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They get rhythm—Who could ask for anything more?

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Psychology is harder than physics, and developmental psychology is harder still. The monograph by Karen Brakke and Matheus Pacheco (2019) reveals some of the reasons why, and its many positive features emphasize the virtues of the extended monograph form and the utility of focusing on the often complex details of how seemingly simple behaviors unfold in time.

At its core, developmental psychology seeks to explicate the nature of behavior and its change across time in terms of states internal to the child and influences external to her. The task is an especially hard scientific problem because some of the internal states are directly measurable (e.g., genes, hormone concentrations, neural activity and connectivity) to varying degrees of precision while others (e.g., emotional states, thought processes, memories, intentions) are measurable only indirectly. Further, the measurable states relevant to explicating behavior operate at different spatial and temporal scales (e.g., Sejnowski, Churchland, & Movshon, 2014), and despite scholarly progress, huge holes exist in understanding how phenomena across these scales relate to one another. Nevertheless, Brakke and Pacheco (2019) show that progress can be made by viewing behavioral development through the lens of dynamical systems.

Dynamical systems involve states that change over time following some set of rules. Children's minds, brains, bodies, and environments can be conceptualized as coupled dynamical systems. Saying so makes no particular theoretical commitment to the nature or characteristics of these systems. Rather it highlights what questions we must answer in order to understand the relevant phenomena and their interrelationships: What are the states? How do they change over time? What regularities govern the changes in state? The mathematics of dynamical systems provide a descriptive vocabulary useful for characterizing regularities in changes of state: Stable patterns are *attractors*; fixed points are *point attractors* and periodic patterns are *limit-cycle attractors*. Brakke and Pacheco (2019) focus on describing changes in a behavior that naturally lends itself to an analysis in terms of dynamical systems, rhythmic bimanual drumming.

Rhythmic drumming provides an attractive frame for studying behavioral development from a dynamical systems perspective because the relevant external states and their changes across time—the position and motion of the limbs or the limbs + drumstick—are easily measured with relatively high spatial and temporal precision. Drumming involves repeating a sequence of states and motions across time—it is ideally characterized as a limit-cycle attractor—and there is prior theoretical work (e.g., Haken, Kelso, & Bunz, 1985) describing how the dynamics of analogous rhythmic behaviors may be understood in terms of a relatively small number of rules that govern changes in state. Pragmatically, children seem to enjoy mimicking an adult's rhythmic drumming in time to a metronome, and so multiple instances of the target behavior can be elicited within a testing session and across multiple sessions.

The successful use of dynamical systems approaches requires data that are dense in time. Obviously, not all questions of interest to developmental psychologists meet these criteria in practice or principle. Here, however, Brakke and Pacheco (2019) exploit the temporal density of the drumming data and its periodic form to explore how well children match two different types of bimanual drumming rhythms of an adult model. One drumming pattern involves both drumsticks striking the drum at the same time—an 'in-phase' pattern where both limbs move upward and downward in time with one another. The other involves each drumstick striking the drum at different times—an 'anti-phase' pattern where the limbs move in opposite directions. Brakke and Pacheco ask how rhythmic drumming changes across a 12-month period from 15 to 27 months of age, and what factors influence the characteristics of drumming behavior—its consistency within bouts, across bouts and across monthly sessions, relative phase relations between the limbs, phase-locking with the metronome, and other questions.

They find that children vary in the number and duration of in- and anti-phase drumming bouts they produce; that anti-phase drumming does not appear stable until 20 months or later; that children vary limb position and frequency in switching between in-phase and anti-phase drumming but not in any systematic way; and that, children do not match adult model drumming frequencies especially well. (You wouldn't hire them for your rock band, anyway.)

The monograph has numerous strengths. It is clearly written and readable. The data plots show all of the participants, not just summaries. I appreciated the comparisons between raw data and the results of the fitted multi-level models and that the authors described how to interpret fixed versus random effects for intercepts and slopes in these sorts of models. In separate chapters the authors explore several perspectives on what variables best account for the observed patterns, including relative phase between limbs, the involvement of one or more limb segments, and variations in starting position.

Indeed, the breadth and depth of the analyses show why monographs like this still matter. Too often it seems that vital details about the rationale, method, or context, or supplementary, but vital, analyses get cut from empirical articles in outlets with sharper space constraints. In monograph form, authors have space to provide more information about what they did and why, why the findings matter, and how the work might be extended by others. Moreover, as the child development community begins to embrace new practices that bolster scientific integrity, transparency and openness such as the SRCD policies my colleagues and I helped draft (SRCD, 2019), I believe the need to encourage researchers to provide fuller and more complete descriptions of their work will only grow. Where Brakke and Pacheco (2019) are concerned, I hope that they will share with the research community their raw data, data analysis scripts, and if they have permission to do so, videos of the children and the empirical procedures (Adolph, Gilmore, & Kennedy, 2017; Gilmore & Adolph, 2017) so that others may build upon and extend the excellent work they have done here.

The principal weakness I see in the work is one most of us are guilty of: Premature simplification. In an understandable desire to devise low-dimensional, transparent, reliable, and robust characterizations of psychological phenomena, we often simplify the problem. Consider the rhythmic drumming task from a slightly broader lens, focusing on the multiple perceptual sources that are activated. The metronome, adult model, and child participant all produce time-varying sound patterns. There may or may not be other ambient sounds that must be ignored. Depending on the child's point of gaze, what may be in view is the temporally varying movement of the adult model's drumsticks, the adult model's face, the child's drumsticks and drum, or some other objects found within the room. The child's proprioceptive system provides information about limb position and motion, the timing and force of any drumstick contacts, and the grip information from the hands. Arm movements produce counter-torques in the body that must be compensated for in order to maintain balance on the stool; the movement of one limb segment produces dependent forces on other segments, and the force of gravity on the combined body/limb/drumstick system must be accounted for in producing rhythmic strikes. Because the speed of information transmission through the body and nervous system is not constant within sensory channels or across them, external events that occur at the same time (i.e., with the same phase relationship) may not arrive at the central nervous system at the same time or with the same phase relationship. Stepping back, there are many state variables—in the environment, the body, the brain, and in the mind—relevant to performance of what seems like a simple task. In fairness, the Brakke and Pacheco (2019) analyses focus on several of these dimensions of task behavior—limb segment differences, visual gaze behavior— to varying degrees of precision, and the video recordings they collected could provide information about other dimensions which I hope they or others explore. Moreover, the dynamical systems approach they embrace is exactly the framework to tackle these more complex interactions among systems. Nevertheless, the message I hope others take home is that even simple behaviors depend on multiple dynamical systems coupled in complex patterns of interaction. Therefore, to make meaningful progress on important questions in child development, we may all have to complicate our accounts before we simplify them.

In conclusion, I congratulate Brakke and Pacheco on a fascinating and thorough exploration of the developmental dynamics of bimanual rhythmic drumming, an interesting and temporally rich behavior that can be readily measured and usefully quantified. This is work worth spending time reading carefully and thinking about deeply, both for current partisans of dynamical systems approaches and the rest of us who I predict will come around to thinking this way eventually.

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