The Development of Bimanual Coordination Across Toddlerhood

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The Development of Bimanual Coordination Across Toddlerhood

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The Development of Bimanual Coordination Across Toddlerhood

Karen Brakke[1] *and Matheus M. Pacheco*[2]

Abstract As one of the hallmarks of human activity and cultural achievement, bimanual coordination has been the focus of research efforts in multiple fields of inquiry. Since the seminal work of Cohen (1971) and Kelso and colleagues (Haken, Kelso, & Bunz, 1985; Kelso, Southard, & Goodman, 1979), bimanual action has served as a model system used to investigate the role of cortical, perceptual, cognitive, and situational underpinnings of coordinated movement sequences (e.g., Bingham, 2004; Oliveira & Ivry, 2008). This work has been guided primarily by dynamical systems theory in general, and by the formal Haken–Kelso–Bunz (HKB; 1985) model of bimanual coordination, in particular. The HKB model describes the self-organizing relationship between a coordinated movement pattern and the underlying parameters that support that pattern, and can also be used to conceptualize and test predictions of how changes in coordination occur.

Much of the work investigating bimanual control under the HKB model has been conducted with adults who are acting over time periods of a few seconds to a few days. However, there are also changes in bimanual control that occur over far longer time spans, including those that emerge across childhood and into adolescence (e.g., Wolff, Kotwica, & Obregon, 1998). Using the formal HKB model as a starting point, we analyzed the ontogenetic emergence of a particular pattern of bimanual coordination, specifically, the anti-phase (or inverse oscillatory motion) coordination pattern between the upper limbs in toddlers who are performing a drumming task (see Brakke, Fragaszy, Simpson, Hoy, & Cummins-Sebree, 2007).

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This study represents a first attempt to document the emergence of the anti-phase pattern by examining both microgenetic and ontogenetic patterns of change in bimanual activity. We report the results of a longitudinal study in which seven toddlers engaged monthly in a bimanual drumming task from 15 to 27 months of age. On some trials, an adult modeled in-phase or anti-phase action; on other trials, no action was modeled. We documented the motion dynamics accompanying the emergence of the anti-phase bimanual coordination pattern by assessing bout-to-bout and month-to-month changes in several movement parameters—oscillation frequency, amplitude ratio of the drumsticks, initial position of the limbs to begin bouts, and primary arm-joint involvement. These parameters provided a good starting point to understand how toddlers explore movement space in order to achieve greater stability in performing the anti-phase coordination pattern.

Trained research assistants used Motus software to isolate each bout of drumming and to digitize the movement of the two drumstick heads relative to the stationary drum surface. Because we were primarily interested in the vertical movement of the drumsticks that were held in the child's hands, we relied on two-dimensional analyses and analyzed data that were tracked by a single camera. We used linear mixed effects analyses as well as qualitative analyses for each participant to help elucidate the emergence and stability of the child's use of anti-phase coordination. This approach facilitated descriptions of individual pathways of behavior that are possible only with longitudinal designs such as the one used here.

Our analyses indicated that toddlers who were learning to produce anti-phase motion in this context employed a variety of strategies to adjust the topography of their action. Specifically, as we hypothesized, toddlers differentially exploited oscillation frequency and movement amplitude to support change to anti-phase action, which briefly appeared as early as 15 months of age but did not become relatively stable until approximately 20 months of age. We found evidence that many toddlers reduced oscillation frequency before transitioning from in-phase to anti-phase drumming. Toddlers also used different means of momentarily modulating the amplitude ratio between limbs to allow a change in coordination from in-phase to anti-phase. Nevertheless, these oscillation-frequency and amplitude-ratio strategies were interspersed by periods of nonsystematic exploration both within and between bouts of practice. We also observed that toddlers sometimes changed their initial limb positions to start a bout or altered which primary arm joints they used when drumming. When they enacted these changes, the toddlers increased performance of the anti-phase coordination pattern in their drumming. However, we found no evidence of systematic exploration with these changes in limb position and joint employment, suggesting that the toddlers did not intentionally employ these strategies to improve their performance on the task.

Although bimanual drumming represents a highly specific behavior, our examination of the mechanisms underlying emergence of the anti-phase coordination pattern in this context is one of the missing pieces needed to understand the development of motor coordination more broadly. Our results document that the anti-phase coordination pattern emerges and stabilizes through modulation of the dynamics of the movement and change of the attractor landscape (i.e., the motor repertoire). Consistent with literatures in motor control, motor learning, and skill development, our results suggest that the acquisition of movements in ontogenetic development can be thought of as exploration of the emergent dynamics of perception and action. This conclusion is commensurate with a systemic approach to motor development in which functional dynamics, rather than specific structures, provide the basis for understanding developmental changes in skill. Based on our results as well as the relevant previous empirical literature, we present a conceptual model that incorporates developmental dynamics into the HKB model. This conceptual model calls for new investigations using a dynamical systems approach that allows direct control of movement parameters, and that builds on the methods and phenomena that we have described in the current work.

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How do new skills emerge in toddlerhood? In this monograph, Karen Brakke and Matheus M. Pacheco longitudinally document the emergence of a bimanual drumming skill in seven toddlers between the ages of 15 and 27 months. Guided by the seminal Haken-Kelso-Bunz model of bimanual coordination, Brakke and Pacheco focus on transitions from mirror-image (in-phase) to alternating (anti-phase) coordination during drumming bouts and across months of drumming practice. Although each participant followed a unique trajectory in the transition to anti-phase drumming, as a group the toddlers used similar strategies of exploring and effecting behavioral change. The findings of this study provide insight into the mechanisms underlying emergent skill across multiple timescales and demonstrate how principles of motor learning can be adapted to a developmental context.

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