Falling into a Rhythm – The Emergence of Periodicity in Discrete Motor Actions

Abstract. When learning to walk, it has been suggested that humans transition from discrete, aperiodic steps to a periodic gait in order to conserve energy and increase stability. It is possible this same factors apply when humans perform complex movements with their upper limbs. For instance, when a basketball player practices free throws or a tennis player hits many serves in a row, the time between their throws or serves similar becomes more consistent (i.e. periodic) with practice. While this phenomenon is a common, it is not known how or why repeated discrete movements become periodic. More fundamentally, this emergence of periodicity has not yet been quantified. This study aims to demonstrate that when individuals repeatedly perform a discrete action, these actions become as periodic as explicitly rhythmic actions. We further aim to show that this spontaneous emergence of periodicity develops with age. To investigate the emergence of this periodicity, we will ask participants to perform a discrete throwing task and a rhythmic finger tapping task. We predict that as participants practice the discrete throwing task, they will become as periodic as they are in the finger tapping task where they are explicitly instructed to move rhythmically. We also predict that by the end of practice, younger participants will be less periodic compared to older participants. This development of periodicity should mirror decreasing variability in the rhythmic task. Identifying the emergence of periodicity in repeated discrete movements will provide insight into how the central nervous system controls complex, coordinated movements.
Falling into a Rhythm – The Emergence of Periodicity in Discrete Motor Actions

In a prior experiment, we observed that when participants repeated trials of a throwing task, the time between their throws became more consistent (i.e. periodic) with practice. This was unexpected as participants were only instructed to throw to a target as accurately as possible. No instruction on consistency or timing was given. While it is not known how or why this periodicity develops, spontaneous periodicity in repeated discrete actions is actually a common phenomenon, exemplified in athletics: when a basketball player practices free throws or a tennis player hits many serves in a row, their pacing becomes more periodic and is often described as “falling into a rhythm”. The goal of this study is to investigate the development of periodicity in the repeated performance of a discrete task.

To investigate the emergence of this periodicity, we will ask participants to perform a discrete throwing task and a rhythmic finger tapping task. Participants will perform 100 trials of a discrete throwing task, and we will measure the variability of their inter-throw intervals (i.e. time between throws) to quantify periodicity. Next, we will examine how the periodicity in the discrete task compares to the periodicity in a finger tapping task, where participants are explicitly instructed move rhythmically. Lastly, we will investigate if the degree of periodicity in the discrete task varies with age.

Aim 1. Demonstrate that when individuals repeatedly perform a discrete action, these actions become as periodic as explicitly rhythmic actions. We predict that in early practice, inter-throw intervals will be more variable than inter-tap intervals within each individual. However by late practice, we predict that individuals will decrease their variability in inter-throw intervals to the same level of variability in their inter-tap intervals.

Aim 2. Demonstrate that the spontaneous emergence of periodicity when performing repeated discrete actions develops with age. We predict that by the end of practice, the inter-throw periods of younger participants will be more variable compared older participants. This development of rhythmicity is mirrored in a decrease in variability in the explicitly rhythmic tapping task.

Significance. Identifying the emergence of periodicity in repeated discrete movements will provide insight into how the central nervous system learns to controls complex coordinated movements. The emergence of periodicity has been previously studied in locomotion. When younger children learn to walk, their steps are initially discrete and not well-timed. Only after years of practice does locomotion become periodic (1). It has been suggested that this periodicity emerges in order to reduce energy demands and increase stability in the human system (2). Observing emergent periodicity in upper limb movements would suggest that the control objectives that guide learning to walk also guide learning other complex motor skills. In addition, many movement disorders can be characterized by either increased periodicity, such as repetitive stereotypic movements in Autism Spectrum Disorder (3), or by the lack thereof, like arrhythmic
gait in cerebellar disorders (4). A measure of the emergence of periodicity could potentially be sensitive enough to detect subtle motor impairment. Such measures are still needed for neurological diseases like Parkinson’s Disease and developmental disorders where early detection is critical.

**Experimental Design. Participants and Location.** Approximately 300-500 participants of ages 5 to 70 years will be recruited at the Museum of Science. Our two experimental set-ups are exhibited in the Living Laboratory, an initiative of the Museum of Science to educate museum visitors about ongoing research. The data collection devices are located next to the Hall of Life. We will approach visitors and invite them to participate in our two experimental tasks. **Data Collection of the Discrete Throwing Task.** Participants will throw a virtual ball 100 times. The goal of each throw is to hit a virtual target displayed on the screen. The participants first rest their dominant arm on a lever and grasp a wooden ball attached to the distal end (*Figure 1*). To throw the ball, the participants rotate the lever and trigger the release of the virtual ball by lifting their finger from a pressure sensor on the wooden ball. The angular position of their arm is measured with a digital encoder attached to the lever. The angular position and speed of the arm at the moment of release determine the path of the ball in the virtual environment. The arm position and pressure sensor signals will be analyzed to calculate the variability in inter-throw interval. **Data Collection of the Rhythmic Finger Tapping Task.** Participants will tap their index fingers on a force sensor at their preferred period for three 60-second trials (*Figure 2*). As in the throwing task, the force signals from finger contact are analyzed to calculate variability in inter-tap intervals.

**Research Opportunities for Undergraduates.** I have assembled an interdisciplinary team of 8 undergraduate students from Northeastern to assist with this experiment. Their majors include Biology, Behavioral Neuroscience, Biomedical Physics, Electrical Engineering, and Mathematics. Six of these students are fellow female scientists. The undergraduate team will assist me in setting up the equipment, recruiting museum visitors to participate, and running the experiment. After completing the data collection, I will supervise the undergraduate students to address the two aims. Given the richness of the big dataset, undergraduate students can subsequently also analyze it to answer their own research questions.

**Community Outreach.** The experience of conducting an experiment at the Museum of Science is unique. We expect to collect 300-500 subjects. Besides collecting this big dataset, we also have the opportunity to share our lab’s research with the museum visitors. We can explain how our research impacts the community and inspire young children and teenagers to take an interest in science and engineering.

**References**


**Itemized Budget and Justification.** We will need 2 data acquisition boards to conduct this research. The data acquisition board controls and acquires the signals from the sensors and relays to the computer for processing. To accurately measure the variability of inter-throw and inter-tap intervals in the two experimental tasks, the arm position and force signals must have high temporal resolution (i.e. sampling frequency more than 1000 Hz). To achieve such high resolution, the data acquisition board must have a precise internal clock as in the boards specified above.

Given the volume of visitors at the Museum of Science, we must be able to run the two experimental tasks in parallel. Therefore, each task requires a separate high-performance data acquisition board. The Museum of Science has generously provided financial support to use the space in their Living Laboratory next to the Hall of Human Life. However, financial support is needed for developing the equipment needed to conduct these experiments and perform community outreach at the museum.

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1. My name is __________________. I am a researcher studying how people move.

2. We are asking you to help us with our research. If you agree, you will play a throwing game and a finger tapping game. Before you start playing the games, a researcher will tell you what will happen and answer your questions. You can practice and watch others practice first.

3. If you feel uncomfortable or want to take a break or stop, it is okay to tell your parents or a researcher and we will stop.

4. By playing the games, you will help us understand how people move. The more we understand about this, the better we can help other people.

5. You can talk to your parents before you decide if you want to do the study. We will also ask your parents if it is okay for you to do the study. Even if your parents say “yes,” you can still decide not to do it.

6. If you do not want to be in this study, you don’t have to participate. Remember, being in this study is your choice and no one will mind if you change your mind later and want to stop.

7. You can ask any questions that you have about the study now. If you have a question later that you didn’t think of now, you can call me (617-373-5093) or ask me next time. You can also call Nan Regina, the Director of Human Subject Research Protection at Northeastern University, (617-373-4588) if you feel you have been treated unfairly.

8. Signing your name here means that you agree to be in this study. You and your parents will get a copy of this form after you have signed it.

__________________________  _______________________
Participant Name                      Date

Pitchers and Pianists: Timing in Discrete and Rhythmic Motor Skills
Informed Consent to Participate in a Research Study

Your child is invited to take part in a research study that investigates your child’s ability to time movements in a rhythmic and a discrete motor task. This form will tell you about the study, but the researcher will explain it to you first and you may ask this person any questions. When your child is ready, you may tell the researcher if your child wants to participate. If your child does, the researcher will ask you to sign this statement and will give you a copy to keep.

Why am I being asked to take part in this research study?
We are investigating the ability to time movement in rhythmic and discrete motor tasks. We are interested in how humans across all ages may have different limits of timing accuracy in rhythmic and discrete motor tasks.

Why are you doing this research study?
A person’s sense of time, both perceiving time and moving in time, is a skill that most humans possess. This study aims to investigate one’s ability to time movements in two different types of tasks: rhythmic and discrete. Rhythmic actions are not only important for skills like dancing and playing musical instruments, but also in walking or typing on a keyboard. Other activities involve non-rhythmic single actions, like throwing a baseball or reaching for an object. Both rhythmic and non-rhythmic movements require precisely-timed coordination of the body. Our goal is to understand how humans of all ages time these movements. The findings of this experiment may provide insight into how the central nervous system controls sensorimotor behavior. As this is an essential component in children’s development, in motor learning in all ages, and in rehabilitation of neuromuscular diseases, these insights are of great benefit to society.

What will I be asked to do?
If you and your child decide to take part in this study, we will ask your child to perform two tasks: a discrete throwing task and a rhythmic tapping task. You and your child may opt to perform only one of the tasks at any time.

In the discrete throwing task, your child throw a virtual ball that is suspended from a high pole towards a target that is positioned at the other end of the pole. The ball and the target are only presented virtually on the screen in front of your child. In some experiments the ball’s motion may be perturbed and it may be more difficult to hit the target, but this does not affect your arm movements. Your child’s data are recorded by an encoder, a small device that is attached to the lever arm on which you place your arm. Your child will perform the task while sitting down. These trials will be about 10 minutes in length.

In the rhythmic tapping task, your child will be asked to tap your finger onto a platform while seated comfortably in a chair. Your child will be asked to tap at a pace set by a metronome and then continue without the metronome at the same pace. These rhythms will be close to, but also slightly slower and slightly faster than your comfortable pace. Data are recorded by a force sensor, a small device attached to the table used to measure contact between your child’s finger...
and the tapping surface. These trials will be approximately 5 to 10 minutes in length and require very little physical demand.

We will also ask you to fill out a survey that asks simple questions about your child’s age, gender and experience in motor and musical skills.

**Where will this take place and how much of my time will it take?**
Your child will perform these movements in the Living Laboratory® in the Hall of Human Life at the Museum of Science in Boston, MA. Individual trials will last between approximately 10 to 60 seconds and should neither fatigue your child, nor produce any other discomfort. If your child’s hands or arms feel tired, he/she can take a rest. The total experiment will last approximately 15 minutes.

**Will there be any risk or discomfort to me?**
There is no risk involved in this study. Your child will perform movements with his/her arms and hands in the range of normal everyday movements. The tasks are performed in a sitting position. Your child can take breaks between trials whenever you may feel fatigued. If you or your child notice any discomfort during the study, please notify the researchers immediately and the study will be stopped.

**Will I benefit by being in this research?**
There will be no direct benefit to your child for taking part in the study. The hope is that your child may get experience in the process of experimental research on the control of movement. If you are interested, the experimenter can tell you more about the background for this work after the experiment.

**Who will see the information about me?**
Your child’s participation in this study will be handled in a confidential manner. The collected data will remain confidential and nobody outside the principal investigator and the experimenter will have access to the data. Any reports or publications based on this research will use only group data and will not identify your child or any individual as being of this project.

In rare instances, authorized people may request to see research information about your child and other people in this study. This is done only to assure that the research is conducted properly. We would only permit people authorized by organizations such as the Northeastern University IRB or National Institutes of Health and the National Science Foundation to see this information.

**What will happen if I suffer any harm from this research?**
In the unlikely event of any research-related injury (i.e. physical, psychological, social, financial or otherwise), emergency services will be called if needed or you may seek medical treatment and follow-up care from your personal physician. Your child’s insurance carrier may be billed for the cost of such treatment. No special arrangements will be made for compensation or for payment for treatment solely because of your child’s participation in this research.

**Can I stop my participation in this study?**
Your child’s participation in this research is completely voluntary. Your child does not have to participate if you do not want to. Even if your child begins the study, you or your child may
quit at any time. If your child does not participate or if you or your child decide to terminate, you and your child will not lose any rights, benefits, or services that you would otherwise have (as a student, employee, etc.).

Who can I contact if I have questions or problems?
The persons with overall responsibility for this research are [person's name and contact information]

Who can I contact about my rights as a participant?
If you have any questions about your rights as a participant, you may contact Nan C. Regina, Director, Human Subject Research Protection, 960 Renaissance Park, Northeastern University, Boston, MA 02115, Tel: 617-373-4588, Email: irb@neu.edu. You may call anonymously if you wish.

Will I be paid for my participation?
There is no monetary compensation for your child’s participation.

Is there anything else I need to know?
- If your child less than 18 years old, his/her parent or guardian has to give written permission to participate.
- This research is paid for by the National Institutes of Health, the National Science Foundation, and a Living Laboratory® Senior Thesis Scholarship.

I agree to take part in this research.

Signature of parent or guardian agreeing to take part

Date

Printed name of person above

Signature of person who explained the study to the participant above and obtained consent

Date

Printed name of person above
Northeastern University, Departments of Biology, Electrical and Computer Engineering, Physics, and Physical Therapy

Investigator Name:
Title of Project:

Informed Consent to Participate in a Research Study

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In rare instances, authorized people may request to see research information about you and other people in this study. This is done only to assure that the research is conducted properly. We would only permit people authorized by organizations such as the Northeastern University IRB or National Institutes of Health and the National Science Foundation to see this information.

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• This research is paid for by the National Institutes of Health, the National Science
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I agree to take part in this research.

Signature of person agreeing to take part

Date

Printed name of person above

Signature of parent or guardian (if person is under 18)

Date

Printed name of person above

Signature of person who explained the study to the
participant above and obtained consent

Date

Printed name of person above

APPROVED
NU IRB# 15-09-22
VALID THROUGH 9/30/16