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THE UNIVERSITY OF ALBERTA

# EFFECTS OF PRACTICE ON MATCHED PHYSICALLY AWKWARD AND NORMAL BOYS

by

GORDON ERNEST MARCHIORI

A THESIS

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## DEDICATION

It was the best of times, it was the worst of times.

Charles Dickens

A Tale of Two Cities 1859.

In memory of my grandmothers,

Julia Marchiori and Anne Taylor.

## ABSTRACT

Successful skill acquisition depends on the degree of congruency between the person, task, environment, and instructional strategy. Two studies were designed to investigate skill acquisition in age-matched normal and physically awkward boys. The first study investigated the learning of the stationary hockey slap shot by two pairs of age-matched normal and physically awkward boys. In an initial data collection session, the physically awkward and normal boys performed three slap shots, following which the physically awkward boys practiced 400 trials at home every two weeks over a six week training period, under the supervision of their parents. Performance data were collected every two weeks, after 400, 800, and 1200 practice trials. Cinematographic analysis of each subject's three responses per session led to an examination of the kinematics, phasing, and timing of the slap shot. In the initial baseline session, the normal boys exhibited consistency of performance; however, even after 1200 trials of practice supervised by their parents, the performance of the two physically awkward children was still extremely variable. Based on the results of the first, the second study examined the effect of 1000 practice trials on the ball rolling accuracy of four pairs of age-matched normal and physically awkward boys. The data on each subject were collected in 10 sessions over a 20 day span. Analysis of the

1000 behavioural trials revealed that only two subjects (one normal and one physically awkward) improved their performance. The kinematic analysis suggested improved performance for the normal boys across the 10 sessions, with decreasing variability in their kinematic pattern. The physically awkward boys, however, exhibited considerable variability in their performance on all the kinematic variables. Implications of these performance differences between the normal and physically awkward boys on these fairly simple, closed skills, are discussed relative to the person, task, environment, and instructional strategy.

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# I. Introduction

In North American culture, running, jumping, throwing, kicking, striking, and skating are prominent physical skills that are employed in play, games, and sports. Children of all ages are actively involved in social play and game situations where a minimum level of motor ability is required. Successful performance in any motor task requires skillful organization of the spatial/temporal relationships between body segments. Skillful movement involves an intricate weaving of biomechanical, physiological, psychological, and morphological factors and must be coordinated through factors such as culture, age, sex, maturation, and interaction with the environment. Thus, learning and development in the motor domain depends on the demands of the task at hand, the developmental level of the learner, and the nature of the environment in which the learning is to take place (Wall, 1986).

A significant portion of school-aged children, comprising as much as 6% of the total, experiences serious difficulties in learning motor skills (Gubbay, 1975; Keogh, 1968). Performance inadequacies on movement tests provide an initial indication of movement skill problems, but detailed and systematic observation of physically awkward children also is needed to identify the nature of the child's problems. Inability to perform a movement adequately and consistently is the general indication of physical awkwardness. The way in which a child attempts a movement can provide clues about the exact nature of the difficulty a child is having. The definition of clumsy children is presented from various authors' perspectives in order that the reader might fully appreciate the difficulties of this condition.

Physical Awkwardness

The precise identification of physically awkward children is an elusive premise which requires a variety of measurement approaches and involves the professional perspective of the observer. There is very little consensus within or across studies in the criteria for the identification of physically awkward children. No single measure of physical awkwardness has been found that will identify even one-half of those children in a group of physically awkward children (Gubbay, 1975). Children classified as physically awkward seem to be a heterogeneous group, even within one sample, in terms of defining characteristics. This is consistent with other learning disabilities.

Morris and Whiting (1971) defined physically awkward children as those whose performances are subnormal or whose efficiency when performing skills has been hampered in some way. Their motor responses reflect inadequate attempts to perform those skills which can be regarded as being either essential for development or culturally desirable. In this context, impairment signifies the inability of an individual to perform simple every day skills effectively in a controlled and coordinated manner. The inadequacy of their responses may cause them to be labeled clumsy or physically awkward. Their condition can be attributed to a mutually inclusive combination of physiological, environmental, and interpersonal factors (Morris & Whiting, 1971). A definition proposed by Keogh, Sugden, Reynard, and Calkins (1979) is similar in that clumsiness is defined as 'a problem of inadequate movement performance' (p. 32).

Gubbay (1975) suggested that a physically awkward child is 'to be regarded as one who is mentally normal, without bodily deformity, and whose physical strength, sensation, and coordination are virtually normal, but whose ability to perform skilled purposive movement is impaired' (p. 39). Gubbay also suggested a medical definition for clumsiness as 'developmental apraxia and agnosia' (p. 40).

A working definition of physically awkward children was offered by Arnheim and Sinclair (1979). Physically awkward children are 'those individuals who have motor learning difficulties and display asynchronous and inefficient motor behaviour when attempting to carry out movement tasks that they would commonly be expected to accomplish under reasonable circumstances' (p. 42). Arnheim and Sinclair further identified the major causes of clumsiness as: maternal factors, rearing practices, problems of body structure, and cerebral dysfunctions. In general, physically awkward children are usually subjectively identified as those who fail consistently, are continually bumping into things and acquire bruises, drop things, and cannot keep up with their peers in physically active games (Arnheim & Sinclair, 1979).

McMath (1980) suggested that clumsiness is a relative, descriptive term used to explain a syndrome of awkwardness and inept movement. It is a behavioural manifestation of some form of cerebral dysfunction, the roots of which may be located anywhere in the perceptual-motor system. Haubenstricker (1982) presented a list of ten differentiating characteristics that were not necessarily mutually exclusive, but that a particular child may exhibit. He defined physically awkward children as 'those whose motor responses do not fit the situations in which they find themselves' (p. 41). The identification of physically awkward children on the basis of general motor patterns is only the first step in correcting gross motor dysfunction. Haubenstricker also suggested that remedial efforts early in childhood would be most effective in correcting motor problems. Both McMath (1980) and Haubenstricker (1982) suggested that there are many major causes of awkwardness and delineated possible reasons for dysfunction. These authors also made some suggestions regarding remediation of the motor problems of physically awkward children.

Wall (1982), in an attempt to broaden and sharpen the meaning of movement learning difficulties, defined physically awkward children as those 'children without known neuromuscular problems who fail to perform culturally-normative motor skills with acceptable proficiency' (p. 254). Culturally-normative skills are skills which are generally performed within a specific culture at certain ages by a large majority of people. Acceptable proficiency is a difficult term to define since it could have many different meanings in a variety of contexts. Proficiency is characterized by purposeful, planned, accurate, and precise behaviour. The crucial factor in the definition of physical awkwardness is the discrepancy between the attained skillfulness of awkward children and the skillfulness of the majority of their peers (Wall, 1982).

The problems associated with being labeled physically awkward may seriously affect the general well-being and motor skill development of these children. Wall (1982) and Whiting, Clarke, and Morris (1969) note that awkward children may be excluded from social play and game situations and thus withdraw from other group situations. Physical awkwardness in play situations is difficult to disguise from peer group members. As a consequence, physically awkward children are often ridiculed by their peers (Gordon & McKinlay, 1980). In time, the child's peers label him or her as physically awkward and exclude that child from group play situations.

The child ultimately becomes disinterested in performing any skilled action or physical activity openly, and a correspondingly low level of fitness results (Wall, 1982). Wall suggests a need for further theoretical and program development research on the assessment, prescription, instruction, and leisure counselling of physically awkward children.

There have been many definitions of a physically awkward child presented in the literature. There is no universal definition of physical awkwardness that has gained consensus among researchers in the area. Nevertheless, all authors agree that the physically awkward child must receive more attention. The development of appropriate assessment, prescription, and remediation for these children should be stressed in future research. There remains however, a number of constraints to movement that interact to help or hinder the individual during performance.

## Constraints to Movement

Coordinated, effective, goal-directed movements are only possible because of the predictable features of biomechanical, physiological, environmental, morphological, and perceptual factors. Each of these five areas will be reviewed as they pertain to the development of motor skills. An understanding of the constraints underlying 'normal' motor development should be helpful when attempting to identify, evaluate, and remediate awkward children.

Biomechanical Constraints

The coordination and control of the body and limbs during skilled movement reflects an optimal interplay of internal and external forces, including those of the environment, the activity of the individual, and the reactive forces that emerge from interaction between the individual and the environment. The impact of environmental constraints on movement control is considerable. The major environmental constraint is gravity. Human actions must accommodate gravitational forces and, where possible, use the force supplied by gravity to advantage (Newell, 1984). Gravitational forces act on an individual in any medium in which the activity is being performed. The gravitational force varies at different altitudes, with the gravitational force decreasing as elevation increases.

The atmosphere and surface with which the individual interacts can also produce varying environmental forces that need to be integrated with those derived from muscular output. These physical constraints probably do not affect the development of the individual's activities since they remain fairly constant (Newell, 1984). Reduced frictional qualities are exhibited by slippery surfaces such as freshly waxed kitchen floors, icy walkways, and ice skating rinks. Increased friction is imposed by heavy rugs, grass lawns, and artificial turf. With experience, and the ability to adapt to changing surfaces, the individual can adjust to produce effective movement.

Skilled action reflects the optimal confluence of organismic and environmental forces for the specified activity. A characteristic feature of skilled performers is that they integrate, to advantage, the forces in the environment itself, with those forces that result from the body's interaction with that environment (Newell, 1984).

The significant proportion of mechanical variation in the development of motor skills is due to the growth of the individual in terms of height, mass, and individual limb length and mass. The changes in body form and muscular strength that accompany development must be considered when theorizing about the coordination and control of body and limbs in support of action (Newell, 1984).

One major impact of the change in the absolute and relative sizes of body parts is on the moment of inertia of each body part. The moment of inertia of each body part can be viewed as an index of its resistance to angular acceleration. The only examination of the effects of growth on the moment of inertia of children's body parts was conducted by Jensen (1981). Jensen selected 12 Caucasian boys so that one endomorph, one mesomorph, and one ectomorph were examined at the ages of 4, 6, 9, and 12 years. The children were somatotyped (Heath & Carter, 1967), and the principal whole body moment of inertia calculated, using standard biomechanical procedures at the beginning and end of the 12 months. The results of Jensen's (1981) analysis showed that as a consequence of growth changes, the moment of inertia of the centroidal transverse axis reflected individual increases ranging from 12% to 57% (mean 30.8%), while the increments for the longitudinal centroidal axis varied from 8% to 92% (mean 33.5%). The percentage changes in moments of inertia for most of the children far exceeded the percentage changes in age, height (mean 4.7%), and mass (mean 15.8%). Jensen proposed that the best indicator of the constraints on rotational movements imposed by growth was the product of the mass and the square of the standing height. Jensen found no relationship between body type and the amount of change in the moment of inertia and concluded that strength gains generally have to be proportionately greater than length and mass gains to maintain parity in performance during physical growth. Caution has to be taken when interpreting Jensen's results due to the small number of subjects used in his study.

Physiological Constraints

Studying the physiological constraints of motor control offers a guide to the functional complexity of the neuromuscular system. Although brief and not totally inclusive, this review should present an understanding of the complex arrangement of the neuromuscular system and its influence on motor control and movement.

One physiological change that tends to correlate with brain growth and general functioning of the individual is myelination of cerebral neuronal axons. The process occurs in a definite sequence with respect to the pathways involved in the development of fundamental activities outlined by Wyke (1975). Myelination continues until adolescence, but many efferent and afferent pathways involved in movement control remain unmyelinated. The efferent and afferent pathways transmit neuronal impulses to and from the peripheral musculature, respectively, so that the efferent pathway is sometimes labeled motor outflow and the afferent pathway the sensory return. Myelination increases the diameter of the nerve fiber systems and hence the conduction velocity of the impulses of the central nervous system (e.g., the Babinsky reflex). The increase in conduction velocity that follows myelination of nerve fibers has sometimes been advocated as the basis for the faster reaction time observed through the passage of childhood (Hodgkins, 1963). This growth period, however, is also associated with exponential increments in body size, thus lengthening the communication distance between the cortex and the muscular apparatus. Wyke (1975) claims that these gains in body size are accommodated by myelination, so that reflex times remain relatively constant during childhood, even though voluntary reaction times decrease. Conduction velocity remains a modest constraint, however, with respect to temporal aspects of movement control, with motor outflow time from cortex to hand musculature being on the order of 10 msec for adults (Milner-Brown, Stein, & Lee, 1975).

The development of neuromuscular behaviour in the developing child is merely the temporal extension of a complex series of neurological processes that are genetically produced before the child is born (Wyke, 1975). Neurological mechanisms that produce and control bodily movement throughout the first year of each individual's biological existence are entirely reflex. These mechanisms involve changes in the patterns of activity of motor units that are determined by an increasingly varied array of afferent inputs fed into the neuraxis from the progressively differentiating and maturing receptor systems located in the various tissues of the body. During the first year of its biological existence a human organism does not move voluntarily; instead it is moved by the multitude of mechanical and chemical stimuli to which its central nervous system is continually exposed before, and immediately after birth. Only when some three months have elapsed after birth can 'learning' processes be said to be involved in the emergence of a baby's neuromuscular behaviour (Wyke, 1975). There are opposing viewpoints to the above claims by Wyke. (See, for example: Bower (1966); Bruner, Olver, and Greenfield (1966); and Goldie and Hopkins (1964)).

The role of reflexes as a prerequisite to human movement is still undergoing analysis. Zelazo, Zelazo, and Kolb (1972) have shown that exercising the stepping reflex during the first and second months of life can accelerate the onset of voluntary walking in infants. Lagerspetz, Nygard, and Strandwick (1971) made corresponding findings for crawling. Bower (1975) has demonstrated the role of experience in facilitating the onset of reaching and grasping skills. These findings suggest that specific experiences, in this case, exercising the reflex that forms the substrate for the voluntary activity, can facilitate the onset of fundamental skills. Mere activity or training does not always accelerate the voluntary control of a given skill (Gesell & Thompson, 1929), which indicates that the appropriate antecedent behaviour is an important determinant of the effects of experience on the development of motor skills. On the other hand, the exercise of the reflex may be just that, in the sense that it realizes all the traditional training benefits of exercise, particularly increasing muscular strength and endurance. Thus reflexes are important for the development of skills. Easton (1972) views reflexes as preorganized acts that may be activated by the higher levels of the central nervous system as all or part of a movement. Furthermore, reflexes may prime the relevant motor neurons for some postures of movements. For example, the tonic neck reflex (Hellebrandt, Rarick, Glassow, & Carns, 1961) may prepare movement in the direction of gaze and facilitate the speed of response. Conversely, reflexes may have inhibitory effects on response production, particularly if incompatibility exists between the reflexive postural set and the movement sequence.

The relationship between reflexes and stereotypic behaviours in the formulation of fundamental movement patterns has not yet been addressed. Basic responses to stimuli are reflective of the biological substrate of action, and their development provides both inhibitory and facilitative constraints to the organization of voluntary movement.

Environmental Constraints

The nature of skill acquisition during later stages of learning is a function of the type of environmental control under which the movement is performed (Gentile, 1972). Environmental constraints relate to the predictability of the spatial and temporal elements in the environment and the absence or presence of spatial and temporal changes between trials (Higgins, 1972, 1977). At one end of the continuum are those skills which take place under fixed, unchanging environmental conditions, called closed skills (e.g., bowling). Environments with high degrees of predictability are spatially and temporally certain; movements must thereby match the spatial characteristics. At the opposite end of the continuum are open skills (e.g., hitting a baseball), which take place in a dynamic spatial/temporal environment.

Environments which are spatially and temporally uncertain reduce the predictive qualities of the performer about the spatial and temporal events (Gentile, 1972; Higgins, 1977; Higgins & Spaeth, 1972). As skill acquisition progresses, the closed skill performer will evidence increasingly consistent movement patterns. In contrast, the open skill performer will develop a repertoire of movement patterns to match the particular environmental constraint under which performance proceeds.

Higgins & Spaeth (1972) investigated the nature of movement patterns developing during the acquisition of an open and a closed skill. Two ten-year-old males performed a dart throwing task. The subject performing the closed skill attempted 200 trials with the target apparatus stationary. Forty trials were filmed with a high speed camera and subsequently analyzed. The open skill subject also performed 200 trials but at six different target combinations. All trials were recorded on film and analyzed. Data collection was completed in five days. The results of the data indicated that open skills moved towards a diversity of patterns of movement matched to dynamic environmental conditions whereas the closed skill performer moved towards consistency in patterns of movement.

## Morphological Constraints

Morphological constraints are factors that relate to the overall structure and form of the organism and the relationship between structure and function. These constraints include such anatomic factors as skeletal arrangement and articular structure. In addition to these specific anatomic considerations, morphological constraints are also related to such perceptual processes as the sensory detection-processing system, pattern recognition, decision-making, and memory. Organismic variables are also included under morphological constraints. The organismic variables of age, sex, height, weight, and experience have a direct relationship to the nature of the movement produced for any skill (Higgins, 1977).

Structural morphological constraints include such factors as the structure, design, and composition of the skeletal system, muscles, tendons, and ligaments. These structures give the human body its form and provide the mechanism for production of movement. The morphological constraints imposed by the skeletal system relate to the length, size, and shape of bones and to the structural characteristics of articular surfaces and ligaments.

The muscular system of the body provides the forces by which humans are able to move. Most of the skeletal muscles cross one or more articulations and attach themselves to the bones via tendinous tissue. Movement of the body segments occurs at the articulations. The muscles of the body, therefore, produce forces which move a lever system consisting of links of bone. The morphologic constraints imposed by the structure of the muscle are related to three factors: the sensory-motor control properties; the general anatomic structure of the muscles and their related function; and the anatomic design of muscle placement on bones and across their respective articulations (Higgins, 1977).

The uniqueness of the pattern of movement for a particular performer for a specific task is a function of morphological constraints. Organized human movement entails compensating for these constraints.

Perceptual Constraints

Perceptual processes affect the organization of movement and they are directly related to specific structures and forms of the individual. Perceptual processes relate to sensory and motor structures and functions: sensory detection, storage, memory, translation, retrieval, and motor output. The perceptual processes required for performance of a skill depend upon the environmental conditions under which the skill is carried out (Higgins, 1972). A major perceptual variable the performer must control to achieve success when performing or acquiring a motor skill is the time lag inherent in the system (Higgins, 1977). Time lag is the system time required to receive internal and external environmental information, process this information, predict the spatial and temporal features of the object and thus anticipate where it will be at some point in the future, and generate a motor response that will coincide with the object.

Experience and practice aid the learner in accomplishing this series of tasks (Higgins, 1977).

The study of the development of motor skills from a behavioural approach is also recognized in this section on perceptual constraints. A more detailed analysis of the behavioural approach is presented in a following section on motor development.

Summary

The purpose of this section on constraints to movement was to outline ways in which various physical properties of both the human system and the environment constrain the control and coordination of the performer in skilled movement. A significant aspect of development, from the embryo to the adolescent, is that the physical properties of the system are dynamic. Thus, physical constraints of the human system and the environment are not stable or predictable from moment to moment.

Of the five sources of constraint to movement, environmental constraints produce the highest degree of variation in movement patterns within performers (Gentile, Higgins, Miller, & Rosen, 1975). These movement patterns reflect the uniqueness and variation inherent in the spatial and temporal properties of the environment. There is a constant interaction between the five constraints and regulation of these constraints is what produces skilled movement (Higgins, 1977).

## Motor Skill Acquisition

Wall (1986) views the developmental skill acquisition process from a four component perspective. He proposes that factors relating to the person, task, environment, and instructional strategies interact to either facilitate or hinder learning. Successful skill acquisition depends on the degree of congruency among these four key components. In terms of the person, it is important to assess the developmental skill level of the individual in terms of that person's knowledge about action. Wall, McClements, Bouffard, Findlay, and Taylor (1985) stress that declarative knowledge, procedural knowledge, affective knowledge, metacognitive knowledge, and metacognitive skills underlie the developmental level of an individual. Secondly, they contend that the degree to which a person has developed sport-specific or task-specific knowledge must be considered and also of importance is the stage of learning that an individual has achieved on a task-to-be-learned. The beginning stage, which requires the learner to get the idea of the movement, requires very different practice and instructional strategies from those that would be appropriate for the automatized phase of skill acquisition in which the learner is attempting to regulate the kinematic patterns associated with a given action or action sequence. The nature of the task must also be considered because a person will react substantially differently to a given task depending on whether it is response-loaded, perceptually-loaded, or cognitively-loaded. For example, an open skill such as tennis which is played in a highly changing environment under time-stressed conditions (cognitively-loaded) is very different in terms of task demands from a closed, response-loaded skill such as bowling. Thirdly, the type of environment in which a task is learned or performed will dramatically affect the performance of an individual. The fourth factor is the instructional strategies, and the experienced instructor utilizes information on all of these variables and their interaction with each other before selecting appropriate instructional strategies for intervention in the learning process.

The skill acquisition process which has been identified by Wall (1986) eventually leads to skilled motor performance. The learning of new skills, modifying styles and techniques, refining the movement pattern, developing consistency of performance, all relate to the acquisition and mastery of skill. The mastery of skilled actions by elite performers is a consequence of long, difficult, and often indirect circuitous pathways of extended practice and effort (Glencross, 1978). Glencross (1980) has identified four major characteristics of skilled motor performance: motor constancy, uniqueness of action, stability and consistency of action, and modifiability of action. Motor constancy is the ability of the motor system to produce a wide range of goal-directed movements that are identical or closely related, but utilize different muscles and movements. Uniqueness of action involves motor actions of the same response or action pattern that are not identical on successive trials or occasions. Over repeated trials the spatial/temporal pattern of an action occurs within a certain bandwidth of variability. Stability and consistency of action suggest that the more skilled the performer, the more stable the temporal arrangement of actions. This feature is associated with specific styles of a performer. Modifiability of action refers to movements which are continually modified and amended in response to the environmental changes introduced to the performer (Glencross, 1980).

Many different abilities are required for an individual to move skillfully. Skilled movement does not just happen, but must be moulded and shaped to attain a level of acceptable proficiency. Practice is important for the development of motor skills (Adams, 1971; Schmidt, 1975; Wall et al., 1985), however, the appropriate type of practice to increase skill level must be considered (Gentile, 1972).

Outcomes and actions can be achieved by a variety of means. Thus we are confronted with the question of how a vast array of possible movement patterns might be stored, accessed, and retrieved in the brain. There have been various theoretical approaches in which the learning and development of motor skills have been characterized or explained in the past fifteen years. These behavioural theories can be categorized as follow: open-loop, closed-loop, schema, information processing, and a knowledge-based approach. An explanation of each theory will be presented as it corresponds to motor development.

## Behavioural Theories of Motor Development

Open-loop control (e.g., a traffic control light) (Adams, 1967, 1968; Adams & Bray, 1970; Lashley, 1917) usually operates via a set of prestructured commands that carry out various actions without the use of ongoing information about the nature of the system's output (Schmidt, 1980). Adams (1971) suggests that an open-loop system has no feedback or mechanisms for error detection and regulation. The input events for such a system exert their influence, the system effects its transformation on the input, and the system has an output. The system is inflexible since it has no compensatory capability.

In contrast to the open-loop system, a closed-loop system (Adams, 1971) utilizes information from the element of the system being controlled, the 'computation' of an error indicating the direction and/or the extent of deviation of the system's output from some reference of correctness, and the correction of this error. A closed-loop system's major function is to minimize the extent of error in terms of the deviation of the system's output from the reference of correctness (Schmidt, 1980).

The frame of reference of Adam's (1971) closed-loop theory is the instrumental learning of simple, self-paced, graded movements, like drawing a line. The theory proposes two states of memory termed the memory trace and the perceptual trace. The memory trace is responsible for initiating the movement, choosing the movement's initial direction, and determining the earliest portions of the movement. The strength of the memory trace is developed as a function of knowledge of results (KR) and practice. The perceptual trace is responsible for guiding the limb to the correct location along the trackway in positioning responses. The perceptual trace is formed from past experience with feedback from earlier responses and represents the sensory consequences of the limb being at the correct endpoint. During the movement, the subject compares the incoming feedback against the perceptual trace to determine if the limb is in the correct final location. If the limb position is correct, the subject stops responding, and if it is not, the subject makes a small adjustment and the comparison is made again until the limb is in the correct location. With increased exposure to feedback and KR, the perceptual trace is strengthened, and the individual becomes more precise and confident in responding (Adams, 1971).

A different approach to discrete motor skill learning was proposed by Schmidt (1975). To correct for the shortcomings (storage problem, novelty problem, and error detection problem) of the existing open- and closed-loop theories in earlier motor learning studies, Schmidt (1975) developed his theory of schema. He adopted many of his major ideas from previous researchers (Adams, 1971; Bartlett, 1932; Pew, 1974) and incorporated them into this theory. A schema may be thought of as networks or packets of interrelated knowledge within a given domain (Wall et al., 1985). Schmidt's (1975) schema theory postulates two separate states of memory, one for recall and one for recognition. Basically, when an individual makes a goal-directed movement, four details are stored: the initial conditions, the response specifications, the sensory consequences, and the actual outcome. The specific roles of recall and recognition memory depend slightly on the type of task, but basically the recall memory is the state responsible for the generation of impulses to the musculature that carry out movement (or concomitant corrections), while recognition memory is the state responsible for evaluation of response-produced feedback that makes possible the generation of error information about the movement. Therefore, the recall schema is the relationship built up over past experience between the actual outcome and the response specifications. The recognition schema operates in an analogous way, but the variables of concern are initial conditions, sensory consequences, and actual outcomes (KR). On each trial, the sensory consequences and actual outcome are paired and are used to develop the relationship between sensory consequences and actual outcome (Schmidt, 1975).

Any new theory stimulates concomitant criticisms that arise with the developing research. The schema theory proposed by Schmidt (1975) has several problems associated with validating the recall and recognition schemas. Van Rossum (1980) noted problems associated with the recall schema notion, specifically the differential effect of experimental manipulation, similarity of tasks, and extra practice. Shapiro and Schmidt (1982) suggest problems associated with validating the recall schema concept. They express concern that the underlying motor program representations may not be as the theory has assumed. These studies have necessitated revised and inspired thinking by Schmidt and his colleagues on the schema concept.

Norman and Shallice (1980, 1986) propose a different concept in their theory of action in motor development. Schemas play a major role in this theory as they store packets of knowledge which develop through mental and physical practice. Schemas can be in one of three states: dormant, activated, or selected, with the usual state of the schema being dormant. In the dormant state the schema does not play an active role in current processing but resides within the permanent memory store. When a schema is brought to a state of readiness and given an activation value, it is said to be activated. Selected schemas are those that have sufficient activation to exceed their own threshold and thus control internal processing and external movement actions.

There are two factors controlling action sequences, depending on the amount of conscious control required. Horizontal threads represent action sequences that require minimal attentional control because they are well learned. Vertical threads represent deliberate attentional control and indirectly influence each other.

For well learned tasks, an autonomous strand of processing structures and procedures can usually carry out the required activities without need for conscious control. Component schemas are selected, in part, according to how well the 'trigger conditions' of the schema match the contents of the 'trigger data base.' Such a sequence is often characterized by a relatively linear flow of information among the various psychological processing structures and knowledge schemas involved: a horizontal thread (Norman & Shallice, 1980).

A basic constraint that Norman and Shallice include in their model is that priority in the schema selection process must be based on the single variable of the amount of activation associated with a given schema. Three major activational influences act upon a given schema within a horizontal thread: vertical threads, contention scheduling, and trigger condition influences.

When attention to a particular task is required, vertical threads are activated. Attention operates upon schemas only through manipulation of activation values. Thus attentional processes oversee and bias ongoing action by alteration of activation values. Motivational variables are assumed to play a similar role in the control of activation, by working over longer periods of time.

Contention scheduling is the mechanism that is proposed to resolve conflicts between simultaneous action in cooperative acts and the problems associated with simultaneous action in conflicting ones. The proper timing of schema selection is under the control of trigger conditions that must be exactly met before schema selection occurs. The adequacy of the match between the existing environmental conditions and the trigger specifications determine the activation level that is generated.

The Norman and Shallice (1986) model addresses the performance of skilled action (effective goal achievement with a high degree of consistency). It depends, however, on learning processes such as mental and physical practice, feedback, and deliberate attentional control. The supporting evidence for this theory of action is somewhat lacking and no genuine research to support or refute the theory has yet been presented in the published literature.

The above theories are concerned with the learning and development of motor skills for typical children and adults.

The absence of theories to explain motor learning and development for awkward children led to the development of the knowledge-based approach by Wall et al. (1985).

Wall et al. (1985) developed a holistic model of the development of skilled action. These authors emphasize the importance of an integrated knowledge base which includes procedural, declarative, affective, and metacognitive knowledge about action. A detailed explanation of the knowledge-base theory is presented because the studies outlined in subsequent sections are based primarily on this theory.

Procedural knowledge underlies the performance of skills within a given domain. In the motor domain, procedural knowledge underlies all aspects of an action including the perceptual, cognitive, response initiation, and execution phases (Singer, 1980; Stelmach & Diggles, 1982). The execution of any motor skill depends on the use of this procedural knowledge that has been acquired through learning and experience. Hence, the repertoire of motor skills that children develop depends on the quality and quantity of practice that they have experienced. By definition, physically awkward children are deficient in such procedural knowledge about action.

Declarative knowledge about action refers to factual information stored in memory which will influence the development and execution of skilled action. As children grow older, they gain more experience in the use of actions and the objects that their actions influence. As their declarative knowledge base increases they begin to attach conceptual meanings to their actions and these verbal concepts, in turn, allow them to more readily control their actions. This interplay between procedural and declarative knowledge seems to be at the heart of the skill learning process. Thus, the ability to integrate different types of knowledge about action seems to be essential for the optimal learning and control of motor skills. Unfortunately, physically awkward children often have developed a very limited procedural and factual knowledge base in the action domain. This is not surprising given the fact that they have limited experience in physical activity settings.

Affective knowledge is the third type of knowledge about action that children develop. Every action that children perform or attempt to perform is executed within a given context. As children gain procedural and declarative knowledge they attach subjective feelings to their actions and the situations in which they perform them. In a sense, a major goal of human motor development is the acquisition of the competence and confidence to act independently in the world. Affective knowledge certainly influences the acquisition of procedural and declarative knowledge about action. Again, clinical experience indicates that physically awkward children often have very negative feelings about themselves in action situations. In fact, as noted above, many of them are reticent about being involved in culturally-normative play and sport situations (Clifford, 1985; Wall et al., 1985).

Metacognitive knowledge and skills reflect higher level declarative and procedural knowledge about action. Metacognitive knowledge refers to knowing about what one knows. Physically awkward children often have a relatively limited metacognitive knowledge base simply because they have developed less procedural and declarative knowledge about action. In the same way, they often exhibit difficulty in planning, monitoring, and evaluating action; that is, they have very inefficient metacognitive skills.

Thus, physical awkwardness is viewed as a developmental problem which stems from a lack of acquired knowledge in all five types of knowledge about action. Support for the knowledge-based approach (Wall et al., 1985) to motor development has yet to be produced. There has been one longitudinal study of three years in an elementary school setting and some clinical experience to support the acquisition of procedural knowledge by physically awkward children (Wall et al., 1985). Measurement and evaluation techniques using the knowledge-based approach which adequately assess the capabilities of physically awkward children need to be developed. Also, there exists a need for physical skill tests which accurately and reliably reflect the real differences in motor development between physically awkward and typical children (Wall et al., 1985).

Summary

There are numerous and diverse motor learning theories presented in the published literature. Each theory adopts a particular position and attempts to explain motor learning and development in skill acquisition. Each theory has its particular strengths and weaknesses, with research generated to either accept or refute the respective theory. Some of the theories are recent, and therefore have been subject to limited published research.

A theory of how movements are learned must be based on the understanding of how movements are controlled. A motor learning theory that does not explain how movements are learned will fail to provide an understanding of the motor learning process. For example, almost nothing is known about how a complex series of muscular contractions (e.g., playing a musical instrument or pole vaulting) associate so effectively and efficiently into a single unit (Shapiro & Schmidt, 1982). When the motor learning theory explains this phenomenon, the first step will have been taken towards designing proper learning environments for the performer.

## Physically Awkward Children

There has been limited published research regarding the acquisition and development of motor patterns of physically awkward children. The majority of research has used typical children as they grow and develop motor patterns to fit the situations in which they find themselves. The available research on physically awkward children has been concerned primarily with the identification and remediation of these children into the normal patterns of society.

Research conducted on typical developing children, with an emphasis on the kinematics of movement patterns and the consistency of movement will be outlined as it relates to skillful performance in order to present a basis for comparison with physically awkward children. The few studies that have been conducted on physically awkward children will be presented in a following section.

Motor Development in the Typical Child

It would seem logical that the key to skillful performance in any situation is the consistency and stability of movement performance over time (Glencross, 1980). There are variations in movement that do occur across trials, but the ability of the observer to recognize individual styles in a multitude of skills attests to their consistency and stability (Wall et al., 1985). There is a major criticism of consistency, however, as an indicator of skillful performance. Consistent performance may not be equivalent to good or acceptable performance; for example, errors in technique and timing may be displayed by the performer with increasing consistency. The investigator or teacher examining the results or watching the performer has to guard against consistent patterns of movement with error introduced somewhere along the chain. The error has to be removed so that meaningful (i.e., goal-directed) movements can occur. Schmidt (1976) has found that the time to relearn a correct movement after practicing an error filled movement is approximately one-half times longer than if the subject had learned the correct movement response in the first place.

Recent descriptions of motor skill development have used the term 'stages' to represent the regular transformations in spatial/temporal organization which purportedly occur in motor skills over time (McClenaghan & Gallahue, 1978; Seefeldt, 1980; Wickstrom, 1970). Wohlwill (1973) has pointed out, however, that the 'stage' designation implies generality in development across several tasks; intra-task developmental levels should be called 'steps' to avoid confusion with the broader stage concept (Roberton, 1978). One task of the motor development researcher is to determine the degree to which any developmental sequence is universal, invariant, and stable (Wohlwill, 1973). Universality means that all people pass through all steps of the sequence. Invariance means the sequential order is irreversible. Stability means that people at a given step of sequence will exhibit movements predominantly from that step and that people in transition will show movements characteristic only of adjacent steps in the hierarchical order.

Roberton (1977, 1978) has demonstrated a scheme for evaluating the universality and invariance of her hypothesized developmental sequences. The procedure involves two phases. The first phase is a pre-longitudinal screening of the developmental sequence by examining age-matched subjects' movements across trials at one point in time. The second phase is longitudinal research to provide additional testing of the developmental sequences. The second phase would be necessary only if there was no across-trial invariance or stability.

This paradigm has been used by Roberton in her studies of the developmental sequence of the overarm throw. A pre-longitudinal screening of 73 first grade children to describe motor stage stability was conducted by Roberton (1977). Forty-two males and 31 females (6.4-8.0 years) performed 10 trials of a forceful overarm throw. Two high speed cameras operating at 64 frames/s recorded the action, one camera from the rear; the other camera from the side. Three practice trials preceded the film trials. The subsequent analysis of the film trials provided information on the hypothesized categories in each of two components studied (action of arm and pelvis-spine). Prior to data reduction, the investigator and a trained observer independently categorized thirty randomly selected trials from the data. Inter- and intra-observer reliability were .95 or better. The results indicated that developmental categories, hypothesized to be arm action stages in the throw, met the three stage criteria of stability, intransitivity, and universality; all subjects had at least 50% of their trials in one category (stability) and all variation across trials was only to adjacent categories in the hypothesized stage ordering (intransitivity). These categories were, therefore, ready for longitudinal testing. Stage categories hypothesized for action of the pelvis-spine in the throw did not meet the same criteria; one child had less than 50% of his trials in one category, and several children showed variation to non-adjacent categories. From the results, however, a new stage ordering for pelvis-spine action was proposed.

Roberton (1978) extended her pre-longitudinal screening experiment to a longitudinal study to determine if her hypothesized developmental sequences for the arm, forearm, and pelvis-spine would be supported. The results from her study indicated that over three years of analysis, of 54 children examined, 43% showed arm change and 35% showed progressive change. Half the children retained the same arm action that they had used in the first year of the study. For the forearm, 26% showed stage progression in the order hypothesized; 15% regressed in the order hypothesized; and 59% showed no development over three years. The pelvis-spine data showed that 41% progressed or regressed in the order predicted; 4% skipped categories; and 56% did not change. Of the 54 children studied, 6% showed progressive change in all three components over three years; 20% progressed in two components; 39% progressed in one component; and 35% showed no change or regressed in at least one component. Roberton suggested that the movement components did not develop in a parallel, lock-step fashion, nor did they change in the same relationship from person to person. The issue of stages, then, must be confined to the ordering within the components rather than to the total body configurations.

One difficulty with Roberton's longitudinal testing (Roberton, 1978) was that development in the three components studied (action of arm, forearm, and pelvis-spine) occurred slowly during the years examined (kindergarten through second grade). While all children moved through some of the developmental steps in the order hypothesized, few children went through all levels in the three years. Roberton realized that a much longer longitudinal study was needed to provide additional testing of her hypothesized sequences.

Halverson, Roberton, and Langendorfer (1982) continued the research initiated by Roberton (1978). An extension to the previous study was planned to increase the longitudinal, descriptive information on the overarm throw available on the 54 children in seventh grade. The purpose of their study was threefold: to verify the accuracy of the yearly predicted rate of change in ball velocities, to assess subsequent changes in the children's throwing movements, and to compare the amount and type of throwing experience which the boys and girls would report. The average age of the 22 seventh grade boys and 17 girls was 12 years 11 months and 13 years respectively. The film and ball velocity data collection procedures used when the children were younger (Roberton, 1978) were repeated at seventh grade. The results of this study suggested the following conclusions about the development of the overarm throw. The overarm throw is not fully developed in seventh graders. Sex differences in the development of the throw included: different values for the annual mean rate of change in horizontal ball velocities (5-8 feet/s/yr = 1 development year for boys; 2-4.5 feet/s/yr = 1 development year for girls). These differing rates of change leave the girls approximately five years behind the boys by seventh grade. Potentially different levels of within-group stability across the years were evident, with girls more likely to retain their relative group position. Different rates of development in the motor components of the throw were also evident, with the boys being 5-6 years ahead of the girls. Lastly, boys reported greater participation in throwing than girls over the elementary/middle school years.

The research by Roberton and colleagues suggests that motor skill development does not advance in whole 'chunks', but rather in a step-like progression within certain aspects of the kinematic chain. Their research indicates that there are different developmental patterns for the arm, forearm, and pelvis-spine and that skillful performance does not emerge rapidly but is time consuming and is moulded through practice.

A biomechanical approach was used by Seefeldt and Haubenstricker (1982) to divide the developmental process into stages, from its most rudimentary to its most mature form. They observed tasks as they were performed by numerous children from 1 to 12 years of age. The ultimate criterion of 'mature' performance was defined by observing the task as it was performed by highly skilled adult athletes. The shift from one stage to another was characterized by an abrupt change in the positioning of one or more limbs or body segments in relation to their previous position in the sequence of joint actions. This change in position within the series of joint actions always resulted in the potential for the task to be performed more proficiently by permitting one or a combination of the following to occur: permitting a greater range of movement around the force-producing joints; adding more rotating joints to the 'power train'; permitting greater 'flow' or less interruption of the movement; and better positioning of the body for a maximum production of force (Seefeldt & Haubenstricker, 1982).

Seefeldt and Haubenstricker (1982) explained that their stages describe the total body configuration during the performance of a skill. They agree with Roberton (1978) that all of the patterns or subroutines within their defined stage do not advance as an indivisible unit. They have found, however, sufficient cohesion between certain of these subroutines so that listing them within a stage best describes a particular developmental task.

Another concept of stage theory has been developed by Wickstrom (1970) who also used a biomechanical approach to study motor development. He suggested that the changes in motor patterns in some fundamental skills are better expressed in terms of broad developmental trends rather than clearly defined stages. Trends are usually indicated as changes in a particular part of the movement pattern over an extended period of time. They can be described in terms of timing, range of motion, changes in joint angles, segmental interrelationships, segmental velocities, and angular velocities. Stages and trends are not mutually exclusive interpretations of improvement in developmental motor patterns. Both can be used satisfactorily to describe certain aspects of improvement for a particular motor skill.

Developmental stages and developmental trends signify progress toward mature skill patterns. The stages are not steps upon which all children must tread on their way to the mature pattern and the trends are not smooth, sure progressions for all children. The type of progress varies from one child to another and the rate of progress tends to be variable. Knowledge of the kinds of patterns the child uses prior to achievement of mature form (mature has been defined by Wickstrom (1970) as 'patterns exhibited by highly skilled performers' (p. 12)) has several practical values. It establishes the identity of immature movements and patterns, assists in setting expectations for skill development, and helps in evaluating progress (Wickstrom, 1970).

It is evident that Wickstrom (1970) and Seefeldt and Haubenstricker (1982) agree with respect to observing and delimiting fundamental motor patterns. Wickstrom (1970) establishes both views with the following statement: 'In general, the fundamental motor pattern can be thought of as a broad model of good forms which is not exclusively encumbered by minute detail' (p. 13). The young child should not be viewed as a miniature adult who therefore has not developed the subtleties of the skill as performed by highly skilled athletes. Roberton's (1978) approach to motor skill analysis is more detailed. She decomposes segmental movement into its respective actions along the chain. Although the approaches are somewhat different, each of these researchers is striving towards identifying underlying aspects of motor development.

Motor Development in the Physically Awkward Child

Research conducted using physically awkward subjects is not abundant in the literature, however, existing studies are presented. Also, research dealing with the motor development of mentally handicapped children might provide some insight in this area and is thus included in this review.

Seventy boys (aged 8-10 years) with no known medical limitations or disabilities were observed by Morris and Winter (1975). The boys were ranked by the physical education teacher according to their scores on items of Keogh's (1966) physical performance test and their abilities in a variety of tasks that form part of the normal physical activities in school. A group of ten boys at the lower end of the scale were judged by their teacher to be motor impaired. A second group of ten boys was selected at random from a normal distribution according to height, weight, and IQ scores. Stott's (1966) test of motor impairment was then administered individually to both groups of boys in order to compare its screening efficiency with that of the teacher's assessment. The investigation showed that of the ten children considered motor impaired by the teacher's assessment, five were identified as being impaired according to Stott's (1966) test. Failure of the test to screen half of the children considered to be motor impaired by the teacher casts some doubt upon its validity. Similar results were observed by Whiting, Clarke, and Morris (1969). To alleviate this difficulty, Morris and Winter (1975) suggested that adjustments and a possible reduction in the number of subtests and a refinement of the scoring system in Stott's (1966) test might prove worthwhile in identifying and assessing motor impairment in children at school.

Keogh et al. (1979) used three different procedures to measure clumsiness in movement skills and movement-related behaviors. The first procedure was a 29-item checklist developed for both questionnaire and interview use. The second procedure was observation of boys in physical education activities during two instructional sessions of 30 minutes each. The boys were rated using an eight-point scale on movement skills and movement behaviors. A five-item test used to measure movement skills was the third procedure. A total of 54 (34 normative-RS-F and 20 movement problem-MP) kindergarten and first grade boys were the subjects used in this study. A somewhat different set of boys was identified as physically awkward by each procedure. There was also an inability to identify as physically awkward more than 20-30% of boys in the MP group. The authors suggested that research considerations require existing data on physically awkward children be viewed with caution since the attributes of clumsiness has not yet been assessed or identified in a consistent manner.

Roberton and DiRocco (1981) extended the research efforts of Roberton (1978) by applying her hypothesized throwing sequence to mentally retarded populations. They studied 22 mentally retarded (MR) persons of which 11 were educable (EMR-6-8 years), five were trainable (TMR-5-8 years), and six were severe-profound (PMR-13-16 years) mentally retarded. The data collection techniques were similar to Roberton's earlier studies (Roberton, 1977, 1978). The results indicated that two new arm action profiles would have to be added in the developmental sequence for developmentally primitive throwers (either very young children or those developmentally delayed). No movements were observed that could not be categorized developmentally. The EMR/TMR children tended to be developmentally delayed but not as much as achievement scores (ball velocity) alone suggested. The PMR children were considerably delayed. This study indicated that the developmental stages in the overarm throw for force are exhibited by all types of children in their general motor development regardless of cognitive processing ability.

A similar study was conducted by Jensen and Prud'homme (1980). The purpose of their investigation was to use vector representation of reaction forces to analyze the consistency of performance of a standing broad jump in a learning disabled child and to compare the results with those of a more typical child of similar age, height, and weight. The whole body profiles for mass distribution and moments of inertia (Jensen, 1976, 1978) were found to be similar. A mathematical model of 14-linked-segments was used to represent the body for the kinetic analysis of the jumping performance of the two boys. The subjects practiced the jump under simulated filming conditions and then performed five consecutive jumps, the first three of which were filmed for analysis. Filming was conducted at 100 Hz with a Locam camera and the data sampled at 50 Hz. The results indicated that the learning disabled child was inconsistent in his jumping performance, whereas the more typical child showed consistency across trials. The authors suggested that consistency of performance of motor tasks be investigated in learning disabled children.

Henderson and Hall (1982) reported on the results of a two-year investigation of clumsiness among children in normal schools. Teachers in four schools for normal children aged between five and eight years identified 20 children from a total of 400 who met the following criteria: had poor motor coordination for their age, and whose poor motor coordination was affecting their schoolwork. The teachers' assessments were compared with those of a paediatric neurologist and a psychologist, and were shown to be very accurate. The group of children identified as clumsy scored significantly poorly in relation to a control group on several measures of motor performance, and had a higher incidence of other educational and social problems. The heterogeneity of the group emphasized the difficulty of identifying a specific syndrome of clumsiness in children.

<u>Summary</u>

The studies reviewed above have pointed out significant difficulties in motor skills exhibited by physically awkward and handicapped children. More research is required to elucidate the nature of those difficulties and improve the processes of identification, instruction, and remediation of physically awkward children.

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## II. Kinematic Analysis of Skill Acquisition in Normal and Physically Awkward Boys Performing a Hockey Skill[1]

Movement plays an important role in the lives of most children. Movement competence early in development allows children to explore their environment, while later on it facilitates social development through participation in different types of play and sport experiences. The joy of moving and interacting with the environment is experienced by many children; however, a significant number of school-aged children experience serious difficulties in learning motor skills; some of these children have been referred to as physically awkward (Wall, 1982). Gubbay (1975) and Keogh (1968) suggest that physically awkward children may comprise 6% of school-aged children. Wall and Taylor (1983) indicate that the incidence of physical awkwardness in school-aged children may be as high as 9%.

Wall (1982) defines physically awkward children as those 'children without known neuromuscular problems who fail to perform culturally-normative motor skills with acceptable proficiency' (p. 254). Culturally-normative skills, such as playing hockey or basketball in North America, are generally acquired within a specific culture at certain ages by a majority of people. Acceptable proficiency in these skills is

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characterized by purposeful, accurate, and precise behaviour, and varies with the age, sex, physical activity context, as well as the socio-cultural environment of the individual. In fact, children's proficiency in these culturally-normative skills usually increases with age and reflects the increasing complexity of their educational, social, and recreational environment.

In play situations, physically awkward children have great difficulty disguising their lack of motor proficiency from others. As a consequence, they are often ridiculed by their peers (Gordon & McKinlay, 1980). In time, their peers may label them as 'clumsy' and often exclude them from group play situations. Thus, it is not surprising that physically awkward children ultimately decide to avoid participating in physical activity especially in public settings (Gordon & McKinlay, 1980; Whiting, Clarke, & Morris, 1969).

Unfortunately, this choice to avoid physical activity results in a lack of practice of the very skills such children need to enjoy participating in culturally-normative play and sport environments. Such reduced practice time inhibits skill development and heightens the performance differences which already exist between physically awkward children and their peers. If the withdrawal behaviour is allowed to continue, a significant decrease in physical fitness can be expected (Wall & Taylor, 1983). The delay in motor development produced by the combination of physical awkwardness, reduced participation in physical activity, and the ensuing loss of fitness can also generate negative social consequences. In fact self-confidence may become so eroded that physically awkward children develop a pattern of disruptive behaviour in an attempt to mask their movement difficulties (Gubbay, 1975; Keogh, Sugden, Reynard, & Calkins, 1979).

A systematic investigation of the problems faced by physically awkward children must be based on a sound theory of general motor development. A comprehensive approach to motor development that emphasizes the importance of knowledge about action and how learning contributes to the development of that knowledge was proposed by Wall, McClements, Bouffard, Findlay, and Taylor (1985). These authors emphasize the importance of an integrated knowledge base which includes procedural, declarative, affective, and metacognitive knowledge and skill about action.

Procedural knowledge underlies the performance of skills within a given domain. In the motor domain, procedural knowledge underlies all aspects of an action including the perceptual, cognitive, response initiation, and execution phases (Singer, 1980; Stelmach & Diggles, 1982). The execution of any motor skill depends on the use of this procedural knowledge that has been acquired through learning and experience. Hence, the repertoire of motor skills that children develop depends on the quality and quantity of practice that they have experienced. By definition, physically awkward children are deficient in such procedural knowledge about action.

Declarative knowledge about action refers to factual information stored in memory which will influence the development and execution of skilled action. As children grow older, they gain more experience in the use of actions and the objects that their actions influence. As their declarative knowledge base increases they begin to attach conceptual meanings to their actions and these verbal concepts, in turn, allow them to more readily control their actions. This interplay between procedural and declarative knowledge seems to be at the heart of the skill learning process. Thus, the ability to integrate different types of knowledge about action seems to be essential for the optimal learning and control of motor skills. Unfortunately, physically awkward children often have developed a very limited procedural and factual knowledge base in the action domain. This is not surprising given the fact that they have limited experience in physical activity settings.

Affective knowledge is the third type of knowledge about action that children develop. Every action that children perform or attempt to perform is executed within a given context. As children gain procedural and declarative knowledge they attach subjective feelings to their actions and the situations in which they perform them. In a sense, a major goal of human motor development is the acquisition of the competence and confidence to act independently in the world. Affective knowledge certainly influences the acquisition of procedural and declarative knowledge about action. Again, clinical experience indicates that physically awkward children often have very negative feelings about themselves in action situations. In fact, as noted above, many of them are reticent about being involved in culturally-normative play and sport situations (Clifford, 1985; Wall et al., 1985).

Metacognitive knowledge and skills reflect higher level declarative and procedural knowledge about action. Metacognitive knowledge refers to knowing about what one knows. Physically awkward children often have a relatively limited metacognitive knowledge base simply because they have developed less procedural and declarative knowledge about action. In the same way, they often exhibit difficulty in planning, monitoring, and evaluating action; that is, they have very inefficient metacognitive skills.

Thus, physical awkwardness is viewed as a developmental problem which stems from a lack of acquired knowledge in all five types of knowledge about action. The major purpose of this exploratory study was to examine differences in the procedural knowledge base of physically awkward children and their age-matched peers. The specific skill selected for study was the culturally-normative stationary hockey slap shot. The first purpose of this study was to examine the performance differences between the two subject groups. The second purpose was to investigate the pattern of performance changes which might accrue from 1200 practice trials of the slap shot by the two physically awkward children. Data collection and analysis constraints dictated the use of a case study design with its inherent limitations.

The knowledge-based theory is the most recently developed approach that examines the role of knowledge about action in motor development. The theory was based on the ideas of Brown (1975, 1977, 1978), Flavell & Wellman (1977) and Newell & Barclay (1982). The knowledge-based approach will be utilized to provide empirical support for the role of knowledge domains in the performance of the slap shot. The results of this initial study will concentrate on the role of procedural knowledge in the development of the stationary hockey slap shot. The interaction of the other components of knowledge is acknowledged, but they were not examined in this study.

## Method

Subjects

Two physically awkward boys and two control boys acted as the subjects in this study. As can be seen from Table II-1, the physically awkward boys were 7.0 and 8.2 years of age while the control boys were 6.3 and 7.2 years of age. Thus

**Table II-1. Height, Weight, and Age of Matched Subjects**

| Subject | Height (metres) | Weight (kg) | Age (years) |
|---|---|---|---|
| PA1 | 1.38 | 38.5 | 7.0 |
| C1 | 1.28 | 25.0 | 6.3 |
| PA2 | 1.37 | 36.5 | 8.2 |
| C2 | 1.25 | 24.0 | 7.2 |

Note: PA=Physically Awkward Subjects; C=Control Subjects

the physically awkward boys were slightly older than their control peers. The physically awkward boys attended the Motor Development Clinic at the University of Alberta. They were referred to the Clinic by their teachers and their parents had agreed that they would benefit from attending the remedial and counselling program at the Clinic. Both physically awkward boys had scored below the tenth percentile on at least three of the seven gross-motor items on the Motor Performance Test Battery (Taylor, 1982). They also scored below the tenth percentile on at least two of the six items on the Canada Fitness Test (Gauther, Quinney, Massicotte, & Conger, 1980). It is on the basis of such a profile analysis that children are accepted into the Clinic. The control subjects were selected at random on the basis of class lists from two elementary schools in Edmonton. Control subject 1 (C1) had played organized hockey for one year; however, the other control subject (C2) had no organized hockey experience. Furthermore, the physically awkward boys had no formal hockey experience and were taller and heavier than their control counterparts.

Procedure

The initial data collection session for each subject (physically awkward and control) consisted of performing the stationary hockey slap shot in the Sport Performance Unit (SPU) at the University of Alberta. The children were instructed to strike a sponge rubber puck as forcefully as possible toward a goal two metres wide by one metre high outlined on a wall five metres from the starting pad. Any puck that hit the wall within the goal boundaries was judged an acceptable trial. Three acceptable trials for each subject concluded the session.

A six-week practice program was implemented in an attempt to improve the performance of the slap shot by the physically awkward boys. After the initial data collection session, the physically awkward subjects practiced the slap shot at home, under the guidance of their parents, for the next two weeks. The parents were given instructions on key skill cues (e.g., hand placement on the hockey stick, height of backswing, puck placement with respect to the feet, amount of force to contact the puck, and how and where to aim the puck) that the children should attend to during practice. The practice session at home consisted of 40 trials per day on any five days of the week, generating a total of 200 practice shots per week. The physically awkward subjects returned to the SPU after the two week practice session to perform three more acceptable trials. The physically awkward boys then returned home to practice. Again, explicit instructions regarding practice were given to the parents. In addition, the experimenter demonstrated to the subject and his parents the practice protocol that was to be followed for the next two weeks. Over the entire six weeks, the total number of supervised practice slap shots performed at home by the subjects equalled 1200. The number of data collection sessions in the SPU equalled four (pre, after two weeks, four weeks, and six weeks practice).

Equipment

A Photo Sonics 16mm 1PL camera, equipped with an Angenieux 20-120mm lens and an internal timer, was used to record the slap shot performance of the first control subject and the two physically awkward subjects at a running speed of 100 Hz. The other control subject was filmed at 150 Hz. The camera was loaded with Kodak 7250 Video News film (ASA 400) and was positioned on a tripod 14 metres perpendicular to the plane of motion. The shutter angle was set at 30 degrees, exposure time of 1/1200 second, and the f stop was set at 4.

Three Colortran Quartz-King lamps (1000 watts each) and three Smith Victor K-33 lamps (600 watts each) were utilized to project sufficient light for the cinematography. Prior to filming, a light meter reading using a Pentax 1 degree Spotmeter VI was taken to measure the light conditions.

The films were projected via a Traid VR100 16mm film analyzer approximately 30% of life-size onto a Bendix Digitizing Board with a point accuracy of 0.01in (0.0254 cm). All subsequent input points (Humanscale 1/2/3, Diffrient, Tilley, & Bardagjy, 1974) were entered into a Hewlett Packard 9825B micro computer via a Hewlett Packard 9864A Digitizer and stored on magnetic computer tapes. The movement sequence was analyzed starting from the top of the backswing and ending well past puck contact to allow the data smoothing routine to operate properly. High frequency noise was reduced by a 2nd order bi-directional low pass filter (Walton, 1981) using an 8 Hz cut-off frequency (Pezzack, Norman, & Winter, 1977). The 8 Hz cut-off frequency was established from a visual comparison of several cut-off frequencies plotted with the raw data. The best fit with the raw data was the 8 Hz frequency level. Central differences (Miller & Nelson, 1973) were used to obtain the displacement-time histories of the performance variables. Absolute linear velocity of the puck (km/hr) and absolute angular velocity of the stick (rad/s) (dot product identity) were calculated from the data.

## Results and Discussion

**Two main questions were central to this study: Are there major skill performance differences between the physically awkward boys and age-matched control boys on the stationary hockey slap shot? What skill performance changes would result from 1200 trials of parent-supervised home**

practice of the hockey slap shot by the physically awkward boys?

The knowledge-based theory to motor skill acquisition was utilized to examine the performance differences between the subjects in this study. The knowledge-based theory was recently developed by Wall et al. (1985) and this study was an initial attempt to provide empirical support for the procedural knowledge base. In addition, only successful trials by the subjects were analyzed. Any puck that did not land within the boundary conditions was not subjected to further analysis.

Consistency of movement patterns has been utilized by some authors (Franks, 1980; Franks, Weicker, & Robertson, 1985; Franks, Wilberg, & Fishburne, 1982; Glencross, 1973, 1975; Higgins & Spaeth, 1972; Tyldesley & Whiting, 1975) to evaluate skill. The techniques for evaluating movement consistency vary; for the purpose of this study performance consistency was evaluated by visual inspection of the congruency between angular velocity curves of the hockey stick and the occurrence of peak stick velocity in relation to contact with the puck. In order to facilitate comparisons among the different subjects and trials, the angular stick velocities are presented on congruent Y axes ranging from 0 to 45 rad/s.

Figures II-1 and II-2 depict angular velocity patterns of the hockey stick for control subjects 1 and 2,

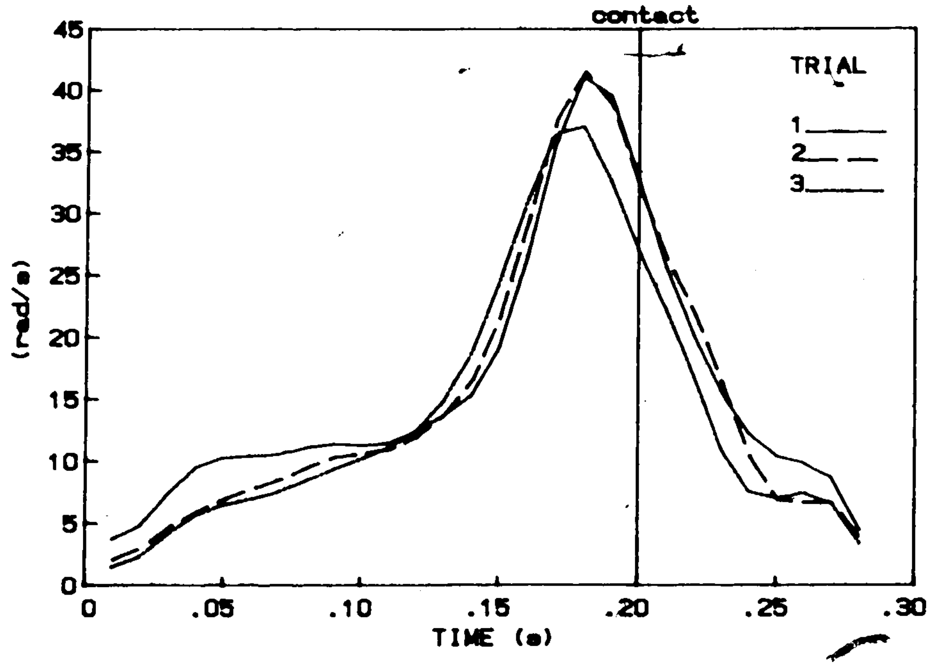


**Figure II-1.** Instantaneous angular velocity of the hockey stick expressed in radians per second (rad/s) for the control hockey player.

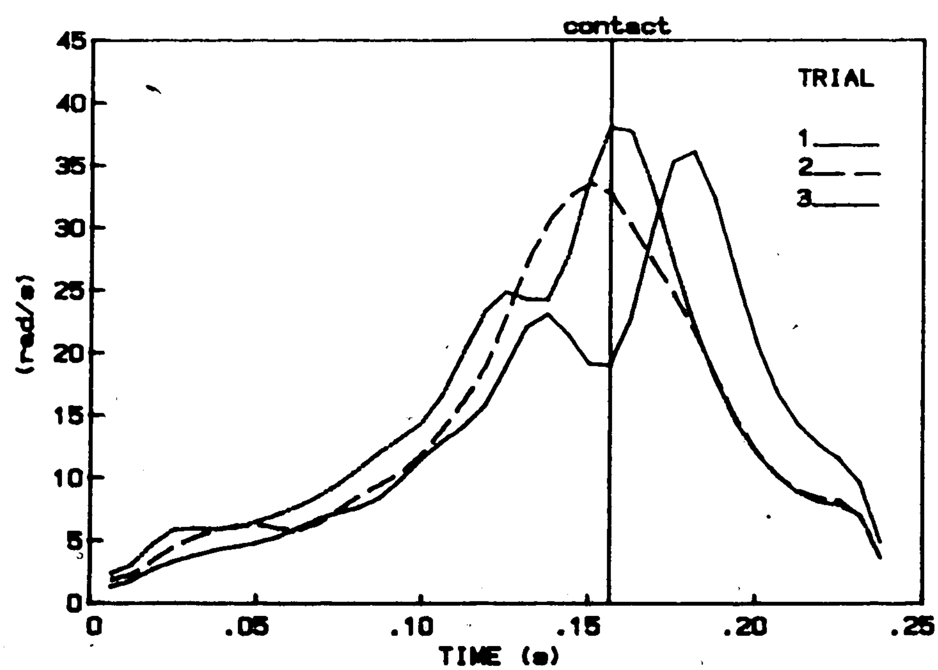


**Figure II-2.** Instantaneous angular velocity of the hockey stick expressed in radians per second (rad/s) for the control non-hockey player.

respectively. As noted above, Subject 1 had completed one year of organized hockey; whereas subject 2 had no formal hockey experience.

As Figure II-1 shows, the stick velocity in all three trials for control subject 1 followed a similar pattern throughout the action. The congruency of these movement patterns reflects a high degree of movement consistency. The timing of C1's action pattern as reflected in the close relationship between the peak stick velocity and puck contact point was also very consistent. Peak angular velocity should occur very near the release of the puck from the stick (Hay, 1978), and this subject demonstrates this characteristic very well. The peak stick velocity values were 41.0, 41.2, and 37.5 rad/s, with resultant puck velocities of 70, 98, and 73 km/hr, respectively. It should be noted that on trial 2 the higher resultant puck velocity was probably due to the fact that the subject's stick made little contact with the floor. In summary, this subject demonstrated a quite consistent action pattern; however, as one would expect from a child of his age and experience, his timing could be improved somewhat.

Figure II-2 represents the three performances that control subject 2 completed in the initial test session. Again, the movement patterns reflected by the angular velocity of the stick are somewhat similar; however, the degree of consistency is considerably less than that achieved by control subject 1 who had played hockey. The peak angular velocities of 36.1, 33.5, and 38.0 rad/s resulted in respective puck velocities of 46, 56, and 55 km/hr which are considerably lower than the first subject's velocity figures. The deflections in two of the curves (trials 1 and 3) before puck contact indicate that this subject hit the floor prior to contacting the puck thus decreasing stick velocity momentarily. Furthermore, for control subject 2, the shape of the angular velocity curve in relation to the point of contact with the puck on each trial is somewhat variable; however, if the peak angular velocity of each curve is placed at the point of contact, the three curves become quite congruent indicating that, for this subject, the kinematic pattern of the shot is relatively well-established but the timing on each trial is still slightly variable. It should be noted that the abscissa for both control subjects are dissimilar due to the different filming speeds. The difference in timing between peak stick velocity and puck contact is minimal for both of these subjects (.02s for the first control subject and 0 to .02s for the second control subject).

Figures II-3 and II-4 represent the angular velocity patterns of the hockey stick when physically awkward subjects 1 and 2 were shooting after 0, 400, 800, and 1200 practice trials. The best of the three trials (represented by highest puck velocity) in each of the four sessions was chosen to.

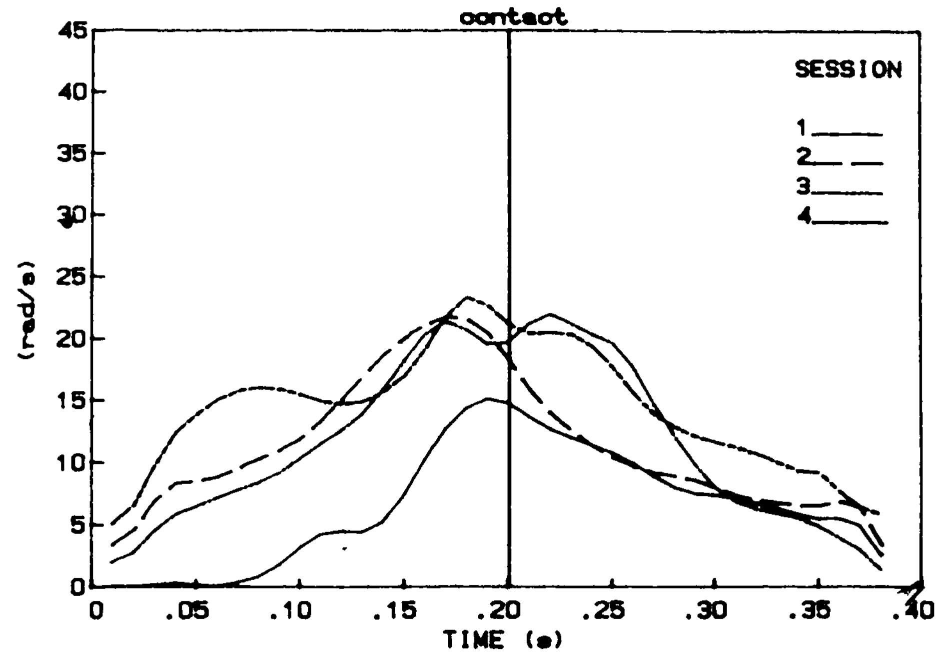


Figure II-3. Instantaneous angular velocity of the hockey stick in radians per second (rad/s) for the best trial by the first physically awkward subject in each of 4 sessions.

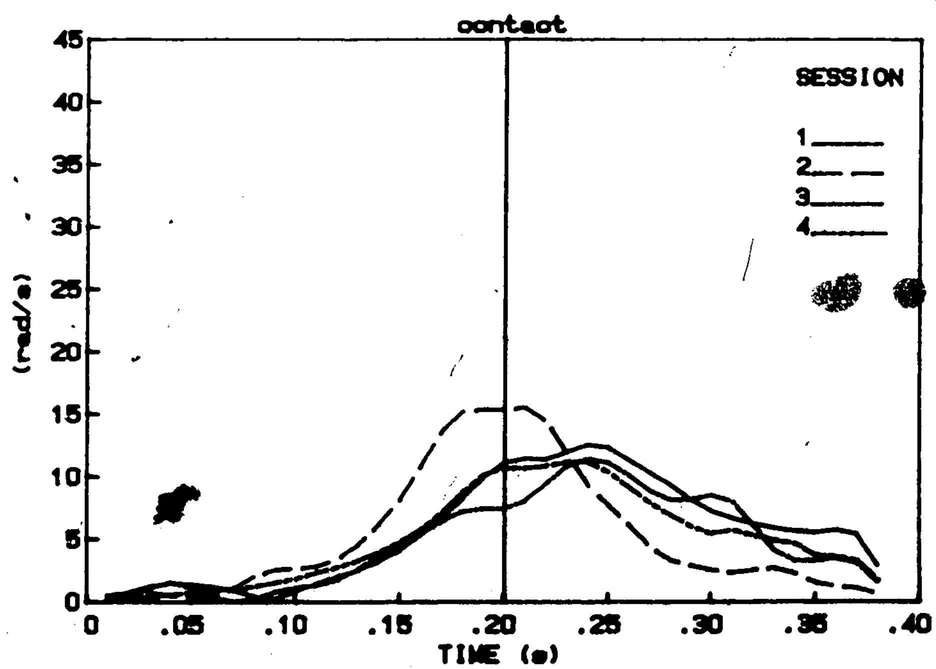


Figure II-4. Instantaneous angular velocity of the hockey stick in radians per second (rad/s) for the best trial by the second physically awkward subject in each of 4 sessions.

illustrate performance of the physically awkward subjects. The best trial in each of the four sessions was chosen because the three trials in each session were very inconsistent and this method best represents the data for the entire experiment. An examination of Figures II-3 and II-4 reveals that the physically awkward subjects had very inconsistent angular velocity patterns. As the subjects practiced the slap shot their movement variability did not decrease across the four sessions. No clearly identifiable pattern emerged with the increased amount of practice. Furthermore, the peak angular velocities of 15.0, 22.2, 23.5, and 24.1 rad/s shown in Figure II-3 for the first physically awkward subject resulted in best puck velocities of 58.6, 61.3, 57.5, and 61.3 km/hr, respectively. The peak angular velocities of physically awkward subject 2 of 13.5, 15.7, 11.1, and 11.2 rad/s shown in Figure II-4, resulted in best puck velocities of 37.5, 48.6, 33.1, and 36.2 km/hr, respectively. Obviously these are much lower puck velocities than those achieved by their matched control subjects.

It is interesting to note that the resultant puck velocities achieved by the first physically awkward subject were fairly similar, but were attained with inconsistent stick velocity patterns (see Figure II-3); clearly, the timing of the subject's movement was quite erratic. The stick was elevated to a different height on each trial, and as a result the peak stick velocity varied. It was expected that with practice the physically awkward children would improve their timing as well as the consistency of their movement patterns over the 1200 trials and would thus attain higher puck velocity. However, the results show that both of the physically awkward subjects had not established a consistent downswing phase for the slap shot and hence, the puck velocities did not increase.

The angular velocity patterns for physically awkward subjects 1 and 2 for all three trials in the fourth session (i.e., after 1200 practice trials) are presented in Figures II-5 and II-6 respectively. The movement variability as indicated by the congruence of the curves on all three trials of the first physically awkward subject is still high even after 1200 practice trials. Peak stick velocities of 23.0, 24.1, and 28.0 rad/s generated puck velocities of 42.0, 61.3, and 52 km/hr for the three trials. Clearly, this subject has not yet formed a stable kinematic pattern for the slap shot.

The results for the second physically awkward subject are presented in Figure II-6. Peak angular velocities of 12.5, 9.4, and 11.2 rad/s generated puck velocities of 29.2, 31.1, and 36.2 km/hr. The results for the second physically awkward subject are poorer than those of the first. This subject started his swing with the stick still in contact with the floor. The horizontal distance the subject moved the stick to contact the puck was very small; a fact that

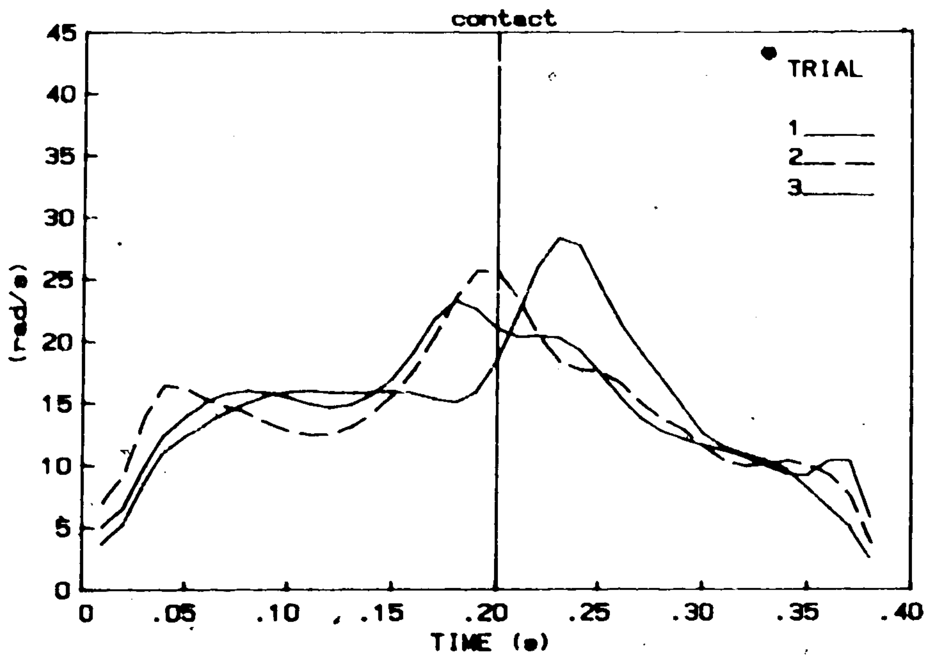


**Figure II-5.** Instantaneous angular velocity of the hockey stick in radians per second (rad/s) for the first physically awkward subject in the fourth test session.

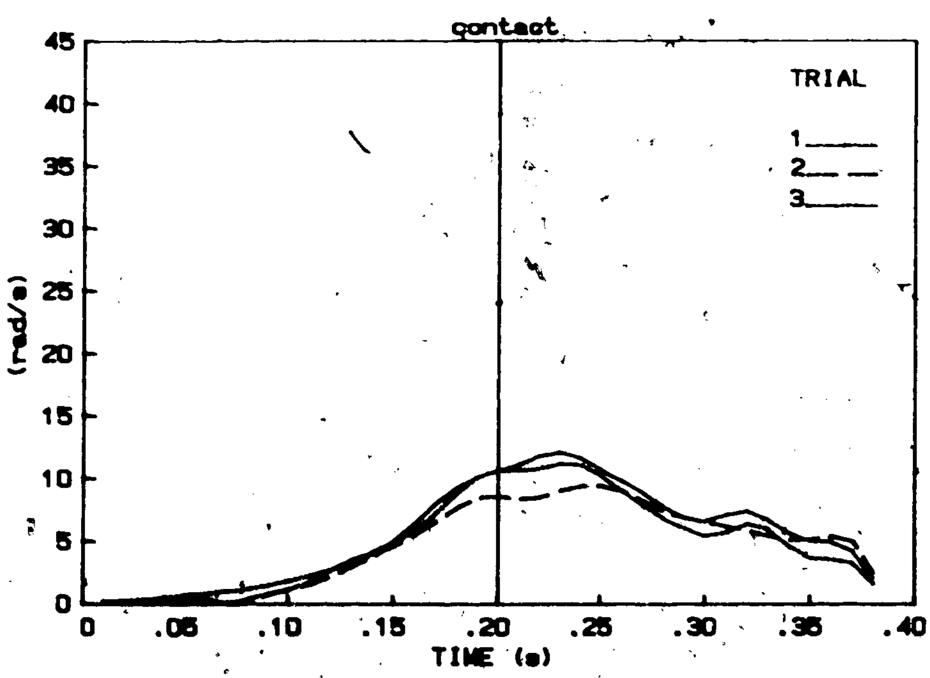


**Figure II-6.** Instantaneous angular velocity of the hockey stick in radians per second (rad/s) for the second physically awkward subject in the fourth test session.

explains the low stick and puck velocities he generated. The horizontal distance he moved the stick prior to puck contact accounts for the relatively consistent stick velocity patterns. The key point is that even after 1200 practice trials, the movement pattern generated was not congruent with the instructions and practice he received prior to filming.

For a typical child, one would expect improved movement consistency with practice (Higgins & Spaeth, 1972; Hoffman, 1974; Jensen & Prud'homme, 1980). The number of practice trials that is required to achieve consistent movement patterns has not been documented in the literature. The control subjects demonstrated that they had achieved at least some consistency in their movement patterns in their only testing session; furthermore, as expected, the hockey player who had practiced more had the most consistent patterns.

Comparison of the graphs for the physically awkward and control subjects reveal very considerable differences between the two groups. The control subjects, without the benefit of 1200 practice trials, performed relatively consistently with respect to stick velocity patterns and the occurrence of peak stick velocity. On the other hand, the physically awkward subjects did not perform consistently or expectedly even after 1200 practice trials. A brief review of recent theories of developmental skill acquisition may provide some understanding of the consistency problems exhibited by the physically awkward children.

The need for practice is the underlying theme in recent theories of motor learning and development (Adams, 1971; Norman & Shallice, 1986; Pew, 1974; Schmidt, 1975; Wall et al., 1985). Such practice, however, must be guided with sufficient and appropriate sensory feedback and knowledge of results (KR). The results of this study clearly indicate that physically awkward children, even after 1200 practice trials, have very great difficulty performing the culturally-normative hockey slap shot.

Wall et al. (1985) have made a number of observations on the developmental problems faced by physically awkward children. These authors suggest that for school-aged children to enjoy participating in play and sport environments, they must develop accuracy and consistency in their physical skills. Skillful players can accurately and precisely control their kinematic response patterns. It is essential that players learn the basic response-loaded skills of a given sport before they are forced to use higher-level strategies in competitive situations. The development of such automatized procedural knowledge depends on practice which facilitates the development of skillful performance.

The control subjects in the current study exhibit a higher level of skill development compared to their physically awkward peers in only three performance trials. They did not require extensive practice to improve their performance. Thus, their procedural knowledge was sufficiently developed and they were able to precisely control the kinematic pattern across three performance trials in the response-loaded hockey slap shot.

Wall (1982) contends that physically awkward children often demonstrate a lack of skill in cognitive-motor tasks as early as the preschool years. As they grow older, this lack of skill forces them to withdraw from physical activity which results in decreased practice opportunities. Most children develop their sport and play skills within culturally-normative physical activity environments; and they usually participate in sport activities with children who are within their own age group. However, in order to be involved in such age-appropriate sport activity a child must have a minimal level of proficiency in the skills required for that sport. Physically awkward children, by definition, do not have sufficient physical proficiency to be able to successfully join such sport situations. Hence, they are often precluded from practice opportunities which would allow them to acquire the very skills they need for positive participation (Wall, 1982). The results of this study demonstrate very clearly the difficulty faced by physically awkward children in culturally-normative sport situations such as hockey.

The results of the performance data for the physically awkward subjects demonstrate their inability to improve on a response-loaded closed skill after 1200 practice trials. The data also suggest that even with informed parental supervision, physically awkward children can not achieve the environmental goal with acceptable and appropriate kinematic patterns. It would appear that the physically awkward children are deficient in acquired knowledge and this is reflected in their performance scores and patterns. Thus, it appears that these physically awkward subjects are lacking knowledge in factual information, pertinent biomechanical factors, and key contextual cues that readily influence the initiation and control of the hockey slap shot. Their inability to analyze the demands of the task or to choose and use suitable strategies to accomplish the task appropriately suggests that these physically awkward children are lacking in essential knowledge regarding hockey slap shot performance.

The results of this study represent an initial attempt to demonstrate the procedural knowledge difficulties faced by physically awkward children. Clearly, these results need to be replicated. However, they are congruent with the clinical observations of adapted physical educators. If such findings are in fact correct, they reinforce some of the observations Wall et al. (1985) made regarding remedial strategies to help physically awkward children. Parents, teachers, and coaches need to consider carefully the developmental skill level of the children in their programs and ensure that their children have the necessary skills for successful participation. Also, the activities should be designed to match the skill level of the participants.

In order to minimize their movement difficulties, physically awkward children should be encouraged to learn the basic requirements for response-loaded skills that emphasize the organization and timing of one's own movements. Such skills as running, swimming, skating, and skiing, should be acquired before such individuals try to learn motor skills that require perceptual and cognitive processing prior to the execution of a response. Evidently, considering their procedural knowledge difficulties, physically awkward children will experience minimal success if they are placed in competitive sport situations in which they must respond quickly and accurately to the action of others. It would seem more sensible for them to practice response-loaded motor skills in less pressured situations where the environment is closed and structured. It would also be in their best interests to receive ample guidance and feedback about their performance.

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## III. Mechanical Analysis of Bowling

To the casual observer, the sport of five-pin bowling appears to be a simple task, the objective of which is to knock over the pins by rolling a ball from a distance of 60 feet (18.29m). The underlying complexity of the skill may be realized by noting that a one degree deviation from the vertical in the arm swing at release produces a change in location of the ball by 1.05 feet (.32m) at the head pin (Broer & Zernicke, 1979). The sport's complexity becomes more apparent when one considers the amount of pin and ball deflection upon impact. Also, the coordination of the upper limb and the feet during approach and the delivery form at the foul line affects the direction in which the ball is thrown. It can be summarized, therefore, that the skill of successful bowling is a highly complex motor pattern with a narrow tolerance for error.

Bowling, because of its complex nature, has been subjected to scientific investigation by numerous researchers. Most of the research has been conducted in the United States on ten-pin bowling. The earliest research in bowling established norms and learning curves for college women (Phillips & Summers, 1950), norms to evaluate and classify college men and women of different bowling skill levels (Martin, 1960), and to establish bowling norms for college men and women in elective physical education classes (Martin & Keogh, 1964).

Also, from 1960 on, numerous theses examined various components associated with the sport of bowling. All three phases of bowling: preparation, force production, and follow through, as well as many different components relating to the sport of bowling have been examined. A list of some of the investigators and their research is provided. The various aspects of investigation included: types of instruction (Bennet, 1969; Bierscheid, 1969; Church, 1963; Cox, 1963; Crona[illegible] 1968; Hall, 1958; Tredway, 1972), number of steps in the approach (Bladen, 1960; Songster, 1961), practice (Kahn, 1959; Robertson, 1969), force production (Klatt, 1965), and relationship among anthropometric, strength, and performance measures (Sabol, 1962; Widule, 1966).

A novel approach to investigate bowling was adopted by Rothstein and Arnold (1976). The authors reviewed research literature that utilized videotape feedback to acquire information relative to the teaching or coaching of the specific bowling skill. Rothstein and Arnold reviewed the bowling literature and applied the model of motor skill learning proposed by Gentile (1972) to this literature. In summary, the literature suggested that improvement in learning is dependent upon the learner's ability to use information gained through selective attention to formulate a motor plan with a high probability of success; execute the plan; and then, using feedback about both the movement and the outcome of the movement, assess the interactive effectiveness of both and decide what to do on the next trial. The teacher or coach plays a crucial role in the successful completion of each step leading to goal-attainment.

Biomechanical analyses were also conducted on bowling. In 1974, Murase, Miyashita, Matsui, Mizutani, and Wakita analyzed the motion of the bowling ball during the approach and delivery using biomechanical methodologies. Eight righthanded subjects were asked to deliver the ball ten times at all ten pins. The subjects were filmed at 43.3 Hz in the sagittal plane. The subsequent data analysis suggested that the coordination of the bowling arm and the feet during the approach and the form of delivery were quite consistent each time for the high-average subjects. On the other hand, timing in push-away, backswing, and forward and downward swing during approach were not consistent each time in the case of low-average subjects. The results also indicated that there was no distinct difference in the final ball speed between the skilled and unskilled subjects even though the height of backswing differed greatly among the subjects. The authors concluded that the factor of accuracy is more important than ball speed to achieve high scores in ten-pin bowling.

A recent biomechanical investigation by Finch (1985) examined the effects different ball weights had on the kinetics and kinematics of the shoulder action during the bowling delivery of slow and high speed bowlers. Twenty-four bowlers (12 slow and 12 high speed) performed three trials which were filmed in the sagittal plane at 76 Hz using a Photo Sonics 16mm camera. Data reduction was performed using a Numonics digitizer interfaced with an Univac 1140 computer. Three phases were identified to examine particular variables during the bowling approach and delivery: push-away to vertical arm position; vertical arm position to height of backswing; and height of backswing to ball release. The following conclusions were presented: the bowling approach can not be accurately described as a cadenced movement down the lane; ball weight influenced the resultant ball speed; the vertical position of the shoulder was decreased during the push-away and downswing, and elevated in the backswing phase; different maximum and minimum shoulder torques were applied from phase to phase by both speed groups; and, the armswing employed during the delivery by the intermediate bowlers should be described as an accelerated pendulum rather than a simple free-swinging pendulum.

Research on bowling has been very diversified as shown by the numerous investigations presented. The major research emphasis, however, has been on the technique for ten-pin bowling. No published research has been conducted on the Canadian version of bowling -- five-pin. The major differences between five-pin and ten-pin bowling include: ball size and weight; the number of pins as well as pin placement and position; and the scoring. All the other factors are similar (i.e., lane length and width, foul line placement, and gutters).

Bowling has evolved from something of a curiosity game to one requiring highly developed skill. The standard five-pin bowling game requires a five inch (12.7cm) diameter inertial sequential pylon destabilizer (ball) weighing as much as 58 ounces (1.65kg), and an arithmetically progressive semistable pylon array (five 12 3/8 inch (31.4cm) pins) at a distance of 60 feet (18.29m). The bowler must control aim, speed, and spin by developing a smooth, routine, and unaffected delivery technique to hit the pins consistently. An understanding of the mechanical principles and general movement pattern from the sport of bowling will provide necessary background information to understand the complexities involved in this sport. The mechanical principles are summarized from Broer and Zernicke (1979).

Bowling uses the underhand pattern of movement, and the general mechanics for the production of force and thus control of direction are similar to any activity that utilizes an object that is rolled or thrown along the ground. The underhand pattern does not produce maximum force because of restrictions on body rotation, however, it does allow for maximum use of gravity in the production of ball velocity.

The skill of bowling can be divided into three phases: preparation (general body position), force production (push-away, backswing, and release), and follow through. The bowler should adopt a comfortable and relaxed stance. The ball should be gripped with the dominant hand under the ball, and supported by the other hand, elbows in and close to the sides of the body, with the ball held approximately at waist level. Both feet should be firmly on the floor and reasonably close together, although one foot may be slightly ahead of the other (Broer & Zernicke, 1979).

The push-away is the first component in the force production phase. The ball is pushed forward at full upper limb length with the beginning of the first step. When the ball is pushed away from the body, the upper limb and ball form a pendulum on which gravity acts and causes it to accelerate toward the floor and into the backswing phase. The free hand and upper limb should be held slightly away from the body to help balance the weight of the ball.

From the end of the push-away, the upper limb and ball go down and into the backswing phase. It is not necessary to exert great force to reach the top of the backswing. The height that the ball travels in the backswing depends on the length of the bowler's upper limb and the height achieved in the push-away phase. The higher the push-away, the greater the momentum, and the higher the backswing. From the top of the backswing gravity again brings the ball down and forward to the point of release. The velocity with which the ball is travelling at the bottom of the swing is dependent upon the height the ball reaches in the backswing phase.

The effectiveness of a given force in producing rotary motion (torque) is dependent upon the perpendicular distance from the line of force application to the fulcrum. The ball, therefore, must be pushed away from the body to increase the force potential. The greater the distance from ball to shoulder, the greater the moment of gravitational force. The motion of the upper limb during this approach phase is a smooth pendulum swing -- out, down, back, forward, and follow through. Any variation from a straight pendulum swing increases the chances of missing the target. The ball should be released at the lowest point in the pendulum swing for utmost accuracy.

The distance the ball hand can be raised straight backward is limited by the bony structure of the shoulder joint. A forward lean of the trunk is used to increase the height of the backswing without causing the swing to deviate from its straight path. Additional momentum is produced by the use of the approach in bowling. Since the velocity of the body can be transferred to an object held by the body, the horizontal velocity which the bowler acquires through the use of the approach (3, 4, or 5-step approach), if timed with the swing of the ball, is transferred to the ball and augments the velocity produced by the arm swing. Any twisting of the body during the approach may interfere with the straight path of the swing and should thus be avoided.

Maximum force in rotary motion is at right angles to the radius: thus the ball should be released when the upper limb and ball are perpendicular and close to the floor. This is accomplished by lowering the body through flexion of the knees and hips while maintaining a well-balanced body position. The final forward step onto a deeply flexed lead lower limb and the slide both flatten the forward arc and contribute to a smooth release. The slide also allows for a gradual decrease of the momentum of the bowler.

Since the ball continues to move in the same direction as it was moving at the moment of release, a ball moving in an arc travels along a path which is tangent to that arc at the point of release. This means that there is only one point at which a ball swung in a semicircle around the body can be released and still travel in the desired direction. The accuracy of the rolling ball, therefore, is dependent upon the arc of the swing and the release point of the ball. The bowler must adhere to the mechanical principles governing bowling, therefore, to maximize pin fall and to enjoy the sport of bowling.

<u>Summary</u>

The preceding discourse has discussed the contribution of research to the sport of bowling and the mechanical principles that relate to the underhand pattern used in bowling. This brief review provides insight into the mechanically correct pattern used by expert bowlers. The experiments on ball rolling for accuracy that follow will indicate the pattern of learning used by selected young boys. Their patterns are not necessarily mechanically correct, but do provide an understanding of the patterns incorporated by developing boys.

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# IV. Kinematic Analysis of Skill Acquisition In Normal and Physically Awkward Boys Performing a Bowling Skill

The benefits of practice greatly influence the skill development of the individual. The goal of the individual is to become more skilled as the amount of practice increases. Glencross (1978) proposed that the mastery of skilled actions is a consequence of long, arduous, and often indirect circuitous pathways of extended practice and effort. Clearly, practice is an important determinant in the development of motor skills (Adams, 1971; Schmidt, 1975a; Wall, McClements, Bouffard, Findlay, & Taylor, 1985), however, the type of practice must be appropriate for a given individual in order to increase skill proficiency (Gentile, 1972).

Bruner (1973) suggests that goal-directed, skilled action is the construction of serially ordered constituent acts whose performance is modified toward less variability, more anticipation, and greater economy by benefit of sensory feedback and knowledge of results. In a similar vein, Glencross (1978) suggested that the development, modification, and refinement of the action sequence or plan in learning is dependent, at all stages, upon the information available to the learner. The availability of information, as well as the quality of information, must be considered when an action is performed. Information feedback can be verbal, visual, kinaesthetic, extrinsic or intrinsic, supplemented or augmented. The necessity and provision of information in the best possible manner is the primary concern for learning to occur. In order to utilize the different types and levels of information, the learner must be in a particular stage of development and at an appropriate skill level on a given task.

Wall (1986b) views the developmental skill acquisition process from a four component perspective. He proposes that factors relating to the person, task, environment, and instructional strategies interact to either facilitate or hinder learning. Successful skill acquisition depends on the degree of congruency among these four key components. In terms of the person, it is important to assess the developmental skill level of the individual in relation to their knowledge about action. Wall et al. (1985) stress that declarative knowledge, procedural knowledge, affective knowledge, metacognitive knowledge, and metacognitive skills underlie the developmental level of an individual. Secondly, they contend that the degree to which a person has developed sport-specific or task-specific knowledge must be considered as well as the stage of learning that an individual has achieved on a task-to-be-learned. The beginning stage, which requires the learner to get the idea of the movement, requires very different practice and instructional strategies from those that would be appropriate for the automatized phase of skill acquisition in which the learner is attempting to regulate the kinematic patterns associated with a given action or action sequence. The nature of the task must also be considered because a person will react significantly differently to a given task depending on whether it is response-loaded, perceptually-loaded, or cognitively-loaded. For example, an open skill such as tennis, which is played in a highly changing environment under time-stressed conditions (cognitively-loaded), is very different in terms of task demands from a closed, response-loaded skill such as bowling. Thirdly, the type of environment in which a task is learned or performed may dramatically affect the performance of an individual. Finally, the fourth factor includes the instructional strategies and the experienced instructor utilizes information on all of these variables and their interaction with each other before selecting appropriate instructional strategies for intervention in the learning process.

The skill acquisition process which has been identified by Wall (1986b) eventually leads to skilled motor performance. Glencross (1980) has identified four major characteristics of skilled motor performance and actions: motor constancy, uniqueness of action, stability and consistency of action, and modifiability of action. Motor constancy is the ability of the motor system to produce a wide range of goal-directed movements that are identical or closely related, but utilize different muscles and movements.

Uniqueness of action involves motor actions of the same response or of action patterns that are not identical on successive trials or occasions. Over repeated trials the spatial/temporal pattern of an action occurs within a certain bandwidth of variability. Stability and consistency of action suggest that the more skilled the performer, the more stable the temporal arrangement of actions and the narrower the bandwidth. This feature is associated with the specific style of a performer. Modifiability of action refers to movements which are continually modified and amended in response to the environmental changes processed by the performer (Glencross, 1980).

In order to guide the individual through the skill acquisition process, there are some very important concomitants (e.g., knowledge of results (KR), motivation, reinforcement, and knowledge of performance (KP)) associated with skill development and learning. These factors are briefly acknowledged here as they relate to the whole process of skill acquisition. Bilodeau and Bilodeau (1961) and Newell and Kennedy (1978) suggested that the single most important variable governing the learning of motor skills is KR. Newell and Kennedy (1978) proposed that the optimal level of KR is usually associated with the maturity of the individual and the readiness to learn. Other authors stress the benefits of motivation (Gentile, 1972; Landers, 1975), reinforcement (Gentile & Nacson, 1976; Moxley & Moxley, 1976), and knowledge of performance (Gentile, 1972; Higgins & Spaeth, 1972; Hoffman, 1974; Newell & Walter, 1981; Tyldesley & Whiting, 1975). All of these variables are influential and should be considered when examining motor skill development and learning.

The preceding paragraphs have outlined the relative importance of practice, knowledge of results, and learning on skill acquisition. Little detail, however, is provided in most programs relating to the kind of feedback most appropriate for the child to learn a particular task. Also lacking is the schedule of practice that the child should adopt in learning, and the contribution that motivational factors should play in learning. Further, there is a paucity of experimental evidence on how children acquire skills. In an effort to somewhat alleviate this scarcity of research on motor skill acquisition in children, the following experiment was designed.

The primary purpose of this study was to evaluate the effect of 1000 practice trials distributed over 10 practice sessions on the ball rolling accuracy of four pairs of age- and anthropometrically-matched physically awkward and normal (control) boys. The practice protocol did not include knowledge of performance feedback; however, knowledge of results and intrinsic and extrinsic sensory feedback information was readily available. A secondary purpose was to examine the effects of a structured teaching protocol for two physically awkward subjects based on essential performance changes of their matched peers.

## Method

Subjects

The process of subject selection was completed in two stages. First, four physically awkward male subjects were identified from the Motor Development Clinic at the University of Alberta and from two elementary schools in Edmonton. The age, height, and weight of the physically awkward subjects were assessed. Second, based on the age and anthropometric measures of the physically awkward boys, and assuming similarities in the pattern of learning of matched subjects, four normal boys were selected from two elementary schools in Edmonton. Two of the four control boys were randomly selected as teaching controls for their matched awkward peers. A qualitative analysis of the performance for the two control subjects along with the teaching plan for their awkward peers is presented in Appendix A. Any boy with a chronic medical problem, physical or behavioural difficulty was removed from the list of possible subjects. Informed parental consent was obtained prior to subject participation. Table IV-1 provides a summary of subject information.

Procedure

The initial data collection session for each subject consisted of performing a modified bowling skill in the Sport Performance Unit (SPU) at the University of Alberta. There

**Table IV-1. Age, Height, and Weight of the Matched Subjects**

| Subject | Age (years) | | Height (cm) | | Weight (kg) | |
|---|---|---|---|---|---|---|
| JN&TJ[a] | 8.3 | 8.4 | 129.0 | 140.0 | 28.0 | 35.0 |
| KL&DE | 12.0 | 11.8 | 159.0 | 159.0 | 37.0 | 47.5 |
| DL&MW | 10.2 | 9.8 | 136.0 | 144.0 | 31.0 | 42.0 |
| DM&WC | 11.2 | 10.9 | 146.0 | 139.0 | 44.5 | 30.0 |
| mean | 10.4 | 10.2 | 142.5 | 145.5 | 35.0 | 38.6 |
| s.d. | 1.6 | 1.5 | 13.0 | 9.3 | 7.1 | 7.7 |

[a]-first subject is control, second subject is awkward

were slight modifications from the regular five-pin owling skill for this particular experiment. The modifications were necessary to allow data collection in a laboratory situation and to reduce extraneous factors. These modifications included: a one-step approach; smaller and lighter balls than the normal five-pin bowling balls; contact with only the centre target (criterion) pin from the total of five pins; larger pin size; and one-half of the regular distance to the target pin. Figure IV-1 illustrates a schematic of the testing apparatus utilized.

In the first data collection session, an explanation of the equipment involved and the procedure to be followed was provided to each subject. The subject then watched a videotape demonstration (approximately 30 seconds in duration) of the required skill performed by an expert adult

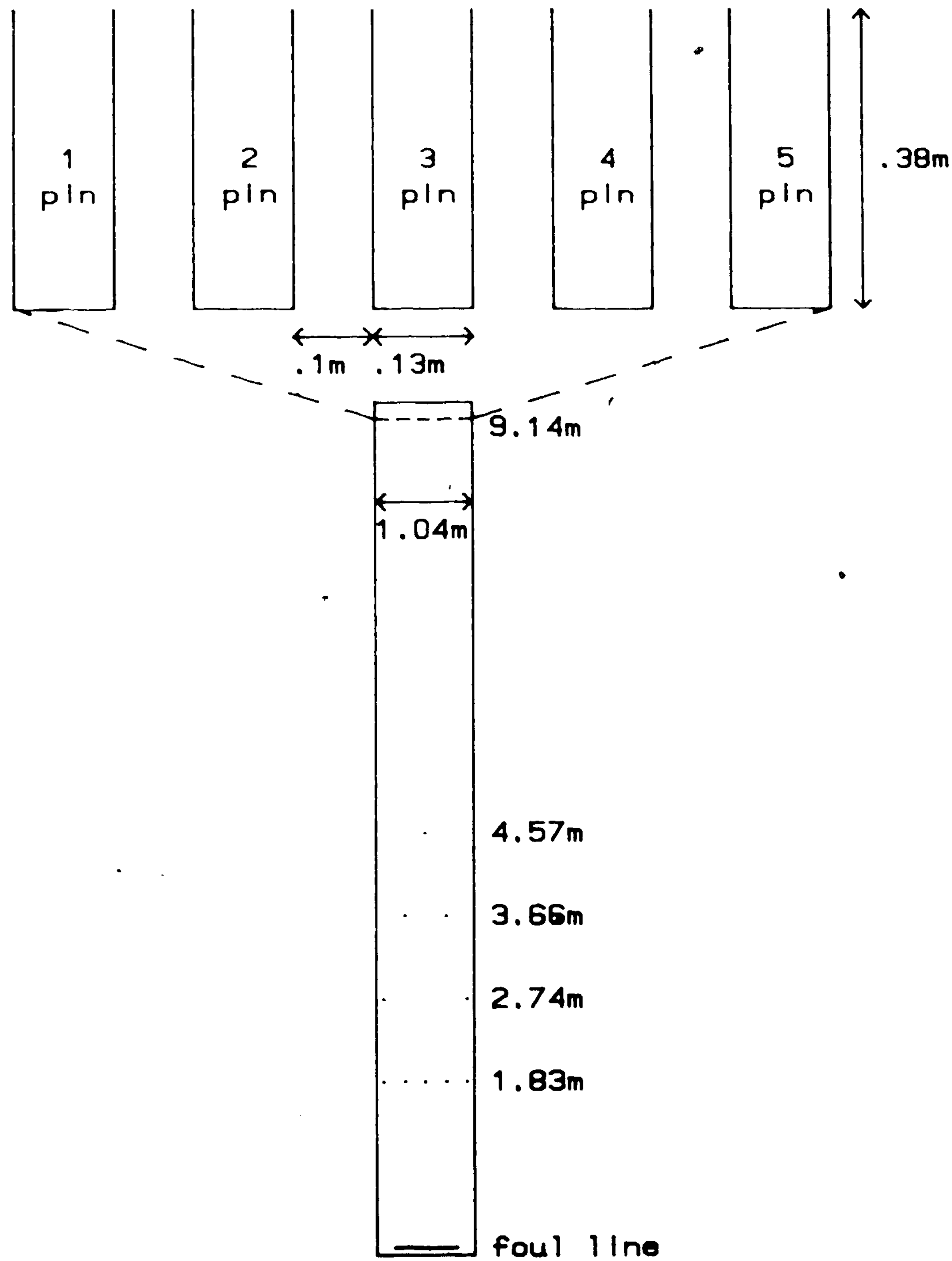


**Figure IV-1.** Schematic of the experimental testing condition for the normal and physically awkward subjects.

bowler. Three trials were demonstrated on the videotape and the subject was requested to carefully view the performance. Next, the investigator demonstrated the bowling skill for each subject and again informed them of the proper procedures. The subject was instructed to closely observe the performance given by the investigator, from a point perpendicular to the plane of motion. At the end of the demonstration, any questions the subject had relating to subsequent performances were answered by the investigator. The subject was then instructed to begin and to perform at his own pace. The subject's performance was recorded on videotape and the investigator recorded the pin number that the ball contacted on each trial. The subject was informed of pin contact within two seconds after each trial. The inter-trial interval was approximately 10 seconds for trials 1-9 and 30 seconds between 9 and 10. On the tenth trial the subject's performance was recorded on 16mm film for subsequent analysis. When the camera attained proper operating speed, the command 'GO' signalled the subject to begin the performance. After the completion of the tenth trial the subject recorded the number of target pin successes on a chart while the investigator collected the balls. The session continued in this manner until the subject had completed 10 blocks of 10 trials totalling 100 trials. A total of ten sessions (1000 trials) concluded the experiment for each subject. The above procedures were conducted during the subsequent sessions.

Equipment

Bocce balls were used instead of regular bowling balls to contact the pins. The balls averaged 586.8±3.8gms in weight and 31.5cm in circumference. The pins were constructed from plexiglass and each pin measured 5in wide X 15in high (12.7cm X 38.1cm). The pins, 4in (10.16cm) apart, were mounted by a small, dampened door hinge onto a plexiglass support so they would swing freely when contacted and quickly return to a stable and motionless position.

A Photo Sonics 16mm 1PL camera, equipped with an Angenieux 20-120mm lens and an internal timer operating at 10 Hz, was used to record the performance at a filming rate of 50 Hz. The camera was loaded with Kodak 7250 Video News film (ASA 400) and was positioned on a tripod 7 metres perpendicular to the plane of motion. The exposure time was set at 1/1200 second and the f stop was set at 4. Prior to the filming of each subject's performance, a reference measure of 1m was filmed in the plane of motion. The image of this measure during film analysis provided a known length which was used to calculate a conversion factor from film measurements to actual distances.

Two Colortran Quartz-King lamps (1000 watts each) were utilized to project sufficient light for the cinematography. Prior to filming, a lightmeter reading using a Pentax 1 degree Spotmeter VI was taken to measure the light conditions and the appropriate f stop was set on the camera.

The cinefilms were projected via a Traid VR100 16mm film analyzer approximately 30% of life-size onto a Bendix Digitizing Board with a point accuracy of 0.01 in (0.0254 cm). All subsequent input points (Humanscale Data, Diffrient, Tilley, & Bardagjy, 1974) were entered into a Hewlett Packard 9825B microcomputer via a Hewlett Packard 9864A Digitizer and stored on magnetic computer tapes. High frequency noise was reduced by a 2nd order bi-directional low pass filter (Walton, 1981) using an 8 Hz cut-off frequency (Pezzack, Norman, & Winter, 1977). Central differences (Miller & Nelson, 1973) were used to obtain displacement-time histories. The following kinematic parameters were obtained for analysis: relative angular upper limb velocity (limb velocity times radius of rotation in m/s); absolute ball velocity at release (m/s); height of ball (m) and angle to the horizontal at release (rad); distance of the lead foot behind the foul line (m); and step length (m). These parameters were chosen for analysis from a mechanical analysis (Hay, 1984) of the bowling movement prior to the study. The dependent variable was the number of contacts (accuracy) with the criterion pin.

Means and standard deviations were calculated on the kinematic variables. An error analysis (Schmidt, 1975b) was conducted on the 100 filmed pin contacts as well as ~~the~~ 1000 pin contacts. Contact with the criterion pin registered a 0. Pin contact to the left of the criterion registered -1, -2, and -3 respectively. The -3 score was for any ball that rolled off the floor. Conversely, any pin contact to the right of the criterion pin registered +1, +2, and +3 respectively.

Precision and Consistency of Measurement

Measurement precision and consistency were desired throughout this study. To estimate the total error involved in the digitizing process, the guidelines of McLaughlin, Dillman, and Lardner (1977) were followed. A 50cm distance was digitized 50 times and the average absolute error was identified. This value served as the best *a priori* estimate of the error associated with each data point. To estimate the extent of variability of measuring a point on the digitizing surface, 50 repeated measures of three points were digitized. This value served as an indication of the degree of precision to which a point could be measured on the digitizing board surface. One trial from each subject was randomly chosen and the entire movement was re-digitized to test the consistency of the X and Y coordinates and the reliability of the digitizing sequence.

**Results**

The analysis of results is presented separately for each matched pair of control and physically awkward subjects. The results are divided into two sections. The first section includes the complete behavioural data with the analysis of the 1000 trials across the ten sessions. Criterion pin contact and error analysis, namely constant and variable, (Schmidt, 1975b) are presented for each of the ten sessions. The second section presents the results of the film data. The results of the kinematic analysis was based on the filming of ten trials in each of the ten sessions. The last trial in each block of ten trials was the one selected for filming. Criterion pin contact and error analysis are also presented for the film data (100 trials) to allow comparisons with the more complete behavioural data (1000 trials). The kinematic variables selected were identified from an a priori mechanical analysis of the bowling movement and further supported through stepwise regression. These variables included: resultant ball velocity at release, relative upper limb velocity at release, ball release angle and height, step length, and the distance the lead foot remained behind the foul line.

Precision and Consistency of Measurement

A 50cm distance on the film was digitized 50 times and the error estimate was ±5mm. Since the calculation of the distance involved two points, the total error was divided by two to obtain an accuracy measure of ±2.5mm. The 50 repeated measures of discrete points yielded an error of ±1.5mm. This 1.5mm value implies that any single point can be determined with a precision of ±1.5mm. This precision measurement is for a well-defined point only. The landmarks of the human body are not well-defined, but with a familiarity of the body segment landmarks, careful cinematographical procedures, and proper alignment of the film projector and digitizer, the best _a priori_ estimate of locating body landmarks is ±1.5mm.

The reliability of the investigator was examined by randomly selecting one trial from each subject's performance and re-digitizing the sequence. The X and Y values for each point from the original data were compared to the re-digitized data. The reliability for the shoulder, elbow and wrist positions for all subjects ranged from .97 to .99 and .92 to .95 for the ball coordinates.

Comparison Between JN and TJ

As Figure IV-2A indicates, JN (the first control subject) hit the target pin more frequently than did his age-matched physically awkward counterpart, TJ. Furthermore, whereas JN made considerable improvement over the ten sessions, TJ showed, at best, very minimal gains in performance.

The results of both error scores, namely constant and variable error, supported the above target pin accuracy results. As Figure IV-2B shows, JN had considerably less variable error than TJ throughout the ten sessions supporting the fact that JN was more accurate and stable in his bowling performance. The constant error results presented in Figure IV-2C show that JN did not reflect a response bias of the

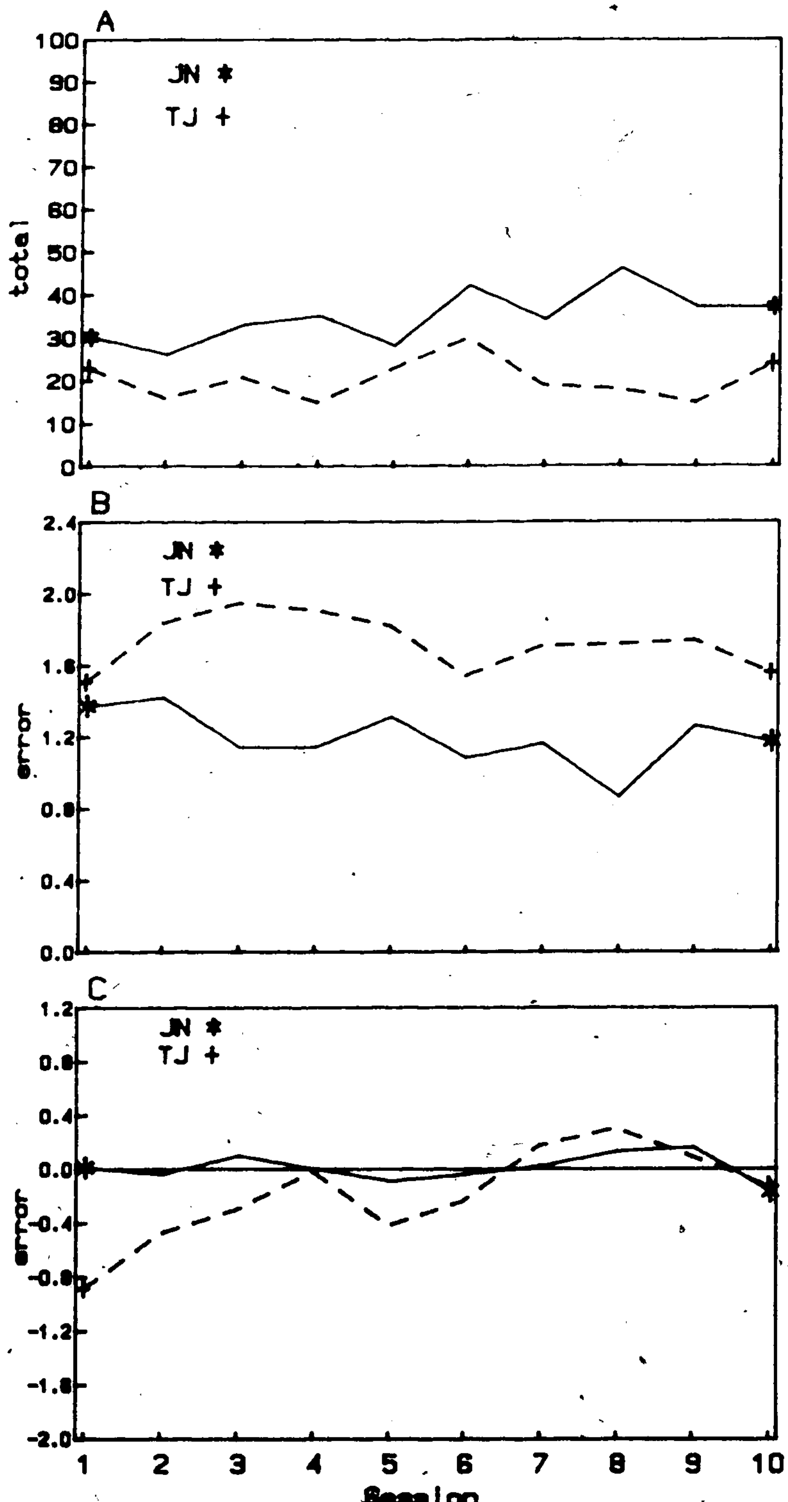


Figure IV-2. Comparison between JN and TJ across the 10 sessions from the behavioural data. A. Criterion pin contacts. B. Variable error. C. Constant error.

target over all sessions, whereas TJ hit left of the criterion pin 70% of the time. The variability of JN's performance was also much less than TJ's reflecting again a lack of consistency in skill execution for TJ.

As outlined earlier, the subjects were filmed on every tenth trial in all 10 sessions generating a total of 100 filmed trials in the experiment. In general, the results of the filmed trials were congruent with the behavioural measures collected on all trials, however, at certain times the expected congruency did not occur. An examination of the film data for JN and TJ follows.

As Figure IV-3A indicates, JN bowled consistently better than his physically awkward peer, TJ, over all sessions. Unfortunately, the improvement across sessions by JN found in the more complete behavioural data, was not supported by the data collected on film. Again, TJ made little or no gains in performance over the ten sessions.

The variable error data from the film is presented in Figure IV-3B and is congruent with the findings from the behavioural data. JN is clearly more accurate and less variable over all ten sessions. Again, the constant error presented in Figure IV-3C demonstrates a rather equal distribution of responses to both sides for JN while TJ was hitting targets on the left side of the criterion in 90% of his trials.

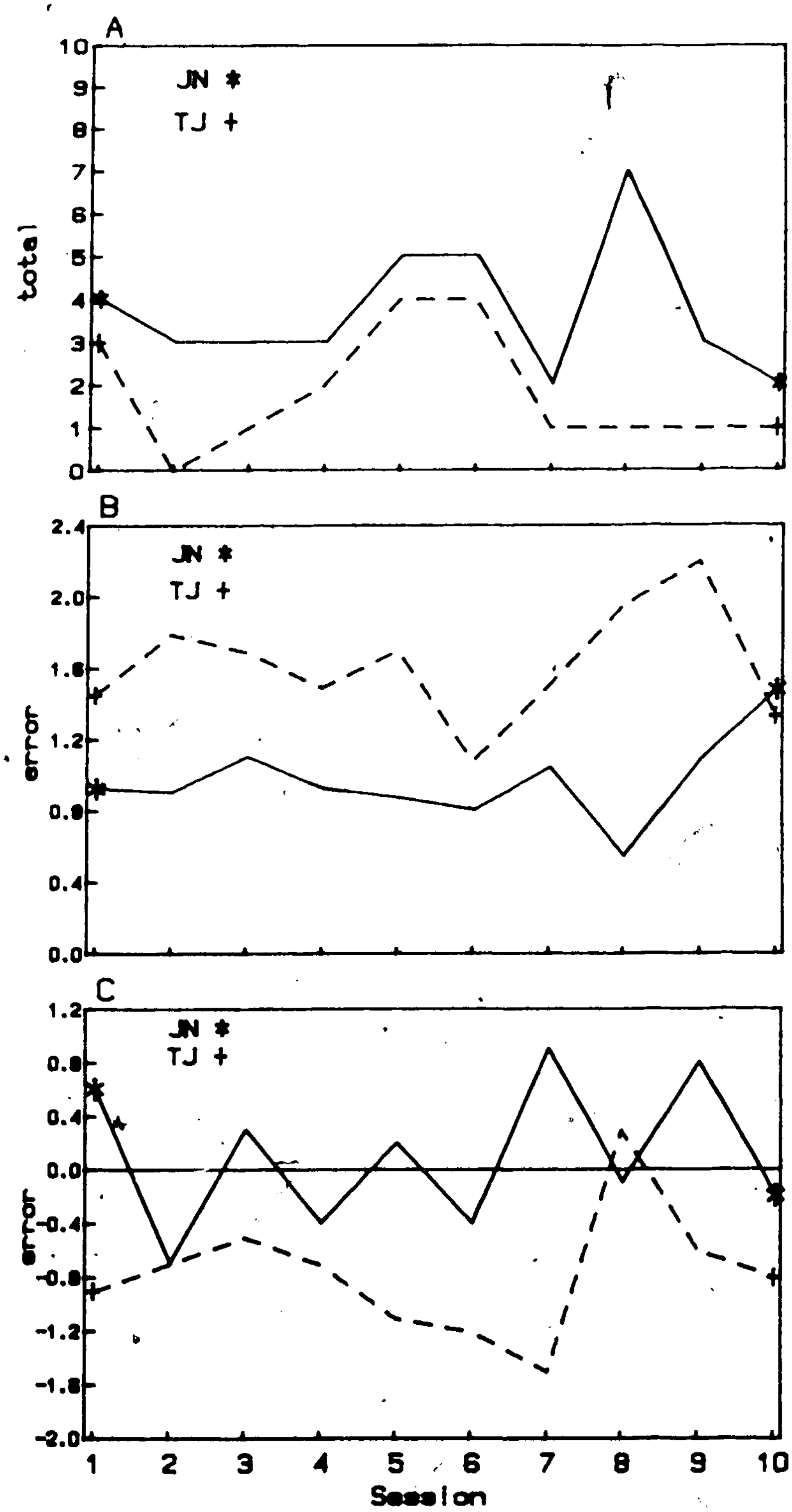


Figure IV-3. Comparison between JN and TJ across the 10 sessions from the film data. A. Criterion pin contacts. B. Variable error. C. Constant error.

The kinematic film data for each respective pair of subjects will be presented with means and standard deviations. This type of presentation will elucidate the performance differences between the matched subjects.

As Figure IV-4A shows, JN bowled the ball faster than his physically awkward peer in all ten sessions. Both boys, however, appeared to be bowling the ball at an appropriate velocity. The term 'appropriate' will be used throughout this result section when the performance of the matched subjects falls within a qualitatively acceptable bandwidth of performance.

As would be expected, the upper limb velocity results (see Figure IV-4B) for both JN and TJ parallel the ball velocity scores over the ten sessions. Again, JN has a higher upper limb velocity than TJ throughout the ten sessions. Careful consideration of Figures IV-4A and IV-4B indicate that both boys appeared to flex the wrist at release thus imparting slightly more velocity to the ball. The contribution of the hand velocity (by flexing the wrist) to absolute ball velocity was not measured due to the inherent error involved.

The results for the release angle variable shown in Figure IV-5A reflect that JN had a much more stable and mechanically appropriate release angle than TJ. Furthermore, as would be expected of a physically awkward boy, TJ's angle

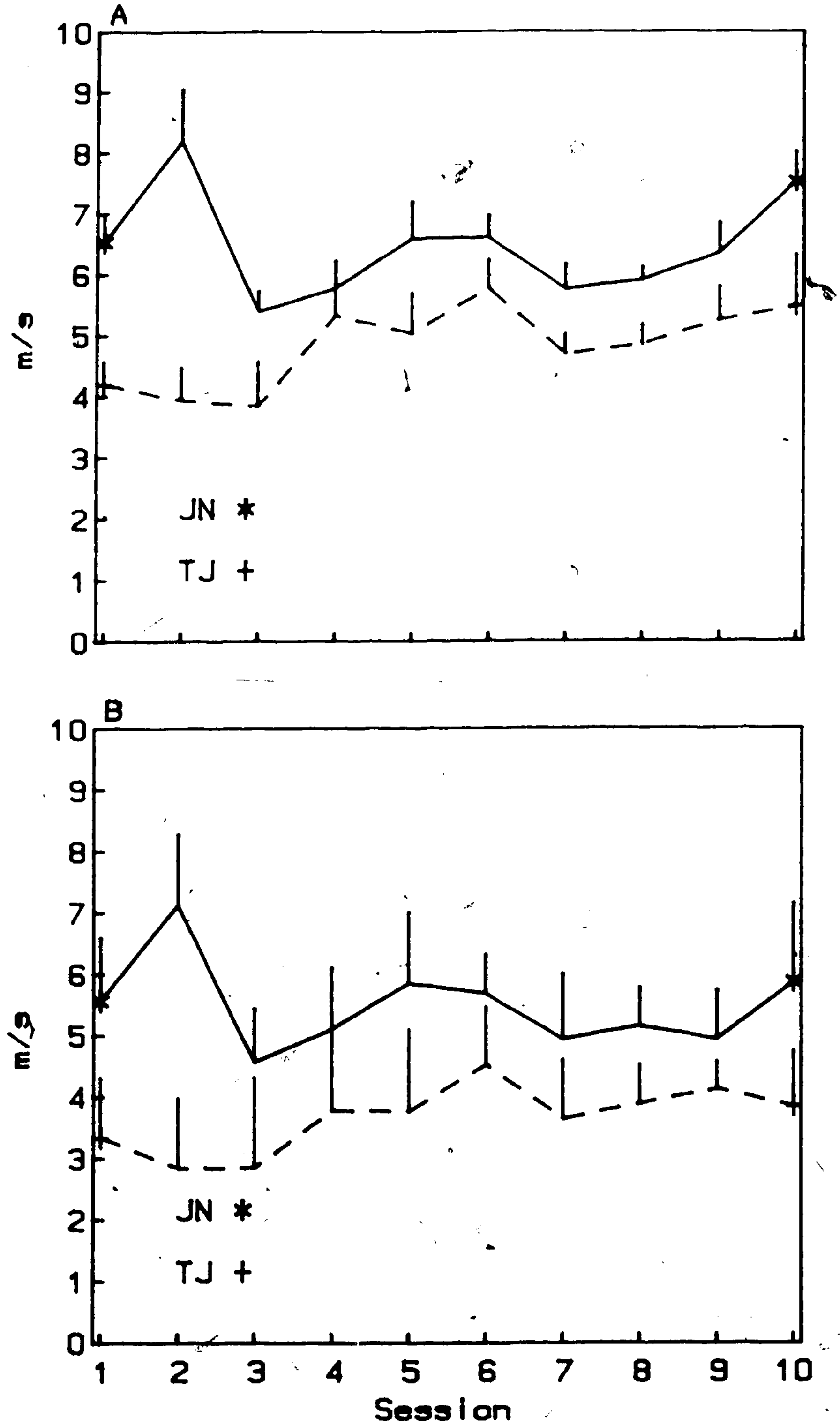


**Figure IV-4.** Comparison between JN and TJ across the 10 sessions from the kinematic data. A. Ball velocity. B. Upper limb velocity.

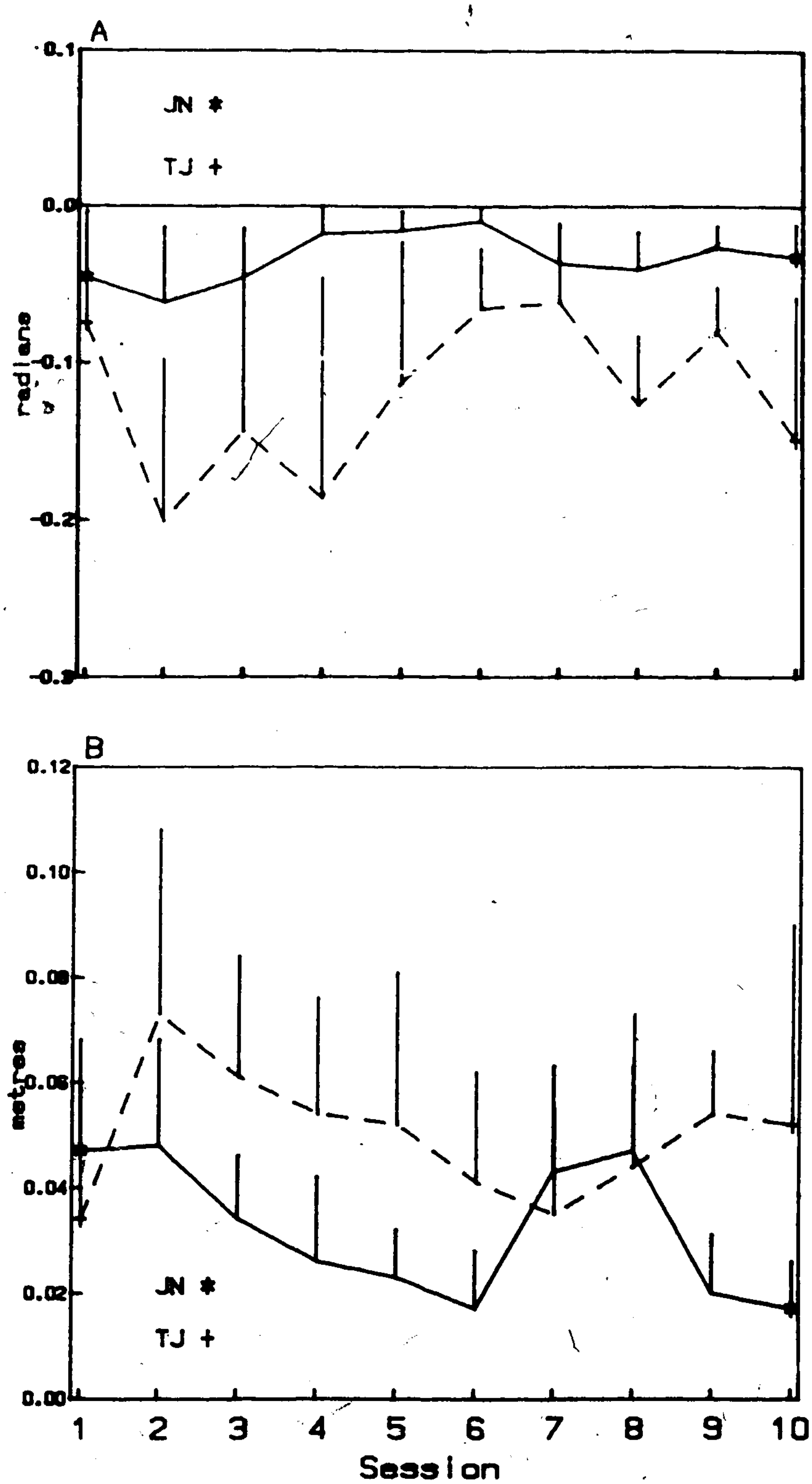


Figure IV-5. Comparison between JN and TJ across the 10 sessions from the kinematic data. A. Release angle. B. Release height.

of release was much more variable within and across the ten sessions.

The results of the release height of the ball data presented in Figure IV-5B show minimal differences between JN and TJ. TJ, however, was still much more variable within each session than JN on this kinematic measure.

Figure IV-6A presents the results of the stride length measures. Again, minimal differences in the stride length for JN and TJ are evident. Both boys appeared to generate appropriate stride lengths for their body size throughout the ten sessions.

Finally, the distance the lead foot of each subject was behind the foul line is presented in Figure IV-6B. TJ, who received specific instruction on this aspect of his performance, was much closer to the line than his non-awkward peer, JN. However, both boys seem to be within an acceptable bandwidth of performance on this component.

<u>Comparison Between KL and DE</u>

As Figure IV-7A shows, KL, the second control subject was able to hit the target pin more often than DE, his physically awkward peer, in all sessions. An analysis of both curves indicates that very little change in performance was evident in either subject's scores across the ten sessions.

Figure IV-7B presents the results of the error variance for both KL and DE over the ten sessions. Again, as was

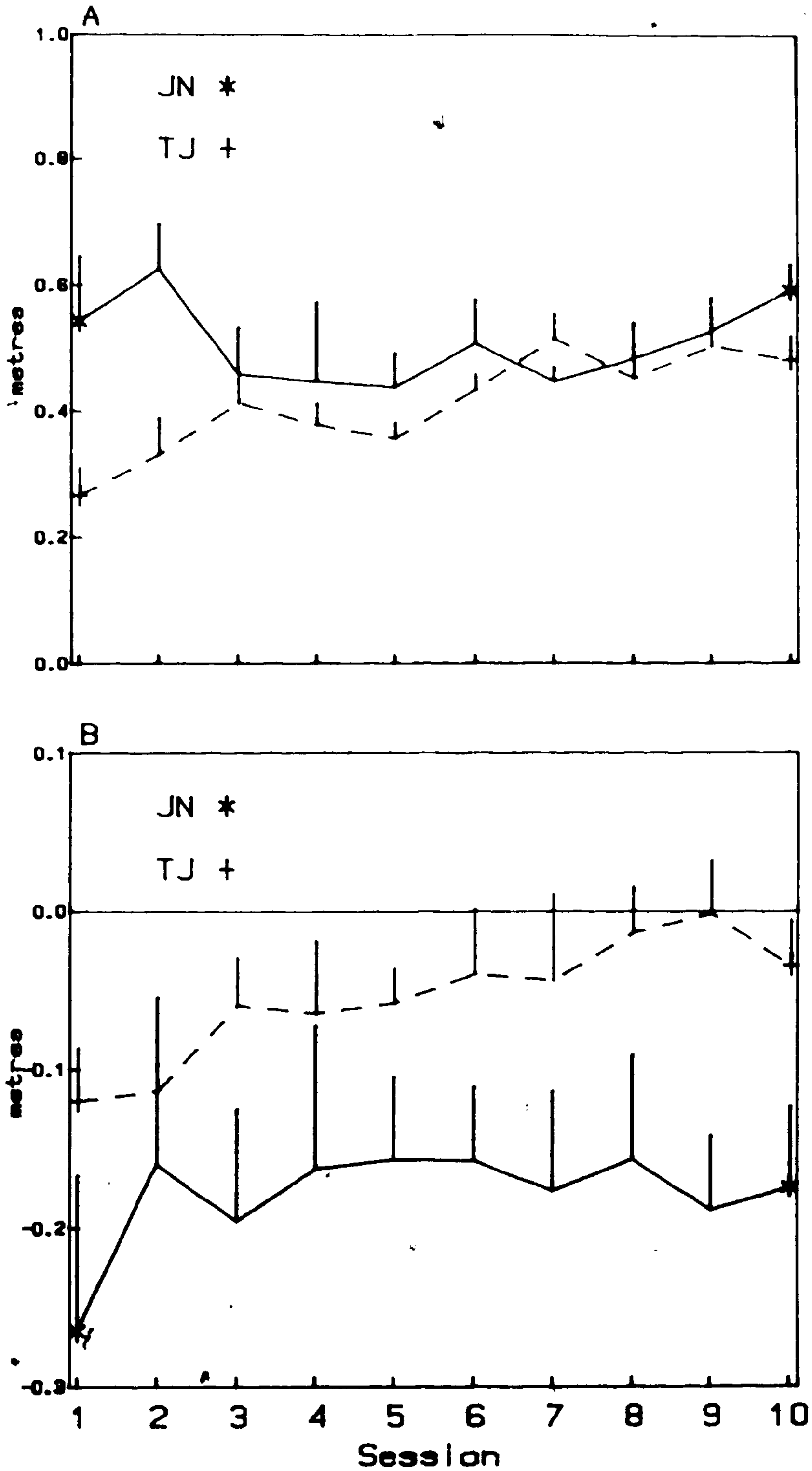


**Figure IV-6.** Comparison between JN and TJ across the 10 sessions from the kinematic data. A. Stride Length. B. Lead foot distance behind the foul line.

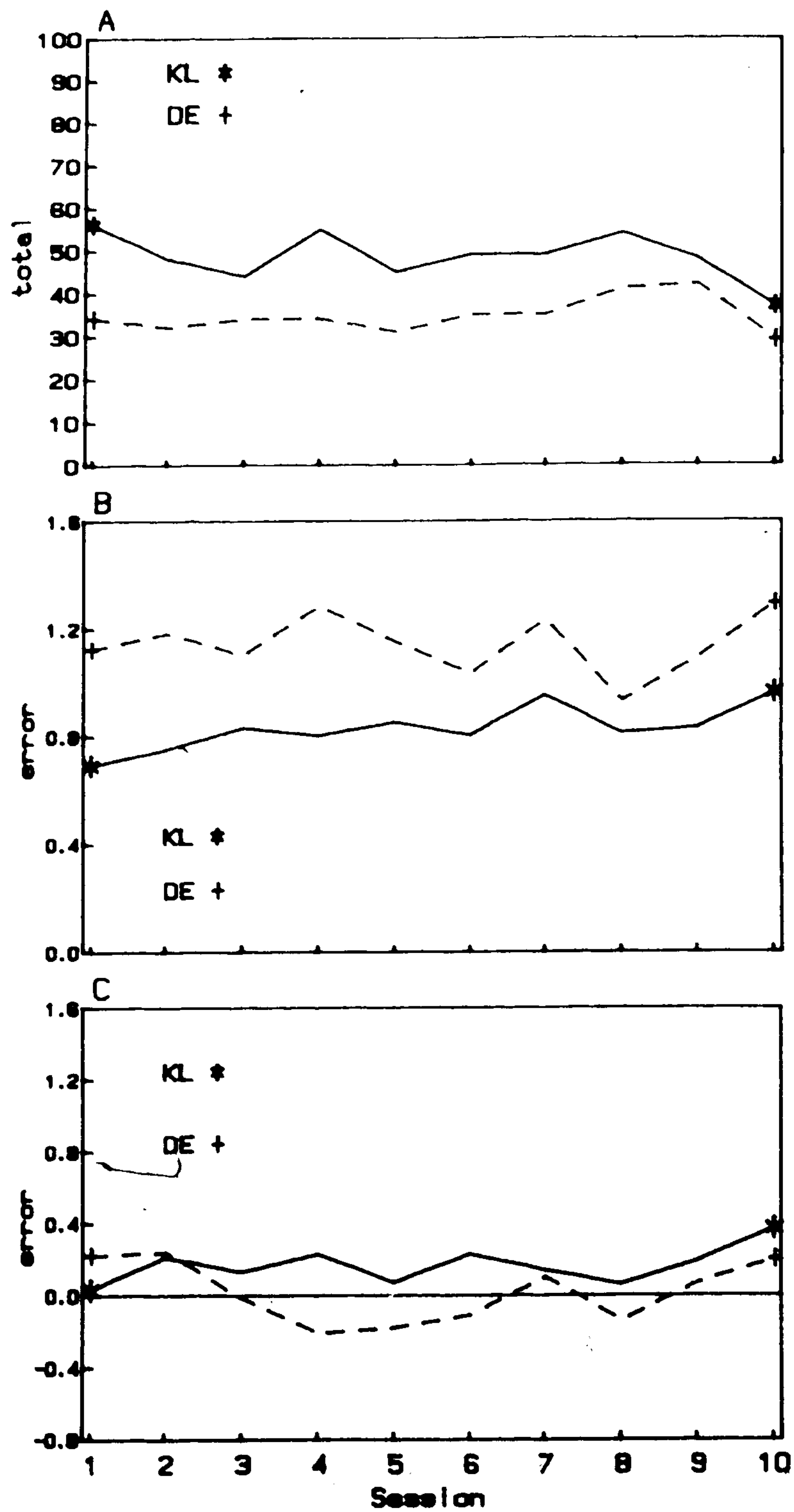


**Figure IV-7.** Comparison between KL and DE across the 10 sessions from the behavioural data. A. Criterion pin contacts. B. Variable error C. Constant error.

expected, KL's variable error was lower than his physically awkward counterpart DE. Thus, the accuracy and stability of KL's bowling performance over the ten sessions was better than DE's.

Figure IV-7C shows that KL's response bias, measured by his constant error, was always to the right, whereas, DE's was on both sides of the criterion pin across the ten sessions. Very little constant error was evidenced by these two subjects indicating the majority of trials centred about the criterion pin and there really was no difference between the two boys.

Figure IV-8A presents the results of contact with the criterion pin for the film data. In contrast to the behavioural data where KL was clearly better than DE, there was really no difference between the two boys on the sample of filmed trials.

The results of the variable error scores on the filmed data indicate that KL had lower error scores in 7 of the 10 sessions, however, a careful analysis of Figure IV-8B indicates basically no differences between the two boys. The filmed data is not congruent with the larger sample of behavioural measures presented above. Possible reasons for this occurrence will be given in the discussion section.

The results of the constant error analysis (see Figure IV-8C) is again quite different than the more extensive behavioural measures. KL's response bias was 20% of the

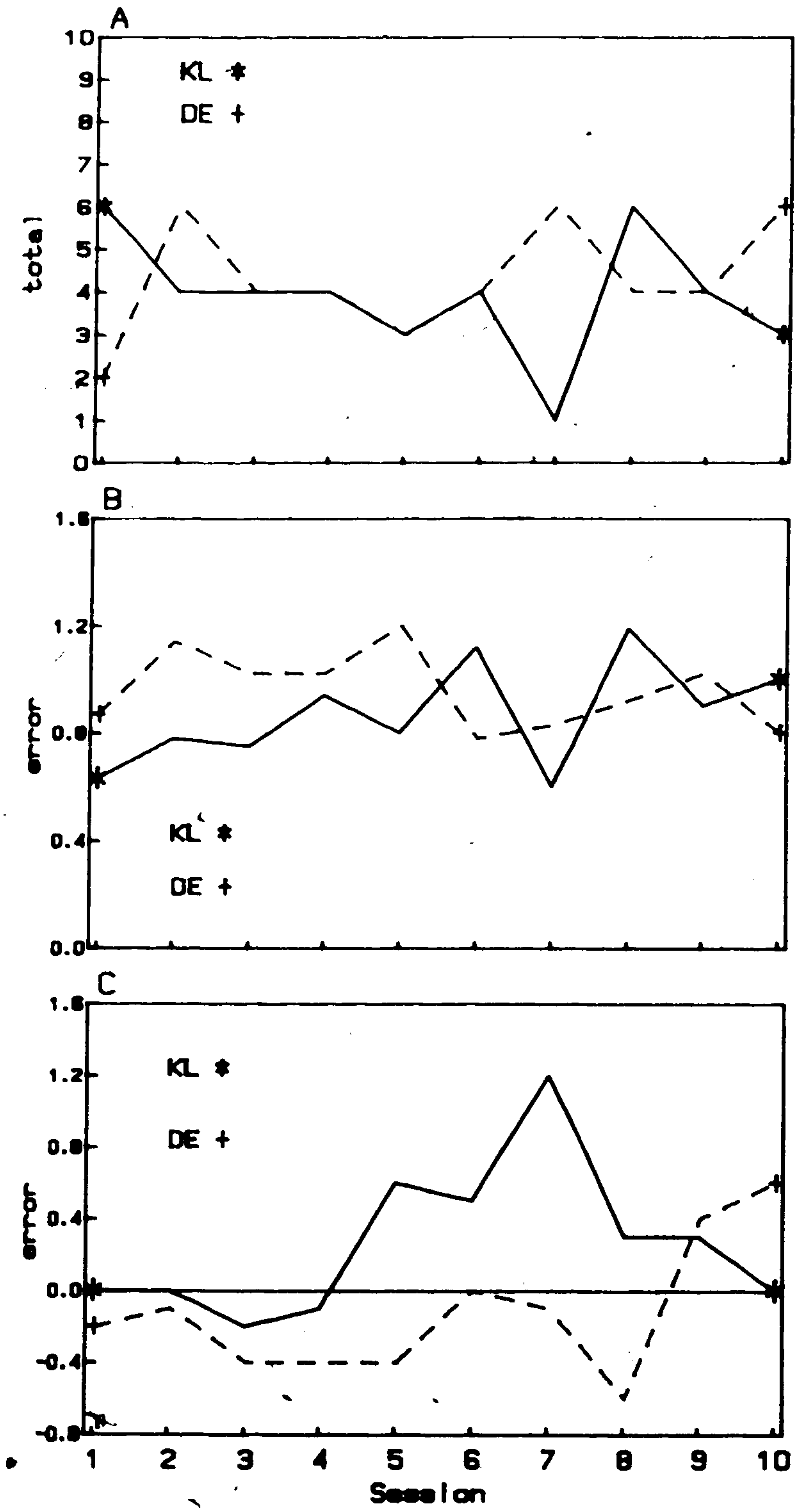


**Figure IV-8.** Comparison between KL and DE across the 10 sessions from the film data. A. Criterion pin contacts. B. Variable error. C. Constant error.

trials to the left of the target pin whereas DE's was 70% to the left. KL had a particularly large response bias to the right in Sessions 5, 6, and 7.

The ball velocity scores plotted over the ten sessions for both KL and DE are presented in Figure IV-9A. No obvious difference between the boys is evident with the mean values falling in an acceptable range.

The upper limb velocity scores are shown in Figure IV-9B with a slight difference evident between the performances of the two boys. A closer examination of the figure reveals KL's large contribution of wrist flexion at release to impart greater velocity to the ball. DE's contribution from wrist flexion to the ball velocity was somewhat lower during the earlier sessions, however, he did increase the contribution from wrist flexion to ball velocity in the final three sessions.

The release angle scores which are presented in Figure IV-10A indicate a much lower and more effective delivery for KL than for DE. Furthermore, DE's release angle varied much more than KL's within and across sessions.

Figure IV-10B presents the results for the release height of the ball used by both boys. Again, KL had a much lower and more mechanically effective release height than did DE. Of special interest in this figure is the dramatic learning effect attained by DE over the course of the ten sessions in which his release height values nearly reached

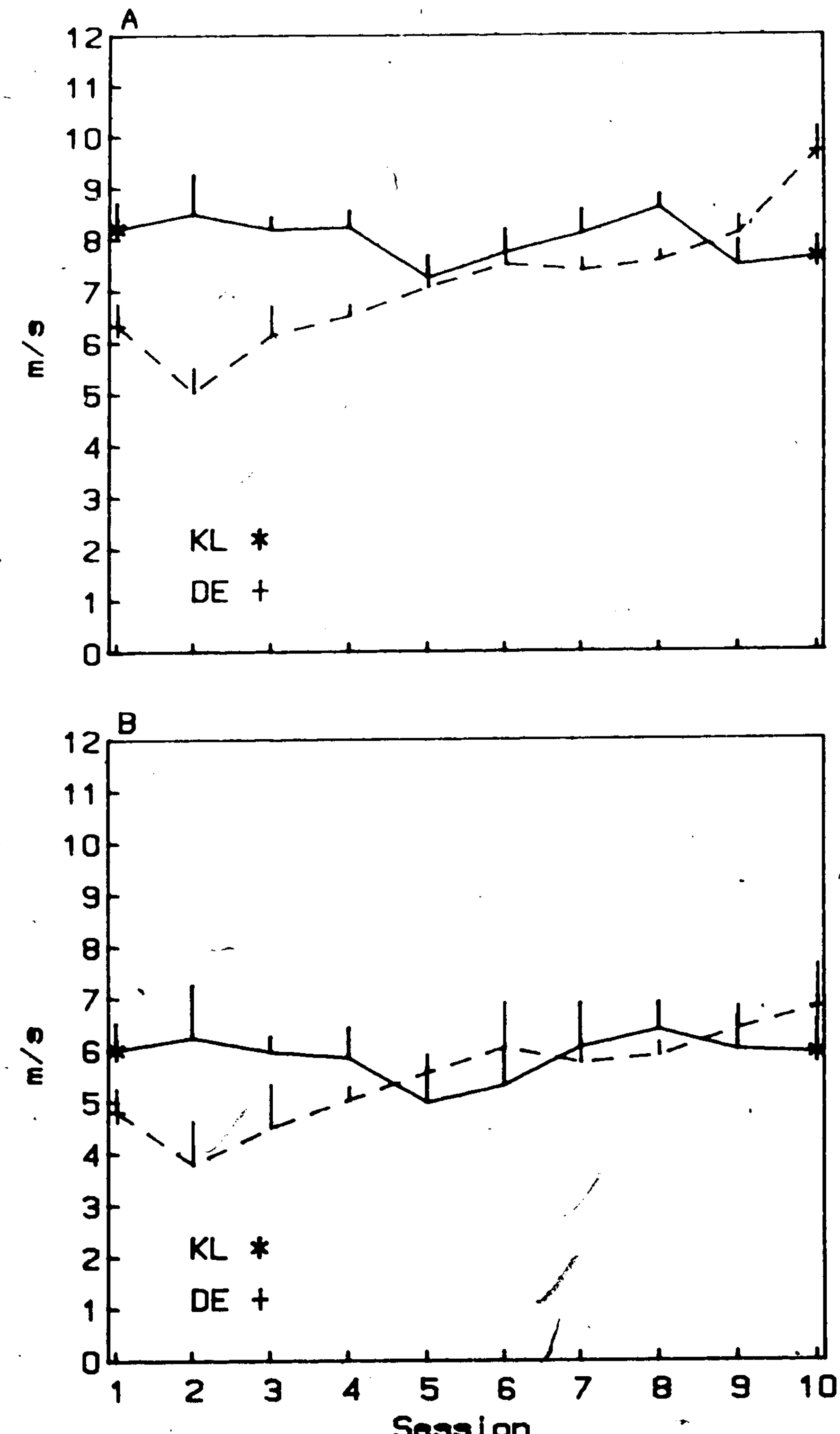


**Figure IV-9.** Comparison between KL and DE across the 10 sessions from the kinematic data. A. Ball velocity. B. Upper limb velocity.

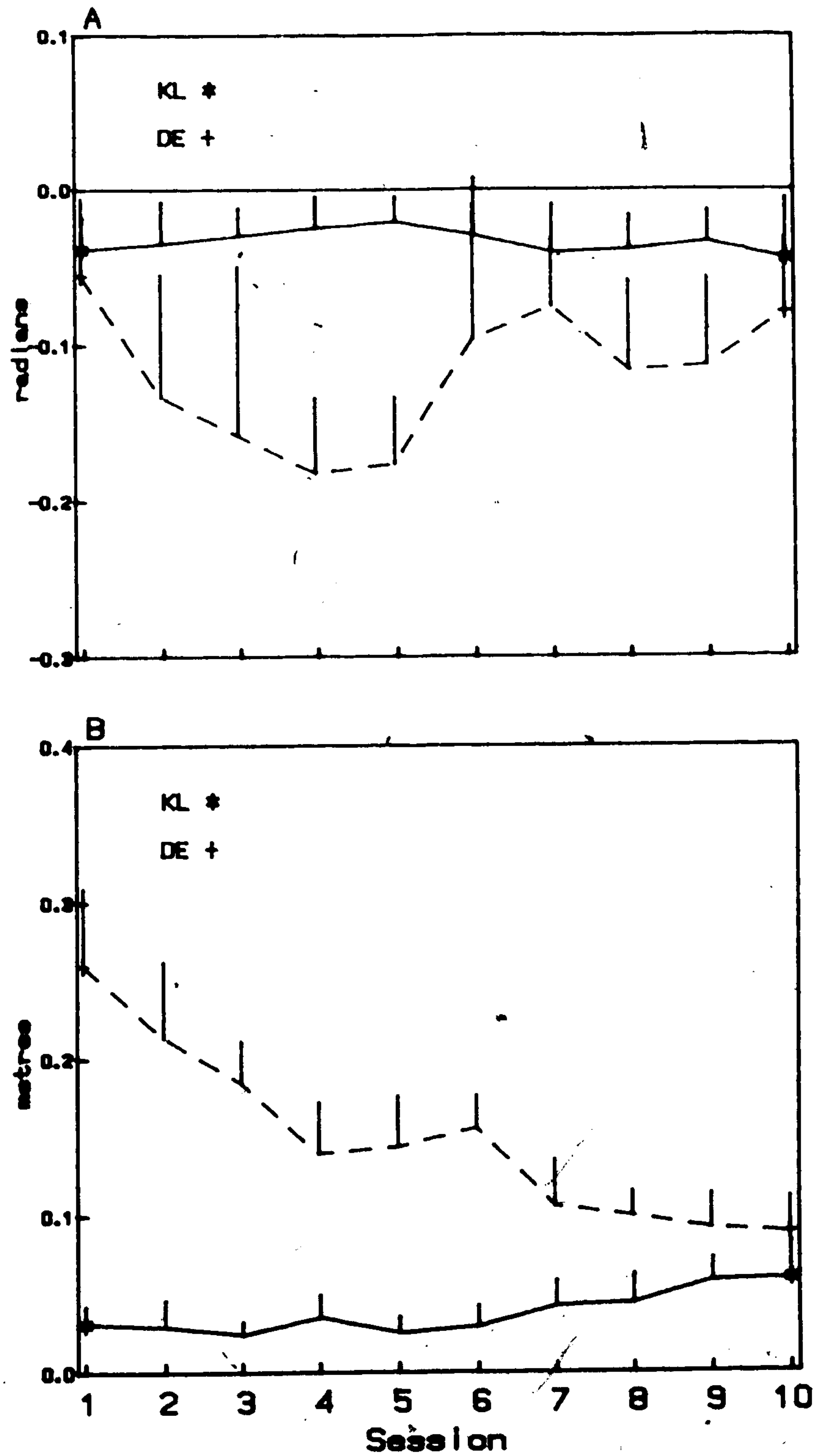


Figure IV-10. Comparison between KL and DE across the 10 sessions from the kinematic data. A. Release angle. B. Release height.

that of his non-awkward counterpart.

The stride length scores of each of the boys are presented in Figure IV-11A. Both boys used appropriate stride lengths for their body size at the end of the experiment.

The mean values for the distance behind the foul line are presented in Figure IV-11B. Again KL's performance is closer to the foul line and less variable than DE's performance.

Comparison Between DL and MW

As Figure IV-12A indicates, DL (the third control subject) clearly hit the target pin more frequently than did his age-matched physically awkward counterpart, MW. DL showed no improvement across the ten sessions, whereas MW showed some gains in performance. It should be noted, however, that there was still a large performance difference between the two subjects, with the physically awkward subject performing at a much lower level. MW was the other physically awkward subject that was instructed on certain components throughout the 10 sessions.

In terms of error scores, the results of both error scores supported the above target pin accuracy results for DL and MW. As Figure IV-12B shows, DL had less variable error than MW throughout the ten sessions suggesting more accuracy and stability in his bowling performance. The constant error results presented in Figure IV-12C showed that both subjects

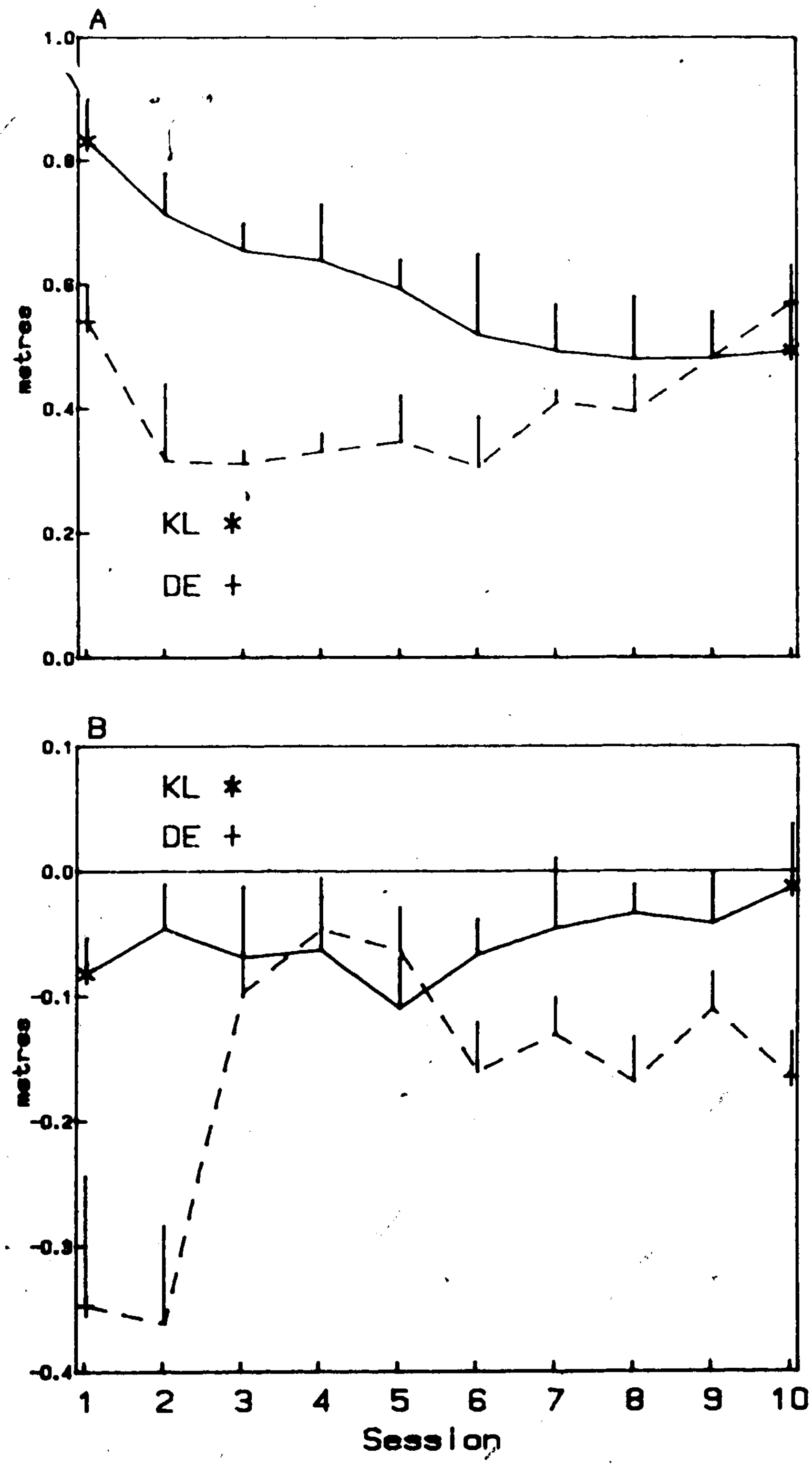


**Figure IV-11.** Comparison between KL and DE across the 10 sessions from the kinematic data. A. Stride Length. B. Lead foot distance behind the foul line.

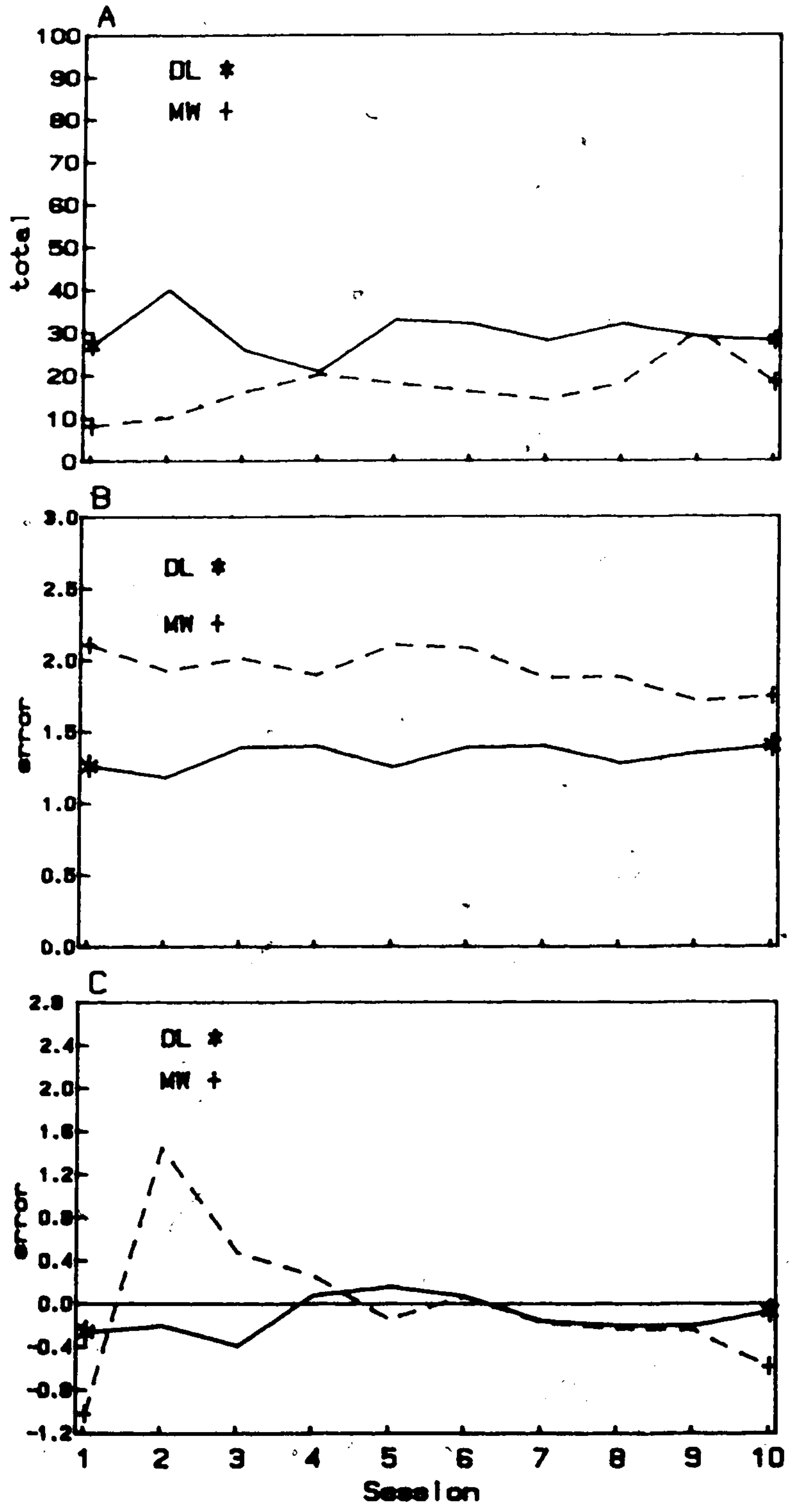


**Figure IV-12.** Comparison between DL and MW across the 10 sessions from the behavioural data. A. Criterion pin contacts. B. Variable error. C. Constant error.

reflected a response bias to the left of the target over 60% of the sessions. The variability of DL's performance was also much less than MW's reflecting again a lack of consistency in skill execution for MW. One factor which should be mentioned is that MW was the only left handed subject in the experiment, so that contacts to the left of the criterion reflect a ball release with supination of the forearm and/or a deviation from the vertical at release.

The criterion pin film data shown in Figure IV-13A indicate that DL bowled consistently better than his physically awkward peer, MW. However, there was no appreciable difference in the totals over all the sessions between the two subjects. MW's performance in Sessions 8 and 9 reflects his improved performance in criterion pin contacts. (See the behavioural data in Figure IV-12A).

The variable error data from the film is presented in Figure IV-13B and is congruent with the findings from the more complete behavioural data. DL is more accurate and less variable over all ten sessions. Again, the constant error presented in Figure IV-13C demonstrates a rather equal distribution of responses to both sides for DL while MW was hitting targets on the right side of the criterion in 60% of the throws.

As Figure IV-14A shows, there is no appreciable difference in ball velocity between DL and MW over all 10

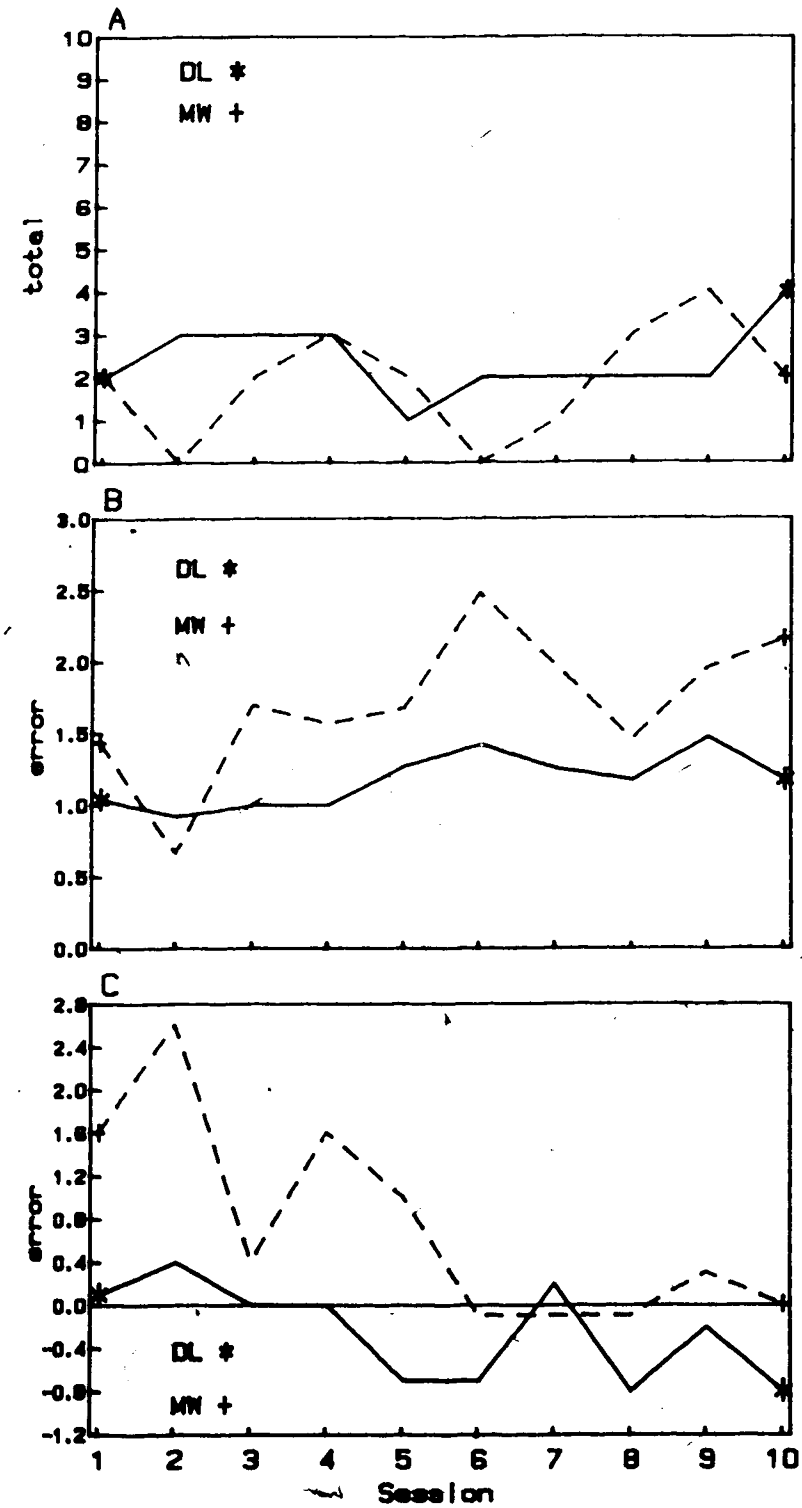


**Figure IV-13.** Comparison between DL and MW across the 10 sessions from the film data. A. Criterion pin contacts. B. Variable error. C. Constant error.

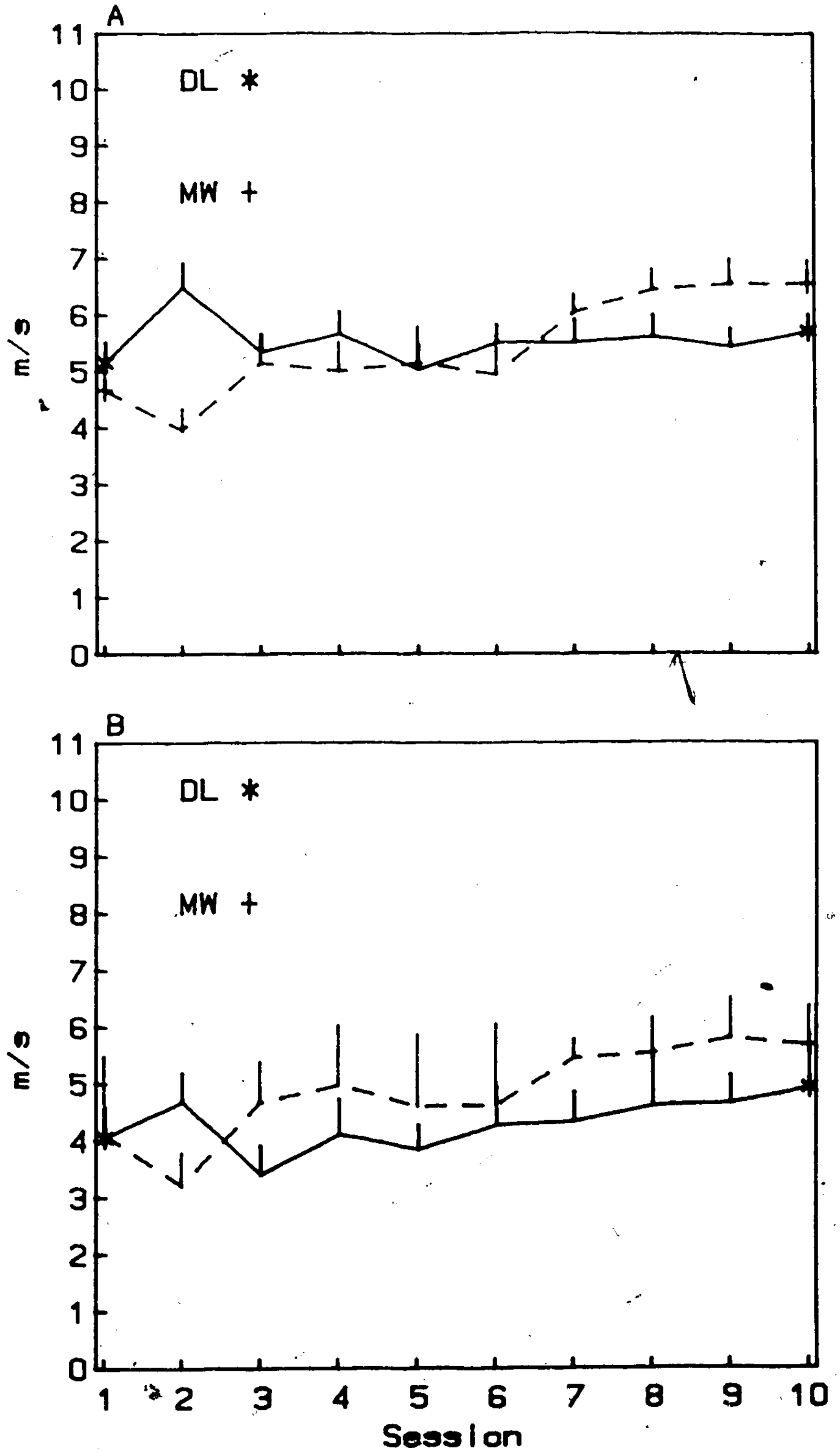


**Figure IV-14.** Comparison between DL and MW across the 10 sessions from the kinematic data. A. Ball velocity. B. Upper limb velocity.

sessions. Both boys, however, appear to be bowling the ball at a low but acceptable velocity.

As would be expected, the upper limb velocity results (see Figure IV-14B) for both DL and MW parallel the ball velocity scores over the ten sessions. The contribution to ball velocity through wrist flexion was much higher for DL compared to MW. It appeared from a qualitative analysis of MW's performance (see Appendix A) that he dropped the ball from his hand and thus contributed very little through wrist flexion to ball velocity.

The results for the release angle variable shown in Figure IV-15A reflect that DL has a much more stable and mechanically appropriate release angle than MW. Furthermore, MW's angle of release is much more variable within and across the ten sessions. It appears that MW allowed the ball to drop from his hand rather than releasing it smoothly and this is also evidenced in the release height values.

The results of the release height of the ball data presented in Figure IV-15B show large differences between DL and MW. DL releases the ball consistently and very near the floor, whereas MW is extremely erratic with his release height.

Figure IV-16A presents the results of the stride length measures. Again, large differences in the stride length for DL and MW are evident. DL's stride length is somewhat long for his height and MW's is slightly short.

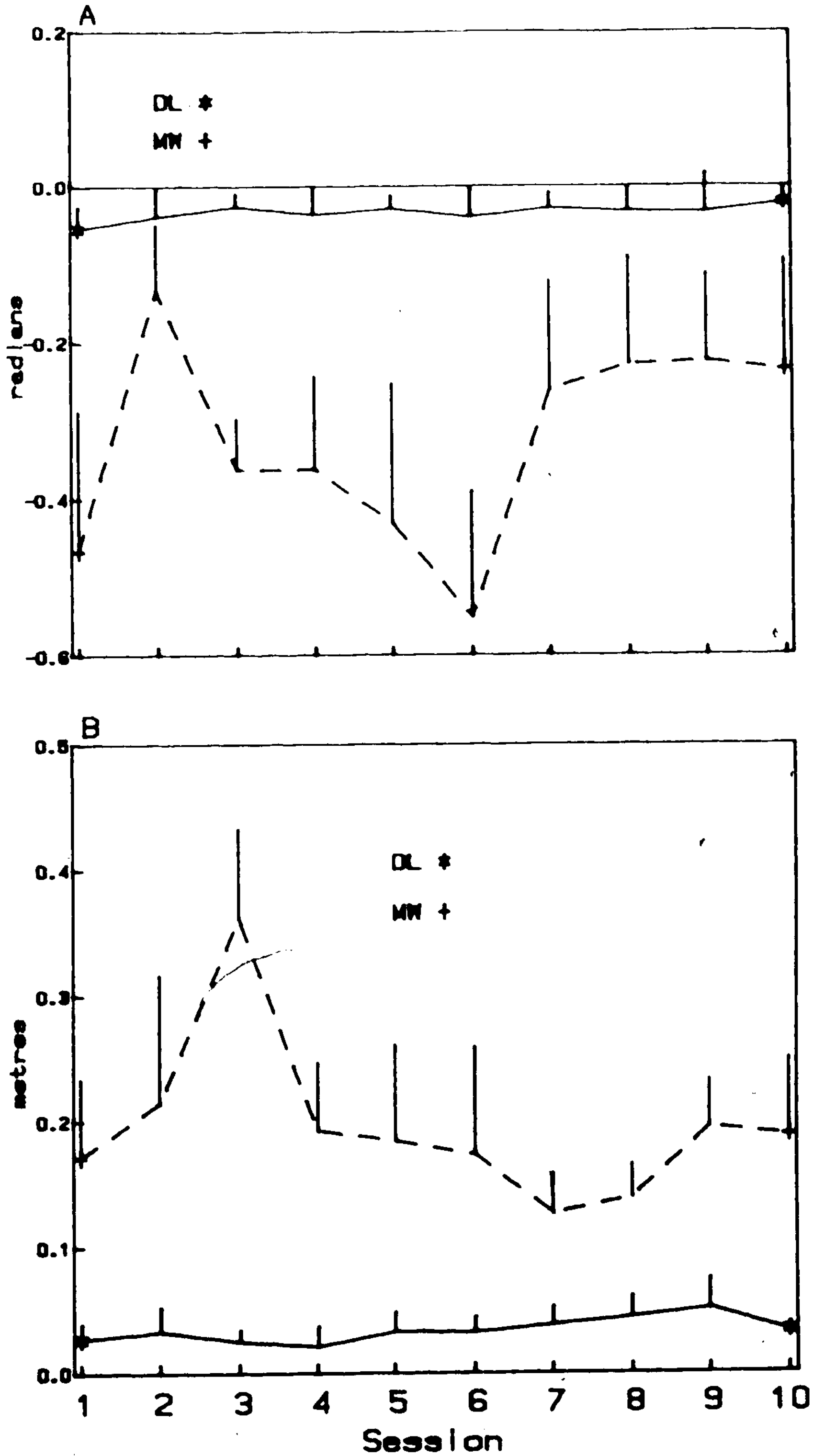


**Figure IV-15.** Comparison between DL and MW across the 10 sessions from the kinematic data. A. Release angle. B. Release Height.

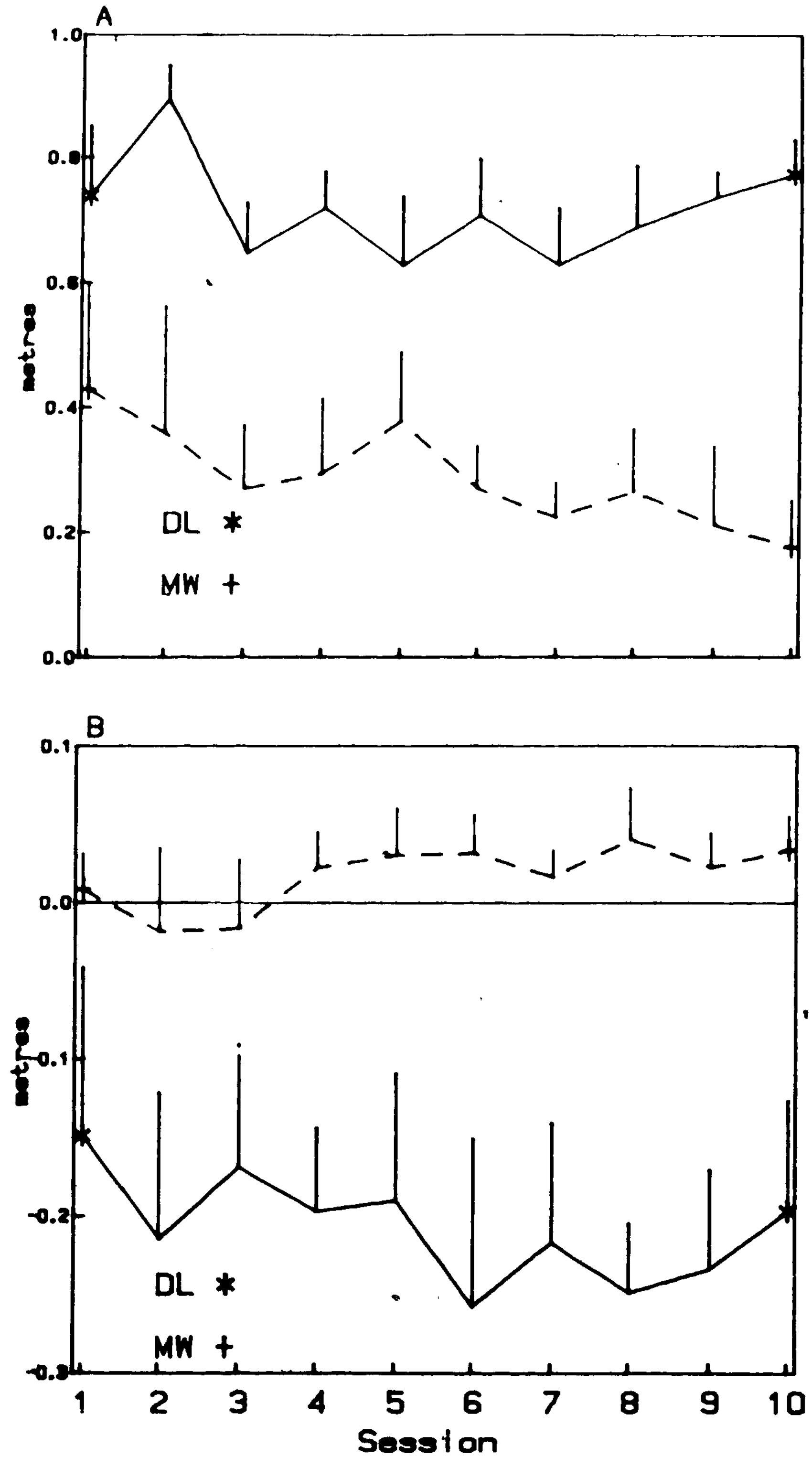


**Figure IV-16.** Comparison between DL and MW across the 10 sessions from the kinematic data. A. Stride Length. B. Lead foot distance behind the foul line.

Finally, the distance that the lead foot of each subject was behind the foul line is presented in Figure IV-16B. MW is clearly deficient in this variable with his foot placement over the foul line in 8 of the 10 sessions. DL is moderately variable with his foot placement within each session, but remained within an acceptable bandwidth of performance on this component.

Comparison Between DM and WC

As Figure IV-17A shows, DM, the fourth control subject, and WC, his physically awkward peer, are not different on criterion pin accuracy in all sessions. An analysis of both curves indicates that very little change in performance was evident in either subject's scores across the ten sessions.

Figure IV-17B presents the results of the variable errors for both DM and WC over the ten sessions. Again, as was expected from the criterion pin contact data, the variable error obtained by DM over all trials in each session is not different than that obtained by WC.

Figure IV-17C shows that DM's response bias measured by his constant error is 100% to the left of the criterion pin, suggesting a deviation from the vertical whereas, WC's is 60% to the left side of the target across the ten sessions.

Figure IV-18A presents the results of the criterion pin contact for the film data. In contrast to the behavioural data where there is no difference between the two subjects, the filmed trials indicate that the physically awkward

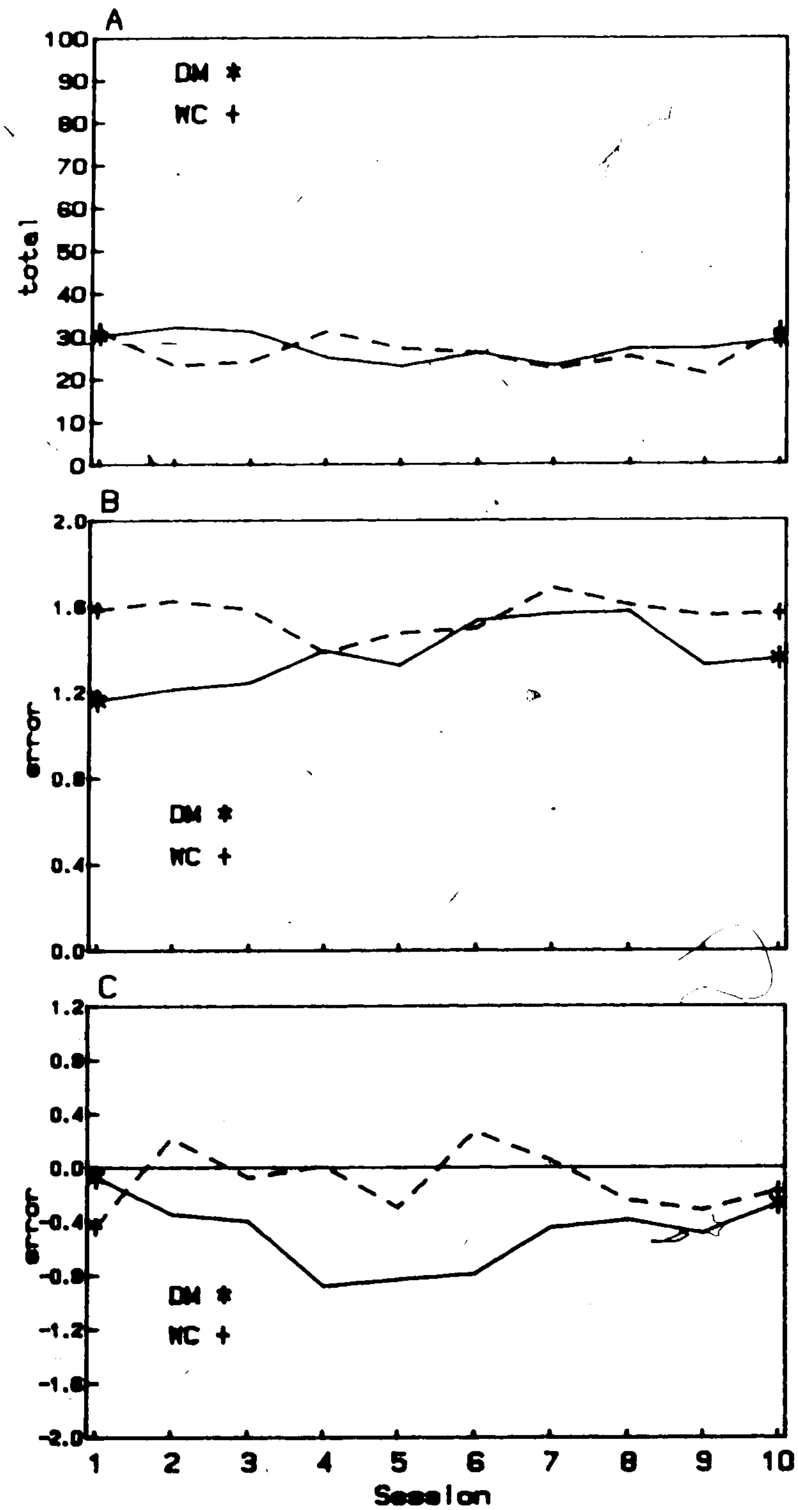


**Figure IV-17.** Comparison between DM and WC across the 10 sessions from the behavioural data. A. Criterion pin contacts. B. Variable error C. Constant error.

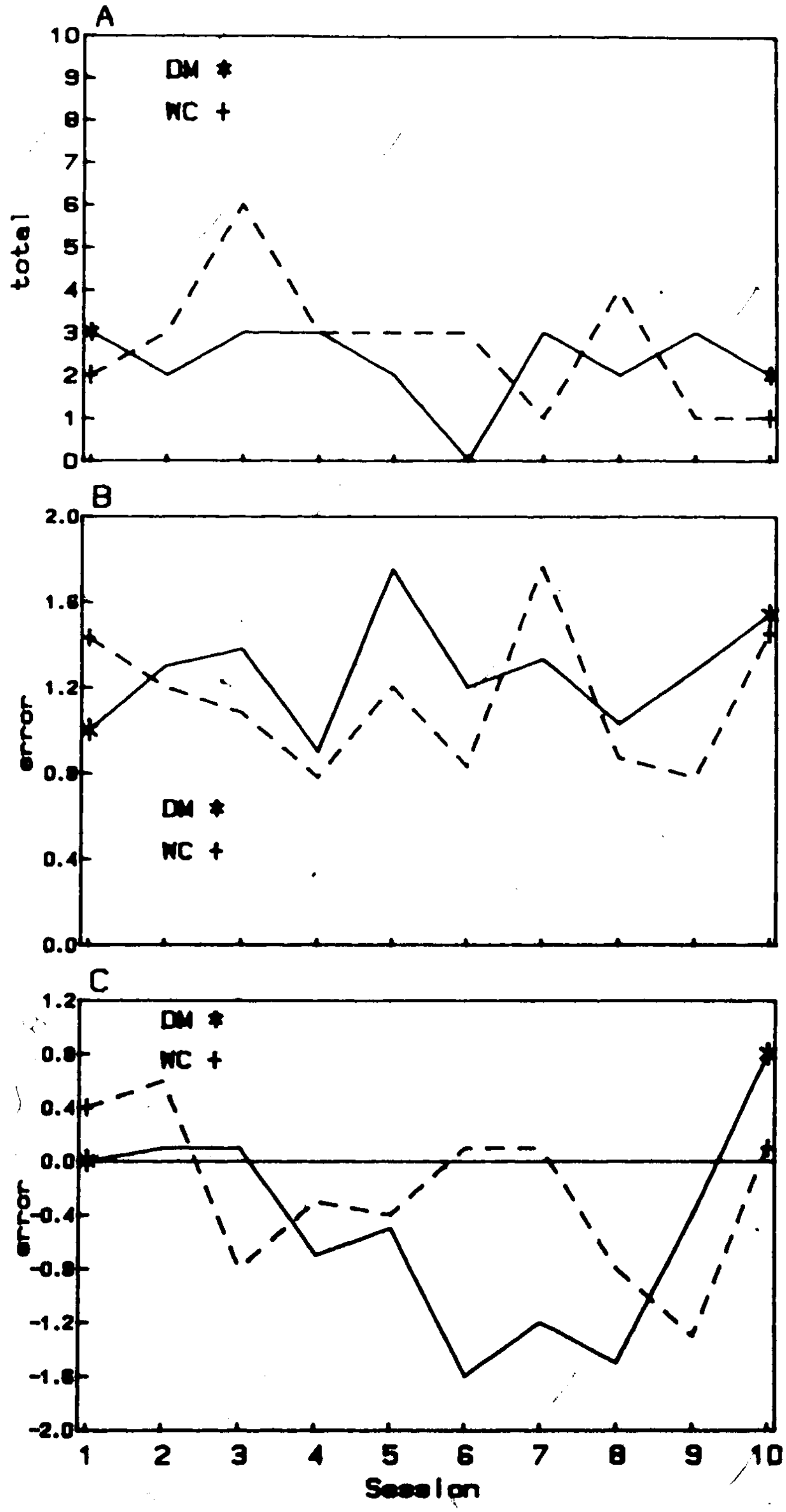


**Figure IV-18.** Comparison between DM and WC across the 10 sessions from the film data. A. Criterion pin contacts. B. Variable error C. Constant error.

subject, WC, performed slightly better than DM.

The results of the variable error scores are presented in Figure IV-18B on the film data and reflect the filmed pin contact with little or no difference between the two boys.

The results of the constant error analysis is presented in Figure IV-18C. Again, there are no appreciable differences between the two subjects.

The ball velocity scores plotted over the ten sessions for both DM and WC are presented in Figure IV-19A. No obvious difference between the boys is evident in the first four sessions. In the remaining six sessions, DM increased his scores slightly, whereas WC decreased his scores. The mean values, however, are within an acceptable bandwidth of performance.

The upper limb velocity scores are shown in Figure IV-19B. Similar differences are evident between the performances of the two boys as observed in the ball velocity scores. The contribution of wrist flexion to ball velocity appeared to be similar for both boys.

The release angle scores which are presented in Figure IV-20A indicate similar results between DM and WC. Both subjects have a large angle of release in the first session with high variability, and then gradually decrease the angle towards a more effective angle across the remaining sessions. The variability within each session is still fairly high for both subjects.

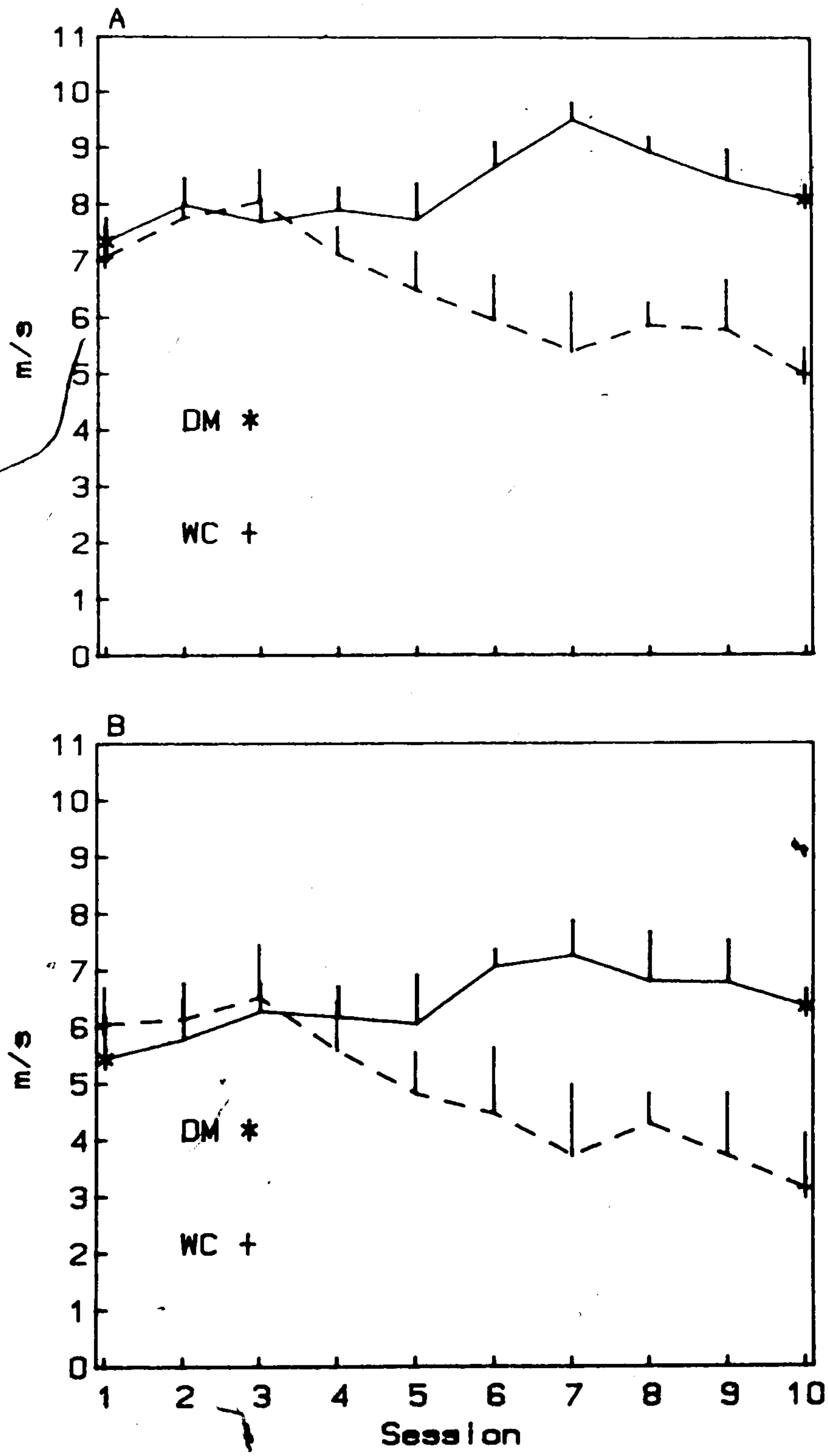


Figure IV-19. Comparison between DM and WC across the 10 sessions from the kinematic data. A. Ball velocity. B. Upper limb velocity.

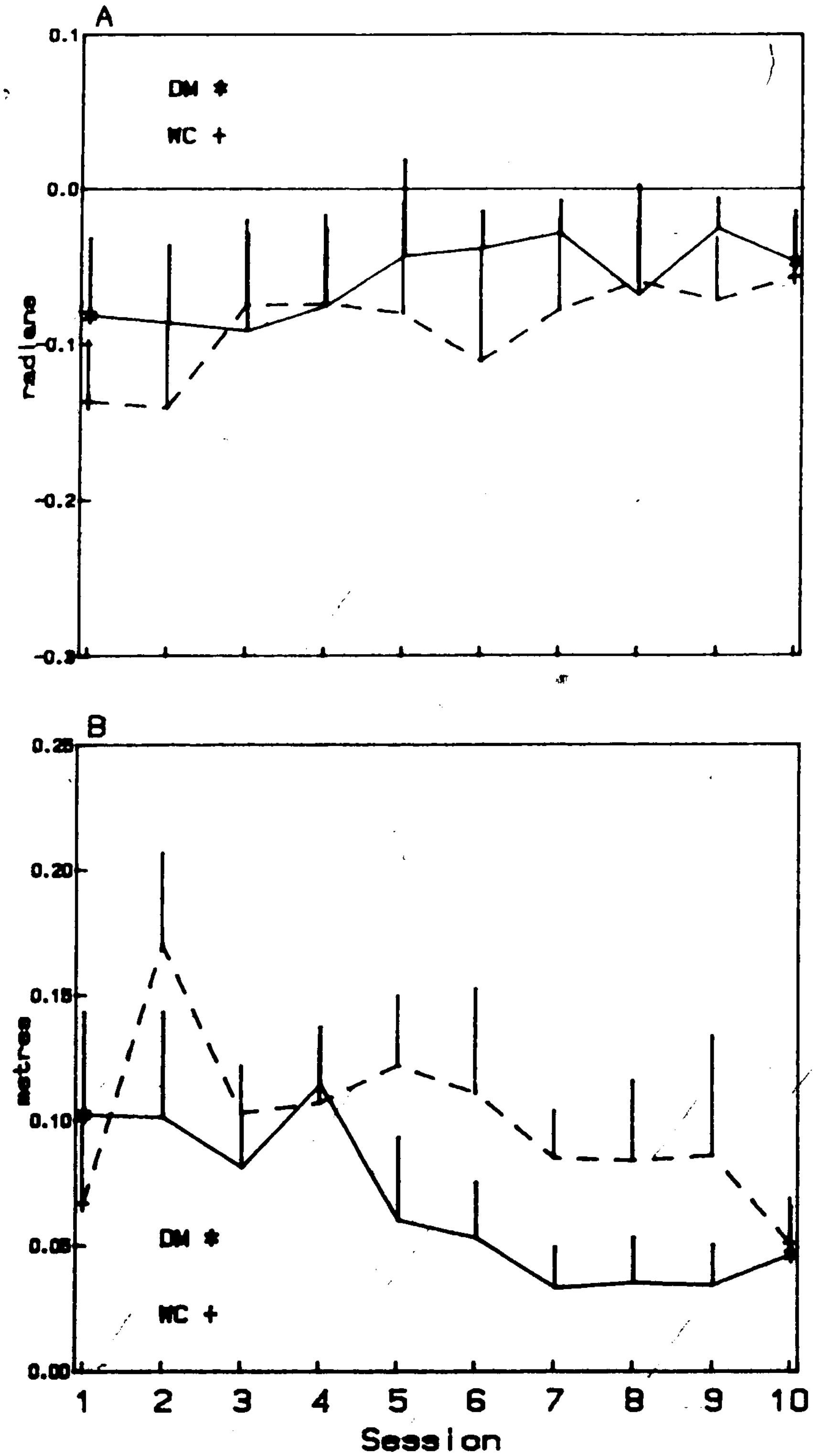


Figure IV-20. Comparison between DM and WC across the 10 sessions from the kinematic data. A. Release angle. B. Release height.

Figure IV-20B presents the results for the release height of the ball used by both boys. Again, both subjects start with a relatively high release height and then effectively lower their scores across the ten sessions. The variability within each session is lower for DM.

The stride length scores for each of the boys is presented in Figure IV-21A. Both boys are using appropriate stride lengths and there is no appreciable difference between the two boys.

The means for the distance behind the foul line are presented in Figure IV-21B. DM is fairly consistent within and across the ten sessions, whereas WC progressively increases the distance away from the foul line until Session 6 and then decreases his distance in the remaining four sessions. Clearly, no apparent pattern is evident for WC's performance.

<u>Summary</u>

The results presented indicate vast performance differences between the matched control and physically awkward boys. Notable exceptions were found between the physically awkward subjects who received instruction based on the performance of their non-awkward peers. The results for these subjects are presented in Appendix A.

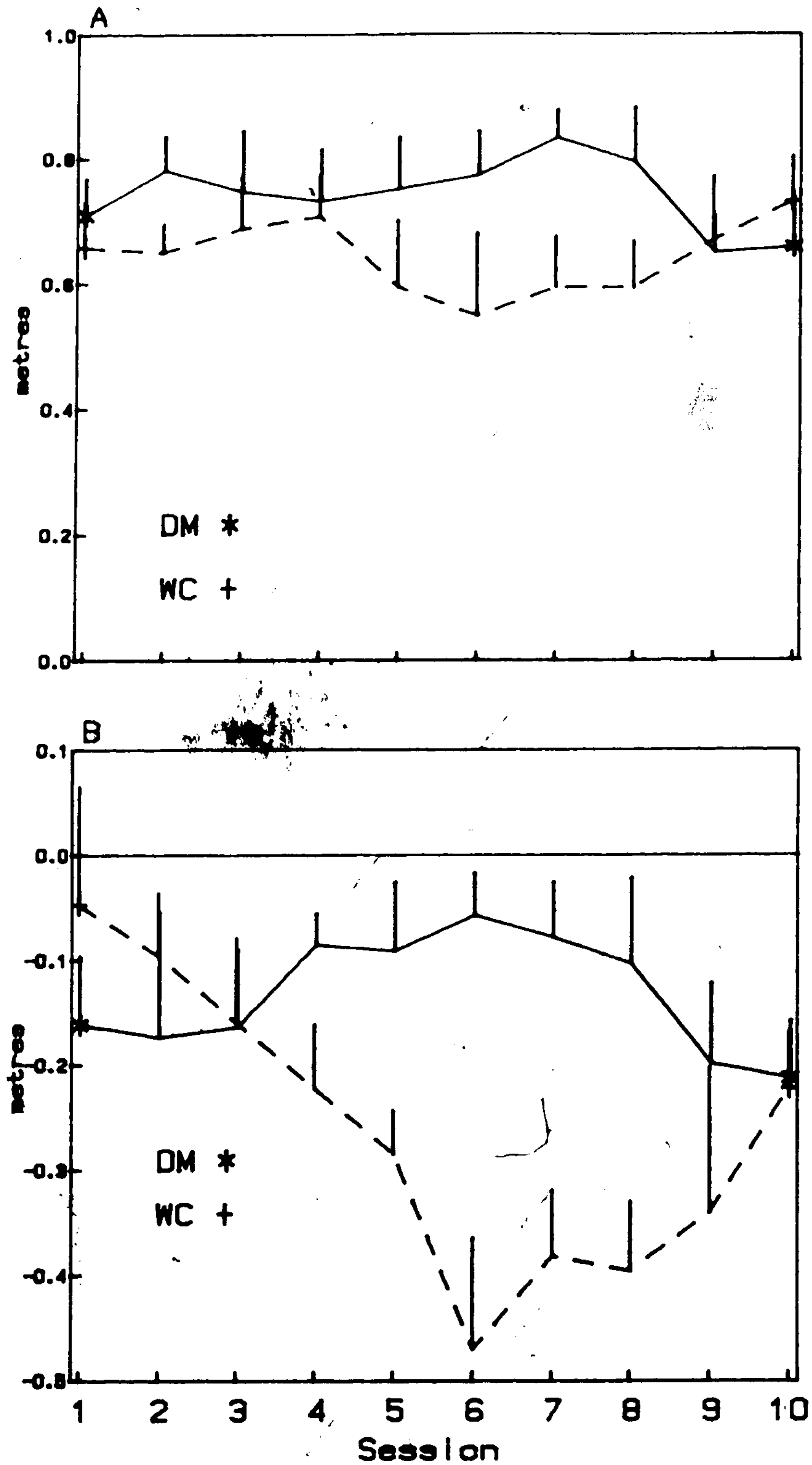


**Figure IV-21.** Comparison between DM and WC across the 10 sessions from the kinematic data. A. Stride Length. B. Lead foot distance behind the foul line.

# Discussion

The primary purpose of this study was to evaluate the effect of 1000 practice trials distributed over 10 sessions on the ball rolling accuracy of four pairs of age-matched physically awkward and normal boys. The data on each subject were collected over a 20 day span. The hypothesis was that a clear performance deficit exists in physically awkward boys in comparison to their age-matched normal peers even after large amounts of guided practice. A second hypothesis implied that physically awkward subjects could be taught a skill based on the essential performance changes exhibited by their peers. The culturally-normative skill of bowling was chosen to reflect this performance deficit. Accuracy (criterion pin contact) in this bowling skill was selected as the dependent variable. Improvement in performance as well as stability and consistency were measured from both behavioural and film data. The film data allowed for detailed analysis of the following key kinematic variables: ball velocity, upper limb velocity, release angle, release height, stride length, and the distance the lead foot remained behind the foul line.

## Behavioural Analysis

Each pair of matched subjects performed a relatively simple skill in a closed environment where the pins were stationary and remained 30 feet (9.14m) from the foul line for each trial. Each subject performed 100 trials/session in 10 blocks of 10 trials each. Performance was self-paced so that the subject could control the inter-trial interval duration. Within two seconds after pin contact, verbal knowledge of results (i.e., pin contact) was presented to each subject. Also, any contact with the criterion pin sounded a buzzer (approximately 2s). Therefore, the subjects received visual and auditory feedback the moment the ball contacted the pin as well as verbal feedback within 2s after pin contact relative to pin accuracy.

The inclusion of verbal knowledge of results (Newell & Kennedy, 1978) in the present study was used to enhance the learning of the bowling skill. Currently, the literature suggests that knowledge of results provides information to the performer relative to the environmental goal (Adams, 1971; Newell & Walter, 1981; Salmoni, Schmidt, & Walter, 1984; Schmidt, 1975a). This information, generally given in verbal form, is then processed and a decision made by the performer regarding the nature of the modifications required to alter the action plan on succeeding trials so that performance level may be ultimately improved. Therefore, the informational content of the feedback derived from the outcome of a response is viewed as an important determinant of the success of the ensuing action (Newell & Walter, 1981).

The subjects in the present study received adequate knowledge of results and intrinsic feedback to process information and to make the necessary adjustments relative to response outcome. The amount of intrinsic and extrinsic sensory feedback that the subjects received should have provided optimal learning conditions for improvement in bowling accuracy performance across the 10 sessions. Unexpectedly, the performance gains did not materialize for all the subjects on criterion pin contact. This lack of performance gain in the present study was also confirmed by the behavioural data error scores.

The results of the criterion pin contact in the complete behavioural data indicated that only two subjects, JN, in the control group, and MW, in the physically awkward group, largely improved their performance over the 1000 practice trials. The other six subjects, both awkward and normal, did not appreciably improve their performance as would be expected with a large number of practice trials, especially in the normal boys.

The improvement of the environmental goal is usually associated with increased amounts of practice (Higgins & Spaeth, 1972; Newell & Kennedy, 1978). Not mentioned in the research literature is the schedule and the amount of practice that the child should adopt in learning a novel skill (Newell, 1977). A few studies have reported environmental goal improvement with minimal practice (less than 200 trials) (Hicks, 1930; Higgins & Spaeth, 1972; Hoffman, 1974). The low number of practice trials to achieve environmental goal improvement reported in these studies is in contrast to the results in the present study. A possible explanation for the lack of environmental goal improvement for six of the eight subjects on this response-loaded skill centres on the amount of practice in one session.

The subjects in the current study practiced 10 blocks of 10 trials each totalling 100 trials/session over a ten session period lasting 20 days. The time to complete 100 trials was generally less than 30 minutes. A question arises as to the proper amount of practice per session in a laboratory setting where such factors as boredom, fatigue, motivation, age and developmental skill level, last session effects, and simply too much practice in one session could affect the performance of these young children. Every attempt was made to eliminate the extraneous factors and to keep the task interesting by encouraging the subjects to do their best and to improve upon their previous score from the block of 10 trials. The subjects were questioned throughout each session if they were getting bored or fatigued with the practice and their answers usually indicated that they were neither bored nor tired. In fact, a post hoc analysis of variance on variable error scores indicated no significant differences between first and second half scores. Also, it appeared that in over half of the sessions, the variable error was lower in the second half of trials. The studies mentioned above were conducted with practice trials in the range from 10 to 40/session. Perhaps the amount of practice in the present study was too much to obtain any improvements in the environmental goal. Clearly, more research needs to be conducted on the number of practice trials/session and total practice while controlling some of the intervening factors alluded to above.

There is one other noteworthy comparison to be made on the criterion pin contacts from the behavioural data and that concerns performance differences within each matched pair. Three of the four pairs showed large differences (greater than 130 pins) in total pin contact across the ten sessions with the normal boys attaining the higher score. The behavioural error scores reflect this difference with the normal boys exhibiting less error across all 10 sessions than their physically awkward peers. The fourth pair of matched subjects exhibited minimal differences on both criterion pin contacts (12 pin difference) and error scores with the normal boy performing slightly better. This lack of performance difference between these two subjects can not be fully explained. Both of these subjects were identified from a screening conducted in the schools (Wall, 1986a) and one or both boys could have been wrongly diagnosed. The analysis of the kinematic data in the next section should help to clarify the occurrence of the minimal differences between the fourth pair of matched subjects.

Kinematic Film Analysis

Evidence for the development of kinematic consistency over trials has been demonstrated in a number of sport skills studies (e.g., Franks, Weicker, & Robertson, 1985; Higgins & Spaeth, 1972; Hoffman, 1974; Tyldesley & Whiting, 1975). Kinematic consistency in the present study was observed in the analysis of the kinematic variables. The results of the kinematic data, in which every tenth trial was filmed, generating a total of 100 film trials, suggested a high degree of consistent performance within and across sessions for the normal boys compared to their physically awkward peers in all six of the kinematic variables examined. The normal boys' bowling performance, as measured by the kinematic variables, was generally stable and consistent across the 10 sessions. Their within-session variability was low and generally declined across the 10 sessions suggesting improved performance. Thus, kinematic consistency across the 10 sessions was demonstrated by the normal boys on all kinematic variables. In contrast, the performance of their matched physically awkward peers was erratic and extremely variable across and within each session for most of the kinematic variables. The only exceptions were the two physically awkward subjects (TJ and MW) who were taught on specific components throughout the experiment. This lack of variability on some of the kinematic variables for the teaching control physically awkward subjects suggests that physically awkward subjects can reduce variability and become consistent in some aspects when instructed and physically manipulated into the proper position. Hence, practice without guidance in a structured environment for the physically awkward may not be adequate. The physically awkward subjects who were not taught exhibited much more variability in their performance.

The analysis of the pin contacts and the error analysis from the film, however, did not differentiate within three of the four matched pairs. The only clear difference existed between the matched subjects, JN and TJ. This lack of differentiation could be a result of a number of factors which could not be controlled. The addition of cinematography on every tenth trial, with increased waiting time and the high speed camera and bright lights, may have had a differential influence on the subjects' performance.

Thus, the examination of the results of the kinematic variables suggests some learning and skill improvement had been acquired by the normal boys compared to their physically awkward peers after 1000 practice throws, even though there was no appreciable improvement in the environmental goal. The kinematic consistency exhibited by the normal boys agrees with the definition of skilled motor performance proposed by Glencross (1980).

<u>Knowledge-Based Approach to Skill Acquisition</u>

The following discussion examines the contribution of the knowledge-based theory of skill acquisition and learning proposed by Wall et al. (1985). The results of the present study are discussed relative to certain knowledge bases that are inherent in the individual.

Learning and development in the motor domain depend on the demands of the task at hand, the developmental level of the learner, the type of instruction, and the nature of the environment in which the learning is to take place. For school-aged children to enjoy participating in play and sport environments, they must develop reasonable accuracy and consistency in their physical skills. It is essential that children learn the basic response-loaded skills of a given sport before they are forced to use higher level strategies in competitive situations. The development of such automatized procedural knowledge depends on guided practice which facilitates the development of skillful performance (Wall, 1986b).

The kinematic results of this study suggest, that with guided practice, the normal boys learned the basic response-loaded skill of bowling for accuracy with ever increasing consistency, whereas the physically awkward boys had not yet established any consistent patterns. This consistency by the normal boys is evidenced by the decline in kinematic variability as the sessions and, subsequently, learning, progressed. The physically awkward subjects, on the other hand, did not exhibit kinematic consistency and performed considerably lower than their normal peers in reference to the environmental goal.

Siegler (1983) emphasizes the influence existing knowledge has on the learning process. He notes that as children acquire more knowledge they begin to use more specific strategies in accessing and integrating knowledge. Acquired knowledge refers to the knowledge that is gained through experience which increases with development. Declarative knowledge is one type of acquired knowledge. Declarative knowledge about action refers to factual information stored in memory that can influence the development and execution of skilled action. As children grow older and acquire knowledge through practice, they begin to understand the morphological, biomechanical, and environmental constraints under which they are operating.

In order to examine the declarative knowledge base of the matched subjects in the present study, certain key questions were asked relating to knowledge of self, biomechanical, and environmental constraints. The questions and answers appear in Appendix B. The answers suggested that the normal boys had a richer declarative base relating to bowling compared to their physically awkward peers. The main answer from the physically awkward boys was, 'I don't know'. The number of questions that were presented to each subject were few (eight) in number. It was decided, however, that even though the number of questions was low, they should still represent a sample of the subject's declarative knowledge base. Eight questions are clearly too few upon which to make broad generalizations, but results do suggest that physically awkward children have less declarative knowledge in action situations. It appears, therefore, that the normal boys were better prepared to practice and their kinematic consistency confirms this.

Another aspect of skill acquisition refers to the degree of attentional control required to execute an action. A fundamental observation in the skill acquisition process is that deliberate attentional control is required at certain times. Gentile (1972) postulated that motor skills are usually acquired in three distinct phases: cognitive, associative, and autonomous (Fitts, 1964). The cognitive phase requires the involvement of considerable cognitive resources, whereas the associative and autonomous phases are automatically controlled. Such conscious control is relatively costly in terms of the speed and consistency of a given performance (Norman & Shallice, 1986), furthermore, by definition, novices are usually operating in just such a costly control mode. The results of the present study suggest that the normal boys, evidenced by their consistent kinematic performance within and across sessions, were utilizing automatic phases of control. Their matched awkward peers, on the other hand, were perhaps still operating in the conscious control mode and thus had not established an automatic phase of execution.

Clearly, the physically awkward boys are lacking in the declarative and procedural knowledge domains compared to their matched normal peers. The interaction of these two knowledge domains is essential for the successful completion of any action sequence; in this case, a bowling skill. There is also a complex interaction among other knowledge bases.

The knowledge-based approach views motor development from a broad perspective that emphasizes the importance of a child's procedural, declarative, affective, and metacognitive knowledge about action. It also stresses the heterogeneity of development and the importance of domain-specific knowledge. The performance differences that existed between the matched normal and physically awkward boys can be likened to the differences between experts and novices and their respective domain-specific knowledge (Allard, Graham, & Paarsalu, 1980; Chi, 1978; Jones & Miles, 1978). In all of these studies, the experts were able to use their domain-specific knowledge to generate more effective problem solving strategies than their less-informed peers. This effective use of domain-specific knowledge supports the relationship among procedural and declarative knowledge and metacognitive skills; it also suggests that such metacognitive skills as planning, monitoring, and evaluating are directly influenced by the domain-specific knowledge of the person. Clearly, the normal boys in the present study were more effective in using domain-specific knowledge to effectively improve their kinematic performance than were their matched physically awkward peers.

The knowledge-based approach to skill acquisition also recognizes the relative stability of development and the role of domain-specific knowledge in development (Macnab, 1979). When the developmental level of the child in the motor domain is considered, very broad differences in knowledge and skill are observed due to the past experiences of the child. Large differences in the procedural knowledge base were observed between the normal subjects and their matched physically awkward peers in the present study. Some indication towards a deficiency in declarative knowledge by the physically awkward was also suggested. The future needs of the physically awkward child in the motor domain need to be addressed. The physically awkward child can not be effectively instructed at the same level or schedule of practice as the normal child. The demands of the task vary with skill and developmental level of the learner and thus careful consideration is required for the child to learn and perform a given task.

Thus, it appears that refinement of certain kinematic parameters relating to the accuracy component in ball rolling, occurs with practice in normal boys. One thousand practice throws generated an ever increasing trend in kinematic consistency of the movement sequence. The attainment of the environmental goal, however, did not increase in three of the four normal boys. One thousand throws for three of the four physically awkward boys was not enough practice to develop performance improvements or kinematic consistency. The fourth subject who improved the environmental goal was still far inferior to both his physically awkward and normal peers. This finding suggests that more practice is needed, especially in young children, to show improvement in the environmental goal.

The amount and schedule of practice could also be modified to reflect improvement in the environmental goal. The trials could have been reduced to 50 throws/session while keeping the total number of practice throws (1000) in the experiment the same. The number of throws in a non-laboratory situation (e.g., a bowling alley), where the individual is intrinsically motivated to continue practicing, could be higher and this should be examined.

Also, a number of different factors should be considered in the future to observe skill changes in a ball rolling skill or any elementary response-loaded skill in children. These factors include: larger sample size; varying ages of participants; different environments; motivational levels; boredom; knowledge of results and knowledge of performance; number of trials in one practice session; and total amount of practice. The examination of these factors is a tremendous task which would take resources from a variety of sources to be successful. In this way, a progression of kinematic consistency and the environmental goal can be obtained.

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## V. General Discussion

There are large individual differences in development due to age, sex, intelligence, and socio-cultural origins that must be recognized in the skill acquisition process (Wall, 1986). In spite of individual differences, however, physically awkward children by definition, are unable to execute culturally-normative motor skills with acceptable proficiency and are clearly behind their peers in motor development. The first experiment examined the effects of parent supervised practice on the development of skill in the stationary hockey slap shot in physically awkward boys compared to normal peers. The second experiment on bowling examined the kinematic consistency of four pairs of matched normal and physically awkward boys while performing a ball rolling task for accuracy. The basic purpose of both studies was the examination of the pattern of skill acquisition with increased practice of closed skills. The closed skills in both studies were used to observe skill acquisition changes in controlled environments and to increase the likelihood of kinematic consistency with increased amounts of practice (Gentile, 1972; Glencross, 1980; Wall, McClements, Bouffard, Findlay, & Taylor, 1985).

### Practice Effects

The number of practice trials needed to achieve consistency of performance and increased success especially in children, has not been clearly identified in the literature. Many factors may contribute to kinematic consistency and they include: the type of skill performed, the schedule of practice, knowledge of results, knowledge of performance, and the amount of time practicing. In many studies of skill acquisition, the number of practice trials has generally been very low (200 trials or less), yet some authors reported consistency of movement even with the limited number of practice trials (Hicks, 1930; Higgins & Spaeth, 1972; Hoffman, 1974).

Wall (1982) contends that from the earliest motor development period, physically awkward children demonstrate a lack of skill in cognitive-motor tasks. As they grow older, this lack of skill when practicing becomes a vicious cycle producing considerable information overload which results in feelings of failure, frustration, and helplessness. As a result of their lack of skill proficiency, physically awkward children often choose not to participate and hence they prevent themselves from practicing resulting in a serious practice deficit. Without practice, these children can not develop movement consistency.

The total amount of practice was a crucial component of these experiments. Total practice for the physically awkward children in the hockey experiment was 1200 trials over a six week period. This practice total was arbitrary, taking into account motivation, boredom, and other such factors that prevent physically awkward children from practicing. The practice was conducted at home under the guidance of their parents who received specific instructions regarding performance from the investigator. After the six week practice session and 1200 trials, little consistency of performance was evident with respect to puck and stick velocity. Clearly, 1200 practice trials did not appreciably help these physically awkward subjects perform appropriately or consistently. The matched normal boys who did not have the benefit of 1200 practice trials performed relatively consistently in the three filmed trials. The results of the matched normal and physically awkward boys in the hockey study lends support to Wall's et al. (1985) contention that physically awkward children are clearly behind their peers in procedural knowledge.

The bowling study also examined the effects of practice on movement consistency. The major difference between the hockey and bowling studies centres on the practice environment. Each matched subject practiced in a lab situation so that intervening effects could be eliminated or controlled and practice ensured. The practice schedule was similar for both groups of normal and physically awkward boys with 100 trials/session, 10 sessions in 20 days, for a total of 1000 practice attempts. A comparison of the totals for the environmental goal indicated that all of the normal subjects scored higher than their physical awkward counterparts, the differences ranging from 12 to 144 criterion pin contacts.

Three of the four normal subjects contacted the criterion pin over 130 times more than their physically awkward matches. Clearly, the physically awkward children are behind their peers in procedural knowledge. With equal amounts of practice physically awkward children exhibit lower scores with respect to the environmental goal.

There are many inherent factors which are assumed to exert direct influence over the potential structure of movement. These factors include: biomechanical, morphological, and environmental, and have been explained in detail elsewhere (c.f., Arend, 1980; Higgins, 1977; Newell, 1984). Wall et al. (1985) mentioned that physically awkward children are behind their peers in the declarative knowledge domain. This deficiency in declarative knowledge could affect performance, as measured by the environmental goal, if the physically awkward children did not have an understanding of the effects of the factors mentioned above. In fact, the questions that were presented to the physically awkward subjects revealed little or no understanding of the environmental, morphological, and biomechanical factors that influence movement. Their matched normal peers, however, answered the questions correctly or appropriately in the first or second session (see Appendix B). The number of questions relating to performance in the bowling skill was an initial step towards developing a more detailed questionnaire on the knowledge of children in motor skill situations.

Further research is required on the declarative domain of all children when performing, especially the physically awkward. Also required is research on the benefits and the amount of extra practice necessary for these children to attain an acceptable level of performance. As Wall (1986) stated, there is a need to develop accurate measurements to assess the developmental level of the learner and the different types of knowledge about action that are required for the learning of a given task. In this way physically awkward children would benefit with increased amounts of practice, given the developmental level of the learner.

Consistency of Movement

A fundamental characteristic of motor development is the acquisition of motor skills that allow a person to efficiently meet the increasing task demands of the environment. Glencross (1980) has identified four major characteristics of skilled motor performance: motor constancy, the uniqueness of action, the stability and consistency of action, and the modifiability of action. The most obvious feature of the skilled performer is the consistency and stability of performance (Glencross, 1980). This characteristic was examined with respect to the angular velocity curves in the hockey study and the standard deviation values of the kinematic variables in the bowling experiment.

The angular velocity patterns of the normal boys in the hockey experiment indicated relatively consistent patterns over their three filmed trials. Erratic patterns of movement, even after 1200 practice trials, were evident for their matched physically awkward counterparts. Examination of the standard deviation values of the kinematic variables for both the matched normal and physically awkward subjects in the bowling experiment revealed interesting differences. The standard deviation values for the normal boys were low in value, tightly banded together, and generally followed a decreasing trend across the ten sessions. The results from the normal boys in the two studies were supportive of the conclusions drawn from earlier studies (Higgins & Spaeth, 1972; Tyldesley & Whiting, 1975) that skilled performance is normally characterized by a highly consistent and reproducible pattern of movements. This low and decreasing trend in standard deviation scores characterizes the kinematic consistency and higher performance scores elicited by the normal boys in the bowling experiment. In contrast, the standard deviation values for the physically awkward boys were characterized by higher and somewhat erratic values across the ten sessions. The physically awkward boys had not yet attained kinematic consistency and their performance scores reflected this. Thus, further support is provided for the knowledge-based approach to skill acquisition in the procedural knowledge domain.

The physically awkward boys in these studies are behind their peers when measured on environmental goal performance and kinematic consistency. These findings agree with Wall (1982, 1986) with respect to performance. However, Wall's (1982, 1986) suggestions can be expanded by incorporating remedial programs based on the individuals' developmental level, interests, domain-specific knowledge, and appropriate practice schedules. This type of program will have to be developed for physically awkward children so that they may acquire the necessary skills to perform in the 'real' world. Perhaps developing a teaching protocol based on essential performance changes observed in normal children would be beneficial for the physically awkward child. In this way the physically awkward child could perhaps progress at a similar rate to a matched normal peer. A teaching protocol, based on the above premise, was designed for two of the four physically awkward subjects and is discussed next.

Teaching Protocol

Two of the normal boys in the bowling experiment were chosen randomly as teaching controls for their matched awkward peers. Performance changes with respect to selected kinematic variables as learning progressed were identified both qualitatively and quantitatively. These performance changes in the normal boys were used to devise a teaching protocol for their matched awkward peers. It was hypothesized that perhaps the physically awkward boys could be taught in a manner which effectively reflected the performance changes observed in their matched normal peers. Certain key kinematic variables were held constant throughout the sessions to reduce or eliminate extraneous movements and to ensure a higher degree of success. The remaining kinematic variables were selected to be instructed along similar performance guidelines exhibited by the normal subjects. Unfortunately the performance characteristics exhibited by the normal subjects could not be matched by their awkward peers. A few explanations for the performance differences between the matched pairs of normal and physically awkward are offered.

The characteristics of skilled action proposed by Glencross (1980) could possibly explain why these performance changes in normal boys could not be matched by the physically awkward boys. In other words, the generation of skill acquisition patterns is individual and the patterns and the rate of acquisition used by one person can not be easily taught to other individuals.

Another possible explanation as to why these performance changes could not be matched is that observed by Siegler (1983). He emphasized the influence existing knowledge has on the learning process. Siegler notes that as children acquire more knowledge they begin to use more specific strategies in accessing and integrating knowledge. Thus, as children increase their domain-specific knowledge, if learning and instructional strategies are to be effective they should be directly related to the knowledge bases of individual children. Therefore, a rich knowledge base in a given sport might enhance the learning of specific skills simply because such knowledge might provide a better context for learning and problem solving.

This last statement supports the contention of Arend (1980) and Newell (1984) who proposed that skilled action is limited by three major constraints: biomechanical, morphological, and environmental factors. This movement-relevant knowledge about the self, others, and physical objects within the environment is a major product of cognitive-motor development (Wall et al., 1985). If the physically awkward child could improve the declarative knowledge base in a particular skill, this improvement in declarative knowledge might enhance the procedural knowledge the individual is trying to acquire. As Siegler (1983) points out, the instructor must adjust questions, priorize learning objectives, and correct errors in relation to the knowledge level of the performer. Thus the improvement of the declarative knowledge base can directly affect the procedural knowledge base and enhance learning.

Finally, Wall (1986) suggests that in the developmental skill acquisition process, four factors interact to either facilitate or hinder learning. Successful skill acquisition depends on the degree of congruency between the person, task, environment, and instructional strategy. In order to successfully instruct physically awkward children, all four factors have to be carefully selected.

The bowling experiment was designed to control, as much as possible, the extraneous effects related to the task and the environment. The basic response-loaded task of bowling in a structured environment was chosen to examine performance differences in matched normal and physically awkward boys.

The skill acquisition process requires careful consideration of the task-to-be-learned. The demands of the task will vary with the skill and developmental level of the learner. Thus, a careful examination of task demands must be made in relation to the learner's knowledge base. Wall and his colleagues (Wall, 1982, 1986; Wall & Taylor, 1983; Wall et al., 1985) as well as the two studies presented in this thesis demonstrate performance difficulties of the physically awkward learner compared to their age-matched normal peers.

In order to minimize their movement difficulties, physically awkward children should be encouraged to learn the basic requirements for response-loaded skills in a structured environment that emphasizes the organization and timing of their own movements. In cooperation with these skills, the instructor should emphasize some of the constraints to movement that interact with the learner's performance and thus increase problem-solving skills and declarative knowledge. This type of instruction would enable motor skill development to occur at a rate appropriate for the learner.

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## APPENDIX A

### Qualitative Analysis and Teaching Plan for the Matched Normal and Awkward Subjects

The qualitative analysis of performance was conducted on Subject 1 (JN) and Subject 3 (DL) for purposes of devising a teaching plan for the two awkward control subjects (chosen randomly) in the bowling experiment. The qualitative analysis focused on the kinematic variables outlined in the method section of the bowling study, as well as the initial starting position for each subject. In other words, the qualitative analysis permitted observation of the pattern of learning of the two normal boys, with respect to the kinematic variables, and then based on this information, a teaching protocol was devised for the awkward control subjects. There were four areas of concern in the analysis: starting position; top of backswing; release; and follow through.

Subject 1 (JN)

The initial position for JN remained relatively unchanged throughout the ten sessions. The ball was held at waist level with the lower limbs slightly flexed and the trunk moderately flexed. The ball position prior to movement changed slightly throughout the 10 sessions. JN extended his elbow more as the sessions progressed and this action resulted in the ball position starting closer to the floor.

The height of the backswing varied throughout the ten sessions. As the sessions progressed the height of the backswing decreased because the initial position of the ball was closer to the floor.

Step length was fairly consistent throughout the ten sessions; in Sessions 2 and 10, however, he did increase the length of his step. The distance the lead foot remained behind the foul line became consistent after the first session. In the first session, so as not to step over the foul line, the subject remained a fair distance behind the line. In subsequent sessions, he moved closer to the foul line and remained consistent thereafter.

The ball velocity at release varied throughout the ten sessions. If the step length was increased, the resulting ball velocity was also increased. With the emphasis of body movement in the delivery, the upper limb velocity was also affected. In every trial, the upper limb velocity at release was lower than the ball velocity. It would appear that JN flexed his wrist at release thus imparting more velocity to the ball and increasing the follow through distance. JN had a very high follow through (above head) after release.

The ball was generally released near the floor and approximately at the same angle throughout the sessions. As the sessions progressed however, the ball release height decreased towards the floor as the elbow was allowed to extend. The point of release was generally near vertical (shoulder and ball in a vertical line position) throughout the ten sessions suggesting that JN did not release the ball prematurely or late.

To summarize the changes in skill development as learning progressed, JN progressed towards a lower initial ball position resulting in a lower backswing. The ball release angle and ball velocity remained relatively consistent with little or no variability during the session. The ball release height progressed closer to the floor during the first four sessions due to increased knee flexion and then remained consistent for the remainder of the sessions. The follow through of the throwing limb progressed to a somewhat high position due to the upper limb velocity at release.

These kinematic changes as learning progressed do not reflect an ideal or mechanically correct performance, nor were they meant to be. These changes reflect the performance of an individual learning a new skill and the kinematic and qualitative patterns incorporated in this learning. These performance changes were used to devise a teaching plan for JN's matched awkward subject (TJ). The teaching plan is outlined in a subsequent section.

<u>Subject 3 (DL)</u>

DL's initial position remained fairly constant across the ten sessions. The ball was held at chest level and the lower limbs and trunk were slightly flexed. As the sessions progressed, the initial ball position did increase somewhat (held the ball higher) with increased elbow flexion.

The height of the backswing generally increased as the sessions progressed to a position just above horizontal. With a higher initial ball position, it generally follows that the backswing height would increase.

The ball release point was usually past vertical which suggests he held on to the ball too long and guided the ball toward the pins rather that allowing gravity to assist his delivery. The elbow at release in the first session was extended, but as the sessions progressed the elbow flexion increased, which was not mechanically desirable.

The ball velocity at release remained very consistent over the ten sessions, with a slightly higher ball velocity occurring in Session 2. It appeared that DL was controlling the speed and point of release rather than allowing gravity to assist, with the resulting follow through not being very high.

In the first session DL was closer to the foul line than in the remaining nine sessions. The distance behind the line increased as the sessions progressed. The step length was somewhat inconsistent throughout the ten sessions suggesting DL had not yet chosen an optimal step length for success.

The upper limb velocity at release was lower than ball velocity in every trial with wrist flexion occurring to increase the velocity of the ball. He was similar to JN in this respect.

To summarize the changes in skill development as learning progressed, DL exhibited a higher backswing due to an increase in the height for the initial ball position. The angle and velocity of the ball at release were very consistent as the sessions progressed with little or no change within each session. The release height of the ball increased slightly over the last four sessions due to an increase in elbow flexion and a release point well past the vertical. The distance of the lead foot behind the foul line increase probably due to a variable steplength within sessions. The upper limb velocity was fairly consistent with a slight increase across the ten sessions and a low follow through.

Learning the modified bowling skill produced different and varying methods to achieve success by the two individuals. Based on this performance information, a teaching protocol was devised to instruct the matched physically awkward subjects.

Teaching Plan for the Physically Awkward Subjects

At the beginning of each session and at 25 throw intervals the instructor reinforced the proper procedures by demonstrating, verbally explaining, and physically manipulating the subject through the proper sequence. This interjection every 25 throws was continued for both subjects for the duration of the experiment. The intersessional interval was approximately 2 days.

Teaching Plan: Subject 1 (TJ)

The matched subject for TJ was JN. The major emphasis of the teaching plan was to manipulate certain kinematic variables that were exhibited by JN in his skill acquisition phase and apply these changes to TJ. Certain kinematic variables were held constant so as to eliminate extraneous movements for a higher degree of success. The variables held constant included: initial body position; step length; and the lead foot distance behind the foul line. These three variables were chosen because JN's performance was relatively consistent across the ten sessions. The variables that were manipulated along similar time frames as JN included: height of backswing; ball height, angle, point, and velocity at release. The teaching plan which follows includes the procedures followed for each session. When the focus changed to a different variable, the investigator decided that the subject had qualitatively progressed on the previous teaching point and it was time to emphasize a new variable.

Session 1: Initial body position with the ball in the dominant hand supported by the non-throwing hand was stressed in the first session. TJ was also instructed on the height the ball should reach at the top of the backswing and the point of ball release. The subject was also instructed to look and aim at the criterion pin.

Session 2: The procedures were similar to those of Session 1.

Session 3: The emphasis was again on a initial starting position in this session and the remainder of the sessions. The important teaching point in this session focused on the height of the backswing. The decision to accomplish a higher backswing was to encourage a higher release velocity. The release point was still emphasized.

Session 4: The major emphasis shifted to the point of release with all previously taught variables remaining constant.

Session 5: The starting ball position and subsequent drop of the ball from the set position was emphasized because TJ was carrying the ball back toward the backswing height. TJ was instructed to allow the ball to drop towards the top of the backswing with the elbow extended and with no deviation from a straight line path backward and forward.

Session 6: The teaching point shifted to the point of release with emphasis on releasing the ball just past the lead foot while flattening the arc.

Session 7: Similar to Session 6.

Session 8: The focus shifted to releasing the ball with greater force while keeping the previously taught variables constant.

Session 9: The emphasis remained on the point of release while extending the elbow fully at release.

Session 10: Refinement of all the factors learned previously was emphasized in this session with the key being the release velocity.

Teaching Plan for Subject 3 (MW)

The matched subject for MW was DL. At the outset of Session 1, MW exhibited great difficulty in accomplishing the required task. As a result of this difficulty, the pre-planned lessons changed dramatically.

Session 1: The initial instructions to MW were similar to those imparted to TJ: initial body and ball position, height of backswing, and release point were stressed. MW was also given specific instructions to aim at a point on the floor six feet (1.83m) from the foul line.

Session 2: Similar to Session 1.

Session 3: MW was having difficulty with the sequencing of body parts and it was decided to change the initial body and ball start position and eliminate the step prior to ball release in order to achieve greater success. The major emphasis was on a straight arm swing path to release. The subject was again instructed to aim at a point on the floor six feet (1.83m) distant from the foul line.

Session 4: Similar to Session 3. MW was encouraged to decrease the total movement time because he hesitated a great deal in order to determine if he was in the proper position.

Session 5: Similar to the previous two sessions.

Session 6: The starting position was altered again to a position where the ball was held vertically downward (directly beneath the shoulder) with MW having placed his lead foot near the foul line with the trunk flexed. The major emphasis was on a straight path for ball movement to the height of backswing and then forward to release. The point of release was also stressed.

Session 7: The major emphasis was on the release point with a flattened arc at a point just above and slightly past the lead foot.

Session 8: The major emphasis was on continuous movement of the upper limb (e.g., no stopping at the height of the backswing) with the point of release being the same as in the previous session.

Session 9: Similar to Session 8.

Session 10: Similar to previous two sessions. The emphasis was on refinement of all the variables taught previously. MW was unable to begin the movement from the initial starting position described in the first two sessions.

Qualitative Analysis for TJ and MW

The qualitative analysis of performance was conducted on two control subjects: Subject 1 (TJ) and Subject 3 (MW).

Subject 2 (TJ)

The initial body and ball position for TJ remained relatively unchanged throughout the ten sessions. The ball was held with a flexed elbow at chest level with the trunk slightly flexed and an overall relaxed body position. TJ was instructed on the proper starting position and this position was reinforced at the start of each session. He maintained this initial position throughout the 1000 throws with very little variation.

The height of the backswing increased as the sessions progressed. In the early sessions TJ carried the ball backwards to the height of backswing rather than allowing the ball to drop and swing freely as he was instructed. The height of the backswing in the early session did not progress past hip height. During the later sessions, however, he accomplished the proper ball movement and allowed the momentum generated in the starting phase to carry the ball to the height of the backswing. This height of the backswing was almost parallel with the floor.

Step length generally increased across the ten sessions with little or no variability within each session. TJ did, however, lift his stepping foot rather high off the floor in the early sessions. During the later sessions he improved the step phase with a lower foot height clearance off the floor. He was not instructed on how to step; rather, he observed the performance of the instructor and adjusted accordingly. The distance the lead foot remained behind the foul line was fairly consistent with a slight movement toward the foul line as the sessions progressed. He was instructed on placing his foot behind the foul line at the beginning of the first session and achieved this condition satisfactorily throughout the remainder of the sessions.

The ball velocity at release increased slightly across the ten sessions with somewhat variable within session values. TJ was instructed to gradually increase the ball velocity as the sessions progressed by developing a higher backswing and imparting more force to the ball at release. It appeared, however, that TJ was reluctant to extend his elbow fully at release and guided the ball off his fingertips rather than exerting muscular force to throw it. The follow through of the throwing limb was generally very low. The upper limb velocity at release paralleled, but was lower than the ball velocity in all sessions. Again, TJ was guiding the ball at release even after verbal instruction not to do so during the sessions, and there was little horizontal body movement during the stepping phase, but he did include a high degree of vertical movement.

The ball was released at approximately the same angle and height above the floor in each session. TJ was instructed on these variables. Occasionally TJ held onto the ball too long prior to release, thus guiding the ball down the lane. At these times, the resultant ball velocity varied. The point of release was usually past vertical with the elbow slightly flexed.

Subject 3 (MW)

The starting body and ball position for MW was altered by the instructor throughout the ten session experiment. Again, MW was instructed on the starting position in the same matter as TJ. During the first two sessions the ball was held at chest level with the ball throwing sequence starting from that point. The subject experienced difficulty in coordinating the body parts in the proper sequence, and as a result, Sessions 3, 4, and 5 started with an altered body and ball position. The investigator decided to eliminate some of the movement sequence prior to ball release in order to simplify the action sequences and to increase success. Therefore, the subject started the sequence with the ball at the height of the backswing, the lead foot near the foul line, and the trunk flexed over the lead thigh. The starting position changed again in Session 6 because MW exhibited increased success (qualitatively and criterion pin). MW moved to a position where the ball was held vertically downward near the lead foot and the rest of the body remained as in Sessions 3-5. The sequence began with ball movement to the top of the backswing and then forward again to ball release. These starting positions of the body and ball remained unchanged for the duration of the teaching sessions.

The height of the backswing was altered by the investigator at discrete points in the teaching sessions. To reiterate, the instructor decided it was beneficial in Sessions 3, 4, and 5 for MW to begin movement with the ball starting at the height of the backswing. In Sessions 6-10, MW was instructed to swing the ball back to the height of the backswing and then forward to release. The height of the backswing in the remaining sessions varied because MW was inconsistent and had not yet established an optimal height for his backswing. The height of the backswing occasionally went past the horizontal (parallel with the floor) but generally raised to a position below the horizontal.

The step length decreased as the sessions progressed. However, from the third session to completion of the teaching sessions, MW placed himself in the throwing position as he was instructed to do so by the investigator. Due to this change in initial starting position, the distance between his feet decreased as the sessions progressed. In other words, MW decreased his base of support throughout the sessions. The distance the lead foot was behind the foul line generated some interesting data. He was instructed to place his lead foot behind the foul line before he threw the ball. Except for Session 2 and 3, he placed his lead foot over the foul line anyway, regardless of instruction. The instructor continually reminded and physically placed his foot behind the line, but when left on his own, his foot edged over the foul line.

Ball velocity gradually increased across the ten sessions with some variability within each session. The emphasis on the height of the backswing throughout the sessions had some effect on the ball velocity at release. MW was encouraged to impart more force to the ball at release with the release point closer to the floor as the sessions progressed. The physical manipulation of MW's upper limb in the throwing sequence enabled him to throw the ball with more force when on his own. The upper limb velocity scores paralleled the ball velocity scores across sessions and in all cases was lower than ball velocity. The follow through of the throwing limb was generally very low throughout the sessions.

Summary

The two subjects, TJ & MW, received different instructions to achieve the environmental goal, based on the pattern of skill acquisition of their matched normal counterparts. The degree of success of the teaching protocols is discussed in the general discussion of the thesis.

## APPENDIX B

Questions asked to each subject at the completion of each session.

1. What changes the speed of the ball?

   A. Appropriate answer (e.g., change in hand speed, height of backswing, force delivered in throwing motion)
   B. Inappropriate or Did Not Know

2. What [illegible]es the ball curve to the right or left?

   A. Appropriate answer (e.g., spin on ball, speed of ball)
   B. Inappropriate or Did Not Know

3. What are you looking at when you throw the ball?

   A. Foul Line
   B. Marks on the Floor from Figure IV-1
   C. Pins

4. In this task, do you feel that you need to be:

   A. Lucky
   B. Skillful

5. Do you feel this task is:

   A. Very Easy
   B. Fairly Easy
   C. Fairly Hard
   D. Very Hard

6. On this skill, do you feel you are:

   A. Very Good
   B. Pretty Good
   C. Average
   D. Fair
   E. Poor

7. Did you feel you improved Yes or No?

8. Why do you feel you improved (did not improve)?

Answers provided by each matched pair of subjects for the first 7 questions.

JN & TJ

| Session | Question # 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | A,B | B,B | C,A | B,A | B,C | B,B | Y,Y |
| 2 | A,B | B,B | C,A | B,B | B,D | B,C | Y,Y |
| 3 | A,B | A,B | C,A | B,B | B,C | B,B | Y,Y |
| 4 | A,B | A,B | B,A | B,A | B,C | B,B | Y,N |
| 5 | A,A | A,B | B,B | B,A | B,C | B,B | Y,Y |
| 6 | A,B | A,B | B,B | B,B | B,B | B,D | Y,Y |
| 7 | A,A | A,B | B,B | B,A | B,C | B,D | Y,N |
| 8 | A,B | A,A | B,B | B,A | B,C | B,B | Y,Y |
| 9 | A,B | A,A | B,B | B,B | B,B | B,B | Y,Y |
| 10 | A,B | A,A | B,B | B,A | B,C | B,C | Y,Y |

KL & DE

| Session | Question # 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | A,B | A,B | B,B | B,B | B,B | B,C | Y,Y |
| 2 | A,B | A,B | B,B | B,B | B,B | B,C | Y,Y |
| 3 | A,B | A,B | B,B | B,B | B,B | B,C | Y,Y |
| 4 | A,A | A,A | B,B | B,B | B,B | B,C | Y,Y |
| 5 | A,A | A,A | B,B | B,B | B,B | B,C | Y,Y |
| 6 | A,A | A,A | B,B | B,B | B,B | B,C | Y,Y |
| 7 | A,A | A,A | B,B | B,B | B,B | B,C | Y,Y |
| 8 | A,A | A,A | B,B | B,B | B,B | B,C | Y,Y |
| 9 | A,A | A,A | B,B | B,B | B,B | B,C | Y,Y |
| 10 | A,A | A,A | B,B | B,B | B,B | B,C | N,N |

DL & MW

| Session | Question # 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | A,B | B,B | B,B | B,A | B,C | B,C | Y,Y |
| 2 | A,B | B,B | B,B | B,A | B,C | B,C | Y,Y |
| 3 | A,B | B,B | B,B | B,A | C,C | B,C | Y,Y |
| 4 | A,B | A,B | B,B | B,A | B,C | C,C | N,Y |
| 5 | A,B | A,B | B,B | B,A | B,C | B,C | Y,Y |
| 6 | A,B | A,B | B,B | B,A | B,C | B,C | Y,Y |
| 7 | A,B | A,B | B,B | B,A | C,C | B,C | Y,Y |
| 8 | A,B | A,B | B,B | B,A | B,C | C,C | Y,Y |
| 9 | A,B | A,B | B,B | B,A | B,C | B,C | Y,Y |
| 10 | A,B | A,B | B,B | B,A | B,C | B,C | Y,Y |

DM & WC

| Session | Question # 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | A,B | B,B | C,C | B,A | B,A | B,B | Y,Y |
| 2 | A,B | B,B | C,C | B,A | B,B | B,C | Y,Y |
| 3 | A,B | A,B | C,C | B,B | B,C | B,B | Y,Y |
| 4 | A,B | A,B | C,C | B,A | B,A | B,C | Y,Y |
| 5 | A,B | A,B | C,C | B,A | B,C | C,B | N,Y |
| 6 | A,B | A,B | C,C | B,B | B,B | B,B | Y,Y |
| 7 | A,B | A,A | C,C | B,A | B,C | C,C | N,Y |
| 8 | A,B | A,A | C,C | B,A | B,B | B,B | Y,Y |
| 9 | A,B | A,A | C,C | B,B | B,C | B,B | Y,Y |
| 10 | A,B | A,A | C,C | B,A | B,C | B,B | Y,Y |

The answers to #8 were generally the same by each subject. The general feeling of each subject relative to improvement concerned the number of pins they contacted in each session compared to how they had done in previous sessions. Some of the physically awkward boys answered with, 'I don't know'. Not any of the boys answered relative to the kinematic variables.