Article

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Throwing Skills: Analysis of Movement Phases in Early Motor Learning

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Abstract

Traditionally, motor learning scientists have evaluated the process of learning a new motor skill by considering the skill as a whole. Yet, motor skills comprises various phases, and in the motor learning literature, it is not clear whether new learner show similar or different learning across various phases. We provide exploratory data on learning movement phases by novices, using baseball pitching as the learning task. Eight participants (four male, four female, *M* age = 23.7 years, *SD* = 2.4) performed five trials each in the pretest followed by three blocks of 10 trials each in the acquisition phase. Finally, two retention tests of five trials were conducted by each participant 10 minutes and 7 days after the last acquisition block, respectively. Intra- and interlimb coordination of upper and lower body segments were measured as dependent variables. We found significant differences between the stride phase and the other phases at pretest, during the acquisition phase, and on both retention tests across all kinematic variables. Participants experienced more trouble coordinating the stride phase than the other phases of pitching, perhaps because the stride phase is the only phase in which the participants had to move their upper and lower body parts simultaneously. We discuss implications for motor learning generally.

Keywords

movement phases, motor learning, coordination, baseball pitching

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Introduction

In the study of motor skill learning, Kugler, Kelso, and Turvey (1980) proposed an embedded sequence of "coordination, control, and skill." "Coordination" refers to the motions of several body segments in relation to each other and occurs as intralimb coordination (i.e., the relations between the motions of the parts of a single limb such as the right hip in relation to the right knee) and interlimb coordination (i.e., the relations between the motions of several limbs such as the right shoulder in relation to the left shoulder). The term *control* describes the process of the scaling and parameterization of the movement pattern; and a perfectly scaled and parameterized movement is termed a *skill* (Horn & Williams, 2004). Bernstein (1967) developed the concept of degrees of freedom and pointed out that the main problem for learners in the initial phase of motor skill learning (i.e., coordination) is to select and combine particular degrees of freedom (at joints and muscles) into a functional coordinative unit. According to Bernstein (1967), during the process of motor learning and control, learners initially freeze various degrees of freedom in an attempt to simplify the to-be-learnt motor skill. In the later stages of motor skill learning, they attempt to release various degrees of freedom again in order to perform the skill fluently and accurately.

Traditionally, motor learning scientists have measured the process of freezing and releasing the various degrees of freedom by evaluating the whole movement as a unit (i.e., overall movement). For example, Hodges, Hayes, Horn, and Williams (2005) investigated how people learn a soccer chip shot by having unskilled subjects practice the motor task for 9 days with the nondominant foot. They examined movement kinematics such as the range of motion of the hip, knee, and ankle of the nondominant foot. Kinematic data were provided by considering the range of motion from the beginning of the knee flexion prior to ball interception to the end of the peak hip flexion. Similarly, Breslin, Hodges, Williams, Curran, and Kremer (2005) and Breslin, Hodges, Williams, Kremer and Curran (2006) examined how novices learned a cricket bowling action. The range of motion of the motor task was shortened from when the flexion of the right elbow of the bowling arm began (starting point) to the full extension of the bowling arm after the ball was released (end point). That is, the unit of analysis was always and only the complete movement. Similarly, D'Innocenzo, Gonzalez, Williams, and Bishop (2016) investigated whether guiding the novices' gaze toward relevant regions during action observation could facilitate the learning of a new and complex motor skill. Again, they compared exclusively the complete movement of the novices and no comparison of between the movement phases was included.

Despite this traditional line of research, most motor skills consist of multiple sequential movement phases; and research has yet to determine whether individuals learn these various movement phases in different or similar ways. For example, cricket bowling comprises four clearly definable phases of movement including elbow flexion, elbow extension, ball release, and follow-through. Yet, previous studies of this skill (Breslin et al., 2005, 2006) failed to analyze these learning phases separately in any detail.

The present research was designed as an exploratory analysis of movement phases during early stages of motor learning (i.e., coordination) of a baseball pitching. Baseball pitching has received substantial prior attention in the sports biomechanics literature (Dillman, Fleisigand, & Andrews, 1993; Fleisig, Barrentine, Zheng, Escamilla, & Andrews, 1999; Pappas, Zawacki, & Sullivan, 1985). It is characterized by a clear phase structure, making it a good model for a detailed kinematic analysis of movement phases during motor learning. An analysis of movement phases could have important theoretical and practical implications for optimal learning and could help coaches better understand interfering problems learners encounter during early learning stages.

Thus, we aimed to investigate whether novices learn different movement phases of a complex sport skill in the early stages of motor learning (i.e., coordination) with similar or different velocities. The study was exploratory, since, to our knowledge, no prior research has been compared different movement phases during motor learning. We assumed that particularly complex or fast movements (e.g., stride and arm acceleration) would produce greater learning difficulty than other phases.

Method

Participants

Study participants were eight volunteer students (four female and four male, mean age = 23.7 years, $SD = 2.4$) of the University of Oldenburg (Germany). They were recruited from different courses via personal contact and various postings on University notice boards of the University. Through an initial questionnaire, participants reported that they were right handed and were novices with respect to the motor task used in this study. The research was performed in accordance with the ethical standards described in the Deceleration of Helsinki (1964). All participants were briefed on the aim of the experiment and provided written consent.

Motor Task

As noted earlier, baseball pitching was selected as the motor task because it has been heavily studied previously and consists of a clear phase structure, including windup, stride, arm cocking, arm acceleration, arm deceleration, and follow-through (Figure 1). This makes it possible to perform a detailed analysis at both the levels of overall movement and individual movement phases.

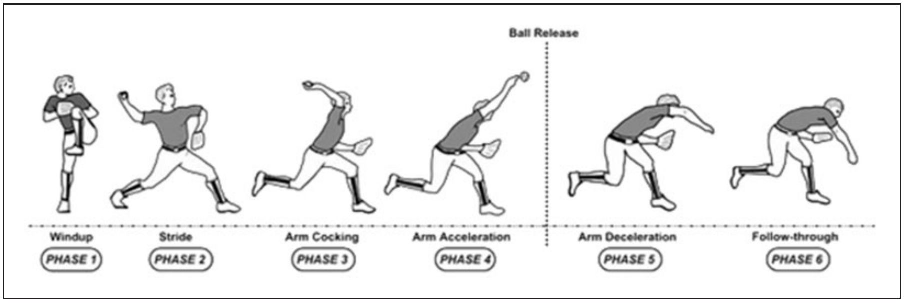


Figure 1. Phase structure of baseball pitch (adopted with permission from Rojas et al., 2009).

Procedure

Participants were tested individually. They were first given general information about the experimental process and then asked to complete a questionnaire on their age, gender, laterality, and previous baseball experience. Retroreflective markers were placed on their upper and lower body parts of the participants (see Breslin et al., 2005, 2006). Finally, participants were given instructions on how to pitch a baseball, which consisted of a series of images of the pitching phases (as shown in Figure 1) and brief descriptions of the main features of the phases. Participants were asked to perform the body positions and the movements of pitching as correctly as possible. To familiarize participants with the experimental setting, they performed two trials within a marked area of 2.1×1.1 m. Then, they performed five trials for a pretest, three blocks of 10 trials for acquisition, and two retention tests consisting of five trials administered at: (a) 10 minutes and (b) one week after the last acquisition block.

Kinematic Data

Kinematic data were provided by comparing the coordination profile of each participant with that of an expert. To do this, the intralimb coordination profile of the upper and lower body limbs, including the right shoulder-elbow (throwing arm) and left knee-ankle (striding leg), and the interlimb coordination profile of the right elbow-left knee were compared with those of the expert. The expert was a semiprofessional, right-handed, male pitcher with 8 years of experience in the second league in North Germany.

The deviations in the intra- and interlimb coordination patterns of the participant from that of the expert were measured in terms of the normalized root mean squared difference (NoRM-D; see Horn, Williams, Scott, & Hodges, 2005). The smaller the NoRM-D score, the less the participant's coordination pattern deviated from that of the expert. The NoRM-D score was calculated separately for the individual movement phases of the pitch. To match the participant's range of motion to that of the expert, we performed a linear interpolation to standardize the starting and end points of each movement phase. A total of 250 data points were assigned to each phase on the basis of time the expert took to perform the respective phase. The numbers of points for the phases were 100, 90, 15, 10, 10, and 25 for the six phases of windup, stride, arm cocking, arm acceleration, arm deceleration, and follow-through phases, respectively. We smoothed the data with a recursive fourth order low-pass Butterworth filter using a cut-off frequency of 7 Hz to the displacement data before analysis (see Breslin et al., 2006).

Statistical Analysis

One-way analyses of variance with the movement phases as the independent variable and the NoRM-D values as the dependent variable were used to analyze participants' performance at pretest, during the acquisition phase, and on the retention tests. Scheffé tests were used as the post hoc test. The significance level was set at $p < .05$. Partial eta-squared ($\varepsilon^2_{\mathrm{par}}$) values are calculated and reported for all effects.

The NoRM-D scores from the different movement phases were analyzed at pretest, during the acquisition phase, and for the early and late retention tests. Significant differences in the NoRM-D scores between the movement phases would indicate that the participants experienced various difficulties in learning to coordinate the respective movement phases. In other words, participants experienced less trouble in movement phases with lower NoRM-D values. The logic behind this assumption is that a lower NoRM-D value represents less error, and it might be interpreted as better learning the respective movement phase.

Results

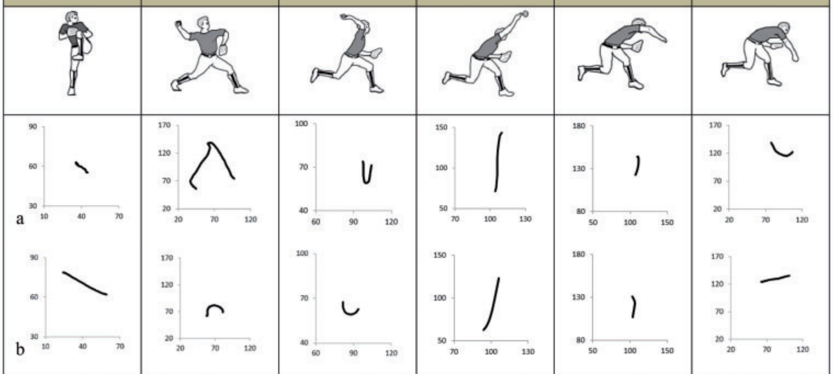
Descriptive Data

The NoRM-D scores and the angle–angle plots of the movement phases for shoulder-elbow intralimb coordination are summarized in Table 1. It is clear that the participants performed the arm acceleration phase more like the expert when qualitatively compared with the other phases. The most difficult phase for participants was the stride phase.

The NoRM-D scores and the angle–angle plots of the movement phases for knee-ankle intralimb coordination are summarized in Table 2. The results showed that participants' execution of the arm cocking phase was more similar to the expert than the other phases. The most difficult phase for participants was again the stride phase.

Table 1. Angle–Angle Plots and NoRM-D Values for Shoulder-Elbow Intralimb-Coordination in Pretest.

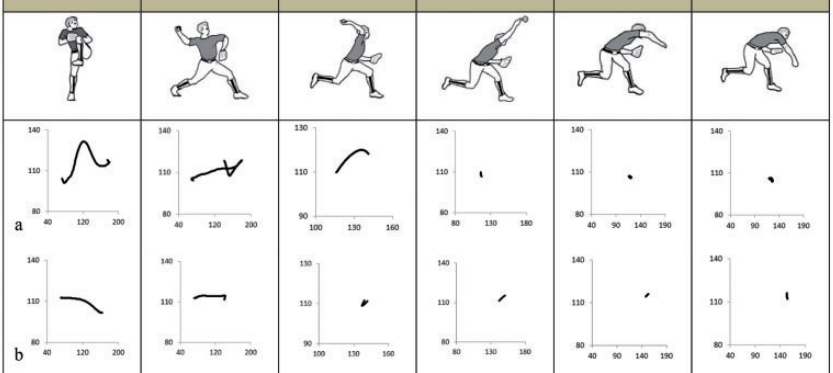
Wind-up	Stride	Arm cocking	Arm acceleration	Arm deceleraion	Follow-through
NoRM-D = 30.21	NoRM-D = 49.43	NoRM-D = 26.11	NoRM-D = 26.25	NoRM-D = 18.75	NoRM-D = 27.06



Notes for angle–angle plots: x-axis = elbow angle (°), y-axis = shoulder angle (°); a = plots of expert, b = mean plots of participants.

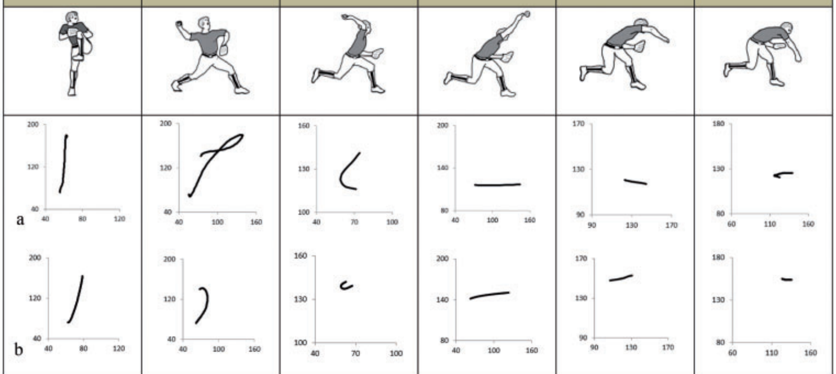
Table 2. Angle-Angle Plots and NoRM-D Values for Knee-Ankle Intralimb-Coordination in Pretest.

Wind-up	Stride	Arm cocking	Arm acceleration	Arm deceleraion	Follow-through
NoRM-D = 39.16	NoRM-D = 48.46	NoRM-D = 23.93	NoRM-D = 30.55	NoRM-D = 35.76	NoRM-D = 33.15



Notes for angle–angle plots: x-axis = knee angle (°), y-axis = ankle angle (°); a = plots of expert, b = mean plots of participants.

Table 3. Angle-Angle Plots and NoRM-D Values for Elbow-Knee Interlimb-Coordination in Pretest.

Wind-up	Stride	Arm cocking	Arm acceleration	Arm deceleraion	Follow-through
					
NoRM-D = 39.16	NoRM-D = 48.46	NoRM-D = 23.93	NoRM-D = 30.55	NoRM-D = 35.76	NoRM-D = 33.15

Notes for angle–angle plots: x-axis = elbow angle (°), y-axis = knee angle (°); a = plots of expert, b = mean plots of participants.

The NoRM-D scores and the angle–angle plots of the movement phases for elbow-knee interlimb coordination are summarized in Table 3. The results indicate that participants performed the arm cocking phase more like the expert compared with the other phases. The most difficult phase for participants was again the stride phase.

General Statistical Analysis

Shoulder-elbow (intralimb coordination). The results of the statistical analysis showed a significant difference between the movement phases on the pretest, $F(5,42) = 5.96$, $p < .001$, $\varepsilon^2_{par} = .41$. In the acquisition phase, the results indicated a significant difference between the movement phases, $F(5,42) = 5.63$, $p < .001$, $\varepsilon^2_{par} = .40$. On the early retention test, the analysis demonstrated a significant difference between the movement phases, $F(5,42) = 4.97$, $p < .01$, $\varepsilon^2_{par} = .37$. Finally, on the late retention test, a significant difference between the movement phases was indicated, $F(5,42) = 8.20$, $p < .001$, $\varepsilon^2_{par} = .49$.

Knee-ankle (intralimb coordination). The results showed a significant difference between the movement phases on the pretest, $F(5,42) = 6.68$, $p < .001$, $\varepsilon^2_{par} = .44$. In the acquisition phase, the results showed no significant differences between the movement phases, $F(5,42) = 1.68$, $p > .05$, $\varepsilon^2_{par} = .16$. Regarding the early retention test, the analysis revealed no significant differences between the movement phases, $F(5,42) = 2.05$, $p > .05$, $\varepsilon^2_{par} = .19$. Finally, on the late retention test, a significant difference between the movement phases was demonstrated, $F(5,42) = 3.39$, $p < .05$, $\varepsilon^2_{par} = .28$.

Elbow-knee (interlimb coordination). The results of the statistical analysis showed a significant difference between the movement phases on the pretest, $F(5,42) = 8.18$, $p < .001$, $\varepsilon^2_{par} = .49$. In the acquisition phase, the results demonstrated a significant difference between the movement phases, $F(5,42) = 5.38$, $p < .01$, $\varepsilon^2_{par} = .39$. On the early retention test, a significant difference was observed between the movement phases, $F(5,42) = 4.83$, $p < .01$, $\varepsilon^2_{par} = .36$. Finally, on the late retention test, the results indicated a significant difference between the movement phases, $F(5,42) = 6.13$, $p < .001$, $\varepsilon^2_{par} = .42$.

Movement Phases

Phase 1 (windup). Post hoc analyses indicated a significant difference between the windup phase and the arm cocking phase for the knee-ankle intralimb coordination on the pretest ($p < .05$).

Phase 2 (stride). For the shoulder-elbow intralimb coordination, post hoc analyses revealed significant differences between the stride phase and the arm acceleration, arm deceleration, and follow-through phases on the pretest ($p < .05$). Moreover, the stride phase differed significantly from both the arm acceleration and the arm deceleration phases on the acquisition phase and early retention test ($p < .05$). On the late retention test, the post hoc analyses showed that the stride phase coordination differed significantly from that of the arm cocking, arm acceleration, arm deceleration, and follow-through phases ($p < .05$).

For the knee-ankle intralimb coordination, the stride phase showed significant differences from both the arm cocking and arm acceleration phases on the pretest ($p < .05$). Moreover, there was a significant difference between the stride phase and the arm cocking phase on the late retention test ($p < .05$).

For the elbow-knee interlimb coordination, the post hoc analyses revealed that the stride phase was significantly different from the arm cocking, arm acceleration, arm deceleration, and follow-through phases on the pretest ($p < .05$). On the acquisition phase, the results showed that the stride phase was significantly different from the arm cocking and arm deceleration phases ($p < .05$). There was a significant difference between the stride phase and the arm cocking phase on the early retention test ($p < .05$). It was also observed that the stride phase was significantly different from the arm cocking and arm deceleration phases ($p < .05$).

Phase 3 (arm cocking). Post hoc analyses revealed a significant difference between arm cocking phase and windup phase for the knee-ankle intralimb coordination on the pretest ($p < .05$). Moreover, the results indicated a significant difference between the arm cocking phase and the stride phase for the shoulder-elbow intralimb coordination on the late retention test ($p < .05$). For the knee-ankle intralimb coordination, a significant difference was observed between the arm cocking phase and the stride phase on the pretest and on the late retention test ($p < .05$). For the elbow-knee interlimb coordination, the results revealed that the arm cocking phase was significantly different from the stride phase on the pretest, the acquisition phase, and the early and the last retention tests ($p < .05$).

Phase 4 (arm acceleration). The results showed a significant difference between the arm acceleration phase and the stride phase for the shoulder-elbow intralimb coordination on the pretest, the acquisition phase, and the early and the last retention tests ($p < .05$). For the knee-ankle intralimb coordination, there was a significant difference between the arm acceleration phase and the stride phase on the pretest ($p < .05$). The results revealed that the arm acceleration phase was significantly different from the stride phase on the pretest, the acquisition phase, and the early retention tests for the elbow-knee interlimb coordination ($p < .05$).

Phase 5 (arm deceleration). For the shoulder-elbow intralimb coordination, there was a significant difference between the arm deceleration phase and the stride phase on the pretest, the acquisition phase, and the early and the last retention tests ($p < .05$). The results showed that the arm deceleration phase was significantly different from the stride phase on the pretest, the acquisition phase, and the last retention test for the elbow-knee interlimb coordination ($p < .05$).

Phase 6 (follow-through). For the shoulder-elbow intralimb coordination, there was a significant difference between the follow-through phase and the stride phase on the pretest, and the last retention test ($p < .05$). For the elbow-knee interlimb coordination, the results revealed a significant difference between the follow-through phase and the stride phase on the pretest ($p < .05$).

Discussion

In this exploratory analysis of how novices learn movement phases in the early stages of motor learning, referred to as "coordination" by Kugler et al. (1980), we examined whether individuals learn different phases of a new motor skill with similar or different velocities. We assumed that particularly complex or fast (e.g., stride) phases would result in more learning difficulty than other phases. Consistent with this hypothesis, novice participants in this study experienced more coordination problems in the stride phase of the pitching a baseball in comparison with the other phases in the early stages of learning for all kinematic variables. As seen in Tables 2 and 3, average participant deviations from expert baseball pitching (i.e., mean NoRM-D scores) were much larger in early phases of baseball pitching than in later phases. Moreover, the lower NoRM-D scores of later phases (Phases 3 to 6) indicate that the participants' coordination was more similar to the experts (see Hayes, Hodges, Huys, & Williams, 2007). These results raise the question of why the participants showed more problems in learning the earlier stride phase of pitching.

Kinematic details of the phases of pitching, shown in Figure 1, reveal that an individual initiates the pitch by elevating the striding leg in the windup phase (i.e., the major motion belongs to the striding leg). After the windup phase, in the stride phase, the striding leg moves downward, and the throwing arm moves upward at the same time. Once stride phase is over, the striding leg is placed on the ground and does not move much until the end of the pitch (i.e., it plays a supporting role). However, the throwing arm continues to move during the phases of arm cocking, arm acceleration, arm deceleration, and follow-through in order to throw the ball efficiently and finish the movement properly (see Dillman et al., 1993). This kinematic description makes clear that the stride phase of the pitch is the only phase in which individual moves the throwing arm and the striding leg simultaneously. In the other phases (i.e., windup, arm cocking, arm acceleration, arm deceleration, and follow-throw), the pitcher moves only the throwing arm or only the striding leg. Thus, a likely reason for the higher error scores for the stride phase across all kinematic variables is the greater complexity associated with moving the throwing arm and the striding leg simultaneously, requiring the individuals to coordinate more degrees of freedom (Bernstein, 1967) in this movement phase than other phases which involved the motion of only a single limb (i.e., fewer degrees of freedom).

Among the limitations of the present study, a very small sample size is problematic as it was associated with relatively low statistical power. A larger sample might yield more significant differences between movement phases of this task. Also, participants with different laterality (i.e., handedness) should be measured reliably (e.g., Eidenberg handedness inventory, Purdue Pegboard test; Verdino & Dingman, 1998) and compared with determine if laterality has a considerable impact on learning baseball pitching. Finally, due to minimal prior research, these data had to be interpreted in accordance with face-validity implications. Further research with other populations will permit more sophisticated comparative interpretive processes.

In summary, the present research involved an exploratory analysis of how novices learn movement phases in the early stages of motor learning. The well-structured baseball pitch used in the experiment enabled us to conduct such a phase-related analysis. The results revealed that the participants experienced more coordination problems in learning the stride phase of the pitch in comparison with the other phases. The reason may be that the participants had to coordinate more degrees of freedom in the stride phase of the pitch in comparison with the other phases. Further research is needed, involving various sports skills and different biomechanical constraints in order to improve the understanding of the learning of movement phases in the early stages of motor learning. In addition to theoretical considerations, the above-mentioned results have practical implications in a sports context. To provide proper player feedback, a coach must accurately analyze the details of a sports skill and compare a given player's performance to an ideal, emphasizing learning phases in which many degrees of freedom must be controlled by the learner because of simultaneous coordination requirements. These exploratory data support that learning process.

Author Note

The study reported was done when first author worked at Institute of Sport Science, University of Oldenburg, Germany.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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