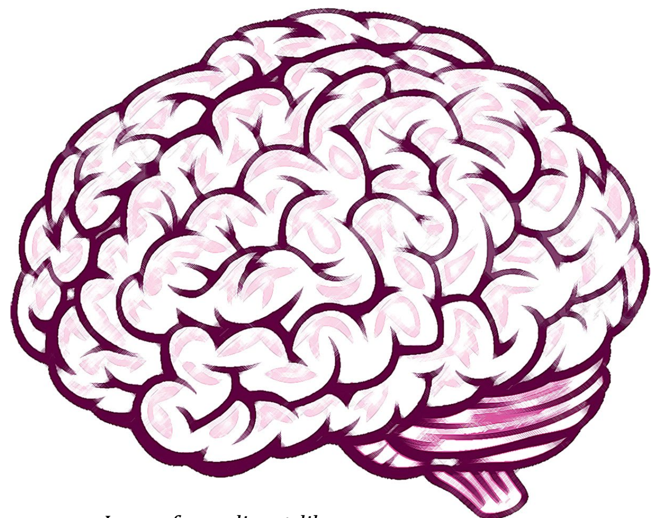

Image from clipart-library.com

2. Explore the brain atlas further, and look for websites on "brain motor control areas". What other structures or regions of the brain might be involved in motor control? Map these as well. Why did you select these areas – what functions did you consider important to include when considering motor control?

Part II. Clinical Application (advanced activities)

As a complex behavioral system, bimanual coordination is sensitive to disruption through a variety of acute and chronic pathologies. Some developmental disorders that research suggests involve impaired or altered bimanual competencies include Developmental Coordination Disorder, Cerebral Palsy, Dyslexia, Down Syndrome, and Autism Spectrum Disorders. Other relevant pathologies have later onset, including Multiple Sclerosis, Parkinson's Disease, and Stroke.

Activity 1: Locating the Research. Select one of the disorders listed above, and find an empirical research article that describes the changes or deficits in bimanual activity that are associated with it. List your disorder along with a full bibliographic citation of your article, and summarize the article's findings here:

Activity 2: *Developing a Bimanual Assessment*. Because the precision and timing of bimanual coordination is sensitive to disruption, it can serve as a nonverbal diagnostic tool. In some cases, interventions may include some bimanual activity as part of the rehabilitative or adaptive-learning process. Given what you read about the disorder and the bimanual disruption that you read about in the article you selected, develop an assessment task for bimanual competency. Describe the task in as much detail as possible here: