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Predicting Children's Overarm Throw Ball Velocities From Their Developmental Levels in Throwing

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This study examined the movement process-product relationship from a developmental perspective. The authors used multiple regression to investigate the changing relationship between qualitative movement descriptions of the overarm throw and the throwing outcome, horizontal ball velocity. Seventeen girls and 22 boys were filmed longitudinally at ages 6, 7, 8, and 13 years. Their movements were assessed using Roberton's (Roberton & Halverson, 1984) developmental sequences for action of the humerus, forearm, trunk, stepping, and stride length. The sequences accounted for 69–85 % (adjusted) of the total velocity variance each year. The components that best predicted ball velocity changed over time, although humerus or forearm action always accounted for considerable variance. Gender was a good predictor of ball velocity, but if the developmental descriptions were entered first in a stepwise regression, gender then explained no more than 2 % additional variance.

Key words: motor development, multiple regression, longitudinal, gender differences

Those studying motor development have used two basic measures to represent change in motor behavior: (a) the outcome or "product" score produced by the movements under study (e.g., running speed, distance jumped), and (b) verbal descriptions of the qualitative changes that occurred in those movements. However, rarely has the relation between the two types of measures been assessed. While outcome measures are easier to obtain, their developmental validity has been challenged, because their relationship to qualitative change is unclear (Halverson, 1971). Presumably, primitive movements produce poor outcome measures, and advanced movements produce superior outcomes. It is the relationship along the continuum between those extremes that remains unknown. Providing additional complication is the developmental question of whether the movement-product relationship changes over the lifespan.

These questions have theoretical as well as practical importance. From a measurement standpoint, knowing the validity of a dependent measure is critical. Having two traditional measures of motor development whose relationship has not been quantified is unacceptable in a mature field of science. Moreover, understanding the relationship between outcome and qualitative change can contribute to the effort to form a unified theory of movement change, one that might encompass the study of both motor learning and motor development (Newell, 1996). Taking the perspective of Kugler, Kelso, and Turvey (1980, 1982), change in motor behavior over time is a process characterized by the acquisition of coordination modes, control of those modes, and their refinement into skillfulness. In retrospect, it may be that the area of motor learning has focused primarily on outcome measures as a reflection of control, while motor development has focused on coordination changes, frequently ordered into developmental sequences. Thus, the two subdisciplines may have been *looking at different points in the same process* but asserting that

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the phenomena of "learning" and "development" were different. Systematic exploration of movement outcome as it relates to shifts in coordination and control is part of formulating a theory of change that would conceptualize motor learning and development as different aspects of the same phenomenon—skill acquisition.

From a practical perspective, outcome measures are the customary feedback source to the learner about success in the task. Yet, the teacher's focus is often on the qualitative changes expected in the learner's movement. Understanding the relation between movement and product would help clinicians know when to focus the learner on his or her movement and when to take advantage of the learner's natural propensity to focus on the outcome score.

A further practical consideration is that physical education teachers, who wish to assess changes in motor development resulting from instruction, need to know what to measure. Given two valid measures, they, like all instructors, will want to use the measure that is easier to administer and track over time. Knowing the relationship between developmental sequences and their product scores would help teachers make these assessment decisions.

To date, only two studies have reported the relationship between the developmental assessment of the movement used in a motor task and the concurrent product. Both studies used developmental sequences as descriptors of the movement. Developmental sequences are verbal descriptions of the qualitative changes that occur in the way individuals use their bodies as they perform the same motor task over time. The descriptions are ordered according to their time-related sequence of appearance. In an unpublished paper, Fountain, Ulrich, Haubenstricker, and Seefeldt (1981) reported correlations between running velocity and the Seefeldt, Reuschlein, and Vogel (1972) developmental sequence for running. In children ages 2.4–5 years, Pearson's *r*s were -.44 for boys and -.54 for girls. The data were mixed longitudinal. More recently, Haubenstricker and Branta (1997) studied how well the Seefeldt et al. (1972) developmental sequence for the standing long jump correlated with the distance jumped. The 1,352 participants in their study ranged in age from 2–5 years. The largest number of children were 3 years of age (*n* = 584). Correlations changed slightly over the age range. They were .27 at the age of 2 years and .37 at the age of 5 years, with the highest correlation occurring at the age of 3 years (*r* = .466). Thus, the Seefeldt et al. (1972) stages accounted for a maximum variance of 22% in jumping scores and 29% in running scores. While change can be inferred from the Haubenstricker and Branta (1997) study, their data were also mixed longitudinal; hence, differences in correlations from one age to another may have been confounded by the changing composition of the sample. To date, no one has looked at change in the outcome-movement relationship in a single cohort over time. Further, no one has quantified the ability of movement or product to predict the other.

Because of the need for additional data in this area, we wished to continue the work of Haubenstricker, Branta, and colleagues in studying the ability of a developmental sequence to predict performance outcome. For this analysis, we felt the overarm throw for force would be particularly useful, because it has been studied extensively from a developmental perspective (Halverson, Roberton, & Langendorfer, 1982; Roberton, 1977, 1978a; Roberton & Langendorfer, 1980; Wild, 1938). Information was also available on changes in the horizontal velocity of the ball at release (Halverson et al., 1982)[1]; however, only a few authors have tried to relate throwing movements and ball velocity. These studies were primarily kinematic or kinetic analyses of adults (Atwater, 1971; Escamilla, Fleisig, Barrantine, Zheng, & Andrews, 1998; Feltner, 1989; Feltner & Depena, 1986; Kunz, 1974; MacWilliams, Choi, Perezous, Chao, & McFarland, 1998; Toyoshima, Hoshikawa, Miyashita, & Oguri, 1974). A few kinematic studies of children's throwing have appeared (Marques-Bruna & Grimshaw, 1997; Sakurai & Miyashita, 1983; Yan, 1993), but these have focused more on age or gender differences than on the movement-outcome relationship per se.

The developmental sequences we chose to study are in a format known in the motor development literature as the "component approach" (Haywood, 1993). Instead of creating one sequence to describe changes in the total body during the development of throwing (see Wild, 1938), Roberton validated several sequences, each describing change in a different body section or "component" (Roberton, 1977, 1978a; Roberton & Langendorfer, 1980). She presented data showing that the components developed relatively independently (Roberton, 1978a, 1978b) and argued that this independence is largely responsible for the within-age individual differences observed in the developing throw. We chose her published components of humerus action, trunk action, and forearm action (Roberton & Halverson, 1984) and her unpublished components of stepping action and stride length for the following study (see Table 1).

All studies of forceful throwing, whether focused on distance thrown or ball velocity, have reported that boys are considerably more advanced than girls at every age. Thomas and French (1985) concluded from an extensive meta-analysis that the forceful overarm throw was one of the few motor skills in which vast gender differences were clearly evident from the youngest ages. Knowing that gender would be a moderate to strong predictor of ball velocity, we wondered whether it gave additional information about a child's throwing velocity beyond the information provided by their component, developmental categories. If not, then we could conclude that velocity differences across gender could be explained by developmental differences in boys' movement compared to girls'.

In the following study, we used longitudinal data collected over a 7-year period on one cohort of children. We first examined whether the Roberton developmental sequences for forceful throwing positively correlated with an outcome variable—horizontal ball velocity—and whether this relationship changed over time. We also looked at how relationships between the components themselves changed. We then examined the extent to which the developmental sequences could statistically explain group variance in the horizontal velocity of the thrown ball. Third, we evaluated the usefulness of gender as an additional predictor when the children's developmental levels were already known. Last, we assessed the degree to which the longitudinal cohort still represented the original sample of kindergarten peers.

Method

Participants

For this study, we used longitudinal data that had been collected from 1972–79. Thirty-nine children (22 boys and 17 girls) were filmed at ages 6.0, 7.0, 8.0, and 13.0 years (*SD* = 0.3 years). Originally, 73 children were filmed; 39 completed the 7-year study and were the source of the data reported here. The original sample represented three public schools in Madison, Wisconsin. Previous publications have reported longitudinal changes in the children's

Table 1. Developmental sequences within components of the overarm throw for force

Humerus Action
H1. Humerus oblique. The humerus moves forward to ball release in a plane that intersects the trunk obliquely above or below the horizontal line of the shoulders. Occasionally, during the backswing, the humerus is placed at a right angle to the trunk, with the elbow pointing toward the target. It maintains this fixed position during the throw.
H2. Humerus aligned but independent. The humerus moves forward to ball release in a plane horizontally aligned with the shoulder, forming a right angle between humerus and trunk. By the time the shoulders (upper spine) reach front facing, the humerus has moved independently ahead of the outline of the body (as seen from the side) via horizontal adduction at the shoulder.
H3. Humerus lags. The humerus moves forward to ball release horizontally aligned, but at the moment the shoulders (upper spine) reach front facing, the humerus remains within the outline of the body (as seen from the side). No horizontal adduction of the humerus occurs before front facing.

Forearm action
F1. No forearm lag. The forearm and ball move steadily forward throughout the throwing action.
F2. Forearm lag. The forearm and ball appear to 'lag', i.e., to remain stationary behind the child or to move downward or backward in relation to the child. The lagging forearm reaches its farthest point back, deepest point down, or last stationary point *before* the shoulders (upper spine) reach front facing.
F3. Delayed forearm lag. The lagging forearm delays reaching its final point of lag until the moment of front facing.

Trunk (pelvis-spine) action
T1. No trunk action or forward-backward movements. Mainly the arm is active in force production. Sometimes, the forward thrust of the arm pulls the trunk into a passive left rotation (assuming a right-handed throw), but no twist-up precedes that action. If trunk action occurs, it accompanies the forward thrust of the arm by flexing forward at the hips. Preparatory extension sometimes precedes forward hip flexion.
T2. Upper trunk rotation or total-trunk, "block" rotation. The spine and pelvis both rotate away from the intended line of flight and then simultaneously begin forward rotation, acting as a unit or "block." Occasionally, only the upper spine twists away, then toward the direction of force. In this latter case, the pelvis remains fixed, facing the line of flight, or joins the rotary movement after forward spinal rotation has begun.
T3. Differentiated rotation. The pelvis precedes the upper spine in initiating forward rotation. The child twists away from the intended line of ball flight and, then, begins forward rotation with the pelvis while the upper spine is still twisting away.

Stepping action
S1. No step. The child throws from the initial foot position.
S2. Partial step. The child moves either foot ahead, in place, or laterally less than a foot length.
S3. Full step. The child steps forward a distance at least equal to the length of their own foot.

Length of final stride
L1. Short. The length of the final stride is less than or equal to the length of the child's foot.
L2. Intermediate. The length of the final stride is greater than the length of the child's foot but less than 50% of their standing height.
L3. Long. The final stride is equivalent in length to 50% or more of the child's standing height.

Note. The first three components are described in Roberton and Halverson (1984).

ball velocities (Halverson et al., 1982; Roberton, Halverson, Langendorfer, & Williams, 1979), in their component developmental levels of throwing (Halverson et al., 1982; Roberton, 1977, 1978a), and in their across-component profiles (Langendorfer & Roberton, in press).

Data Collection and Reduction

Each year of the study the children were filmed from the side and rear as they performed 10 trials of the forceful overarm throw. Two cameras were placed at 90° to each other, 30–40 ft (9.0–12.2 m) from the child, depending on the year of filming. Camera speed was 64 fps; 25-mm lenses were used on both cameras. The children threw a tennis ball through a velocimeter (Roberts, 1972), which measured the horizontal velocity of the ball during its second meter of travel. The children stood in a 4 x 6 ft (1.22 x 1.83 m) area marked on the floor, the front of which was 3 ft (.91 m) from the edge of the velocimeter. The velocimeter itself formed a 6 x 6 ft (1.83 x 1.83 m) frame through which the ball passed on its way toward a wall 25 ft (7.62 m) from the child. Further details about the validity and reliability of the velocimeter may be obtained in Roberts (1972) and Halverson, Roberton, Safrit, and Roberts (1977).

Each year of the study the children were given time to warm up. When they were ready, they were asked to throw the ball "hard" or to "crash the ball into the wall," using an overarm throw. No cues other than random praise were given. The children were consistently urged to "throw hard" on each trial.

To reduce the filmed movements into categories of the component, developmental sequences for throwing (see Table 1), side and rear views of the child were projected simultaneously using projectors that could be operated frame by frame. For each trial, the child's movement was placed into a category of the developmental sequence for each component. Further information on using the humerus, forearm, and trunk action sequences to categorize movement is available in Roberton and Halverson (1984). The stepping action and length of final stride sequences are self-explanatory (see Table 1) and were added for this particular study.

Each year of data was reduced from the film by one observer. Over the course of the study several observers reduced the data from different years. Their objectivity was always evaluated before they began their work. To assess intraobserver agreement, the observer independently recategorized 30 randomly selected trials 2 weeks after the first categorization. Each new observer was able to place the movement of each component into the same category in 95% or more of the trials, depending on the component. Interobserver agreement involved a second, trained observer categorizing 30 randomly selected trials independently of the first observer. Both observers agreed on the exact category of trunk action in 90% of the trials. All other components had even higher levels of agreement.

Data Analysis

Regression Procedures. We chose multiple regression procedures to analyze the data, because they allowed us to compare how well the developmental sequences could account for group variance in the horizontal ball velocities each year of the study. Stepwise multiple regression further allowed comparison of the relative explanatory power of the 5 components (action of the humerus, forearm, trunk, stepping, and length of stride). For each component, each child's modal category across the 10 trials was used as the child's developmental level for that year. Because they represented developmentally sequenced, verbal descriptions (see Table 1), the scores on the predictor variables were ordinal.

The dependent variable was horizontal ball velocity averaged over 10 trials. Because all 5 components were assessed on each trial, it was impossible to have one velocity average that would represent the specific trials related to a child's modal behavior on each component. However, in each of the four data sets the children displayed their modal behavior for each component on over 8 of the 10 trials. The only exception was stepping action when the children were 6 years old. That year they averaged 7.81 trials in their modal stepping category. Because of this consistency in their movement, we were able to use each child's average over the 10 trials to represent her or his horizontal ball velocity score.

For each year of the study, the five predictors were first entered as a group into a simultaneous multiple regression with ball velocity as the dependent variable. Second, forward-stepwise regression was performed on the data from each year. This procedure showed the extent to which each predictor variable nonredundantly accounted for variance in the ball velocity. In this process, each movement component was ordered according to the amount of variance it explained in the velocity scores, given the presence of other components. Gender was coded and entered last in the stepwise regression to assess what contribution it made to ball velocity that was nonredundant with the movement variables. All statistical tests were performed at $\alpha = .01$ to minimize the overall alpha level for each "family" of analyses within each year.

Threats to Cross-Validation. While our interest lay in the amount of velocity variance the predictors would explain, the multiple regression procedures also produced equations to predict ball velocity from knowledge of a child's developmental levels in the 5 movement components. To obtain stable regression equations, the recommended relationship between sample size (N) and predictors (p) is 15 to 1 (Stevens, 1996). Thus, the regression equations presented for these longitudinal data may not be reliable, because N/p was ~ 8/1. This means the equations may not generalize well to other data sets.

Multiple regression assumes the independence of predictor variables. Violation of this assumption is known as multicollinearity. If multicollinearity occurs to a high degree, the size of the R^2 (explained variance) will be reduced and, again, the obtained regression equation will be unreliable (Draper & Smith, 1998; Stevens, 1996). Because the predictor variables in this study were all movement descriptions of the developing child's throw, we expected positive correlations between predictors. The question was whether the correlations would be too great to use multiple regression. Across the four data sets, the paired component predictor variables (see Table 3) correlated with each other from -.102 to .831. When the children were 8 years old, the predictors showed the highest intercorrelations. To test for multicollinearity, collinearity statistics were calculated for each year's data set. Both the tolerance statistic and the variance inflation factor supported using the original variables. Tolerance values run from 0 to 1.0. They are estimates of the variance in a variable that is unexplained by its relationship with the other variables (Erbaugh, 1997). The lowest tolerance statistic (.246) occurred in the data for the humerus for 8-year-old children. This value indicated that, at that age, 75% of the variance in the humerus could be explained by its relationship with all the other predictor variables, especially the forearm with which it was correlated at .831. However, the concurrent inflation factor for the humerus was 4.063. Stevens (1996) indicated that inflation factors over 10 are of concern. Therefore, we retained the humerus in the 8-year-old children's data, because its inflation factor was well below 10.

Results

Relationships Within the Data

Table 2 contains the means, ranges, and standard deviations of the scores on the movement components and the dependent variable—horizontal ball velocity—for each year of the study. Table 3 gives the correlation matrices between movement components, gender, and ball velocity over the same years. The univariate matrices revealed a number of interesting relationships (a) between the predictor variables and ball velocity, (b) among the predictor variables themselves, and (c) between gender and the other variables.

Between Predictors and Ball Velocity. Figure 1 illustrates the yearly correlations from Table 3 between the movement components and ball velocity. Four of the 5 components correlated moderately to highly with ball velocity each year of the study. Trunk action correlations were low until the age of 13 years, when they increased to .59. At the age of 13 years, stride length became most highly correlated with ball velocity (.71) while stepping dropped to .27. Some aspect of arm action (either humerus or forearm) showed the highest correlation with ball velocity in the first three ages studied and the second highest correlation at the age of 13 years. At 8 years of age, the developmental category reached by the children in humerus action accounted for approximately 84% of the variance in ball velocity scores. It is logical, from a biomechanical perspective, that the action of the distal levers (humerus, forearm) would be highly correlated to ball velocity, but group variability is also needed for a correlation to be high. The heterogeneity of humerus and forearm action especially during the ages 6–8 years helped make them strong, univariate correlates of ball velocity.

The correlations of the other components with ball velocity also showed the effects of individual differences in the sample. While stepping action was moderately correlated with velocity during the primary years ($r = .62$–$.65$), this relationship had dropped to .27 by the age of 13 years. At that age, all the children were stepping forward at least the length of their own foot. Meanwhile, at the age of 13

Table 2. Variable means, ranges, and standard deviations tracked longitudinally

Variable name	*M*	Range exhibited	*SD*
Age: 6 years			
Humerus action	1.61	1–3	.60
Forearm action	1.51	1–2	.49
Trunk action	1.96	1–2	.18
Stepping action	2.37	1–3	.82
Stride length	1.78	1–2	.41
Horizontal ball velocity	34.42	17.46–57.43	9.41
Age 7			
Humerus action	1.78	1–3	.68
Forearm action	1.56	1–3	.55
Trunk action	1.99	1–2	.08
Stepping action	2.44	1–3	.91
Stride length	1.71	1–3	.53
Horizontal ball velocity	38.83	19.36–59.85	10.37
Age: 8 years			
Humerus action	1.97	1–3	.84
Forearm action	1.73	1–3	.65
Trunk action	2.05	2–3	.22
Stepping action	2.54	1–3	.80
Stride length	1.90	1–3	.60
Horizontal ball velocity	43.07	22.87–60.30	11.34
Age: 13 years			
Humerus action	2.54	1–3	.60
Forearm action	2.23	1–3	.55
Trunk action	2.23	2–3	.43
Stepping action	2.95	2–3	.22
Stride length	2.46	1–3	.55
Horizontal ball velocity	68.11	42.73–92.27	15.11

Note. All variables were ordinal in nature except for ball velocity. The categories are described in Table 1. Horizontal ball velocity was measured in feet per second.

years stride length correlated most highly with ball velocity. At this age, some of the children were stepping distances of over half their height, giving the variable more heterogeneity. Trunk action had low correlations with ball velocity from the ages of 6–8 years, no doubt because most children remained in Category 2—spinal or block rotation. This homogeneity lessened at the age of 13 years, when more children entered Category 3—differentiated rotation.

Among Movement Components. The correlations in Table 3 among the movement components themselves tended to be moderate to low across the years. The only exception was at 8 years of age when the relationships between forearm and humerus action were .83 and .73 between stride length and stepping action. No other intercomponent correlation was greater than .66 at any age. These correlations and the tolerance statistics described earlier suggested that relatively independent information about throwing development was being provided by the separate components during each year of the study. Of all the components, trunk action was notable for its low correlations with every variable shown in Table 3. As mentioned earlier, this result was undoubtedly due to the lack of group variability in this variable.

Between Gender and the Other Variables. A third point, observed in Table 3, is the relationship between gender and the other variables across the 7 years of the longitudinal study. As the literature had suggested, gender was moderately related to ball velocity at every age. Previously unreported in the literature is the additional fact that the relationship steadily increased from the ages of 6 to 13 years. By 13 years, as a univariate variable, gender accounted for 52% of the variance in ball velocities. Correlations of gender with the movement components were also moderate each year of the study.

Perhaps the key developmental finding from Table 3 is partially illustrated in Figure 1. The relationships between developmental components and ball velocity, the components themselves, and all variables and gender continually shifted with time. For example, from the ages of 6 to 8 years, humerus and forearm action gradually became

Table 3. Correlation matrices for movement components, ball velocity, and gender for each age

	Gender	Humerus	Forearm	Trunk	Step	Stride length
Age: 6 years						
Humerus	.432					
Forearm	.501	.461				
Trunk	.250	.228	.232			
Step	.534	.379	.494	.192		
Stride length	.421	.238	.567	.425	.444	
Velocity	.541	.664	.736	.298	.620	.506
Age: 7 years						
Humerus	.565					
Forearm	.435	.655				
Trunk	.185	.190	.168			
Step	.368	.563	.335	-.102		
Stride length	.391	.363	.445	-.091	.622	
Velocity	.618	.769	.749	.110	.631	.657
Age: 8 years						
Humerus	.595					
Forearm	.479	.831				
Trunk	.204	.287	.098			
Step	.470	.608	.517	.136		
Stride length	.548	.621	.573	.237	.725	
Velocity	.666	.917	.802	.306	.651	.656
Age: 13 years						
Humerus	.537					
Forearm	.423	.532				
Trunk	.481	.427	.385			
Step	.264	.407	.099	.127		
Stride length	.741	.499	.203	.539	.408	
Velocity	.720	.685	.629	.593	.270	.711

Note. All correlation coefficients > .37 are significantly different from zero at $p < .01$.

more highly correlated, but by the age of 13 years the relationship had lessened again.

Prediction of Ball Velocity

For each year of the study, ball velocity was first predicted from the five movement variables as a whole. At each age, this regression was significant at $\alpha = .01$. The obtained $F(5, 33)$ for regression ranged from 18.17 at 6 years of age to 42.46 at 8 years of age. The movement components as a whole accounted for a minimum of 73.4% (69.3% adjusted) of the velocity variance when the children were 6 years old and a maximum of 86.5% (84.5% adjusted) when the children were 8 years old. Table 4 lists the regression coefficients (Beta weights) and standard deviations of those coefficients for each component and indicates which coefficients were significantly different from 0. Table 5 gives the regression equations for predicting ball velocity using all five components at each age. As Table 4 indicates, several of the regression coefficients each year were not different from 0. As subsequent stepwise regression analyses also indicated, those components should be dropped (and the remaining variables reanalyzed), if one were looking for the "best" prediction equation. They accounted for little additional variance when the other components were known. In most cases, the regression coefficients not differing from 0 also had the largest standard deviations. Thus, the equations listed in Table 5 are not the best prediction equations for each year (because that was not of interest to the investigators), but they are the equations that resulted when using all five components as predictors.

For each age, the full model analyses were followed by forward stepwise regression analyses. In these, the predictor variables were entered one at a time. The movement variables were purposely entered first, followed by gender. Table 6 contains the components ordered in each year by the amount of ball velocity variance they helped explain, given knowledge of the other components. The increased percentage of explained variance, as each component was added, is also listed in Table 6 as well as the total R^2 adjusted for chance. These amounts are visually depicted in Figure 2. As seen in the univariate correlation matrices,

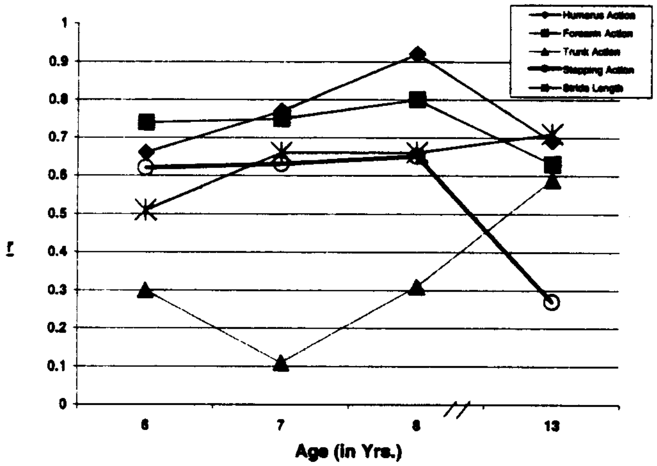

Figure 1. Univariate correlations (r) between 5 components of the overarm throw and ball velocity for 39 children studied longitudinally.

Table 4. Regression coefficients and their standard deviations with related t ratios

Component	Coefficient	SD	t ratios
Age: 6 years			
Forearm action	7.665	2.348	3.26*
Humerus action	5.609	1.644	3.41*
Stepping action	2.868	1.251	2.29
Stride length	1.411	2.776	0.51
Trunk action	2.584	5.347	0.48
Age: 7 years			
Humerus action	5.635	1.843	3.06*
Stride length	5.797	2.043	2.84*
Forearm action	6.130	2.052	2.99*
Stepping action	1.498	1.310	1.14
Trunk action	3.390	10.400	0.33
Age: 8 years			
Humerus action	9.011	1.791	5.03*
Forearm action	2.564	2.120	1.21
Stepping action	1.720	1.393	1.24
Stride length	0.963	1.909	0.50
Trunk action	3.607	3.562	1.01
Age: 13 years			
Stride length	13.812	2.975	4.64*
Forearm action	10.520	2.750	3.82*
Humerus action	5.606	2.860	1.96
Stepping action	-5.208	6.333	-0.82
Trunk action	3.109	3.655	0.85

* Significantly different from 0 ($p < .01$).

Table 5. Regression equations by year for the full component model

Age (years)	Equation
6	Ball velocity = - 0.63 + 5.61 H + 7.67 F + 2.58 T + 2.87 S + 1.41 SL
7	Ball velocity = - 1.1 + 5.63 H + 6.13 F + 3.40 T + 1.50 S + 5.80 SL
8	Ball velocity = 7.25 + 9.01 H + 2.56 F + 3.61 T + 1.72 S + 0.96 SL
13	Ball velocity = 4.80 + 5.61 H + 10.52 F + 3.11 T - 5.21 S + 13.8 SL

Note. H = humerus action; F = forearm action; T = trunk action; S = stepping action; SL = stride length.

action of the humerus accounted for the greatest percentage of velocity variance at ages 7 and 8 years. The value of 84% at 8 years of age is particularly noteworthy. Indeed, at that age knowledge of the developmental categories in all other components explained only 2% more of the variance, given knowledge of humerus development. The three categories of humerus action were displayed almost equally across the children when they were 8 years old.

Usefulness of Gender as a Predictor

Table 6 and Figure 2 also indicate that in all years of the study, knowledge of a child's gender explained no more than 2% additional variance in ball velocity scores, given prior knowledge of their developmental categories in the five components. As indicated in Table 3, gender was a fairly strong predictor of ball velocity. At the age of 13 years, it was the best single predictor. When entered last into the regression equation, however, its predictive power was considerably diminished. The well documented gender differences in throwing ball velocities can be overwhelmingly expressed by the movement patterns used by the two sexes. If the movement profile of a child is known (i.e., their developmental levels across components), then gender is an irrelevant predictor of throwing velocity.

Table 6. Stepwise multiple regression for predicting ball velocity from overarm throw developmental sequences at each age

Stepwise order	Component	R^2 (%)	Adjusted R^2	Change in R^2 (%)
Age: 6 years				
1	Forearm action	54.18*		
2	Humerus action	67.54*		13
3	Stepping action	72.72*		5
Forced	[Trunk action, stride length]	73.40		1
Forced	[Gender]	73.40	68.4	0
Age: 7 years				
1	Humerus action	59.15*		
2	Stride length	75.59*		16
3	Forearm action	80.19*		5
Forced	[Trunk action, stepping action]	81.00		1
Forced	[Gender]	82.50	79.2	2
Age: 8 years				
1	Humerus action	84.10*		
Forced	[Forearm action, trunk action, stepping action, stride length]	86.50		2
Forced	[Gender]	88.20	86.0	2
Age 13				
1	Stride length	50.60*		
2	Forearm action	75.11*		25
Forced	Humerus action, trunk action, stepping action]	78.40		3
Forced	[Gender]	78.90	75.0	1

Note. $N = 39$; "Forced" refers to a process during the stepwise procedure in which predictors, which have been eliminated previously, are re-entered into the equation.
*Partial F significant at $p < .01$.

Sample Representativeness

The strength of longitudinal studies is in showing the sweep of development; their weakness is that participants who continue in a longitudinal study may not represent those who drop out. To assess how well the data represented the original sample, we compared the results for these 39 children as 6 year olds to results reported by Roberton, Halverson, and Erbaugh (1981) for 67 of the original children when they also were 6 years old. For that early study, 11 predictors had been used as well as a different trunk action sequence. The latter was subsequently shown developmentally invalid (Roberton & Langendorfer, 1980). Regardless, in the earlier study 75% of the variance in ball velocities was accounted for by action of the forearm, humerus, trunk, and stepping. In the present sample, 73% of the variance was accounted for by the same variables in the same order, with the exception of trunk action. In 67 children, humerus action accounted for 56% of the variance; in 39 children it accounted for 54% of the variance. As in the current study, gender added little (less than 1%) to the explained variance when entered last in the stepwise process. Thus, comparison of the results of the two multiple regression studies gives confidence that the behavior of the longitudinal participants reflected behavior of their original cohort.

Discussion

This study examined the product-movement relationship in one skill using a developmental perspective. The strong ability of these particular movement descriptions to predict the outcome was an important finding. Further, the question of whether the outcome-movement relationship would change over time was also answered by these data. The "interweaving" process of motor development (Roberton, 1988), described metaphorically by such developmental pioneers as McGraw (1935/1975) and Gesell (1946), was clearly seen in Figure 1. The mixed-longitudinal results reported by Haubenstricker and Branta (1997) that suggested correlations between jumping movements and their product changed over time were supported by these longitudinal data on throwing.

This finding makes it imperative that studies of the product-developmental sequence relationship continue so that we can track such changes over the lifespan. Most important will be research that monitors change continuously in comparison to the yearly and greater intervals used in this study. Perhaps an across-trials paradigm (Newell, 1996; Roberton, 1977; Roberton, Williams, & Langendorfer, 1980) would be the best place to start, particularly using participants who change developmental levels in one or more components across those trials. Such data would allow immediate tracking of the effect on the product score when qualitative change occurs in a participant's movement. We will discuss additional aspects of the data in the order they were reported in the Results.

Relationships Among the Variables

The changing relationships between the predictor variables and ball velocity, the predictor variables themselves, and gender with ball velocity were analyzed using correlation and regression analyses. In examining the results, it is important to remember that a correlation is a group statistic. Two aspects of the group data affect its size: the size of the *covariance* between two variables relative to the size of the *product of the separate variances* of those same variables. At different times in this study the children showed more or less age-group variance in each predictor variable (see Table 2). Because the predictors each contained only three ordinal categories, it was not surprising that age-group variances would tend to be low at times in

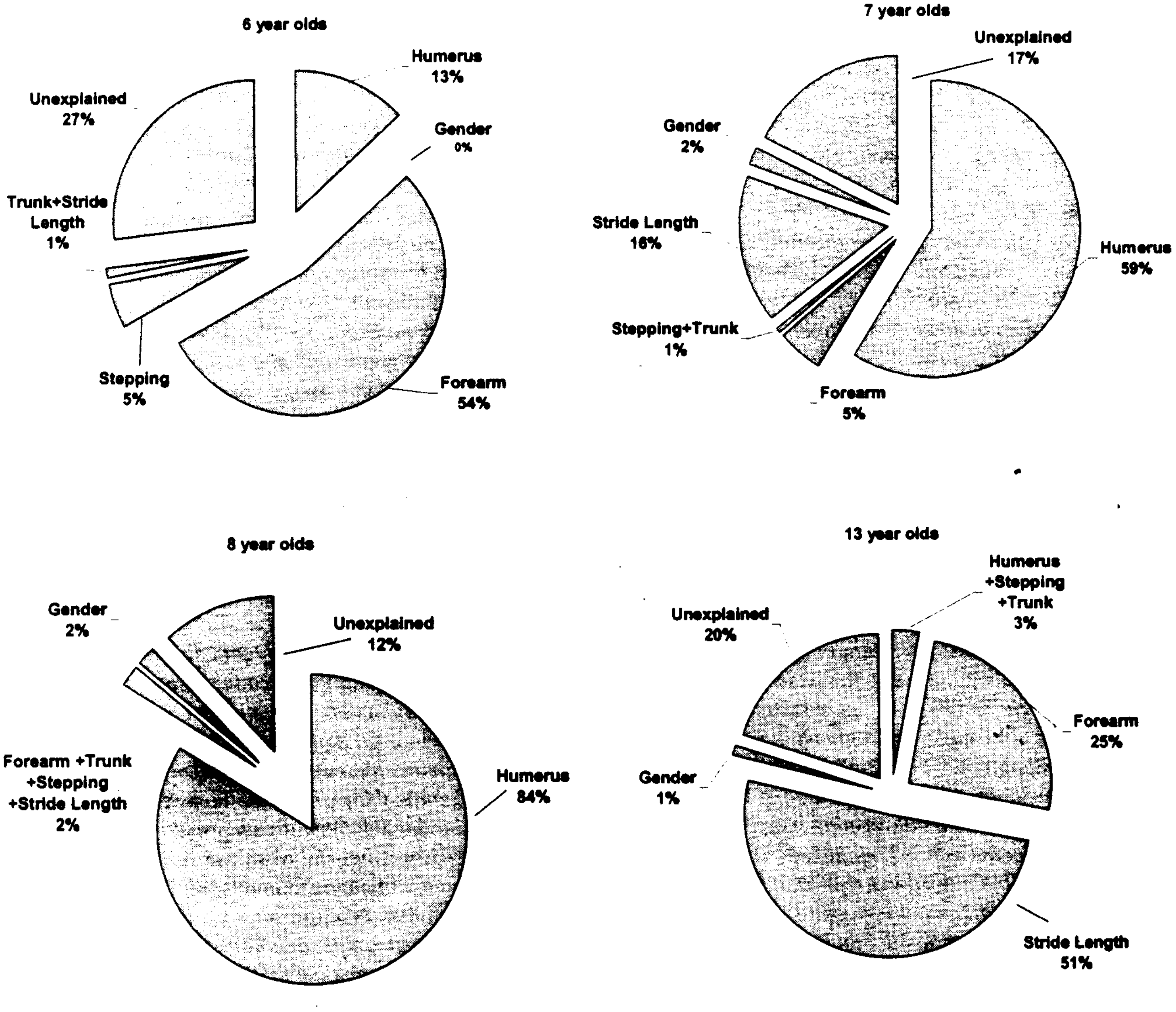

Figure 2. The unadjusted proportion of total variance in ball velocities that is explained at each age by the predictor variables (movement components and gender), given knowledge of the other predictors.

the longitudinal study. This increase and decrease in individual differences within the component developmental levels was partially responsible for the changing size of the correlations. Only when variables themselves vary can they also demonstrate covariance with each other. For instance, a key reason the correlations between components were highest for the 8-year-olds was that this age marked the time of greatest movement differences between the children (see Table 2). Langendorfer and Roberton (in press) reported that 12 different trunk-humerus-forearm profiles were exhibited across the 39 children at this age more than at any other age. Adding the stepping action and stride length components included in the present study would increase the number of profiles even more.

Despite the few categories possible in each predictor across all the years, enough age-group variability was present to reveal a good range of correlations (see Table 3). The exception was trunk action, which had low correlations with all variables, to include ball velocity, until the age of 13 years. As mentioned earlier, this result was clearly due to low group variability on this component. We have long felt that Level 2 of the trunk action component (see Table 1) needed more precision as a descriptor. Perhaps adding range of motion criteria to the block rotation description would help distinguish among individuals currently classified as block rotators. The poor prediction ability of the component as currently defined confirms the need for further research. On the other hand, based on the biomechanics of the throw, it is not clear that trunk action would ever account for sizable variance in ball velocities due to its potential redundancy with the more distal components.

Prediction of Ball Velocity

Explained Variance. The main focus of this study was on discovering the amount of variance in ball velocity scores "explained" by the components. Our interest was in the changing relationships revealed by regression analysis rather than in the prediction equations. As Pedhazur (1982) warned, however, the danger in this more theoretical use of regression analysis is that it is easy to confound "explanation" or "prediction" in a statistical sense with "causation" in a biomechanical sense. For example, although stride length and forearm action accounted for the most nonredundant variance at the age of 13 years, it does not mean that these two components were the dominant biomechanical reasons the 13-year-olds achieved the ball velocity they did. While it was true that higher developmental levels in each component covaried with higher ball velocities, the interrelationships among predictors and the variability of the group on each variable also entered into the final statistical outcome. Thus, statistical prediction is not synonymous with biomechanical causation.

That being said, the results of this study certainly suggest the body components that should be studied further at the level of the individual to better understand their changing contributions to outcome. For example, biomechanical studies of advanced throwers have shown that trunk rotation greatly decelerates by ball release, presumably transferring angular momentum to the throwing arm (Atwater, 1971; Escamilla et al., 1998). Thus, by ball release the contribution of the trunk to ball velocity may be reflected primarily in the actions of the more distal segments. On the other hand, the long stride some of the 13-year-olds were exhibiting lengthens the time for push-off from the rear foot. MacWilliams et al. (1998) found the anterior-posterior ground reaction forces from push-off and forward-foot contact in pitchers correlated strongly with linear wrist velocity. Indeed, studies of advanced throwing show that advanced throwers step a distance of 80% or more of their standing height (Atwater, 1979; Escamilla et al., 1998). This lengthened "drive" onto the forward foot contributes linear velocity directly to the throwing arm. Thus, at 13 years of age stride length explained the most variance in this study, because it differentiated those children stepping over half their standing height from those who were not.

Certainly, the total amount of variance in ball velocity, explained by the components at each age, as the children grew older is quite astonishing, especially because the predictors were only verbal descriptions of the movement. Clearly, the Roberton developmental sequences for forceful overarm throwing are closely related to the outcome of ball velocity. As we noted earlier, other developmental sequences have accounted for less than 30% of the variance in running and jumping scores. While the difference could reflect differences in the three tasks of running, jumping, and throwing, presumably the data for all were collected under conditions of maximal effort. Thus, the likeliest explanation lies in the component model, which provides a more precise description of developmental change than does the whole body model. Indeed, these particular throwing descriptions were originally based in the biomechanics and motor development literature as well as in hours of film study (see Roberton, 1977; Roberton & Langendorfer, 1980). Moreover, the model can describe people who progress in one component but not another (Roberton, 1977). Thus, it allows for greater individual differences in a group of people through the variety of throwing profiles created by the convergence of the different developmental levels across components (Langendorfer & Roberton, in press). By reflecting these individual differences in movement, the model is able to correlate well with an outcome variable. One might speculate that the low relationships between the whole-body developmental sequence for jumping and distance jumped (Haubenstricker & Branta, 1997) may have been due, at least in part, to low age variability in the data.

Most important, relative to throwing, these component sequences describe developmental changes in the action of the humerus and the forearm. At each age, one or the other of these two predictors was most able to account for a large portion of variance in ball velocities (see Figure 2). The developmental categories in these components describe the children's attempts to position their arms to take advantage of the rotational velocity of the trunk. As children enter Level 3 of the humerus and Level 2 or 3 of the forearm, they enable the inertial lag of the forearm that ultimately contributes to elbow extension acceleration in the final milliseconds of the throw (Feltner, 1989). This "crack the whip" phenomenon is responsible for the high ball velocities that can be achieved in overarm throwing. In contrast, Wild's (1938) whole body stages describe the action of the arms in vague terms only.

Prediction Equations. As a final comment on the regression analyses, we recommend that further work be done on the prediction equations produced by the analyses. Before they are used as predictors, the equations reported in Table 5 need to be cross-validated on other larger samples and the "best" equations in terms of parsimony then derived. With the relatively small N/p ratio, it may be that the current equations are sample-specific (Stevens, 1996).

The Usefulness of Gender as a Predictor

A compelling finding in this study was that gender is redundant with developmental level. When held out of the stepwise regression analyses until the movement variables had been entered, gender accounted for no more than 2% additional variance. While going through the same developmental sequences, the girls progressed at much slower rates until they were several "developmental years" behind the boys at the age of 13 years (Halverson et al., 1982). But knowing a child's gender does not add to one's ability to predict their ball velocity, given that one knows the child's developmental levels. Girls were different from boys in their movement but not in any other developmental sense relevant to throwing, at least for these children at these ages.

The question still remains as to why the girls' movement is "behind" the boys' developmentally. Williams, Haywood, and Painter (1996) produced data showing that boys and girls were not statistically different in their ball velocities and were only slightly different in their developmental levels when throwing with their nondominant hand. They argued that this result suggested differences between boys and girls throwing with their dominant hand (a finding they replicated in their study) were due to the effect of greater practice by the boys. Indeed, Halverson et al. (1982) documented practice differences in favor of the boys in the same children who were studied in the present investigation. While the search for an explanation of gender differences in throwing needs to continue, the present study narrows that search to the question of *why* throwing patterns and, therefore, ball velocities are delayed in some girls up through the age of 13 years.

Clinical Usefulness of the Findings

At this point, the major applied contribution of this study is to sensitize clinicians to the fact that throwing components change relations to each other and the movement outcome over time. Langendorfer and Roberton (2000) have studied the course of change across throwing components idiographically. Their study suggests an order to when components will advance in their behavior relative to each other. Such an order may eventually suggest a content progression for teachers. Until that time, practitioners at least need to recognize the many throwing profiles that can occur across children of the same age and tailor instruction toward small groups of individuals with the same profiles. As indicated earlier, well over 12 different profiles occurred in these children when they were 8 years old, that is, second grade students. Thus, the data emphasize the need for teachers to adopt a more individualized approach to teaching the overarm throw.

The developmental levels within components accounted for a large portion of the variance in ball velocity scores at each age. This fact suggests that if practitioners cannot assess the developmental levels of their students, they can measure ball velocity as the next best thing. We advocate that teachers track children's developmental levels in motor skills, using checklists or videotape, but recognize that many teachers now have access to radar guns, which can measure ball velocity directly and easily. Or, a stopwatch could be used to measure the time it takes for the ball to travel a known distance. Charts are available in the 1963 edition of Cooper and Glassow's text, *Kinesiology*, that plot ball velocity as a function of the time it takes the thrown ball to travel 30 feet. Both methods of measuring ball velocity are quite motivating to children and adults alike, thus creating excellent practice as well as assessment situations. If teachers use ball velocity, however, they must keep in mind that from 12–27% of the variance (depending on age) in these scores was unexplained by the developmental levels used in this study (see Figure 2). Presumably, this unexplained variance relates to body size and strength as well as other components of the throwing action. That presumption, of course, awaits further study.

Last, research on the movement-outcome relationship is also warranted in the teaching situation in which the performer is challenged to produce a particular outcome, such as increased ball velocity. This teaching method, called task or goal setting (Halverson, 1982; Roberton, Halverson, & Harper, 1997; Widule, 1981), gives the learner a performance goal ("Can you throw the ball harder this time?") with minimal instruction as to what the movement should look like. In contemporary, dynamic systems terms, the task or goal set for the learner (increased ball velocity) may be synonymous with the control variable for that task (ball velocity; see Southard, Bates, & Sanders, 2000). If the goal moves the performer beyond some critical value in the control variable, change to a new coordination mode (i.e., developmental level) should occur. Unanswered is whether this qualitative change actually does occur and, if so, how it affects the immediate outcome to which the performer's attention has been deliberately focused.

Clearly, much work on the developmental relationships between product and movement still needs to be done for a variety of tasks from both a theoretical and applied perspective. We hope the results reported here will stimulate others to join us in this study and determine if these relationships reflect the development of coordination, control, or skill. Such information should be valuable in formulating an overall theory of skill acquisition.

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Note

1. Because distance thrown is a resultant of ball velocity and the angle of projection of the ball at release, ball velocity is a less confounded assessment of the throwing force a child's body is able to generate (Halverson et al., 1982; Roberton et al., 1979; Sakurai & Miyashita, 1983).

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