Developmental Kinesiology: Maturation of Basic Motor Patterns

Ralph L. Wickstrom

DEPARTMENT OF PHYSICAL EDUCATION, RIPON COLLEGE, RIPON, WISCONSIN

I. Introduction

A. Scope of Developmental Kinesiology

The term "developmental kinesiology" has surfaced only recently and probably is not in the vocabulary of many of those who are currently working in the broad field of kinesiology. Yet it is a term which deals with an important concept and covers a special area of study. Its emergence along with other terms such as "structural kinesiology" (Barham and Wooten, 1973) and "anatomical kinesiology" (Roberton, 1972) marks an effort to clarify the scope of special areas in the study of human movement. The relatively new terms often cover work which has been done over a period of many years but has not had a definite label to identify its focus. This certainly is the case in developmental kinesiology.

Roberton (1972) reported the use of the term developmental kinesiology to describe "the application of kinesiological techniques to the study of motor development." The useful definition implies a biomechanical approach to the study of motor behavior which includes both kinematic

(geometry of movement; displacement, velocity, acceleration) and kinetic (forces producing and affecting motion) analysis of movement. The methodological precision inherent in the application of kinesiological techniques to movement analysis is reasonably clear. But the meaning of the term motor development in Roberton's definition is open to broad interpretation. It is a term which seems to be changing from a concept that limits its purview to changes in motor behavior during childhood (Corbin, 1973) to an approach which considers development a lifelong process (Halverson *et al.*, 1973; Leme, 1973; Roberton, 1972). The life-span concept of development has appeared elsewhere in connection with developmental psychology (Goulet and Baltes, 1970) and developmental physiology (Timiras, 1972) but without overwhelming acceptance in either area of study. Goulet and Baltes (1970), in citing some of the reasons for resistance to the life-span concept in developmental psychology, included "the complexity of the task, 'basic' differences between infants and the aged, methodological problems implicit in the comparison of behavior in humans who vary widely in their response repertoire, the problem of subject availability, and the difficulties associated with long-term longitudinal research." If many of the same reasons prevail in the area of motor development, the practical scope of developmental kinesiology may continue to be restricted primarily to the study of changes in motor behavior prior to adulthood, advances in motor development theory (Connolly, 1971; Schneirla, 1966) notwithstanding. However, the matter is complex because the study of skilled adult motor patterns is important to the study of developmental motor behavior and it is unlikely that there can be or will be a significant separation to the two.

B. Methodology

1. Approach

The study of motor development involves the identification of changes in motor behavior. Research in motor development in the 1930's by Bayley (1935), Gutteridge (1939), McCaskill and Wellman (1938), and many others was concerned mostly with performance scores and the achievement of specific motor tasks. The type of data accumulated in the area of motor development since that early period has also been predominantly product-oriented, that is, basically concerned with *what* changes occur. Examples of product-oriented motor development data include changes in the speed of running, the distance of a throw, and the height or distance of a jump. A fuller understanding of the nature of change in motor behavior is possible only if the *process* which produces

the change is also identified (Connolly, 1971). An interest in the question of *how* change comes about can be traced back to the work of Halverson (1931) and Shirley (1931) with their descriptive approach to development respectively in prehension and locomotion. Wild (1937) used a more advanced kinesiological technique in her study of throwing and there has been a constant improvement in the descriptive approach during the past several decades. An important result is that the study of motor development has been enhanced by the availability of precise and detailed information on the *process* involved in the developmental changes in motor performance.

The design used in the collection of data is another variable in the approach to the study of motor development. The subjects in an overwhelming proportion of the studies in motor development have been selected according to a cross-sectional design. The inconsistency of this model with the idea "that the study of motor development is the study of ontogenetic change in human movement" (Halverson *et al.*, 1973; Roberton, 1972) is apparent. More appropriate is the longitudinal model which provides for repeated observations on the same persons over an extended period of time. The imperfections of both cross-sectional and longitudinal models have been discussed by Schaie (1965) and Baltes (1968) but there remains an "insistence on longitudinal data, not only to take account of individual variations in rate and patterning of development, but to provide direct measures of the parameters of the developmental functions stipulated as the units of analysis, and of their relationship to other relevant variables" (Wohlwill, 1970). The longitudinal approach which was used in a limited way by McGraw (1943) and Shirley (1931) has become a more conspicuous influence in developmental kinesiology with the refinement of the design in the Wisconsin studies (Glassow *et al.*, 1965; Halverson, 1962) and the research done by Sinclair (1971). Although the information from longitudinal studies is limited, it tends to be consistent with the findings from cross-sectional studies in terms of the establishment of distinct developmental movement patterns and the basic sequence of movements within the patterns (Halverson *et al.*, 1973; Seefeldt *et al.*, 1972; Sinclair, 1971). Future research with more refined kinesiological techniques should help to reveal the true relative value of the two research models in the study of motor development.

2. Equipment

All factors considered, the age of the subject is the principle factor in the selection of the equipment used in collecting data; the younger the subject, the more limited the selection of effective means. Many of the more sophisticated techniques are unsuitable for the younger age group

research because they entail restraints and create an unnatural situation in which to collect data (Halverson *et al.*, 1973). For example, multiple instrumentation necessitating the attachment of elgons, electrodes, and rotation belts is quite inappropriate when young children are subjects. If children thus equipped are asked to perform in a specific way, in a particular location, and at a precise instant, the ambience for them is impossibly artificial. Even skilled adults need time to practice their skills and become properly oriented when equipment is attached to their bodies in biomechanical research. Unless adjustment to equipment is allowed, a realistic response cannot be expected from children or from adults under the special testing conditions.

When collecting data on children as young as two and three years of age, the camera is the only realistic choice of equipment and loosely structured cinematography the only proper corresponding procedure. Ample time for orientation to the equipment and environment encourages the child to perform at his best without restriction and with a minimum of tension (Halverson *et al.*, 1973). The resulting film is usually realistic in showing *what* the child can do, but it normally contains little footage that will lend itself to the precise kinesiological analysis of movement patterns. Because of this problem, the literature on motor development contains more descriptive than quantitative analysis of the motor behavior of young children. While general observation and descriptive analysis provide a workable starting point, they must ultimately accede to more refined, more objective kinesiological techniques. The verification of nuances of sequence and timing is the work of more precise procedures. It requires painstaking kinematic analysis which ordinarily includes the measurement of angular and linear displacements of the moving body parts, the calculation of angular acceleration and velocities of the moving parts, and the determination of the integral timing of the parts in the movement sequence. Kinetic analyses involving the determination of the center of gravity of the body segments and the calculation of force production are even more complicated. Refined cinematography using two or preferably three synchronized high speed cameras improves the collection of data and allows more accurate quantitative analysis of movement at all age and skill levels.

Other types of equipment and procedures can be used depending upon the age of the subjects and the nature of the analysis. Roberts (1971) and Roy (1971), for example, have utilized the force platform to study the jumping performance of subjects ranging in age from 5 to 16 years. The force platform shows promise as a research tool in developmental kinesiology but it is not readily available and therefore has been used

only in a limited way. Electromyography (Basmajian, 1971, 1973) and electrogoniometry (Adrian, 1968, 1971, 1973) are additional research procedures, but both require time-consuming preparation and then limit movement to a small space except where telemetry is also a ready resource. The sophisticated computerized equipment utilized by some of those doing biomechanical research on skilled adult performance (Garrett *et al.*, 1968) or on children (Garrett and Widule, 1971) is not generally available. But it is inevitable that research techniques in biomechanics will continue to improve at all levels (Miller and Nelson, 1973; Nelson, 1971) and the improved techniques will be more frequently employed in developmental kinesiology research.

C. Terminology

The growth of developmental kinesiology has been accompanied by the emergence of special terminology. New terms have appeared in the literature and some of them have gained a measure of acceptance. Most of the new terms attempt to give meaning to information gleaned from the biomechanical analysis of human movement and put it in a developmental context. The following is a list of some of the important terms and concepts which appear in the discussion in Section II of this review.

1. *Mature motor pattern.* Mature form for a skill is the basic motor pattern used by skilled adults in the performance of the skill (Espenschade and Eckert, 1967; Halverson, 1966; Halverson and Roberton, 1966; Hanson, 1961; Hellebrandt *et al.*, 1961; Wickstrom, 1970; Wild, 1937). It is what remains in the motor pattern of skilled adults after all aspects of individual style have been stripped away. The mature pattern for a particular motor skill is an important criterion for assessing progress or for measuring the amount of skill development which has occurred. Other terms used to describe the same standard of form are *adult pattern*, *skilled pattern* (Halverson, 1958; Singer, 1961), and *complete pattern* (Leme, 1973).

2. Several terms may be used to describe movement patterns which have not reached the mature or skilled level. Movement patterns meeting minimal form criteria for a skill but not yet equal to the standard for mature form are referred to as *developmental* (Wickstrom, 1970), *immature* (Halverson and Roberton, 1966; Hellebrandt *et al.*, 1961; Wickstrom, 1970), or *unskilled* (Singer, 1961; Zimmerman, 1956) patterns.

3. *Developmental stage.* Developmental stages are definite and reasonably separate motor patterns which appear in the course of the develop-

ment of a particular motor skill (Deach, 1950; Poe, 1973; Seefeldt *et al.*, 1972; Wild, 1937).

4. *Developmental trends.* Gradual changes occurring in connection with the development of a motor skill represent developmental trends (Poe, 1973; Wickstrom, 1970). Trends are observed in connection with gradual change in a part of a pattern or gradual change in an entire pattern.

5. *Arm-dominated.* Arm domination refers to the preeminence of arm action in a movement pattern and means (1) that the arm(s) is the only major contributing segment in the pattern, or (2) that the arm(s) initiates the movement and leads the pattern (Harper and Struna, 1973; Wild, 1937). The term "top dominated" is sometimes used when there is movement of the arms and rotation of the trunk but no change in the position of the feet (Harper and Struna, 1973; Wickstrom, 1970).

6. *Unitary pattern.* An immature motor pattern in which the movements occur essentially in a simultaneous rather than in a sequential manner is a unitary pattern.

7. *Block rotation.* In block rotation there is unitary movement of one area of the body; the entire trunk rotates as a unit on the femur (Halverson *et al.*, 1973; Harper and Struna, 1973).

8. *Opening up.* Opening refers to "the simultaneous movement of separate or distinct body parts in opposite directions" (Harper and Struna, 1973). It is a key concept in the development of several mature motor patterns.

Many of the terms included above have come directly from or are a result of motor development studies done at the University of Wisconsin at Madison.

D. The Velocity Factor

It has been noted that the measurement of motor skill development traditionally has been more concerned with outcome than with process and that evaluation of progress has been made on the basis of how fast, how far, or how high instead of on the basis of how well, expressed in terms of form. Thus, stress on maximum effective velocity has become a common underlying element in the performance goals of most of the basic motor skills used to determine product change in motor development. Moreover, the velocity emphasis is continued when the process aspect of motor development is being determined because the standard of mature form is a result of velocity-oriented effort by skilled adults.

The importance of the velocity factor in the study of motor development suggests the need for keeping the factor constant. Motor patterns seem to be quite different in performances in which the velocity goals vary. As Plagenhoef (1971) states, "Whereas maximum use of trunk rotation and full motion are characteristic of hard throws, trunk stabilization and the restricted use of body segments are characteristic of controlled throws." Differences in form have also been recorded when the standing long jump was done for less than and for maximum distance by the same performers (Waterland, 1967). From this sort of evidence it appears that unless velocity is a controlled variable, the *process* results from a motor development study might present a specious picture.

There are other ways in which the velocity factor has an important bearing upon the study of motor development, especially in the data collecting process. When a child is involved in a research project where the motor task has a high velocity requirement such as throwing for distance, there is a possibility that his filmed performance will not be an accurate representation of his true movement pattern. The use of speed often is out of context with the way the skill ordinarily is used by the child in play. For example, most of the throwing done by children during play is in the moderate speed range. If asked to throw as hard as he can in a filming session, the child might open or close his movement pattern in a distorted way depending upon his age and the magnitude of his effort. This potential problem is of greater consequence in the cross-sectional design than in the longitudinal study where there is an opportunity for the child to adjust during the filming session and eventually display his best developmental form.

Some of those working in motor development are concerned that the performance score based upon velocity can mask problems in the movement pattern used to produce it (Halverson *et al.*, 1973). A study by Singer (1961) illustrates one obvious reason for the concern. She studied the throwing skill of two "good" and two "poor" throwers over a four year period. The skill classification of the elementary school girls was based upon the velocity of the ball at the point of release. One of the "good" throwers demonstrated a step with the leg on the same side as her throwing arm in her pattern at the initial filming and continued in this immature stage through the second year of the study. By contrast, both of the "poor" throwers used the more mature contralateral step in their throwing patterns at the start of the study. Singer's subjects illustrate the risk of separating form and performance when studying motor skill development. The concern is supported by the work of Hanson (1961) which suggests that ball velocity is not an accurate indicator of throwing skill development at the kindergarten level.

II. Developmental Motor Patterns: A Review

A. Running[1]

The run is an important later stage in the progression of upright locomotion which begins conspicuously with various forms of creeping, crawling, and walking (Gesell, 1954). A gradual increase in the tempo of the steps used in walking leads to the development of minimal form for running, i.e., alternate forward leg action and a nonsupport phase during each stride. Before the child can progress from this minimal form toward the more demanding mature form, his mechanisms of balance and coordination must become more refined and, most importantly, he must develop the ability to exert more force (Eckert, 1973).

In the mature running pattern (Atwater, 1973; Bates and Haven, 1973; James and Brubaker, 1973), the support foot lands approximately flat and under the forward moving center of gravity, with the knee and ankle flexing slightly at contact to absorb the kinetic energy of the flight. The propulsive leg continues backward extending fully at the hip, knee, and ankle. A high kickup with the heel occurs in the first half of the recovery phase and the thigh swings forward nearly to the horizontal in the latter part of leg recovery. The arms swing through a high forward–backward arc in a diagonally inward anteroposterior plane with the forward swinging arm bent at about a right angle and the backward swinging arm bent a little less than a right angle at the elbow. The trunk is relatively erect and arm and leg action is in synchronized opposition.

The development of mature form is a gradual process characterized by a series of coincidental changes which represent the adjustments essential to increased running speed. Studies by Beck (1966), Clouse (1959), Dittmer (1962), Fortney (1964), and Wickstrom (1968) have identified some of the gradual and corresponding changes that represent the developmental process. Over a period of time, the length of the running stride increases, the number of strides per second increases, the relative rise in the height of the center of gravity per stride decreases, the amount of leg extension in propulsion increases, the height of the heel of the recovery leg increases, the distance the recovery foot lands ahead of the center of gravity decreases, and the arms swing through a longer and more uniform opposition pattern. In short, the trend is to move away from a bounding, twisting pattern, typical of the early stage of running, to a pattern which emphasizes the development of forward, horizontal velocity (Fig. 1).

[1] See Dillman, this volume p. 193.

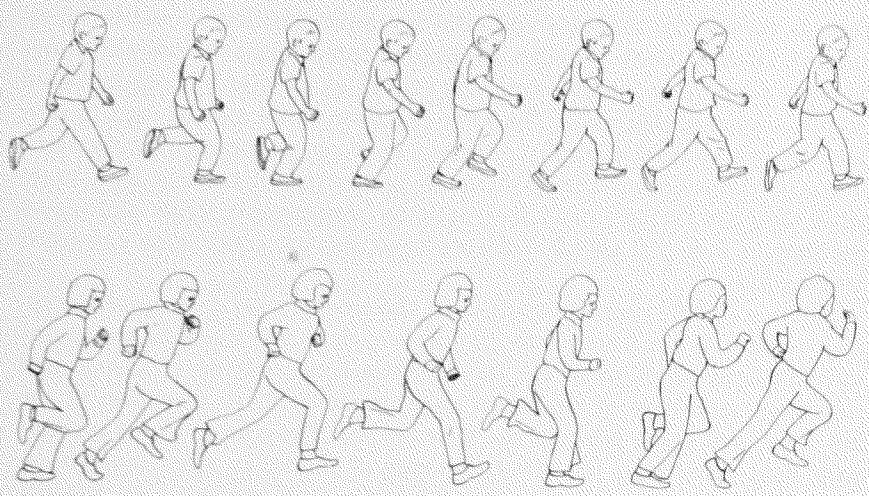

Fig. 1. Upper. Running pattern of a 27-month-old boy showing bounding, vertical emphasis, and limited range of motion. *Lower.* More advanced form of an 8-year-old girl with strong horizontal emphasis and more extensive movement.

As the kinetic and kinematic study of sprinting continues, the types of investigations being conducted on adult performance might be applied similarly and advantageously to the study of developmental form. For example, Payne and associates (1968) used a force platform to measure the horizontal and vertical forces exerted by the propulsive leg of an adult male runner. They attempted to determine the actual components of force exerted during the contact of the propulsive leg and to relate the findings to the theoretical construct. Theoretically, once the runner has achieved his maximum running speed, the propulsive force of his body is primarily vertical because the major need is to reverse the downward direction of his center of gravity which occurs in the nonsupport phase. He presumably needs only enough horizontal force at this point to overcome air resistance and to compensate for any negative horizontal (braking) force exerted by his support leg before it gets into a propulsive position. The findings tended to support the theoretical assumption. The investigators found the mean value of the positive and negative horizontal forces to be approximately zero during the propulsive phase of the full speed running stride. It would be most revealing to use the force platform in the study of the effect of support-foot placement in developmental patterns. The support foot of the immature runner appears to be placed on the ground ahead of the forward moving center of gravity, producing what could be a relatively large braking force. If the braking

force is verified, its relationship to the developmental level could be investigated. A significant negative horizontal force might be an advantage or even a necessity for the beginning runner as he tries to keep his speed within a manageable level. The force platform could also be used in conjunction with cinematography to accept or reject the notion that the technique of throwing one's head back, as inexperienced runners tend to do when they are trying to run fast, actually shortens the stride and places the support foot well ahead of the center of gravity, creating an unwanted braking force.

Dillman's (1971) kinetic analysis of the recovery leg during sprint running represents yet another fruitful approach to the study of the movement pattern of running. He found distinctive patterns of torque and consistent sequences of dominant muscular activity in operation at the hip, knee, and ankle joints of the recovery leg. The study yielded preliminary data concerning the effective range of muscular force involved in producing changes in direction for the lower limb segments. An attempt to obtain a better understanding of the nature of the changes in developmental form must include studies similar to the one by Dillman. It must likewise involve studies which provide electromyographic verification of the results of cinematic analysis of muscular torque.

B. Jumping

Jumping ability invariably is measured by the height or the distance of the jump rather than by the quality of the form used to perform it. For many years a vertical jump or a type of long jump has been used to measure the jumping ability of both children and adults. Hence, it is not surprising that the study of developmental jumping patterns has been confined largely to the identification of changes in these two basic types of jumps. Hellebrandt and associates (1961) observed that the earliest developmental form in an upward jump from two feet was like a bipedal hop with no special forward or upward emphasis. At the mature level, the movement patterns of vertical and horizontal jumps made from a two-footed takeoff show important similarities. The sequential pattern of movements found in both jumps starts with (shoulder) flexion and continues with extension at the hip, then the knee, and finally the ankle in rapid succession (Klissouras and Karpovich, 1967; Roy, 1971; Wickstrom, 1970; Zimmerman, 1956). As a result of these movements the arms are raised overhead about in line with the trunk and the legs are fully extended at takeoff. This ordered and well-coordinated sequence of movements, terminating in extension at takeoff, represents an effective application of a succession of forces applied over a maximum effective distance.

1. Vertical Jump

The early vertical jumping patterns of children tend to include unitary arm and leg coordination and show less than complete body extension at takeoff (Wilson, 1945). The task of jumping as high as possible often is translated by the child to mean "get the feet as high as possible" and his form follows his intent. It appears that the anticipation of getting the feet high interferes with the complete application of available force during the takeoff. The child does not extend fully as he leaves the ground and he immediately bends forward, flexing somewhat at the hips and almost maximally at the knees (Wickstrom, 1968). This difficulty is overcome if the task put before the child is suggestive of full extension. Asking a child to jump up and touch an object held over his head and just out of his standing reach can result in the use of a relatively mature pattern by children as young as two years of age (Halverson *et al.*, 1973). Without the challenge of a specific task requiring an upward stretch, the patterns children normally use for the vertical jump are heavily influenced by flexion.

As the focus of the task becomes increasingly more specific, rapid progress is made toward the mature vertical jumping form. There are several progressive changes which might be identified as developmental trends in the vertical jump (Wickstrom, 1970; Wilson, 1945); arm action is timed earlier to initiate the movement sequence, the preliminary crouch becomes deeper, the trunk remains more upright during the preparatory crouch, and the legs and body become more fully extended at takeoff. There also is less forward displacement of the center of gravity as form improves.

The contribution of arm action to performance in the vertical jump is known to be critical and its specific contribution was verified recently with the benefit of a force platform (Payne *et al.*, 1968). Vigorous use of the arms was found to evoke extra force for upward propulsion of the body and it raised the center of gravity to the highest possible point before takeoff. One of the child's early problems in vertical jumping is to adjust the timing and movement of his arms to get the potential benefit from their action. Little by little the timing problem is solved and the transition to the fully extended, sequential jumping pattern is made.

2. Standing Long Jump

Typical of early long jumping form is a tendency toward a one-footed takeoff and a backward or a sideward–upward "winging" movement of the arms (Hellebrandt *et al.*, 1961). General progress toward mature form in the long jump follows lines similar to those in the vertical jump. As

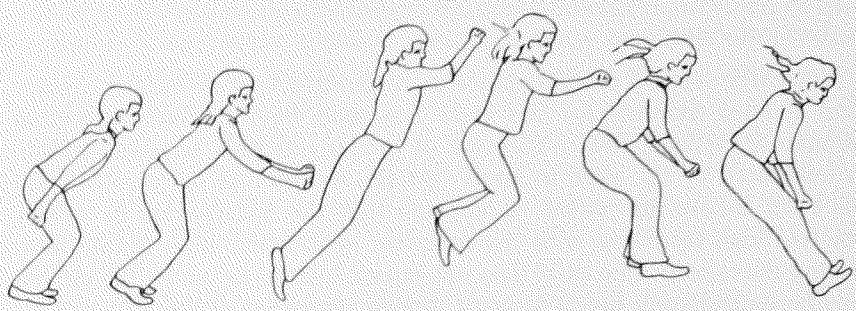

Fig. 2. Nearly mature form in the standing long jump. The arms of the 7-year-old girl have been timed to contribute effectively to extension at takeoff, to inflight adjustments, and to controlled landing.

developmental changes occur, the preliminary crouch gets deeper, the leg angles at takeoff and at landing become smaller, the body extends more completely at takeoff, and the thighs flex to a greater angle during flight (Felton, 1960; Halverson, 1958; Zimmerman, 1956). Arm movement changes from an upward–sideward balancing function to a swing that is timed to initiate the forward propulsive sequence and contribute to more complete body extension (Fig. 2). Inflight movements become more effective as arms and trunk remain straight to react to the rapid forward movement of the legs and as the knees are flexed markedly to minimize angular inertia when the legs are swung forward (Hay, 1973). These improvements in form usually result in improved performance (Hellebrandt *et al.*, 1961).

Roy (1971) conducted an important study relating to the stability of the movement patterns used in the standing long jump. He used a force platform and cinematographic procedures to investigate the kinematics and kinetics of the standing long jump in boys who were average performers in their respective age groups. He analyzed the jumps of 20 boys, five each at ages 7, 10, 13, and 16 years, to determine angular velocity and angular acceleration at the shoulder, hip, knee, ankle, and metatarsophalangeal joints. The observed similarities in the kinematic patterns of the different age groups led Roy to conclude that the standing long jump pattern is well established at the beginning of school age and changes very little through mid-adolescence. Increases in maximal force, impulse, and power occurred at 3-year intervals in the 7 through 16-year age range, and were attributed entirely to changes in mass. Roy's study helped narrow the chasm between the primarily observational information on the jumping patterns of pre-school children and the more sophisticated kinetic study of the performances of skilled jumpers.

3. *Running Long Jump*

The running long jump has not been studied precisely or extensively in connection with developmental kinesiology (Wilson, 1945). This is somewhat curious because it apparently is a more natural type of jump (Cooper and Glassow, 1972) than the ones requiring a two-footed takeoff. Unfortunately the effective coordination of the run with the jump in the testing situation is difficult, and reliable performance in the running long jump is a continuing problem up to advanced levels of skill. If the difficulties connected with the collection of data are eliminated or minimized, the running long jump will provide a fertile area for study by developmental kinesiologists. One anticipated outcome of such research is a better understanding of intertask relationships between developmental motor patterns in jumping skills involving one- and two-footed takeoffs.

C. Throwing

The term *throw* is used in common parlance to embrace nearly all the movement patterns in which an upper limb(s) is used to propel an object. However, the discussion in this section will be confined to the one-handed overarm throwing pattern which has been studied far more extensively than any of the other patterns in this skill category.

The movement pattern a child uses to accomplish a particular throwing task varies considerably according to his experience and his level of physical development. If the task before him is to throw the ball *hard*, or *far*, or *high*, he might respond with an underhand, a sidearm, or an overhand motion. Furthermore, he might use one or two hands to propel the ball depending upon its size. The technique he uses at any given time tends to be the one his experience has shown him would probably be the most practical and successful. Within this context, the general developmental trend for children is to use underhand patterns prior to overhand patterns and two-handed techniques before one-handed versions (Deach, 1950; Gutteridge, 1939; Jones, 1951). Eventually most children adopt a form of unilateral overhand throw.

An early but very influential study of overhand throwing patterns was done by Wild (1937). She conducted a detailed cinematographic analysis of the throwing form of a select group of 32 children representing six month age intervals between the ages of 7 and 12 years. The children presented four distinctly different types of arm movement and five different types of body movement within their complete throwing patterns. These major movements were combined in many different ways to produce whole throwing patterns which ranged from arm-dominated to se-

quential patterns. However, Wild suggested that there were only four clearly defined stages in the development of mature form in throwing. In *Stage I*, the throwing arm was drawn sideward and upward or forward and upward to a position above the shoulder with the forearm well flexed. The forward motion was in the anteroposterior plane with extension at the elbow beginning early in the movement. There was a slight forward trunk sway accompanying the arm movement but the feet remained stationary and the trunk did not rotate. In *Stage II*, the feet remained stationary while the trunk rotated backward in the direction of the throwing arm which was cocked as in Stage I. The arm initiated the forward movement and was joined by the forward rotation of the trunk. Arm action was in a more horizontal plane than was found in the earlier stage and there was a definite forward, downward follow-through. In *Stage III*, the back-swing and the trunk rotation of Stage II were retained, with the body weight shifting slightly to the opposite foot. The forward movements included a step with the foot on the same side as the throwing arm, trunk rotation, oblique or horizontal arm movement, delayed elbow extension, and arm follow-through across the body and downward. In *Stage IV*, there was a forward step with the opposite leg, trunk rotation, and horizontal adduction of the throwing arm. Wild called Stage IV the mature pattern for overhand throwing because it coincided basically with the pattern she found in an analysis of the throwing form used by a professional baseball pitcher. Deach (1950), Halverson (1966), Leme (1973), and others have reported observing essentially the same developmental stages in throwing.

Additional research has helped clarify certain aspects of the process involved in the development of overarm throwing skill. Jones (1951) analyzed the throwing patterns of children ages $4\frac{1}{2}$ to $10\frac{1}{2}$ years and judged that more effective throwing was possible by increasing the number of levers used within a longer (hips–trunk–shoulder–arm) complex. Ekern (1969) found a developmental trend toward the gradual opening of the throwing pattern to take advantage of the potential forces in the largest possible lever system. Her subjects for the cinematographic study included two girls and two boys from grades 2, 4, and 6 who were the best throwers in their respective groups, based on initial released ball velocity. The better throwers of the select group were the older boys whose highly similar movement patterns involved a longer forward step and greater ranges of segmental movement. Skill in throwing among Ekern's subjects seemed to be dependent upon an opening of the movement pattern with effective use of a complexly-timed lever system. The basic sequence of movements for all throwers in her group was essentially the same, but the timing varied considerably.

A better understanding of developmental throwing patterns should result from the recent research conducted on the skilled adult overarm pattern. It is generally agreed that the skilled pattern consists of a forward step, pelvic rotation, spinal rotation, shoulder medial rotation, elbow extension, and wrist action (Atwater and Roberts, 1968) but there are points concerning arm action that are unclear. Leme (1973) concluded that the most variable aspect of the overhand throwing pattern of her subjects was the arm action, and Tarbell (1971) found that even a camera operating at 1500 frames per second did not reveal precisely how a ball leaves the thrower's hand. Included in the research which has clarified arm action is evidence by Atwater (1970) and Tarbell (1971) that forearm pronation accompanies extension at the elbow in the latter phase of the throw. Atwater's study of men with high skill, women with high skill, and women with average throwing skill verified that while all used the same basic movement pattern there was an important difference in the arm action used by skilled and by average throwers. Skilled throwers abducted the humerus of the throwing arm to a position approximately in line with the shoulders and retained this position until the ball was released. Throwers of average skill, by contrast, horizontally adducted the throwing arm to a position significantly in front of a line through the shoulders. This action, in combination with trunk rotation, positioned the elbow in front of the shoulder of the throwing arm and subsequent elbow extension occurred in a sagittal plane causing a "pushing" motion. This ineffective pushing motion had been noted previously (Bowne, 1960; Deach, 1950; Ekern, 1969; Flinchum, 1971; Hanson, 1961) but it had not been described so explicitly. The recent findings on arm action in the skilled throwing pattern strongly suggest that the "horizontal adduction" described in Wild's Stage IV mature pattern might be questioned and that this stage be further clarified to distinguish between the whipping arm action of the skilled thrower and the pushing motion of the average or unskilled overarm thrower (Fig. 3). This would help avoid a recurrence of the problem of research workers (Flinchum, 1971; Flinchum and Hanson, 1972) accepting a pushing arm action as the adult model to be used in the study of the motor patterns of young children.

The exact nature of the "flinging" or "whiplike" arm action used in vigorous overhand throwing continues to be an intriguing but enigmatic topic. Research which has provided clues to the understanding of whip action in the arm motion includes the investigation by Dobbins (1970). His study, while limited to one adult male subject, suggests that the actual use of the triceps muscle in the throw might be quite different from that which can be inferred from the observed movements. He proposed that triceps action has an indirect rather than a direct influence on ball

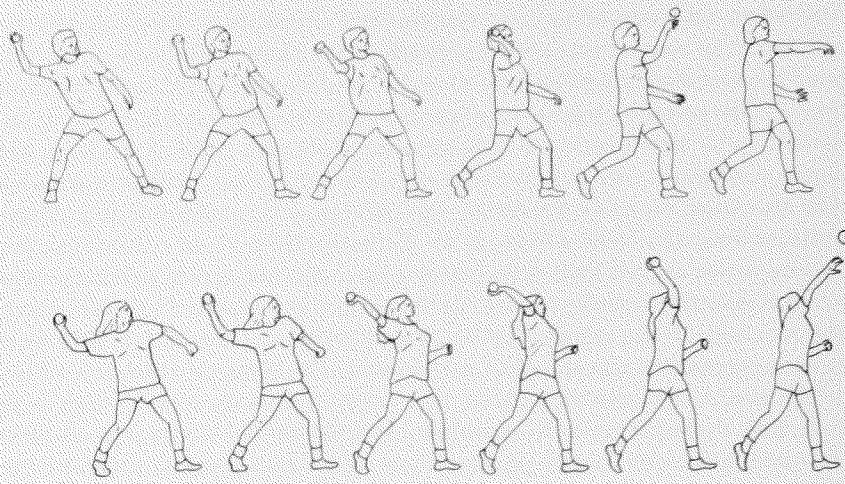

Fig. 3. Overhand throwing patterns of adult females. *Upper.* Immature push-type arm motion. *Lower.* Mature whip-type arm action.

speed in the overhand throw. By anesthetizing the triceps muscle he was able to show that the normally high rate of elbow extension in the overarm throw can be achieved without participation by the prime extensor. Deutsch (1971) mentioned that momentum rather than direct triceps action might be responsible for forearm extension in the throwing motion, and Atwater (1968) proposed earlier that centrifugal force caused by trunk rotation seemed to be responsible for extension at the elbow. All these proposals have a possible bearing on the explanation of the whipping arm motion in skilled overhand throwing.

Another aspect of skilled form which might be closely related to the whipping action of the arm is the blocking or support action of the forward leg during vigorous throwing. Dyson (1970) and Tricker and Tricker (1967) suggest that the slowing of the movement of the lower section of the body actually increases the velocity possible in the overhand throwing motion. Skilled throwers tend to have a relatively stable position in terms of the angle at the knee of the forward leg during the final unfolding of the throwing motion (Atwater, 1970; Lyon, 1961). And yet little attention has been directed to the role of the forward leg in the complex link system of torque which is developed around a number of axes when a ball is thrown in vigorously using an overhand pattern (Plagenhoef, 1971). The matter obviously requires further study.

D. Striking

Striking skills tend to be task specific with each having a set of unique features. Each skill requires a particular object to be struck basically in an overhand, sidearm, or underhand pattern with either a special implement or a designated part of the body. It is interesting to note that the kinesiological studies relating to developmental form in striking have been principally concerned with one-arm and two-arm sidearm patterns which are rudimentary forms of special sport skills. This is in contrast with a more natural striking motion in the overhand pattern. The naturalness of the overhand striking pattern is supported by evidence that it is used by young children in their initial efforts in many striking tasks. An example of this tendency was reported by Deach (1950) who observed overhand throwing and striking motions in the initial attempts of young children who were trying to perform an underhand volleyball serve. There is also substantial evidence that children revert to the overhand pattern when they seek the highest assurance for success in striking (Halverson and Roberton, 1966). As a general developmental trend in striking, there is gradual progress from the forward-facing overhand pattern to the side-facing horizontal pattern (Halverson and Roberton, 1966; Wickstrom, 1970).

1. Overhand Pattern

In the early form used in the overhand swing, adjustment is made to the height of the ball by bending forward at the waist and at the knees. This adjustive action by the trunk and legs is similar to that used in chopping and it usually precedes arm action (Wickstrom, 1970). If adjustment to the height of the ball is not necessary, the striking movement tends to be arm-dominated with a bit of accompanying forward body sway. This is similar to the Stage I throwing pattern from Wild's classification. As progress is made toward the sidearm swing, the medial rotation of the arm action in the overhand pattern can be accompanied by block rotation and a forward step (R. L. Wickstrom, unpublished study, 1968).

2. Sidearm Pattern

The earliest striking motions that young children make in the horizontal plane also tend to be arm-dominated (Halverson and Roberton, 1966) and essentially unitary patterns (Fig. 4). Block rotation of the trunk and pelvis occurs at about the same time as the forward arm swing in this stage of development. Case studies of the one-arm sidearm swing show slight differences in the timing of trunk and arm action. Halverson

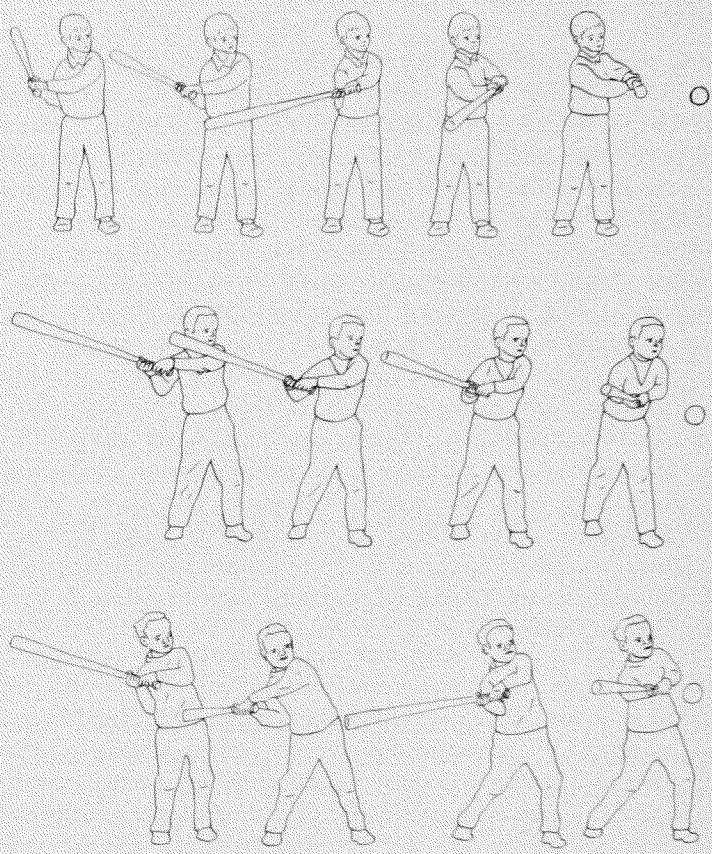

Fig. 1. General stages of developmental form illustrated with sidearm striking patterns of 4½-year-old boys. *Upper.* Arm domination. *Center.* Unitary action. *Lower.* Opening pattern.

and Roberton (1966) reported that block rotation of the trunk and pelvis immediately follows the initial forward arm movement while Harper and Struna (1973) indicated that block rotation and arm motion are started at the same instant.

Progress in the sidearm striking pattern continues as the pattern opens and the rotatory movements gradually unlock. In case studies involving a 3-year-old girl and a 3-year-old boy (Harper and Struna, 1973) it was observed that the first appearance of opening was coincidental with the

appearance of a forward step in the striking pattern. Hyperextension of the wrist was also noted as part of the phenomenon. The amount of opening increased with the lengthening of the forward stride and with the intensification of the effort put into the swing.

Opening has a double contribution to make in the production of the velocity of the striking implement; it increases the distance over which force may be applied (Hay, 1973), and it places the muscles on a stretch for more forceful contraction (Cooper and Glassow, 1972). The child wisely forgoes the maximum benefit of opening when he concentrates on accuracy and contact rather than on speed. However, the impulse to swing hard is strong, especially among boys, and most children progress toward the mature (Atwater, 1973) sidearm striking pattern.

3. Oblique Striking Pattern

There has been a preliminary study of the diagonally downward striking pattern used in the golf swing (R. L. Wickstrom, unpublished study, 1968). A group of children between the ages of 2 and 5 years were filmed while using a bat in an attempt to strike a stationary ball which was on the floor in front of them. The youngest children used an overhand chopping motion when swinging at the ball. With increasing age the overhand pattern gave way to a sidearm pattern. The child tended to lower his upper body by bending at the waist and the knees and then used an adaptation of the sidearm swing. Many of the children studied were familiar with the sidearm swing and had developed the forward weight shift and trunk rotation used in that swing. The general trend from an overhand to an adapted sidearm swing in an oblique plane strongly suggests intertask developmental similarities in striking patterns.

E. Kicking

Kicking is yet another form of striking. It is a variation of walking and running in the sense that pelvic rotation is followed by hip flexion and knee extension in a forward swinging motion (Cooper and Glassow, 1972). Children have the capacity for the vigorous hip rotation required in effective kicking by age 2 years (Roberts and Metcalfe, 1968) and increase in skill gradually at successive age levels. The basic kicking patterns which emerge from the early experience of children in the United States are the straight place kick and the punt. There is little exposure to the instep kicks so prominent in soccer. The question of which kick or kicks might be considered as part of the natural development of kick-

ing patterns is primarily of academic interest because of the high degree of sameness in the basic patterns of most kicks. Plagenhoef (1971) determined that toe kicks in football and in soccer are identical from the standpoint of technique, and noted that the kicking motion in instep kicks also follows the same basic sequence of movements. Similar findings have been reported by Burdan (1955) and Cooper and Glassow (1972).

The mature kicker swings his kicking leg forward by rotating around his left hip (supporting leg) and bringing his thigh forward quickly while the lower leg flexes. Flexion at the hip decelerates as the lower leg extends at the knee until the thigh is essentially motionless at the instant the ball is contacted (Glassow and Mortimer, 1966–1968; Plagenhoef, 1971; Roberts and Metcalfe, 1968). The foot gets much of its velocity at impact by the decelerating action of the thigh and the vigorous straightening of the leg to almost full knee extension at the precise moment the ball is struck by the foot.

1. The Place Kick

The child has two main problems in the early stages of skill development in place kicking: (1) he has difficulty placing his support foot in an effective position in relation to the ball when approaching it, and (2) he has to contend with the uncertainty of keeping his balance on one leg while performing a forceful motion with the other (Espenschade and Eckert, 1967). Deach's study (1950) of the development of kicking skill in children ages 2 to 6 years revealed changes in the pattern used to kick a stationary ball from a stationary position immediately behind it. The *first* stage was simply a forward pendular movement with the kicking leg remaining nearly straight at the knee and the position of the upper body scarcely changing. More action of the kicking leg was observed in the *second* stage. The leg was flexed backward at the knee to provide for a longer forward arc in the kicking motion. The additional force generated by the more extensive leg action necessitated a small amount of arm opposition and backward trunk lean as the kicking leg moved forward toward the ball. A *third* stage indicated a definite increase in the range of preparatory movement in terms of hip extension and further backward lift of the foot. These increases were accompanied by preparatory forward bending of the trunk and resulted in significant opposition by the contralateral arm as well as backward trunk movement during the kick. Deach identified a *fourth* stage which was an extension of the movements that occurred in the previous stage. As the kicking leg was cocked backward by bending at the knee and extending at the hip, there was rotation of the hip away from the direction of the kick with an increase in the effective distance over which the forward kicking force

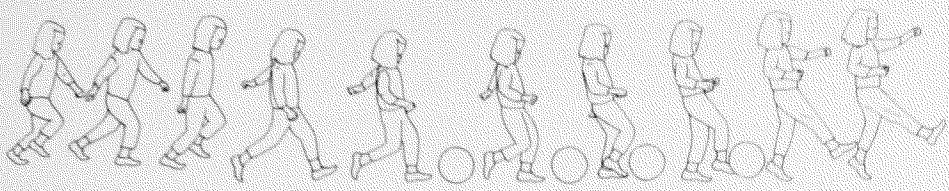

Fig. 5. A girl aged 4½ years demonstrating forward movement which is well coordinated with a place kick. The most immature aspect of her form is the incomplete extension of the knee of the kicking leg at contact.

was applied. Increased arm opposition was required and the follow-through of the kicking leg was higher and more toward the midline of the body than away from the midline as often occurs at the less mature levels. It was apparent that the intent of the kicker changed during the four stages from the hope of merely contacting and moving the ball, to a concerted attempt to propel it as far as possible. Hence, the importance of developing maximum velocity of the kicking foot at contact seems to enter the picture early and probably prevails throughout the developmental phases of learning to kick.

Children advance toward mature form by progressively opening the pattern of movements in the kicking motion and by improving the timing of the successive movements in the sequence. There also is improvement in the coordination of a walking or running approach with the kick. Forward movement prior to the kicking motion helps both performance and form (Fig. 5). It contributes velocity which can be added to the kicking motion and places the body in position for more pelvic rotation which provides a greater distance for the application of force (Cooper and Glassow, 1972).

2. The Punt

The punt is different from the place kick in that the ball is dropped and kicked before it reaches the ground rather than being kicked off the ground. The change from place kicking to punting is problematic for the relatively unskilled child. A tendency to toss the ball upward rather than to drop it puts the ball out of position in relation to the timing of the kicking motion. Hence, if the ball is contacted with the foot or leg, it usually is contacted high and goes straight upward or upward and backward. Another early developmental difficulty in the punt is the lack of at least a one-step approach prior to the drop which is needed to put the ball in forward motion. This motion allows contact to be made on the instep rather than on the foreleg or knee which is the case if the ball is merely dropped from forward-reaching arms. The developmental

changes which represent progress toward mature form include at least one preliminary forward step, lower release of the ball with release occurring before the support foot contacts the ground, faster knee extension, more pronounced arm opposition, more backward trunk lean, and increased extension at the ankle at contact (Halverson and Roberton, 1966; Poe, 1973; Wickstrom, 1970).

The developmental changes in kicking which have been reported are mostly the findings from cross-sectional studies. However, an understanding of the maturation of patterns used in kicking is enhanced by two reports of one important longitudinal study. Halverson and Roberton (1966) issued a preliminary report on the developmental progress made in kicking by four children who had been studied over a time span of 4 years. Poe (1973) recently reported on the developmental changes which occurred in the movement characteristics of the punt for one boy in the study whose progress was followed for 8 years. The major developmental changes were summarized in the following three points: (1) a change from a one-step approach to a two-step approach in the kick with a period of flight occurring in the second step of the approach in the most advanced stages; (2) a change from dropping the ball from a height between waist and shoulder level to a lift release which projected the ball upward and outward from the body at chest level; (3) increasing use of opposition of arm and leg to improve stability following ball contact in the kick. The child had demonstrated an effective kicking motion at an early age and by age 5 years had reached a knee extension velocity comparable to that reported for an adult (Roberts and Metcalfe, 1968). Poe's case study revealed what a cross-sectional approach ordinarily would not, i.e., changes occur during the process of acquiring skill which are inconsistent with minor aspects of mature form but which do not detract from the key aspects. For example, the boy in the 8-year case study developed a hop in connection with his two-step approach. This is associated with mature place kicking form in soccer but rarely is observed in the punting form of skilled adults. He also lowered the point of release on the ball drop but then at a later stage developed a push-type release rather than the usual drop. Neither of these personalized aspects of form detracted from his basic kicking pattern but they might pose problems from the standpoint of future maximum effectiveness.

F. Motor Patterns of EMR Children

Widespread interest in the motor development of educable mentally retarded children is of recent vintage. The modicum of research done on the movement behavior of EMR children has been focused primarily

on performance rather than on process. However, interest in performance led to limited concern about form, and tentative insights relative to motor pattern development have been gleaned from the sparse evidence currently available.

It has been reasonably well established that EMR children lag well behind their normal counterparts in measured motor performance (Francis and Rarick, 1960; Howe, 1959; Rarick *et al.*, 1967, 1970). EMR children are equally behind normal children of the same age and sex in measurable strength. The reasons for slower progress in the development of skill and strength are not entirely clear but both environmental and neurological factors appear to be important (Rarick, 1973; Rarick and Dobbins, 1972).

Research showing the trend of slow motor skill development for EMR children suggests that there probably is a similar laggardly trend in motor pattern development. That is, mentally retarded children conceivably go through the same stages and follow the same course of motor pattern development as normal children but with a later start and a slower rate of progress. An alternate speculation is that the motor pattern development of the mentally retarded child is unique and follows trends quite different from those of normal children but the notion currently lacks sufficient supportive evidence for serious consideration.

Adrian and Oglesby (1971) were interested in the capacity as well as the physical performance of a mentally retarded male child. They used electrogoniometry and electromyography to study the standing long jump performance of a 10-year-old EMR boy. Before analyzing his performance in the aforementioned skill, they ascertained that there was a normal reciprocal interaction between the rectus femoris and biceps femoris muscles which were being monitored. They also found the subject capable of performing a task requiring synchronous bilateral leg action in a sitting position. From this evidence they assumed that no neurological impairment existed and the subject had sufficient capacity for learning. Yet, the performance of the 10-year-old subject showed a jumping pattern typical of that of a child 5 to 7 years younger. None of his standing long jumps exceeded 8 in. and asynchronous leg action occurred in all jumps. The investigators concluded the asynchronous leg action might be due (1) to insufficient leg strength, (2) to his inability to control the position of his center of gravity, or (3) to his inability to time a sequence of contributory forces effectively. None of these factors is necessarily a permanent handicap. The findings of this study add weight to the speculation that environmental factors contributing to opportunities for strength development and motor skill learning are largely responsible for the relatively immature motor patterns observed in EMR children.

Adrian and Auxter (1967) studied the characteristics of the running patterns of 46 educable mentally retarded boys ages 8–12 years. They selected the following ten variables in the running pattern for cinematographic analysis: (1) speed of the runner, (2) percentage of flight time, (3) stride length, (4) contact time, (5) foot position at landing, (6) angle of swinging knee at takeoff and (7) at landing, (8) angle of the swinging thigh with the horizontal at takeoff, and (9) arm position at takeoff and (10) at landing. When the data from the ten factors were compared to similar data on the running patterns of normal children, the EMR children were found to be inferior on all the factors measured. The slower running speed of the EMR boys could easily be anticipated and the finding of differences between the two groups for the other nine factors could then be inferred from the known relationship of the velocity and angular displacement of the limbs to the speed of running. The results of the study strongly suggest that progress toward the mature pattern of running for the retarded children was simply slower and not necessarily otherwise different from that of normal children.

A more recent investigation by Auxter (1973) inquired into the throwing patterns of mentally retarded children. Cinematographic procedures were used in the analysis of the throwing patterns of 72 boys and 38 girls between the ages of 7 and 12 years. Through the age span, the children progressed to more effective throwing patterns in terms of weight transfer, length of stride, body rotation, length of throwing arc, and integration of joint action for improved leverage. Auxter identified 15 different patterns which he suggested were indicative of "increasing developmental levels of efficiency" in the throwing patterns of the EMR child. The 15 discrete throwing behaviors were retained for their greater diagnostic value rather than being generalized into fewer stages as Wild and others have done with the throwing patterns of normal children. However, Auxter suggested that if the data were analyzed in a manner similar to the approach used by Wild, the result would be quite comparable to the four stages described by her. Thus, there are similarities in the types of developmental changes which occur in the patterns reported for EMR and for normal children. Quite obviously much work remains to be done before the development of motor patterns by the mentally retarded child can be understood and before the reasons for any noted departures from normal patterns can be accurately attributed.

One interesting topic for future research is the relationship between motor pattern maturity and IQ rating within the EMR category. One must be very cautious about generalizing on the basis of limited observational evidence, but after examining the running, jumping, and throwing

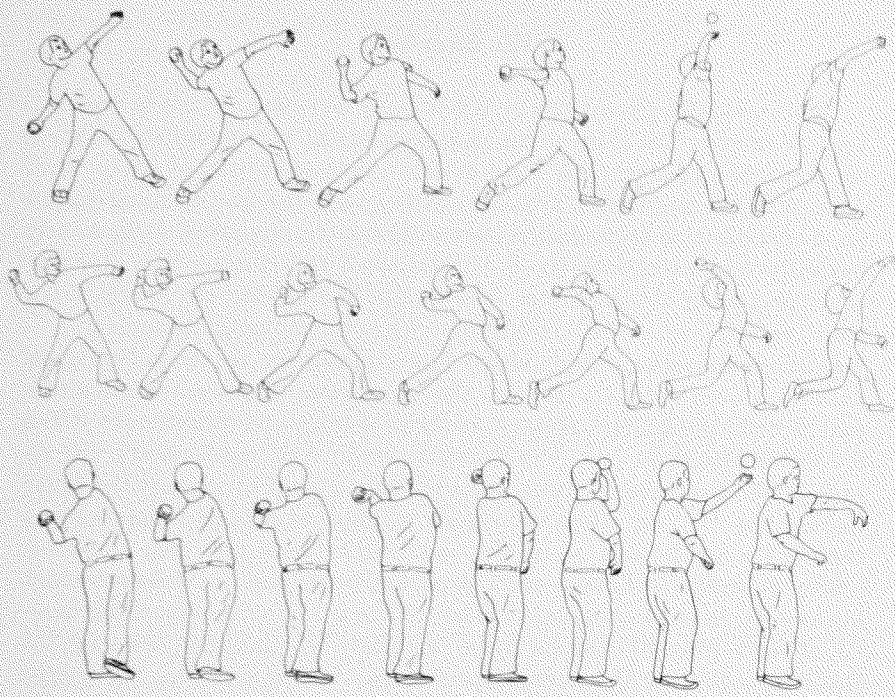

Fig. 6. Throwing patterns of 8-year-old children with different IQ ratings. *Upper.* Boy with IQ of 111. *Center.* Girl with IQ of 78. *Lower.* Boy with IQ of approximately 50.

patterns of several small groups of EMR children, it appears to this writer that the patterns are less mature as the IQ level of the EMR children within an age group drops. Toward the upper limits of the roughly established IQ boundaries of 50 to 80 which form the EMR category, children often have normal and occasionally even superior physical performance and motor skill patterns. It is difficult to distinguish the borderline EMR from the intellectually normal child on the basis of motor performance or movement pattern considering the wide range in the quality of motor behavior demonstrated by both groups (Fig. 6). However, that wide range seems to disappear quickly as the IQ drops to the lower part of the EMR category (Rarick and Dobbins, 1972). Children at this level consistently appear to demonstrate *only* immature movement patterns (Fig. 6). Studies of possible relationships of this sort clearly fall within the broad scope of developmental kinesiology.

III. Summary

Developmental kinesiology is a relatively new term which is presently used to refer to the application of kinesiological techniques to the study of motor development. The term describes a special area of study which deals with the qualitative (process) rather than the traditionally emphasized quantitative (product) aspect of motor development. It is an area basically concerned with the investigation of the changes in motor patterns that occur in connection with specific motor skill development and with the implications of the changes for total motor development.

Both cross-sectional and longitudinal approaches to the collection of data have been used. Of the two, the longitudinal approach is more consistent with the general concept of development but unfortunately it is a difficult procedure and is used infrequently. Yet, significantly, the results of the few longitudinal studies published tend to support the broad findings of the far more numerous studies involving cross-sectional models.

The research technique most commonly utilized in developmental, kinesiology in cinematography. When subjects are quite young, the quality of data from film seems to be enhanced by providing time for the children to become thoroughly familiar with the equipment, the testing environment, and the general procedure. Techniques used to study changes in motor behavior are becoming increasingly more refined and the resulting data more valid and reliable. With older children and adults, methodology is being expanded to include sophisticated instruments such as the electromyograph, the electrogoniometer, and the force platform.

Most of the work in developmental kinesiology has been concentrated on the study of a few fundamental skills normally acquired by all individuals during childhood. Skills requiring high levels of velocity such as running, jumping, throwing, kicking, and striking have been of particular interest because measured performance in these skills has been regarded as a prime indicator of motor development. The motor patterns used by skilled adults when performing these basic skills are generally accepted as mature form and are important standards against which to judge the quality of performance during developmental stages. Trends and stages of motor pattern development have emerged from the comparison of developmental with mature motor patterns but these must be considered tentative and much work remains to be done. Critical to the quality of future research in developmental kinesiology is continued improvement in both approach and technique. Also vital to a deeper understanding of the motor development process is the improved biomechanical research

which can provide greater insight into the nature of mature motor performance.

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