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Prelongitudinal screening of hypothesized developmental sequences for the tennis serve and the effect of sex, experience, and age on developmental level

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PRELONGITUDINAL SCREENING OF HYPOTHESIZED DEVELOPMENTAL SEQUENCES FOR THE TENNIS SERVE AND THE EFFECT OF SEX, EXPERIENCE, AND AGE ON DEVELOPMENTAL LEVEL

by

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APPROVAL PAGE

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A cross-sectional test of the broad criteria of "stability" and "intransitivity" as proposed in motor stage theory was conducted to screen hypothesized developmental sequences within six body components of overhead serving in tennis. In addition, the effects of sex, experience, and age on the hypothesized developmental skill level of males and females in tennis serving were examined.

Sixty male and female tennis players, ages 9-19, were videotaped performing seven trials of a forceful tennis serve. Two observers analyzed the videotaped tennis serves according to the actions defined in the hypothesized developmental sequences.

Results of the prelongitudinal screen test indicated that sequences for three components satisfied the specific criteria of Roberton (1977, 1978a), Langendorfer (1980), and Roberton et al. (1980). The descriptive analysis of sex, experience, and age factors identified more sex differences among younger subjects, ages 9-12, than among older subjects, ages 15-19. Younger males functioned at higher developmental levels in the Forearm/Racket and the Preparatory Trunk II components than did younger females. These same differences were

present among subjects with 1-2 years or less of experience. Older males demonstrated higher developmental levels in the Preparatory Trunk II and Trunk for Force II components than did older females. These same differences were present among subjects with 5 or more years of experience.

The discriminant analysis of sex, experience, and age factors on the hypothesized developmental skill level revealed that age and sex accounted for 45% of the variability displayed in the Forearm/Racket actions and for 32% of the variability in the Trunk for Force II classifications. Experience was not significant in the presence of sex and age.

It was concluded that the broad criteria of "stability" and "intransitivity" as applied in motor stage theory appeared to characterize within the select group of this study the development of the Elbow, Forearm/Racket, and Preparatory Trunk II actions in tennis serving. Sex differences, among younger players, favored higher developmental levels of males in the Forearm/Racket and Preparatory Trunk II actions; among the older players, males were favored in the Preparatory Trunk II and Trunk for Force II actions.

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Special appreciation is extended to: Dr. McKinney for her guidance in directing the study, Dr. Lolas Halverson for reviewing the design of the study, Mrs. Mary Milam of the North Carolina Tennis Association for her assistance in identifying the players, the United States Tennis Association for funding the research, Ms. Betty Byrd Britt for analyzing the videotapes, the 75 players for participating in the study, the graduate students for assisting in the videotaping, and my family and friends for supporting my efforts through their prayers and words of encouragement.

> His (man's) theories grow out of his observations, and each theory he formulates tends to make his observations more acute by establishing a perspective within which they may be more sharply focused, thus enabling him to ask more pointed questions which will in turn elicit more precise information to be used in testing the theory. As a result of this circular process, he may modify his theories, which will then modify his beliefs and practices (Metheny, 1974, p. 1).

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CHAPTER I

INTRODUCTION

Recent research in the area of motor skill development suggests that as fundamental motor skills such as throwing, hopping, and catching are developed over time and with experience, the actions of individual body parts change sequentially in a series of predictable steps. In investigating classical stage theory in the motor skill development of children learning to throw, Roberton (1977) discovered that the action of individual body components rather than the total body configuration changed sequentially. Roberton identified step-like sequences for the changes observed in the pelvic-spinal and arm movements as the throwing pattern changed over time and with experience. Through longitudinal study (Roberton, 1978; Roberton & Langendorfer, 1980), developmental sequences for these same components as well as sequential changes in the actions of the forearm and feet were validated. For example, Roberton observed that changes in the action of the trunk proceeded through three invariant steps from no trunk rotation to block rotation and finally, to differentiated trunk rotation as the child's throwing pattern changed over time. The discovery that the actions of individual body components changed sequentially as the fundamental skill of throwing was developed was significant because a component approach provided a model for observing and describing motor skill development in a variety of fundamental motor skills. Based upon a component approach for investigating motor skill development, several researchers have since observed and described stability and intransitivity in the actions of individual body parts as young performers develop other fundamental motor skills such as the forward roll (Williams, 1980), and the overhead strike (Langendorfer, 1982).

While most recent research has focused upon the sequential changes of body component actions as young subjects develop mature patterns in acquiring fundamental motor skills, the question of what changes occur in body component actions as complex sport skills are acquired has not been addressed. Instructional materials and research findings related to sport skill actions have been derived primarily from one model. That model has been the advanced, elite performer (Broer, 1973). No written or visual guidelines have been devised to describe how a performer "looks" in developing a complex sport skill. Most often, if an illustration of a novice performer is provided, the accompanying description points out that the beginner's action is "incorrect."

When compared to the most mature sport skill pattern, the developing performer's technique often appears to be "incorrect"; however, is it technically correct to classify the actions of the developing performer as "incorrect"? Do the differences observed in the motor skill patterns of developing performers actually constitute "errors in performance" or are they a function of a developmental process?

Just as it is possible to observe differences between advanced, intermediate, and beginning players, it is also possible to observe similarities within these various groups. For example, among advanced performers, although there are individual differences due to variations in height, weight, and body structure, the overall technique used to perform a sport skill may be often quite similar among advanced performers. Among beginners, although they do not look like advanced performers, there appears to be as much similarity in their performance as there is among advanced performers. The differences observed between performers of varying skill levels as well as the similarities observed among performers of similar skill levels suggest the possibility that qualitative changes may occur as performers develop mature sport skill patterns. Furthermore, there may be the possibility that the similarities observed among developing performers at various points in time are orderly and predictable. Is it possible that observed similarities among performers at various points in skill development represent stages which progressively lead toward a mature motor skill pattern?

The description of qualitative changes in the motor skill patterns of individuals in developing sport skills should be studied systematically. To form the basis for systematic study, one must begin to question and to critically observe the developmental process in acquiring sport skills. The results of recent research (Clark & Phillips, 1985; Langendorfer, 1982; Roberton, 1977; Williams, 1980) have shown that body component actions change sequentially as young children develop fundamental skills. Within that research, the component approach has been found to be a useful method for observing and describing motor skill development. Roberton and Langendorfer (1980) who based their work on cross-sectional and longitudinal data validated the sequential ordering and invariance over time of some observed component actions as children developed the fundamental skill of overarm throwing. Up to the present time those procedures have been applied only to fundamental motor skills. There is a need to extend the study of hypothesized developmental sequences to include sports skills to determine whether sequential changes occur in component actions as a performer becomes proficient in these skills.

The overhead serve in tennis has often been cited by players, teachers, and coaches as a skill which requires many years to develop. Years of practice are needed to develop a pattern which is mechanically effective to accomplish most successfully the task of serving. What changes may be observed over time and with experience as performers develop a mature serving pattern in tennis? To determine whether or not the observable changes occur in predictable steps and sequences as a developmental study would hypothesize, the initial task of the researcher is to observe differences in the component actions of performers within varying age and experience groups as they perform an overhead tennis serve. Based upon differences observed between experienced and less experienced performers and upon "errors and faults" cited in instructional guides and texts, developmental steps and sequences for component actions in performing the overhead serve in tennis may be hypothesized. Having hypothesized the developmental sequences, the initial step in validating the sequences should entail a cross-sectional analysis of the serving patterns of subjects of different ages and of varying experience. Furthermore, in accordance with the guidelines suggested by Roberton, Williams, and Langendorfer (1980), data derived from the cross-sectional study should satisfy specific criteria of comprehensiveness, stability, and adjacency prior to conducting a longitudinal study to validate the sequences. Therefore, adhering to the recommended procedures for conducting a cross-sectional, prelongitudinal screen test, this study was designed to investigate hypothesized developmental steps and sequences for the overhead serve in tennis.

Purpose of the Study

The primary purpose of the study was to determine whether the broad criteria of stability and intransitivity, employed in motor stage theory, characterized the body component actions of performers in the execution of an overhead serve in tennis. To establish whether those broad standards were met, first the specific criteria of comprehensiveness, stability, and adjacency, recommended for an across-trials, prelongitudinal screen test (Roberton, 1977, 1978a) were applied to the tennis serve for which hypothesized steps and sequences were generated. Then to complete the prelongitudinal screening, the age and experience of subjects classified within each component step were examined (Langendorder, 1982) and the "closeness of fit" of the cross-sectional curves to an hypothesized longitudinal model were compared (Roberton, Williams, & Langendorfer, 1980). In addition, the effects of sex, experience, and age upon the hypothesized developmental skill level of males and females as the tennis serve is developed were considered. More specifically, answers to the following questions were sought:

1. Is comprehensiveness demonstrated by the appearance of each developmental step for selected body component actions of (a) the preparatory arm/racket backswing, (b) the trunk action in the preparatory phase, (c) the elbow action in the force production phase, (d) the forearm/racket action in the force production phase, (e) the trunk action in the force production phase, and (f) the feet/leg action in the force production phase?

2. Does each subject demonstrate stability across trials as measured by 50% or more trials classified within the modal step?

3. Does each subject demonstrate non-modal steps which are adjacent to the modal step?

4. Do the developmental levels within each sequence increase as the mean age and experience of the subjects increases?

5. Does the "closeness of fit" between the observed and expected graphs of an hypothesized longitudinal model (Roberton et al., 1980) support validation through longitudinal study?

6. Do younger male and female tennis players demonstrate the same developmental steps for body component actions in serving?

7. Do older male and female tennis players demonstrate the same developmental steps for body component actions in serving?

8. Do less experienced male and female tennis players demonstrate the same developmental steps for body component actions in serving?

9. Do experienced male and female tennis players demonstrate the same developmental steps for body component actions in serving?

Definition of Terms

The terms specifically related to this study were defined as follows:

<u>component approach</u>: an observational model which suggests that change occurs sequentially in individual body parts as a motor skill is developed (Roberton, 1977).

experienced tennis player: a player who is ranked within his or her age group or higher at the state level or has played in at least two United States Tennis Association (USTA) sanctioned tournaments within the past year.

fundamental motor skill: common motor activities with specific patterns (Wickstrom, 1983).

developmental sequence: a set of observable sequential steps in individual body actions as a motor skill is acquired.

motor skill development: the lawful relationship between antecedent and subsequent changes in motor skill behavior across the lifespan (Clark, 1982).

movement components: "joint action combinations that together comprise the total body's movements as it performs a motor task" (Roberton & Halverson, 1977, p.36).

prelongitudinal screening criteria: guidelines for assessing the feasibility of longitudinal study based upon cross-sectional data. They are as follows:

adjacency: a prelongitudinal screening criterion used to determine whether non-modal steps are next to the modal level in the sequence order (Roberton, 1977).

comprehensiveness: a prelongitudinal screening criterion used to determine whether all component actions appear within the subject sample (Roberton, 1977).

<u>intransitivity</u>: a criterion of stage-like development in which the order of the developmental sequence is invariant (Roberton, 1978).

<u>modal step</u>: a classified developmental step which occurs 50% or more times across trials for one subject (Roberton, 1977).

<u>non-modal step</u>: a classified developmental step which occurs less than 50% across trials for one subject (Roberton, 1977).

<u>stability</u>: a prelongitudinal screening criterion used to determine whether subjects demonstrate consistently one level at one point in time (Roberton, 1977).

<u>step</u>: a sequential change observed within a motor sequence (Wohlwill, 1973).

<u>universality</u>: a criterion of stage-like development in which all individuals are thought to progress through invariant developmental sequences in acquiring motor skills (Roberton, 1977).

<u>probability stage model</u>: a stage model which assigns a probability value to the possibility of any stage occurring at any time within a population (Roberton et al., 1980).

sport skill: an advanced version of a fundamental motor skill which is performed in the context of a specific sport (Wickstrom, 1983).

stages: "structural wholes that emerge from and transform a previous stage, follow an invariant and universal sequence, and proceed from an unstable period of transition into a final stable period" (Miller, 1983. P. 41).

Assumptions

The study was conducted with the following assumptions:

1. The video cameras, recorders,and monitor were valid instruments for researching developmental sequences.

2. The taped videos were accurate recordings of the actual performance.

3. The actions of individual body components were observable through frame-by-frame analysis of the videotaped performance.

4. The subjects performed the tennis serving task according to the instructions given prior to taping.

5. Seven trials were adequate to assess developmental level (Langendorfer, 1982; Roberton, 1975; Williams, 1980).

Scope of the Study

The purpose of the study was to examine developmental changes in selected body component actions of 60 tennis players consisting of 30 male and 30 female performers of varying age and experience as they individually executed a forceful overhead serve. Only those players were selected for study who held a place in the 1986 North Carolina State rankings, were recommended by teaching professionals, or were experienced in tournament competition. In addition, only players between 9-19 years of age with less than one to 10 years or more of experience were included.

The performance of each player was videotaped from the side and rear viewing angles on regulation outdoor tennis courts at five different sites from June 1-19, 1986. The videotapes were examined between June and December, 1986 by two observers to identify differences, if any, in six body component actions. Prelongitudinal screening criteria were applied to determine the feasibility of future longitudinal study of the hypothesized sequences. A linear discriminant function was used to analyze the effects of sex, experience, and age upon developmental level in learning to serve in tennis.

The primary limitations of the study involved the restricted number of viewing angles and the necessary use of two different models of video cameras. In addition, the unavoidable problem of having to film on five different regulation tennis courts with slightly different backgrounds may have introduced a limiting factor.

There were two other factors that had the potential to limit the study. One was the use of only two observers, although both were experienced tennis teachers, to interpret and analyze the tennis serves according to the hypothesized developmental sequences. The other factor, due to sample size and number of variables, was the necessity for selecting only two components for statistical analysis of sex, experience, and age effects on developmental processes.

Significance of the Study

Whiting (1972, p. 270) explained, "It is only when an awareness of the difficulties involved in passing from the 'unskilled' category to the 'skilled' category are appreciated that the immense complexity of the problem is realized." Unraveling the complexity of what is involved in becoming skilled in a motor activity requires research directed toward understanding the total system and the interrelated processes underlying the acquisition of complex skills. The significance of such research was underscored by Spaeth (1972) who stated that the problem of understanding the processes underlying motor skill acquisition must be solved by the continued search for well-formulated research methodologies and theories. Further support for study of the process of acquisition was provided by Higgins (1972) when he suggested that study of motor skill development may lead to "meaningful principles and guidelines for teaching" (p. 313). If the teacher is to facilitate the acquisition of skill, according to Spaeth (1972), the teacher should understand "the nature of the skill and its development" (p. 358).

Given the paucity of information about the processes involved in complex skill acquisition and given the need for teachers to understand the steps through which a learner progresses to achieve complex skill competence, this study has the potential to contribute to the information on motor skill development and to provide teachers with a more complete instructional model than models that appear to have been employed.

CHAPTER II

REVIEW OF LITERATURE

The literature related to this study is extensive and diverse. Selected for review were those readings that pertained primarily to research methodology, theories of motor development, developmental kinesiology, and motor learning. In addition, biomechanical and intructional literature related to the analysis and teaching of the tennis serve was examined.

Research Methodology

According to Roberton et al. (1980), the first step in examining changes in motor skill development is to hypothesize developmental sequences for selected body component actions in performing a motor skill. The sequences for selected component actions should be hypothesized from differences observed among performers of varying levels of skill and experience. A series of steps which describe discrete changes which may be observed as a performer develops a mature motor skill pattern should constitute the sequences.

Once the developmental sequences for selected component actions have been hypothesized, Roberton et al. (1980) suggested that the next step is to validate those sequences. To validate the developmental sequences, a two-phase procedure was recommended. The first phase of the procedure involves a cross-sectional or single age design. In the second phase, a longitudinal study is necessary. The initial phase provides for screening the developmental sequences for the selected component actions. Such a procedure has been identified as prelongitudinal screening. Although changes in frequency with age may be represented in a cross-sectional design, changes in frequency over time may be determined only through the second phase, longitudinal design (Roberton, 1977; Wohlwill, 1973). While it is imperative that the sequences be validated through longitudinal study, the cross-sectional study may identify misordered sequences and, in turn, determine the feasibility of longitudinal study (Roberton, 1980).

According to Roberton (1977, 1978a), initial criteria for prelongitudinal screening of hypothesized sequences should test the comprehensiveness, stability, and adjacency of non-modal trials across subjects in the cross-sectional sample. Determining the comprehensiveness of the steps within the sample is necessary to ensure that the hypothesized component actions actually exist. The stability of developmental levels across trials assesses the consistency of each subjects's developmental status. If the hypothesized sequences describe progression from one stable level to another stable level, each subject should demonstrate consistency within a modal level across trials. Finally, if the sequence is invariant, then the subjects should demonstrate trials which do not vary to non-adjacent steps. Roberton (1978a) and Roberton and Langendorfer (1980) recommended that sequences which fail to meet these prelongitudinal screening criteria should be modified and rescreened prior to longitudinal study. For example, these researchers reported that component sequences for overarm throwing which met the initial prelongitudinal screening criteria also demonstrated validity through longitudinal study; however, sequences that did not meet the across-trials screening criteria also failed to demonstrate validity across time.

Adding to Roberton's (1977, 1978a) across-trials screening criteria, Langendorfer (1982) proposed that a secondary analysis for screening the cross-sectional data should compare the mean age of subjects classified across each component step. Wohlwill (1973) suggested that developmental function is related to the chronological age of the individual and to the changes observed in the individual's motor response. Therefore, the discrete steps comprising the motor sequence should correlate approximately with points or intervals on the age continuum.

Langendorfer (1982) pointed out that although the mean age screening of subjects across each component step has not received longitudinal support and that since developmental changes are thought to be age-related, mean age increases which correspond to increases in developmental levels should indicate the correctness of sequence order and invariance of the component actions. Following that line of thought, Langendorfer compared the mean age, standard deviations, and number of subjects across component steps for the overarm throw and the overhead strike among young children. He reported that the modal steps for components in striking and throwing showed general patterns of increasing mean ages across developmental levels. Langendorfer concluded that the across-ages screening criterion supported Roberton's (1977, 1978a) screening criteria yet should not be used as the sole predictor of invariant sequences.

Williams (1980) and Roberton et al. (1980) offered an additional means by which age differences in developmental levels might be used to screen hypothesized sequences. These researchers suggested that an hypothesized longitudinal graph may be useful in pointing out the extent to which data from a cross-sectional study might be supported by future longitudinal study. They provided a graph of a model population in which the frequency of observing developmental steps for a component action would rise and decline according to the frequency of occurrence within age groups represented within a population. In Figure 1 curves illustrating the rise and fall of a three-level sequence for the hand/arm component in the late phase of a forward roll performed by subjects, ages 5-9, is shown.

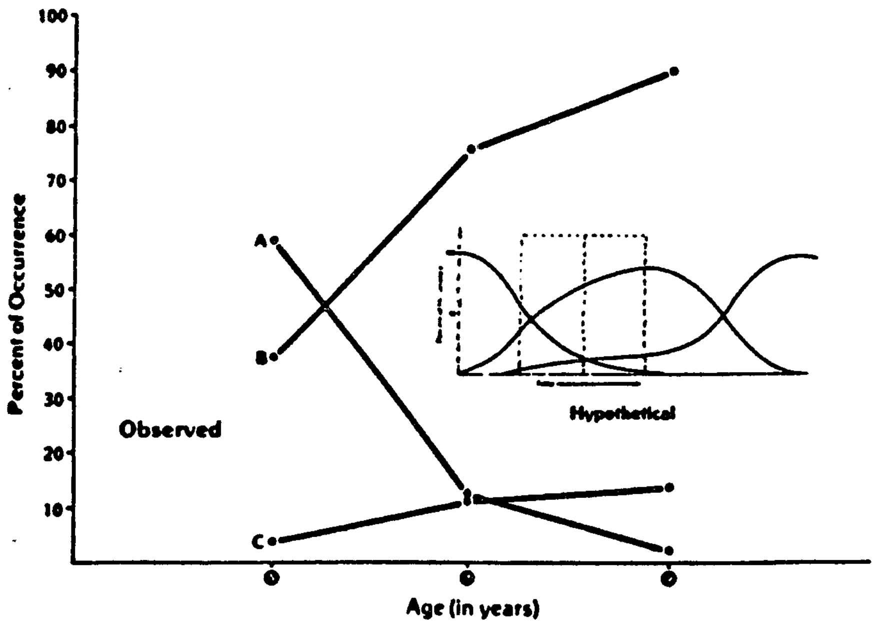


Figure 1. Late phase of the hand/arm component in the forward roll.

Note. From "Developmental Characteristics of a Forward Roll" by K. Williams, 1980, Research Quarterly for Exercise and Sport, 51, p. 709. Copyright 1980 by American Alliance for Health, Physical Education, Recreation and Sport. Reprinted by permission.

Whereas, in Figure 1 the inserted hypothesized longitudinal graph depicts the relative emergence and disappearance of developmental steps as the age of the subjects increases, the researcher should determine the "closeness of fit" between the graphs generated from the cross-sectional data and the hypothesized longitudinal graph. To compare the "closeness of fit" between the cross-sectional and the expected longitudinal graphs, Roberton et al. (1980) recommended that at least as many age groups for cross-sectional screening be selected as there are levels within a developmental sequence. Furthermore, these researchers suggested that two criteria, namely, the sequence order and sign of the slope of the frequency curves, should be considered in using this technique to screen developmental sequences. The sequence order is examined by determining that higher steps do not precede the appearance of lower steps across the ages sampled and that the percentage of step classifications among younger or older age groups follows the expected longitudinal model. Specifically, a higher percentage of younger players should be classified at the lower steps as compared to the percentage of younger players classified at the higher steps. If the percentages associated with the frequency of step classifications do not show these expected relationships, the order of the sequence is questioned. The sign of the slope considers the direction of each step curve. By comparing whether the curve is rising or declining in frequency of occurrence as expected, the "closeness of fit" between the cross-sectional graphs and the longitudinal graphs is determined. For example, as displayed in Figure 1, the least mature action, Step A, occurred most frequently among the youngest subjects and least often among the older subjects. Over time, the incidence of observing Step A diminished and the frequency of observing Step B increased. Finally, Step C, the most mature action, increased gradually across the ages of 5 to 9 years and presumably would continue to increase in occurrence among older subjects. The "closeness of fit" between the observed cross-sectional graph in Figure 1 and the hypothesized longitudinal graph would support the possibility that the sequence would be invariant across time for most subjects.

Comment. Langendorfer (1980) recommended that comparison of mean age increases across developmental levels should provide additional information in screening hypothesized sequences of fundamental motor skills. Whether a similar procedure is appropriate for examining the role of age and experience of older performers in developing sport skills has not been considered.

Furthermore, although the screening of cross-sectional graphs has been recommended as a useful procedure for comparing the rise and decline of developmental levels with age increases, no similar tool for comparing the effect of experience/practice upon body component actions in developing complex sport skills was reported in the literature.

Theories

During the 70's, "developmental kinesiology" emerged as a new approach for studying changes in motor patterns of young performers in developing fundamental motor skills (Roberton, 1972; Wickstrom, 1975). Different perspectives were projected for combining the research methods and findings in the areas of motor development and kinesiology. Wade (1975) recommended that a cross-examination of theories and models in the areas of motor development and motor learning was needed to study behavioral development of young performers in acquiring motor skill proficiency. Not limited only to the study of young performers, Phillips and Clark (1984) pointed out that a developmental perspective was needed to understand "the motor mechanism as it coordinates and controls motor skill performance in individuals of all ages" (p. 21).

Few studies have examined the changes in fundamental motor skill of performers beyond the childhood years (Halverson, Roberton, & Langendorfer,1981). Whether the theories and models employed in the study of children in performing fundamental motor skills apply to older performers in developing complex sport skills has not been determined. To study the process of motor skill development of individuals across the ages, attempts must be made to bridge the theoretical gaps if knowledge of the process of naturally, unfolding changes associated with fundamental and complex motor skill development is to be gained. The summary of literature that follows focuses on the process of adaptive motor skill development and the effects of experience/practice and sex as presented in theories and models in the areas of motor development, developmental kinesiology, and motor learning.

Motor development

Three tasks of a developmental researcher are to identify what develops over time, to determine the interaction of nature and nurture to developmental change, and to ascertain whether the developmental changes are quantitative or qualitative (Miller, 1983). Based upon classical stage theory (Pinard & Laurendeau, 1969; Roberton, 1978a), recent findings in motor development have shed light upon what actually develops, how the development reflects process and product changes, and how experience and the individual interact to produce developmental change.

According to Nagel (1957), development involved a system which possessed not only a definite structure and pre-existing capacities but also entailed a sequential set of changes in the system. These changes produced relatively permanent yet novel increment both in structure and in the modes of operation. Such an endogenous point of view posited a maturational explanation of development as changes occur independent of experience.

Not limited to a genetically determined point of view, development has been defined as a "change over time in the direction of greater differentiation and integration of structure and function" (Scarr-Salapatek, 1975, p. 1) as the developing phenotype interacts with its environment. Appropriately, Wickstrom (1983) defined motor development as "changes over time in motor behavior that reflect the interaction of the human organism with its environment" (p. 1). Whether development is viewed as a fixed relationship between certain genetic inheritances and certain behaviors, or whether development is viewed as the interaction of the developing phenotype within a certain environment determines the direction and interpretation of research findings about development.

Stage theory, as applied to motor development, has been investigated as a viable approach for observing and explaining changes in motor patterns of young children in developing fundamental motor skills. A stage theorist postulates that general laws of development apply to the generic human being (Lerner, 1986). Although stage theorists recognize individual differences in rate of development and final level of development, an underlying principle of stage theory is that developmental change is universal and hierarchical (Lerner, 1973; Roberton, 1982).

According to Roberton (1977), "stages are universal sequences of changing, structural or functional systems which produce sequential changes in the overt movement of the body" (p. 55). Such a definition of "stage" when applied to motor development suggests universality and intransitivity across individuals as neural changes are manifested through observed changes in motor patterns. Roberton examined the validity of stage theory by observing developmental changes in the overarm throwing patterns of young children. Drawing upon extensive accounts of "stages of throwing" in the literature, Roberton hypothesized five levels of motor skill development within the arm action and eight levels within the trunk action. Selecting criteria from classical stage theory, Roberton tested the stage-consistency and intransitivity of stage order of 73 first grade children across 10 trials of the overarm throw. Data derived from the cross-sectional, prelongitudinal screening of motor sequences in overarm throwing led Roberton to conclude that the universality and intransitivity associated with stage theory seemed to apply independently to individual body component actions rather than to the total body configuration (Roberton, 1977). Following a three-year longitudinal study, Roberton (1978a) reported that body component actions developed not only at different rates within individual subjects but also at different rates among subjects. She further recommended that component changes adhered more closely to the principles associated with stage theory than did changes in the total body pattern and that the term "stage" should be reserved for similar developmental levels observed across several tasks. The term "step" should be applied to identify the hierarchical development of individual body components within a single motor skill (p. 77).

Although some researchers prefer the total body configuration approach, others have since employed a component approach to describe and investigate changes in body component actions as young children develop fundamental motor skills. Williams (1980) examined the developmental characteristics of children in performing a forward roll. Modeled after Roberton's (1977, 1978a) component approach, Williams concluded that five of seven components hypothesized for the actions of the hand/arm, head/neck, and hip/leg met the prelongitudinal screening criteria of invariant order and correct sign of the slope of the developmental functions.

Langendorfer (1982), also employed a component approach to compare the developmental levels of subjects, ages 6-10, across two tasks, the overarm throw and the overhead strike. Applying Roberton's (1978a) revised developmental sequences for the overarm throw, Langendorfer investigated the extent to which the sequences for throwing described the actions observed in body components as children performed an overhead strike of suspended and moving balls. With the exception of the forearm sequence which was modified to include the action of the racket, Langendorfer (1982) reported that developmental sequences for the overarm throw could be applied to categorize component actions of different aged children in learning to strike an overhead object. Developmental sequences based upon a component approach have since been hypothesized for the fundamental skills of catching, punting, running, hopping and the standing long jump (Roberton & Halverson, 1984).

Developmental Kinesiology

Phillips and Clark (1984) wrote that an understanding of the "motor mechanism as it coordinates and controls motor skill development" was needed to explain the kinesiological changes in actions used by performers of varying ages to perform motor skills. These biomechanists suggested that differences in the kinetic and kinematic parameters of young performers as compared to elite-skilled-performers should be viewed from a developmental perspective. They recommended that differences observed and recorded in the degree of flexion, extension, and rotation of body parts of performers of varying skill levels should be considered as "developmentally appropriate" (p. 20). They concluded that a framework was needed to understand the motor mechanism as it coordinates and controls motor skill performance of all ages.

Bloomfield, Elliott, and Davies (1979) characterized the patterns of male subjects, ages 2-12, as they performed a soccer kick. Through cinematography and digital analysis, changes in the approach patterns, from no approach to an approach which included a jump step prior to contact, and changes in the amount of knee flexion were reported. The researchers concluded that a general developmental trend must underlie the development of motor skills such as kicking in soccer.

Most recently, Clark and Phillips (1985) investigated hypothesized sequences for arm and leg actions during the propulsive phase of the standing long jump by comparing the actions of young performers, ages 3-7, and adult, elite performers. Through digital analysis, their results supported a developmental approach both in the sequential ordering and in the varying rate of change associated with these two body component actions.

Motor Learning

Several writers have discussed the processes involved in motor skill learning (Fitts, 1964; Higgins, 1972; Paillard, 1960; Spaeth, 1972; Whiting, 1972). Of interest, are the theories and models presented in these reviews which address the process of developing a complex skill such as the overhead serve in tennis. The complexity of the tennis serve in terms of the hierarchical, spatial, and temporal organization of highly integrated component actions places this motor skill within the category of adaptive behavior (Sage, 1977). The summary that follows, therefore, is limited to the theoretical processes that explain how "direct, adaptive movements" as opposed to "indirect, reflexive movements" are acquired (Gentile, 1972).

According to Bernstein (1967), and, later, to other theorists (Gentile, 1972; Higgins, 1972; Spaeth, 1972), adaptive movements are used to accomplish a motor task in which the goal is directed by the environment. Characterized by intentionality, economy of execution, accuracy of achievement, and "delicacy of adjustment" (Paillard, 1960), adaptive motor skills require a protracted learning period (Jokl, 1972; Whiting, 1972).

Eccles (1953), as cited in Paillard (1960), suggested that neural networks form the underlying structure for inherited or acquired responses and that the structural networks are open to remodeling. Paillard (1960) considered that although inherited or most usual modes of action compose the pre-existing neural structures, the process of adaptive learning of new forms of action must require an initial disruption of some pre-existing functional units, followed by a selection of the most useful motor combinations, and then the assemblage of these combinations into a new working unit.

Fitts (1964) also examined the adaptive process by which changes associated with motor skill learning may occur. Of various communication and computer models, he recommended that only an adaptive system with a data storage capacity could incorporate changes in output as a function of experience. Dependent upon hierarchical processes, an adaptive system would rely upon higher-level programs to direct lower-level plans with the unique feature of the system being found in the modifiability of both the lower and higher level plans. He postulated that the lower-level plans or "subroutines" consist of short, fixed, repeatable series of operations which become integrated into higher level "executive" plans. In turn, the "executive" plans direct the flexible, adaptive organization of the motor response. Analogous to the computer model, Fitts speculated that the subroutines by which the executive plan adapts the motor response consist of innate reflexes and, if so, these reflexes would then be incorporated into many motor skills. He concluded that the initial state would not be that of a random state but, that the learner, regardless of age or experience, would begin the acquisition of a new form of skilled behavior "from the background of many already existing, highly developed, both general and specific skills" (p. 260).

According to Bernstein (1967), engrams or "motor images", containing the spatial-temporal details of the movement, must exist in the central nervous system. Similarly, Turvey (1977), extending psycho-linguistic theory to a theory of action, speculated that a "deep structure", located in the central nervous system and consisting of an abstracted system of rules, generated an infinitely large set of "surface structures" or overt actions. These theorists maintained that the motor image or deep structure must be a neural representation of the environmental contingencies. Bernstein (1967) hypothesized that the process of skill learning would involve the formulation of motor problems as the future requirements needed to perform a motor skill are imaged by the learner. The process of motor skill learning would entail the formulation of motor problems and the programming of their solutions based not only upon past and present images of motor solutions but also upon an image of a future solution. The solutions to the motor problems would be found in mastering the degrees of freedom that exist in the many possible forms of actions which could occur given the numerous body joints and muscles within the human system (Bernstein, 1967).

Higgins (1972), also, concluded that environmental demands shape and condition the organization and structure of movement patterns. Selecting a self-regulating control system model, Higgins suggested that this type of system would contain the plans and probabilities for dealing with relationships between the internal and external environments. To maintain equilibrium within a dynamic, changing environment, the process of skill learning would involve programming of the postural and voluntary control mechanisms. Whereas the postural control mechanisms would be responsible for maintaining limb and body positions and postural tone through a lower-level, closed-loop diffuse reflex system, the voluntary control mechanism, as an open-loop system, would be responsible for controlling precise movements through preprogrammed responses. According to Higgins, the adaptive process of skill learning would involve a shift in the control loops that regulate the motor pattern as greater control over the lower-level postural mechanisms is shifted to a higher-level, open-loop voluntary control system.

Todor (1974) wrote, "the body has no magical structure that points out the most effective motor program to accomplish a motor task" (p. 325). Although Higgins (1977) believed that the "pattern of the movement reflected the structure of the movement" (p. 85), Todor explained that the selection and ordering of subroutines during the process of skill acquisition must depend upon the level of development of all the subroutines that may be present to produce a movement. Thus, the observed motor pattern for an individual at a given point in time would reflect the developmental level of all constituent subroutines as well as the total movement.

Schmidt (1975) developed a schema theory of motor skill learning for understanding the processes in acquiring and refining motor skills. Through the abstracted rules and relationships derived from past response outcomes and past sensory consequences, two motor memory states, the recall schema and the recognition schema, improve with practice. Through practice, generalized motor programs adapt thereby permitting the generation of increasingly complex and highly integrated motor patterns as the learner abstracts and incorporates additional response specifications and sensory consequences into ever changing recall and recognition schemata (Schmidt, 1975).

A process view of schema as the set that all brain mechanisms have as they interact to produce a perceptual-motor act should also be considered (Newell & Barclay, 1982). In positing a theory of developing knowledge about action, Newell and Barclay suggested that the notion of schema as the underlying set of abstracted rules be viewed not only as the structure by which the motor product is effected but also as the process by which the motor product is adapted.

Comment. Although the theories are being actively researched in motor learning laboratories and applied settings, no definitive conclusions have been generated to support or refute those theories cited. These theories do, however, provide a framework for studying the changes observed in motor skill patterns as individual body components are adapted over time.

Practice/Experience

No discussion of developing motor patterns would be complete without a consideration of the influence of experience and practice on changes in those patterns. In both the motor development and motor learning literature, experience and practice are viewed as facilitators of change. Distinctions are often made. Experience is reported to be related more closely to maturation and the timely interactions of the child within the environment, while practice is said to be associated more often with learning through repetition and the conscious attention of the learner to the process. Perhaps the similarities between the two concepts are more easily understood by defining what constitutes experience/practice for the young child and for the young sport skill performer. Whereas experience/practice for the young child consists of the opportunity to engage in fundamental motor skills throughout childhood, experience/practice for the young sport skill performer often includes opportunities for participation, instruction, years of practice, and records of successes and failures. To resolve the differences, if any, between experience and practice as facilitators of change in motor skill development, a review of these factors as applied in the motor development and motor learning literature follows.

The effect of experience/practice upon the product and process scores of children in developing fundamental skills has been reported in several studies in the motor development literature. Halverson, Roberton, Safrit, and Roberts (1977) surveyed the literature to uncover what was known about the effect of instruction upon the throwing performance of young children. They determined that instruction seemed to improve distance scores but not velocity scores and that the effect of instruction upon the content of the movement had not been carefully researched. Subsequent to this review, they employed a component approach to analyze the product scores and throwing patterns of kindergarten age children enrolled in an instructional program. They concluded that instruction did not significantly improve ball velocities; however, instruction did significantly improve the developmental level of four of seven component actions in the overarm throwing pattern (Halverson & Roberton, 1978).

Halverson, Roberton, and Langendorfer (1982) also examined the effect of instruction and practice upon the ball velocities and overarm throwing patterns of older children. Through longitudinal study of children filmed at grades 1, 2, and 7, they discovered that although velocity scores improved across the seven years, the overarm throwing pattern was not fully developed by seventh grade. They recommended that instruction be continued for boys and girls at the middle school.

East and Hensley (1985) used a stepwise multiple regression to analyze the relative contribution of sociocultural variables to overarm throwing performance of male and female subjects across kindergarten to third grade. Using throwing distance as the dependent variable and several sociocultural factors as independent variables, these researchers reported that nurture experiences play a varied role in the socialization and development of motor skills during the first three school years. Whereas sociocultural factors of parental influence, hours of television watched, and extracurricular play experiences influenced most significantly the overarm throwing performance of the youngest subjects, biomechanical factors became relatively more important among older subjects.

A review of the motor learning literature revealed that few studies have investigated the effects of long term practice on the acquisition of complex motor skills. Furthermore, even fewer studies have examined the effects of practice on changes in limb configuration (Southard & Higgins, 1987). The investigations that have been concerned with the effect of practice on performance have been limited to relatively simple motor responses or the sequencing of previously learned motor reponses in the motor learning laboratory (Adams, 1984).

Comment. Jokl (1972) considered practice as the most significant determinant of performance without which "the full potentialities of the neuromotor skill cannot unfold themselves" (p. 259). Although a few longitudinal studies reported in the motor development literature have examined the role of instruction in the development of mature motor skill patterns, the amount of practice and instruction needed to develop mature fundamental skill patterns is still unknown. Further study of the effect of instruction and years of practice upon developmental changes in fundamental motor skills and sport skills would be warranted.

To study the role of practice and instruction in developing a sport skill, a description of the changes which may be observed as performers of varying ages and experience perform the skill over an extended period of time is needed. Furthermore, although recent attempts have been made to uncover the experiential factors which contribute most significantly to proficiency in performing fundamental motor skills, there is the need to identify the constituents of experience/practice which influence most significantly the development of sport skills.

Sex Differences

The extent to which one's gender plays a critical role in motor skill development is relatively unknown. It has been postulated that differences in the motor performance of males and females in executing fundamental skills is related more closely to sociocultural factors, which regulate the opportunities and incentives for participation during childhood and adolescence, than to physiological differences (East & Hensley, 1985; Eckert, 1973).

Williams (1980) reviewed the motor development literature to uncover what is known about sex differences of young children in performing fundamental skills. She reported sex differences favoring males in the product and process scores in throwing, jumping, and running. In contrast, females demonstrated more mature patterns in skipping and hopping. Williams reported that the actions used by males and females in performing forward rolls were similar.

Halverson et al. (1982) uncovered marked differences over a seven year period in the rate of development and the changes in the mean velocity scores of males and females in developing an overarm throw. They concluded that the throwing patterns used by males were 5-6 years ahead of the females and that mean velocity differences of 5-8 feet/sec/year for males as compared to only 2-4.5 feet/sec/year for females, placed the females five years behind the males with respect to product scores.

Keogh and Sugden (1985) reviewed the normative data from several studies to trace changes in the product scores of males and females, ages 6-17, in performing running, jumping, and throwing skills. They reported that mean performance scores of males in these play-game skills continued to improve across the adolescent years whereas the mean performance scores of females leveled off at approximately age 12. Although mean performance scores of the males were higher across the age range, a comparison of the median scores across the studies revealed considerable overlap among the groups compared particularly in the skill of jumping. Thus, at all ages, some females performed equal to or higher than the mean scores of the male group just as some males performed closer to the mean performance scores of the female group. Similar findings with respect to gender differences in performing fundamental skills were reported by French and Thomas (1984) through their meta-analysis of 358 literature sources.

Although differences in the velocity scores of males and females in serving were reported in the tennis literature, most descriptions of sex differences were limited to the observations of teaching professionals. One recent study was the exception. Elliott (1983) reported differences at contact in the wrist and forearm angles of young female players, ages 12 and 14, as compared to males of the same age and older female and male players. Elliott viewed the forward placement of these body parts as a limiting factor in the ability of the younger female players to produce a power serve.

Comment. Throughout the literature, it has been reported that males score significantly higher than females on product and process measures in performing fundamental skills of throwing, running, and jumping. Most often these differences have been attributed to sociocultural factors which provide greater opportunities and incentives for the young male and, in turn, discourage the young female from similar experiences and rewards for participation in activies which use these skills. There is a need to determine if sex differences continue to define the rate and final level of development of males and females in learning sport skills which are played and enjoyed equally by both sexes. Many boys and girls take up the game of tennis at relatively young ages, developing the skills of the game and achieving recognition in their respective age and sex categories. A study of the serving patterns of males and female tennis players, who have had similar playing and instructional experiences and who have enjoyed similar successes and incentives, should reveal additional information about the influence of these factors upon the development of this sport skill.

Biomechanical and Instructional Literature

Biomechanists, tennis instructors, and playing professionals, writing for tennis magazines, journals, and texts, have contributed to the information available about body component actions in serving a tennis ball. Some writers have been concerned with the mechanics of the serve, others have focused on instruction. Of interest are the findings and recommendations which have implications for understanding the mechanical differences in the serving patterns of developing players.

Biomechanical

Johnson (1957) examined the differences in the serving patterns of 10 advanced female players as related to speed and accuracy in delivering a slice serve. Based upon tracings of filmed serving patterns, accuracy, and velocity scores, Johnson concluded that grip, degree of body rotation, backward bend, and extension of the hitting arm at impact were significant factors in performing a tennis serve. She recommended that stance, backswing, depth of the racket loop, and the forward step had little effect upon success in serving a tennis ball.

More recently, Anderson (1979) investigated the differences in the serving and throwing patterns of females who were skilled and unskilled in performing these tasks. By means of cinematography and electromyography, she reported that skilled tennis servers moved their body segments through a greater range of motion and achieved higher racket head velocities than did less skilled servers.

Beecher (1977) investigated the relationship of forward hip rotation velocity, magnitude of forward hip rotation, and arm-shoulder strength to the velocity of a flat serve. Digital analysis of the serving patterns of

27 advanced female players, age 18-25, revealed that a significant relationship existed between the velocity of forward hip rotation and the velocity of the served tennis ball. Whereas the magnitude of hip rotation was not a significant factor in determining ball velocity, Beecher concluded that variables closer to the point of contact or poorly timed acceleration and deceleration of body segments closer to the racket often prevented the positive transfer of angular momentum to the racket and ball.

Power serving patterns of ranked players, ages 12, 15, and older were investigated by Elliott (1983). He observed that the power serve was characterized by forward rotation of the ball and a 100 mph ball velocity. The forward rotation of the ball, in part, was due to the upward trajectory of the racket immediately prior to impact with a continued forward or upward movement of the racket after impact. By comparing the racket paths of the male and female players in each age group, Elliott reported that the four adults, and, to a lesser extent, the 15 year olds, were able to execute a power serve by moving the racket upward to impart forward rotation to the ball. In contrast, the racket action of the 12 year olds moved in a straight line prior to and following impact, resulting in no forward rotation of the ball.

Elliott (1983) also compared players for the height of impact. He noted that the height at which the racket contacted the ball increased across the ages from 12 years to the adults. The coordinated movement of different body segments was attributed to the achievement of an optimal hitting position by the players. To compare the optimal hitting position, Elliott measured the differences in selected body joint angles of the adult, 15 year old, and 12 year old players. Differences in the wrist and forearm angles of the 12 and 15 year old females were reported as these body segments were positioned forward at the moment of impact, producing angles of approximately 60 degrees with respect to adjacent body segments. Elliott concluded that this less than optimal hitting position contributed to the inability of the young females to produce a power serve. He recommended that an "appropriate technique should be adopted" by players in order to produce a consistent power serve (p. 103).

Although most biomechanics texts devoted a section to the analysis of the tennis serve, only recently have some authors attempted to examine the differences in the serving patterns of players of varying skill levels. In one such text, Kreighbaum and Barthels (1985) suggested that the details of a motor skill pattern are determined by the age, development, strength, and skill of the performer. For example, they recommended that overarm throwing and overhead striking skills be placed along a "throw-push" continuum with factors such as the massiveness, size, and shape of the object and the strength and skill of the performer determining the location of the skills along the "throw-push" continuum. Whereas some skills require "throwlike" patterns to "pull" an object that is allowed to lag behind proximal segments which are moving forward, "pushlike" movements are characterized by the object to be projected being carried in front of the moving segments. Kreighbaum and Barthels classified the tennis serve as a "throwlike" pattern in that the racket is "pulled" along behind the more proximal forearm and shoulder segments. The "throwlike" tennis serving pattern should produce a curvilinear racket path as opposed to a "pushlike" pattern in which the racket follows a rectilinear path prior to and following contact. These authors noted that beginning players often position the elbow ahead of the shoulder prior to contacting the ball, resulting in a "pushlike" pattern and, in turn, a rectilinear racket path. They suggested that this type of "segmental error" is "common to most beginning or immature throwing or striking skills" (p. 631). Furthermore, they noted that beginning players often revert to a pushlike pattern when required to serve or throw for accuracy.

Kreighbaum and Barthels (1985) pointed out that differences in the motor patterns of beginning and intermediate players are also related to differences in the sequencing and timing of component actions. Applying the kinetic link concept, the sequencing and timing of component actions should proceed from proximal to distal joint segments, from more massive to less massive body segments, and from fixed end to free end body parts. These authors described sequential and timing differences in the actions of players of varying skill levels, noting that the novice performer displays more simultaneous patterning of body parts, whereas the intermediate player displays "erratic timing" by frequently moving the linked body segments too early or too late (p. 632).

In addition to the strength and skill of the performer as constraints leading to either a "throw" versus a "push" action pattern, Kreighbaum and Barthels (1985) recommended, "If a performer is to demonstrate a mature pattern with all its segmental moving and timing requirements, then the equipment may have to be made smaller or less massive or both" (p. 633).

Several studies examined the effectiveness of modified rackets upon the success of beginnning students in learning tennis skills (Tatje,1970; Wells,1981). Although Tatje (1970) noted significant differences in the serving scores of beginning players who used shortened rackets, only product scores such as accuracy, placement, and distance of ball bounce were reported. Whether the improved scores were related to changes, if any, in the body component actions composing the serving patterns was not reported in the literature.

Hay and Reid (1982) pointed out that not only the equipment but also the strength of the player dictate the resulting motor skill patterns. They provided a mechanical model for qualitatively analyzing tennis serving patterns. According to the model, the height of the ball at impact, the ball projection angle, and the velocity of the racket at impact govern the magnitude and direction of the ball. Applying the model to the frame-by-frame photo sequence of a young player, several changes were recommended to improve the effectiveness of the player's serve. They suggested that the player increase the amount of flexion and extension of the knees in order to generate more force. Furthermore, they considered body position at contact as critical in determining the direction of the racket prior to ball impact and, consequently, the direction of the ball after impact. They pointed out that the player flexed the hips prematurely, and thus, placed the body in a less than optimal hitting position. The failure of the young player to extend the forearm and racket upward to contact the ball was attributed to the weight of the racket and concomitant lack of strength.

Other tennis experts have drawn upon biomechanical principles in describing the actions of body components in serving a tennis ball. Murphy (1978) advised instructors not to depend solely upon the champion's form as the instructional model but to encourage students to adapt their strokes based upon individual needs and abilities. To guide the tennis instructor, Murphy listed several mechanical principles, some of which applied to the serve. For example, "Racket speed depends not only on the amount of force applied but also on the time for which the force operates" (p. 27). He recommended that racket speed is derived by flexing and extending the knees, by moving the hitting shoulder upward, and by flexing and quickly extending the forearm to contact the ball. In addition to these actions, Murphy noted, "For maximum racket speed the source of force described earlier must be timed accurately and applied in the proper sequence" (p. 30). The body parts that initiate the forward motion were identified as the thigh, trunk, and pelvis; those that complete the forward motion should be the lower arm and hand. According to Murphy, "It follows, then, that the shift of weight and rotation of the hips may properly start even before the arm has completed its backswing" (p. 30).

A thorough analysis of the tennis serve was given by Groppel (1984), a noted biomechanist and instructor. He examined the actions of the feet and legs, noting that the majority of force for a powerful serve should be generated through the pushing action of the feet and legs against the court. He pointed out that too little knee flexion would result in a loss of ground-reaction force, whereas too much knee flexion would produce excessive body motion and insufficient transfer of force from the ground.

In addition to the action of the feet and legs, Groppel (1984) considered the rotation of the hips and trunk to be the most critical component in producing a powerful serve. Through the initial position of the hips away from the net and subsequent rotation of the hips and trunk forward, force is transferred from the legs to the hips and, in turn, to the trunk and upper body. The sequencing of hip and trunk rotation was identified by Groppel as critical in the coordination of the kinetic links. "By the time the trunk reaches its peak rotational velocity, the swing arm should have gone through all of its preliminary actions and should be ready for the forward swing" (p. 135). The author also described two preparatory backswing methods, the "full windmill-type swing" and the "half-swing." In contrast to the full-swing in which the racket head is lowered and carried up to shoulder level with an extended arm, the swinging arm merely rotates to the side and lifts the racket to a position alongside or behind the head in the abbreviated, half-swing method. Groppel suggested that "biomechanically" either preparatory method should be equally as effective in that the action which follows the initial swinging or placing of the racket in both methods is the same.

Interestingly, several of these biomechanists suggested that a developmental approach was needed for the biomechanical analysis of some motor skills. For instance, Gropple (1984) described forward flexion of the hips as opposed to extension of the trunk and hips upon contact with the ball as being similar to an immature action of the hips observed in young children learning to throw. He recommended that an analysis of the developmental stages of throwing might be a useful tool for assisting the player whose serve is not effective.

Kreighbaum and Barthels (1985) noted that the developmental movement patterns used by children during their growth stages are similar to the segmental actions of beginning and intermediate players in performing sport skills. Although Groppel (1984) considered that the developmental stages of throwing may be linked to mechanical inefficiences observed in the serving patterns of older subjects, Kreighbaum and Barthels associated changes observed over time in the fundamental motor patterns of young children to "growth (height) and developmental (strength) factors" (p.637). These authors pointed out the need to study the effect of training and equipment upon the motor patterns of young children in learning to perform fundamental skills and sport skills.

Instructional

A review of selected articles and tennis texts revealed many descriptions of "good" versus "poor" serving techniques. Within these descriptions, common "weaknesses and errors" in body component actions emerged. Coaches and teaching professionals, as well as biomechanists, also noted differences in the preparatory backswing methods. Although the circular downward backswing was most often recommended, Murphy (1969) and Stolle (1978) reported that a few professional players were able to effectively use a short, high backswing. Faulkner and Weymuller (1970) suggested that although greater body and racket momentum is transferred by using a full backswing, the abbreviated backswing permits greater control. Interestingly, the abbreviated backswing was recommended often for the beginning player (Barnaby, 1975, Bradlee, 1962; Gonzalez, 1986).

Premature flexion rather than extension and rotation of the hips was observed by several instructors. Groppel (1984) wrote that only recently have instructors realized the importance of the hips in producing a "great serve" versus a "mediocre one" (p. 133). He recommended that by rotating the hips and, in turn, the linked body segments, greater momentum is generated and transferred to the racket. He pointed out that John McEnroe differentiates the action of the hips and shoulders and that other professional players could improve their serve by rotating rather than flexing the hips and forcing the trunk forward. Heldman (1976) wrote that beginners and intermediates bend at the waist rather than extending, and Van der Meer (1967) observed this action to be a "common fault, especially among women" (p. 47). Similarly, Ashe (1981) instructed that the hips should swing forward toward the court before the racket/arm and shoulder start the forward swing.

Several tennis professionals advocated an extreme rotation of the shoulders when serving (Tanner, 1976; Navratilova, 1979; Gonzalez, 1986). Braden (1977), a teaching professional, advised the player who fails to rotate the shoulders beyond the side facing initial position as "limiting yourself to 180 degrees of rotation instead of going an extra 60 to 90 degrees of rotation with a front shoulder turn" (p. 156). Although all instructors recommended that players initially face the sideline, Murphy (1969) noted the difficulty in teaching players to turn the shoulders and hips on the backswing.

All instructors recommended a well-bent racket arm prior to upward extension to contact the ball. Faulkner and Weymuller (1970) stated that the bent elbow permits the muscles that straighten the arm at the elbow joint to generate more power and, thus, increase the speed of the racket. Murphy (1980) also agreed that the bent elbow and racket, lowered in the backscratching position, provides the major power source as the arm extends to contact the ball. Navratilova (1983) wrote that one of the most common faults she finds with beginners is that they keep their hitting arm straight throughout the swing (p. 66), and Van der Meer (1974) noted this "mistake" is seen often in teaching and correcting serving patterns. Faulkner and Weymuller (1970) observed that "Girls tend to bend the elbow but leave their upper arm parallel to the baseline instead of pointing it behind them" (p. 187).

Several instructors reported that a common problem seen among beginners and champions was the premature swinging of the right shoulder which causes the player to pull at the ball (Heldman, 1973; Van der Meer, 1980). Van der Meer observed that when the shoulder, forearm, and racket move ahead of the ball, a "hammering" motion results which causes the player to push the ball. Leading with the elbow rather than throwing the racket up at the ball produces this "hammering" motion. Van der Meer (1971) advised that it is not easy to teach intermediates how to hit "up and out" (p. 37).

Comment. It is apparent that there are many opinions about the most efficient method to employ in delivering a tennis serve. Although the recommended techniques may provide information about the most mature serving pattern, of interest are the "errors" and "problems" which have been identified repeatedly in the literature. Such information, when noted consistently by experienced instructors and biomechanists, may, in fact, be the hidden descriptors of a developmental process. The extent to which such descriptors reflect the systematic, adaptive process of motor skill development can only be determined when these seemingly aberrant actions are the focus of study.

To "adopt" an appropriate service technique (Elliott, 1982; Hay & Reid, 1982) is quite different from "adapting" the technique (Murphy, 1978). For example, the instructional and biomechanical models often imply that once "segmental errors" (Kreighbaum & Barthels, 1985) are identified, the performer should be able to adopt a more efficient motor skill pattern. On the other hand, an adaptive learning model posits the notion of orderly changes which require time, practice, and instruction. To what extent the adaptive process is orderly and predictable should be determined in order to interpret more accurately and, perhaps expand, the biomechanical and instructional models to apply to players of all skills levels.

CHAPTER III

PROCEDURES

The study of the stability and intransitivity of body component actions in the execution of an overhead tennis serve was conducted according to the procedures described in the following sections: (a) sample selection, (b) instruments and preparatory procedures, (c) data collection and observation procedures, and (d) data analysis.

Sample Selection

The several criteria applied in the selection of subjects for the study were age, sex, experience, and participation in tennis tournaments. The age criterion required the selection of at least 60 subjects who represented an equal number of subjects in each age category of 8-10, 11-12, 13-14, 15-16, and 17-18 years. The sex criterion specified that an equal number of males and females be represented in each age category; therefore, it was necessary to select six males and six females in each of the five age categories. The experience criterion required categories of 1-2 years or less, 3-4, 5-6, 7-8, and 10 or more years of playing experience with males and females equally represented in each category. The criterion for participation specified that each player should hold at least a state ranking or should have participated in at least two USTA sanctioned tennis tournaments within the past year.

Subjects were identified initially from information provided by the North Carolina Tennis Association (NCTA) 1986 Directory. The NCTA Directory listed rankings of all male and female players in the age categories of 10, 12, 14, 16, and 18 years. The 1986 rankings were based on tournament play from October 1, 1984 through September 30, 1985. Additional names and addresses of younger players, ages 8-10, were provided by local tennis teaching professionals. From these sources, 85 players who lived within 50 miles of Greensboro, NC were contacted by mail and asked to participate in the study.

Each player received a packet containing a letter that explained briefly the nature of the study, consent forms, and a questionnaire which surveyed the extent of each player's participation in tennis (see Appendix A). The players were asked to indicate their willingness to participate in the study by completing and returning the questionnaire along with subject and parental consent forms in a self-addressed, stamped envelope.

After the initial contact, a follow-up telephone call was made to each of the 85 players to either establish a videotaping date and time or to determine whether or not the player had received the letter. Of the 85 players who were contacted originally, 37 players agreed to participate in the study. To add to the number of subjects to be studied, teaching professionals recommended 26 additional players; then, 12 more were identified at the Tarheel Junior Qualifying Tournament, held June 6-9, 1986, in Winston-Salem, NC, and at the Tarheel Triad Girls' Tennis Open, held June 13-15, 1986, in Greensboro, NC.

With those additions the total number of players volunteering and undergoing videotaping was 75. From that pool of subjects, 60 were selected to complete the study. The final selection was based on age, experience within the age groups, sex, and accuracy of the videotaped images. In age categories in which more subjects were available than required, the rank and experience of the players were used to reduce the number to six females and six males. Ranked and experienced players were selected over unranked and inexperienced ones. In those instances in which rank and experience were similar, the final six males and six females for an age group were identified randomly. In addition to the elimination of several subjects based on the age, experience, and sex criteria, several more had to be dropped because videotaping errors resulted in the recording of an inadequate number of trials for full analysis. Of the 60 players selected for the study, the youngest was 9 years 4 months and the oldest was 19 years 9 months. The proposed age range included 8 year olds, but none were located. Furthermore, although age 18 was originally proposed as the maximum age, two players, one male and one female, who were ranked in the 18's, had turned 19 by the time of videotaping. In addition, to obtain an approximately equal number of players in each experience category, the number of experience categories was reduced from five to three, resulting in categories of 1-2 years or less, 3-4, and 5 or more years.

Despite the fact that 15 of the pool of 75 players were eliminated from the full study due to reasons cited, an analysis of the serves of each of the 75 players was made. Upon completion of the analysis, each player received an individual serving profile and follow-up letter which explained the profile (see Appendix A).

Instruments and Preparatory Procedures

Preparation for the study was extensive. In addition to the selection and operation of the instrumentation, it was necessary to hypothesize sequences and steps to form the basis for the data, and then to train the observers who would record the data to be analyzed.

<u>Video Cameras</u>

Two video cameras, the Canon VC 30A and the Panasonic WV-3170 along with the Canon VR30A and Panasonic NV8420 videocassette recorders, were used to record the serving patterns of each subject from the rear and side viewing angles. The cameras were set to record at 1.31 ips (33.35 mm/sec) on Scotch EXG Camera T120 VHS videotape cassettes.

The Canon camera, supported on a 4 1/2 foot tripod and positioned to record a rear view angle of the serving patterns, was located 19 feet behind the tennis court baseline and on a line perpendicular to the center of the serving area (see Appendix B). The 19 foot location of the Canon camera permitted its use between the baseline and the fence. The Panasonic camera, on a 4 1/2 foot tripod, was positioned to tape a side view angle. It was placed 30 feet from the center mark along the baseline extended (see Appendix B). All videotaping was done by the investigator and trained assistants.

<u>Videotaping Sites</u>

Videotaping was completed on outdoor tennis courts. With the exception of one court, all courts had dark green windscreens attached to the fence which paralleled the sideline of the court. These windscreens served as a solid background in viewing the subjects from the side angle. The court which did not have a windscreen was adjacent to a solid green cement backboard. On courts where outlets were accessible or within reach of extension cords, it was possible to reposition the cameras to the opposite end of the court for filming the left handed players. However, at one site, the left handed players had to be filmed on an adjacent court which was paralleled by evergreen trees.

Videotapes

Two sets of videotapes were needed to complete the independent classification of the serving patterns by the two observers. Scotch EXG T120 videotape cassettes were selected to record the serving patterns of the subjects and copies of these master tapes were recorded onto Panasonic Premium SDT T120 videotapes. The investigator used the master tapes. The trained observer viewed the Panasonic tape copies.

Subject Numbers

The players were assigned a subject number, 1 through 75, prior to videotaping. These numbers identified each subject on the videotape and reflected the order in which the players were to be filmed.

Trial Markers

Seven tennis balls placed in view of both cameras served as trial markers. As the player picked up one ball for each trial, it was possible to determine the trial number by counting the number of balls which remained on the court.

Hypothesized Developmental Sequences

In view of the fact that no previous studies had applied a developmental model to analyze the tennis serve, the sequences generated for this preliminary investigation had to be derived by the investigator from several sources. The sources included the weaknesses and errors identified in the biomechanical and instructional literature, the Langendorfer (1982) comparison of developmental sequences for throwing and striking, Roberton's (1983) sequences for throwing, the Messick and Tracanna (1984) pilot study, and the investigator's teaching experience.

As no specific model for the tennis serve was found in the sources from which the hypothesized steps were generated, several steps used to describe the development of an overhead striking and throwing actions were integrated into the sequences for the overhead tennis serve. Table 1 illustrates the step actions applied by Langendorfer (1982) in the study of overhead striking and the adaptations of striking made for the tennis serve.

Table 1

Comparison of Overhead Striking Sequences and Sequences Hypothesized for the Tennis Serve

Overhead Strike Sequences[a]	Tennis Serve Sequences
Forearm/racket	
1. No forearm/racket lag.	1. No forearm/racket lag.
2. Forearm/racket lag.	2. Forearm/racket lag.
3. Delayed forearm/racket lag.	3. Delayed forearm/racket lag with upward extension.
Elbow	
1. Elbow collapsed (flexed) or extended.	1. Elbow collapsed (flexed) or extended.
2. Elbow maintained in a partially flexed angle.	2. Elbow partially flexed, 90 degrees or more.
3. Elbow held at a right angle.	3. Elbow flexed, less than 90 degrees.
Feet/Legs	
1. No step.	1. Homolateral step.
2. Homolateral step.	2. Contralateral step.
3. Contralateral, short step.	3. No step.
4. Contralateral, long step.	4. No step or homolateral step with knee and ankle flexion and extension.
Trunk (during force production phase)	
1. No trunk action or forward-backward movement.	1. Minimal trunk action or forward-backward movement.
2. Upper trunk rotation or total "block" rotation.	2. Upper trunk or total trunk rotation.
3. Differentiated rotation.	3. Differentiated rotation with forward flexion of upper trunk.
	4. Differentiated rotation with extension of trunk

[a]Based on Langendorfer's (1982) hypothesized sequences

The sequences arrayed in Table 1 show that Steps 1 and 2 for the Forearm/Racket component are the same for the skills of overhead striking and serving in tennis. Whereas a "delayed forearm/racket" is the same for the most advanced steps across both skills, Step 3 of the tennis serve requires, additionally, the "upward extension" of the forearm and racket.

Steps 1 and 2 of the Elbow component, described in Table 2, are also similar across the two tasks. A slight modification in Step 3 was made to accommodate the extreme flexion of the elbow recommended in executing a powerful tennis serve.

Although five steps hypothesized for the Feet/Legs component in the pilot study included all four steps of the overhead strike sequence, only four, as shown in Table 1, were included for this study with modifications made in the sequence order. The Feet/Legs sequences hypothesized for the two skills of striking and serving are alike in that homolateral actions precede contralateral actions; however, the "no step" action appears as Step 1 in overhead striking and as Step 3 in the tennis serve. In addition to these modifications, a new Step 4, as recommended in the instructional literature, identifies a more advanced feet/legs action in tennis serving.

The major difference in Langendorfer's (1982) sequences for overhead striking and the sequences proposed for the tennis serve is found in comparing the trunk components. Although the same three step sequence for the trunk action in overhead striking is included in the four step sequence for the trunk action during the force production phase in serving, an additional Step 4 was included to distinguish between flexion and extension of the hips prior to contacting the tennis ball. Whereas Langendorfer considered the degree of spinal and pelvic rotation for overhead striking, a separate sequence was proposed for the trunk action during the preparatory phase of the tennis serve. In addition, Langendorfer proposed sequences for the humerus; however, this component was not considered for the tennis serve.

Roberton's (1983) steps for the preparatory backswing in overarm throwing that were employed in the analysis of the tennis serve are arrayed in Table 2.

Table 2

Comparison of Preparatory Backswing Sequences for Throwing and the Tennis Serve

Throwing[a]	Tennis Serve
1. No backswing.	1. Elbow and humeral flexion
2. Elbow and humeral flexion.	2. Circular, upward backswing
3. Circular, upward backswing.	3. Circular, downward backswing.
4. Circular, downward backswing.	

[a]Based on Roberton's (1983) hypothesized sequences

As shown in Table 2, the three step sequence hypothesized for the Preparatory Backswing action in serving is the same as Steps 2, 3, and 4 of Roberton's (1983) sequence for overhead throwing. Step 1, no backswing, was included in the Messick and Tracanna (1984) pilot study; however, only two subjects, age 5, were categorized at this level in that study. The observation of this primitive step by only two of the youngest players seemed to categorize this action as more indigenous to the fundamental skill of overhead striking than to the advanced skill of serving in tennis.

Revised Hypothesized Developmental Sequences

After the initial independent analysis of the serves of the 60 players, distinct differences in the trunk actions of the beginning and advanced players were noted by each observer. The original hypothesized sequences did not adequately distinguish between immature and mature trunk actions in serving. Therefore, the sequences for the trunk during the preparatory and force production phases were modified to reflect the noted differences. A comparison of the original and revised sequences for the trunk action during the preparatory phase appear in Table 3.

Table 3

Original and Revised Sequences for the Trunk Action during the Preparatory Phase of the Tennis Serve

Original Sequence	Revised Sequence
1. No trunk action.	1. No trunk action or forward-backward movement.
2. Forward flexion and backward extension.	2. Minimal trunk rotation.
3. Total trunk rotation.	3. Total trunk rotation.

The step descriptions in Table 3 reveal that the revised Step 1 combined the original Steps 1 and 2. The decision to combine these steps into a single step paralleled Step 1 of the trunk action during the force production phase. The revised Step 2 in the preparatory phase of the trunk differentiated subjects who initiated the serve facing the net from those who had begun to partially turn the shoulders and hips. Finally, the modified Step 3 identified players who rotated fully the shoulders and hips as the racket was carried back. Without these revisions, the original sequence tended to classify any minimal rotation as Step 3. Furthermore, the original sequence classified any forward/backward movement as Step 2 although forward/backward, flexion and extension actions were observed often among advanced players who actually demonstrated complete trunk rotation. The other revisions involved Steps 3 and 4 of the trunk during the force production phase. These revisions appear in Table 4.

Table 4

Original and Revised Sequences for the Trunk Action during the Force Production Phase of the Tennis Serve

Original Sequence	Revised Sequence
1. Minimal trunk action or forward-backward movement.	1. Minimal trunk action or forward-backward movement.
2. Upper trunk or total trunk rotation.	2. Upper trunk or total trunk rotation.
3. Differentiated trunk rotation with forward trunk flexion.	3. Lateral shift of the hips prior to total trunk rotation.
4. Differentiated trunk rotation with hyper-extension followed by extension.	4. Differentiated trunk rotation.

As shown in Table 4, the original Step 3 identified the players who differentiated the trunk, yet "piked" prior to contact and Step 4 identified the players who differentiated the trunk, but also extended the trunk to contact the ball. Although the ability to extend versus "pike" is an interesting observation and perhaps another step in the sequence, the decision was made to identify the precursor to trunk differentiation. Prior to differentiating the hips and upper body during forward rotation, it was hypothesized that an individual begins to shift the hips laterally toward the net. Without modifying the sequence to include this lateral shift of the hips, all players who positioned sideways to the net, regardless of distinct differences in the actions of the trunk, were classified originally at Step 2 unless they were able to differentiate the shoulders and hips during forward rotation. The obvious difference between a player who displays minimal trunk action and the player who is beginning to use the trunk in force production by laterally shifting the hips seemed to characterize more completely the developmental process.

In all, two primary phases of the tennis serve, namely, the preparatory and force production phases, were selected for study. Each phase was broken down into specific body component actions that in turn were divided into either 3 or 4 step actions. Of the six sequences hypothesized originally, the trunk actions during the preparatory and force production phases, were revised early in the study. The detailed descriptions of the selected body component actions which comprise the original and revised sequences appear in Appendix C.

Selecting and Training the Observers

One of the observers was the investigator. The other, an experienced tennis instructor, was trained by the investigator. During the training sessions, the two observers analyzed the serving patterns of the subjects according to the original developmental sequences hypothesized for the overhead tennis serve. Trials for the 24 subjects who had been videotaped during the Messick and Tracanna (1984) pilot study, and trials of the subjects who were eliminated from this study were used for training.

The observational training criterion required that an exact percentage agreement of 80% or higher be achieved between observers in classifying the body component actions (Langendorfer, 1982; Williams, 1980). To achieve this criterion, the observer and the investigator practiced analyzing and classifying the serving patterns during three, two-hour training sessions. During these sessions, to reduce any observer bias toward expecting age and sex differences (Mitchell, 1979), the serving patterns of both the younger and older age groups of males and females who demonstrated both immature and mature serving patterns were observed and classified. After completing the initial training sessions, the trained observer and the investigator independently classified trials for five players who had not been viewed previously during the training sessions. The number of trials for these five subjects varied due to the videotaping errors. Three of the five players performed seven trials and two of the players performed six trials. Trials for each of the five subjects were classified according to the actions of the six body components of (a) Preparatory Backswing, (b) Preparatory Trunk (c) Trunk during Force Production, (d) Elbow, (e) Forearm/Racket, and (f) Feet/Legs.

The foregoing procedure resulted in the classification of 198 trials. From these 198 trials, the number upon which the observers agreed was calculated by determining the percentage of agreement across the 198 trials. The percentage was determined by dividing the number of trials upon which the investigator and the trained observer agreed by the total number of trials. An agreement of 100% was achieved on four of the components. The results were 59% and 88% respectively on the other two components. Complete results for each of the six components are displayed in Appendix D.

Although agreement results were 80% or higher on five of the six components, additional training was needed to increase the percentage of agreement across all components. In order to effect that increase, the trained observer and the investigator independently analyzed trials for five additional players not included in the study. Each player performed seven trials. When a comparison of all trials for each body component action was made, the agreement between the investigator and the trained observer across all trials for each of the six body component actions yielded 100% on three components and 80%, 83%, and 94% on the remaining three. The percentage of agreement reached for each of the six components is displayed in Appendix D. Having satisfied the training criterion of 80% or higher for each of the six body component actions, the observers proceeded to analyze independently all trials of the 60 subjects studied.

Data Collection and Observation Procedures

The data collection entailed the videotaping and analysis of the players' serves according to the sequences hypothesized. Analysis of the videotaped tennis serves required the independent and combined classifications by two observers.

Videotaping

Subjects were videotaped between June 1, 1986 and June 19, 1986. To complete the videotaping, 10 three hour sessions at five sites were needed.

Prior to videotaping, questionnaires and consent forms to be completed were checked for information requested and signatures. In preparation for taping, 1" strips of black tape were placed horizontally and vertically across the hips and shoulders of each subject's white or light colored clothing.

Each subject was encouraged to practice serving on other courts near the camera-equipped court prior to videotaping. The amount of practice varied depending upon the amount of time each subject needed to warm up. During that practice time, subjects were informed that they would be asked to serve "as if you are serving an ace from the deuce court". When the subject indicated a readiness to be videotaped, the instructions were given to take a position along the baseline within two feet of the center mark. Each performer was asked to show to each camera a placard which contained the identifying initials and number of the subject.

Seven balls were placed in the court within view of each camera but away from the player's feet. One ball had to be picked up separately for each trial. Right handed subjects served from the right service court and left handed subjects served from the left service court. All right handed subjects and three of the left handed subjects served with their backs to the sun. The three left handed subjects who faced toward the West did not complain about the angle of the sun. The instructions were to "serve as if you are trying to serve an ace". At least three practice trials were allowed in the designated serving area prior to videotaping. When the player understood that the task was to deliver a forceful serve rather than an accurate one, taping was initiated. The opportunity to serve again was given if the performer expressed verbally that the ball toss "was off" on a trial; otherwise, all seven trials were performed consecutively. The subjects used their own rackets to serve a self-tossed ball.

<u>Observation Procedures</u>

The data collection consisted of the observation and classification of the serving patterns by the trained observer and the investigator, first, working independently, then together. The details of each procedure are described in the sections that follow.

The Canon VR 30A videocassette recorder and a color monitor were used to display the data. The Canon VR30A unit featured 4 heads which permitted the slow motion and frame-by-frame analysis of the serving patterns. A trial-by-trial analysis was made of all seven trials for each of the six components for each subject. All component actions were classified by comparing the side and rear viewing angles. However, it was not possible to view simultaneously the side and rear viewing angles due to the availability of only one Canon VR 30A unit equipped with a 4 head recorder; therefore, the Canon

VR30A unit was used to display the serving patterns of the subjects from the side angle first, then from the rear.

Independent Analysis by Each Observer

The developmental studies (Langendorfer, 1982; Roberton, 1977; Williams, 1980) which provided guidelines for this study recommended the independent analysis of the data by the investigator. In each study, a trained observer then analyzed 30 randomly selected trials to determine the reliability of the investigator's classifications. However, given the exploratory nature of the hypothesized sequences of this study and given that no previous research had considered a developmental approach for analyzing component actions in tennis serving, a decision was made to have two observers analyze all trials for each of the 60 subjects.

As no procedures were located in the literature for analysis by two observers, stringent criteria were established for assessing inter-observer reliability. The 60 subjects were divided into two groups by randomly assigning 30 subjects to Group A and 30 subjects to Group B. The trained observer viewed initially subjects in Group A and then viewed subjects in Group B in a pre-planned order from the lowest to the highest number according to the identification numbers assigned to the subjects for videotaping. A detailed listing of the order by which the investigator and the trained observer viewed the subjects is displayed in Appendix E. The trained observer began with the lowest numbered subject in both the A and B groups and proceeded in order until the highest numbered subject in Group A and then in Group B had been analyzed. For example, the trained observer first viewed Group A, beginning with Subject #1, followed by Subject #3, and so forth, completing Group A with the analysis of Subject #75. The trained observer then proceeded to classify trials for Group B, beginning with Subject #2, followed by Subject #5, and so forth until trials for the last subject in Group B, Subject #74, were analyzed.

The investigator reversed the viewing order by viewing Group B and then Group A. The investigator always began with the highest numbered subject in each group and completed the analysis with the lowest numbered subject in each group. The order of viewing was Subject #74, followed by #59 and so forth, completing Group B with the analysis of Subject #2. The investigator then analyzed trials for subjects in Group A by beginning with Subject #75, followed by Subject #72, and so forth until trials for the last subject in Group A, Subject #1, had been completed. This viewing order procedure was followed to reduce observational bias in classifying the 60 subjects.

All seven trials for each subject were analyzed for each body component action before the next subject was viewed. The order for analyzing those actions was as follows: (a) Preparatory Backswing, (b) Trunk in the Preparatory Phase, (c) Trunk in the Force Production Phase, (d) Elbow, (e) Forearm/Racket, and (f) Feet/Legs. After initially analyzing all trials for the 60 subjects, the observers were permitted to view again trials for one or more of the subjects and make changes in the classifications before a comparison of exact percentage agreement between the observers was determined.

After all trials had been analyzed independently by the observers, inter-observer percentage agreement was determined by comparing the number of trials upon which the observers agreed for each body component action for each subject. The range of 63% - 100% for inter-observer agreement across all trials resulted. For four components, the agreement achieved the 80% or higher criterion (Langendorfer, 1982; Williams, 1980), whereas 63% and 64% were reached across the two remaining components. A detailed listing of percentages obtained for each of the six components is given in Appendix F.

Given the criteria established for reaching agreement between the two observers, several decisions were made concerning the reanalysis of the videotapes. The first decision involved modification of the sequences hypothesized for the trunk actions during the preparatory and force production phases of the serve. Having modified the sequences to accommodate the differences noted by the observers, the observers reanalyzed the serves according to the six original and two revised sequences. Prior to independently reanalyzing the videotapes, a decision was made not to reclassify the preparatory backswing component as 100% percentage agreement had been achieved. Another decision was made not to reanalyze trials of six subjects for which 100% agreement for each component had been attained. Furthermore, given the consistency across trials by all but 11 subjects and the time required to reanalyze the serving patterns of the 54 subjects, the observers were instructed to view all trials, but to classify only the modal step.

Combined Analysis by the Observers

After reanalyzing the serving patterns of those subjects about which there was disagreement, a second comparison was made to determine the percentage of agreement between the observers. The range of agreement was 69% - 91%. Exact percentages achieved for each component are displayed in Appendix F. The second comparison of classifications revealed that the observers still did not agree upon developmental levels for several players; therefore, in keeping with the stringent criteria established for analysis of the tennis serves, the decision was made for the observers to view and discuss together the tapes and decide upon the most accurate developmental level for the component actions upon which they disagreed. The agreed upon step classifications for each subject included in the study appear in Appendix G.

Data Analysis

Descriptive analyses were used to determine whether or not the data satisfied the prelongitudinal screening criteria. Inferential statistics in the form of a linear discriminant analysis were calculated to ascertain the effect of age, sex, and experience on the developmental level of selected body component actions in the tennis serve. The details of each analytical procedure are described in the sections that follow.

Prelongitudinal Screening Criteria

The initial phase in validating the hypothesized developmental sequences was to satisfy criteria for the prelongitudinal screen test. Questions 1, 2, and 3 of the study were answered by applying Roberton's (1977, 1978a) across trials, prelongitudinal screening criteria.

In applying the criteria, comprehensiveness was studied first. A step-by-step analysis within each component was made to determine that each developmental step appeared within the sample. Next the stability criterion was analyzed by determining if 50% or more of the seven trials for each component action were classified within one step identified as the modal step. Non-modal trials were examined then to fulfill the criterion of adjacency (Roberton, 1977, 1978a).

Question 4, pertaining to the age and experience of subjects within each developmental level, was answered by comparing the mean age and experience and number of subjects across modal steps for each component as recommended by Langendorfer (1982). In addition, Question 5, which also considered the relationship of age and experience to developmental level, was addressed by matching the cross-sectional data to an hypothesized graph of a longitudinal model (Roberton et al., 1980). These researchers recommended that the "closeness of fit" between the actual and expected probability stage model would indicate the frequency of observing higher developmental levels as a function of age and experience and, in turn, should provide support for or against longitudinal study.

The age and number of males and females classified at each step were compared to address Questions 6 and 7. More specifically, step classifications of males and females, ages 9-10 and 11-12 years, were examined to answer Question 6. Similarly, step classifications of the older males and female players, ages 15-16 and 17-19 years, were compared to answer Question 7. These players represented the extremes of the ages sampled.

To examine the experience factor, the number of males and females classified at each component step and their years of tennis experience were compared. Although players were assigned to one of three experience categories of 1-2 years or less, 3-4 years, or 5 or more years, only players with 1-2 years or less were considered to answer Question 8 and only players with 5 or more years were included as Question 9 was addressed. The categories represented the extremes of tennis experience sampled.

<u>Linear Discriminant Analysis</u>

Questions 6, 7, 8, and 9 were examined also through the application of discriminant analysis using the SAS statistical program recommended by the Statistical Consulting Center of the University of North Carolina at Greensboro. The size of the sample (N=60) and the number of dependent variables to be analyzed (n=8) did not permit the analysis of each body component; therefore, the decision was made to reduce the number of dependent variables from eight to two. Based on that decision, only the component actions for the Forearm/Racket and Trunk for Force II were analyzed. The fact that the actions of the forearm and trunk had been studied extensively for the overarm throw (Roberton, 1977, 1978a; Roberton & Langendorfer, 1980) and the overhead strike (Langendorfer, 1982), influenced the selection of Forearm/Racket and Trunk for Force II sequences for discriminant analysis. Furthermore, validation of developmental sequences for the forearm and trunk actions through longitudinal study (Roberton and Langendorfer, 1980) and the similarity of the sequences hypothesized for these components in throwing, striking, and serving warranted their selection over other components. The analysis was further limited to Steps 2 and 3 of the Forearm/Racket and Steps 2, 3, and 4 of the Trunk for Force II components. Step 1 of both components was excluded because of its limited occurrence among the performers. The significance level for determining the predictive value of the independent variables of sex, experience, and age was set at .05.

CHAPTER IV

ANALYSIS, RESULTS, AND DISCUSSION

The purpose of the study was to determine whether male and female performers of varied ages and experience demonstrated stability and intransitivity in selected body components during the delivery of a tennis serve. The cross-sectional, prelongitudinal screening of hypothesized sequences for selected body components in tennis serving was based upon the specific criteria of comprehensiveness, stability, and adjacency as developed by Roberton (1977, 1978a). Examination of the age and experience factors expanded upon the work of Langendorfer (1982) and on the hypothesized longitudinal model generated by Roberton et al. (1980).

To determine whether males and females of varying age and experience exhibited the same or different body component actions in executing an overhead tennis serve, descriptive and statistical analyses were employed. The effects of sex, age, and experience upon step classifications for the Forearm/Racket and Trunk for Force II components were analyzed further through stepwise discriminant analysis.

To order and clarify the descriptive data as they are presented for Questions 1-5, statements of conclusions follow the analysis for each question, then a tabled summary of results of the prelongitudinal screening is given after Question 5. A similar procedure is used for Questions 6-9.

Prelongitudinal Screening

Question 1

Is comprehensiveness demonstrated by the appearance of each developmental step for the selected body component actions of (a) the preparatory arm backswing, (b) the trunk action in the preparatory phase, (c) the elbow action in the force production phase, (d) the forearm/racket action in the force production phase, (e) the trunk action in the force production phase, and (f) the feet/leg action in the force production phase?

In addition to investigating the comprehensiveness of each step hypothesized initially for the six body components listed in Question 1, revised sequences for the trunk action during the preparatory phase and the trunk action during the force production phase were examined according to Roberton's (1977, 1978a) prelongitudinal screening criteria.

The prelongitudinal screening criterion of comprehensiveness was analyzed by the frequency with which each sequential step was observed and by determination of modal classifications for each step. A summary of all trials by all subjects classified according to sequential steps observed for each of the body components studied is given in Table 5.

Table 5

Total Trials Classified for Each Sequential Step for All Subjects

Components	Steps 1	2	3	4	Total Trials
Preparatory Backswing	0	21	398	NA[a]	419[b]
Preparatory Trunk I	6	78	335	NA[a]	419[b]
Trunk for Force I	14	321	43	42	420
Elbow	14	95	310	NA[a]	419[b]
Forearm/racket	14	116	290	NA[a]	420[b]
Feet/Legs	11	44	126	239	420
Preparatory Trunk II	14	226	179	NA[a]	419[b]
Trunk for Force II	14	217	104	85	420

[a]NA = not applicable. Step 4 not hypothesized.

[b]Total trials were 420. Videotaping error reduced number.

A review of the summary in Table 5 reveals that all sequential steps were displayed for all body components except Step 1 of the Preparatory Backswing. No performers demonstrated that step on any trial.

To add to the picture of comprehensiveness, the extent to which each step appeared as the modal step was considered. A step was defined as the modal step if it was demonstrated on four or more of the seven trials. The number of modal step classifications for each body component step for all subjects appears in Table 6.

Table 6

Number of Modal Step Classifications for Each Body Component Step

Component	Steps 1	2	3	4
Preparatory Backswing	0	3	57	NA[a]
Preparatory Trunk I	1	11	48	NA[a]
Trunk for Force I	2	46	6	6
Elbow	2	14	44	NA[a]
Forearm/racket	2	16	42	NA[a]
Feet/legs	2	7	17	34
Preparatory Trunk II	2	32	26	NA[a]
Trunk for Force II	2	31	15	12

[a]NA = not applicable. Step 4 not hypothesized.

As shown in Table 6, with the exception of Step 1 of the Preparatory Backswing, each sequential step for the remaining body component actions was identified as the modal step for one or more subjects. For example, 57 subjects demonstrated Step 3 of the Preparatory Backswing component on four or more trials; however, no subject demonstrated Step 1. From the data presented in Tables 5 and 6, it may be concluded that Roberton's (1977, 1978a) prelongitudinal screening criterion of comprehensiveness was met for each component with the exception of the Preparatory Backswing. Each step was demonstrated modally and non-modally.

Question 2

Does each subject demonstrate stability across trials as measured by 50% or more trials classified within the modal step?

The across-trials screening criterion of stability required identification of a modal step of body component actions for each subject. The modal step provided a measure of the consistency or stability with which subjects performed. The number of subjects and the percentage of modal step trials observed are arrayed in Table 7.

Table 7

Number of Subjects and Percentage of Trials Classified the Same as the Modal Step

Component	Number of subjects	Number of trials[a]	Percentage of trials[b]
Preparatory Backswing	60	7	100%
Preparatory Trunk I	59	7	100%
	1	6	86%
Trunk for Force I	59	7	100%
	1	6	86%
Elbow	59	7	100%
	1	5	71%
Forearm/Racket	58	7	100%
	1	6	86%
	1	4	57%
Feet/Legs	54	7	100%
	2	6	86%
	3	5	71%
	1	4	57%
Preparatory Trunk II	59	7	100%
	1	4	57%
Trunk for Force II	59	7	100%
	1	6	86%

[a]Number of trials classified the same as the modal step.

[b]Percentage of trials classified the same as the modal step.

The data in Table 7 show that most subjects demonstrated consistency across trials. For example, all subjects performed 7 or 100% of trials within the same step in the Preparatory Backswing thereby exhibiting high consistency. In all other components, although from 1 to 6 subjects failed to demonstrate 7 or 100% of their trials within the same step, no subject failed to the achieve the required 4 or 50% or more of trials within a modal step. The data presented in Table 7 indicate that the stability criterion established by Roberton (1977, 1978a) was satisfied.

Question 3

Does each subject demonstrate non-modal steps which are adjacent to the modal step?

The relationship of non-modal steps to the modal step was considered to screen for the adjacency criterion. Non-modal steps, identified as steps which appeared less than four times across the seven trials, were required to be adjacent to the modal step. The number of subjects who demonstrated each step and the percentage of trials classified at each step by the subjects are presented in Table 8. In the table, adjacency is denoted by the broken line joining two percentages.

Table 8

Number of Subjects and Percentage of Trials Classified at Each Step

	Step			
Component/Number of Subjects	1	2	3	4
Preparatory Backswing				NA[a]
57			100%	
3		100%		
Preparatory Trunk I				NA[a]
48			100%	
11		100%		
1	86% ----	14%		
Trunk for Force I				
45		100%		
6			100%	
6				100%
2	100%			
1		86% ----	14%	
Elbow				NA[a]
44			100%	
13		100%		
2	100%			
1		71% ----	29%	
Forearm/Racket				NA[a]
40			100%	
16		100%		
2	100%			
1		14% ----	86%	
1		43% ----	57%	

[a]NA = not applicable. Step 4 not hypothesized.

Note. The broken line (-----) indicates the non-modal step was adjacent to the modal step.

Table 8 continues

Component/Number of Subjects	Step 1	2	3	4
Feet/Legs				
33				100%
16			100%	
5		100%		
1			14%----	86%
1			71%----	29%
1		71% ----	29%	
1		57% ----	43%	
1	86%		14%	
1	71%		29%	
Preparatory Trunk II				NA[a]
32		100%		
25				100%
2	100%			
1		43% ----	57%	
Trunk for Force II				
31		100%		
14			100%	
12				100%
2	100%			
1			86%----	14%

[a]NA = not applicable. Step 4 not hypothesized.

Note. The broken line (-----) connecting the percentages indicates the non-modal step was adjacent to the modal step.

From Table 8 it may be seen that the adjacency criterion had to be applied to all components except the Preparatory Backswing. Of the remaining components, only the Feet/Legs, did not show adjacency for two subjects.

It may be seen from Table 8 that in those cases two subjects did not demonstrate Step 2 between Steps 1 and 3 on any of the 7 trials. It may be concluded from the data that the adjacency criterion was met for each component except the Feet/Legs in the cross-sectional, prelongitudinal screening of the tennis serve according to Roberton's (1977, 1978a) adjacency criterion.

Question 4

Do the developmental levels within each sequence increase as the mean age and experience of the subjects increase?

Mean age. The mean age of the subjects across each modal step is displayed in Table 9.

Table 9

Age Mean and Standard Deviations of Age of Subjects Classified within Modal Steps

Component	Steps 1	2	3	4
Preparatory Backswing				
m		16.00	13.11	NAa
sd		.11	2.11	
n		3	57	
Preparatory Trunk I				
m	9.04	13.05	14.03	NA[a]
sd		2.08	2.11	
n	1	11	48	
Trunk for Force I				
m	10.02	13.11	14.10	14.10
sd	1.01	2.10	3.11	1.11
n	2	46	6	6
Elbow				
m	10.09	12.04	14.08	NA[a]
sd	.03	2.06	2.10	
n	2	14	44	
Forearm/Racket				
m	10.09	11.07	15.01	NA[a]
sd	.03	2.01	2.07	
n	2	16	42	
Feet/Legs				
m	10.09	12.08	12.11	15.00
sd	.03	3.09	2.10	2.06
n	2	7	17	34

[a]NA = not applicable. Step 4 not hypothesized.

Note. The mean age of the subjects is given in years and months.

Table 9 continues

Component	Steps 1	2	3	4
Preparatory Trunk II				
m	10.02	13.07	14.10	NA[a]
sd	1.01	2.11	2.09	
n	2	32	26	
Trunk for Force II				
m	10.02	13.03	15.05	14.10
sd	1.01	2.08	2.07	2.11
n	2	31	15	12

[a]NA = not applicable. Step 4 not hypothesized.

Note. The mean age of the subjects is given in years and months.

As shown in Table 9, the mean age of the subjects increased across steps for all components except the Preparatory Backswing and, to a lesser extent, the Trunk for Force I and the Trunk for Force II. In the Preparatory Backswing component, subjects in younger mean age brackets (13.11 years) performed at a higher step than did subjects in older mean age brackets (16.00 years). Although the mean age of the subjects increased across Steps 1, 2, and 3 of the Trunk for Force I, the mean age of subjects was 14.10 years for both Steps 3 and 4. Within the Trunk for Force II component, the mean age increased across Steps 1, 2, and 3; however, the mean age (14.10 years) of subjects classified at Step 4 was a few months younger than the mean age (15.05 years) of subjects classified at Step 3.

Although comparisons and interpretations of the mean ages and their standard deviations may be limited by the unequal number of subjects classified at each component step as shown by n in Table 9, general age trends tend to appear across sequential steps for each component except the Preparatory Backswing.

Experience. In addition to comparing the mean age of the subjects classified at each step, it was necessary to determine whether higher developmental steps were demonstrated as experience, measured by years of participation, increased. The number of subjects classified within each modal step attained by the subjects is displayed in Table 10.

Table 10

Number of Subjects within Each Experience Category Classified within Modal Steps

Component/Experience	n	Step 1	Step 2	Step 3	Step 4
Preparatory Backswing					NA[a]
< 1 - 2 years	20			20	
3 - 4 years	16		1	15	
≥ 5 years	24		2	22	
Preparatory Trunk I					NA[a]
< 1 - 2 years	20	1	3	16	
3 - 4 years	16		3	13	
≥ 5 years	24		5	19	
Trunk for Force I					
< 1 - 2 years	20	2	14	3	1
3 - 4 years	16		12	2	2
≥ 5 years	24		20	1	3
Elbow					NA[a]
< 1 - 2 years	20	2	6	12	
3 - 4 years	16		5	11	
≥ 5 years	24		3	21	
Forearm/racket					NA[a]
< 1 - 2 years	20	2	10	8	
3 - 4 years	16		4	12	
≥ 5 years	24		2	22	

[a]NA = not applicable. Step 4 not hypothesized.

Table 10 continues

Component/Experience	n	Step 1	2	3	4
Feet/Legs					
< 1 - 2 years	20	2	4	9	5
3 - 4 years	16			5	11
≤ 5 years	24		3	3	18
Preparatory Trunk II					
< 1 - 2 years	20	2	11	7	NA[a]
3 - 4 years	16		10	6	
≥ 5 years	24		11	13	
Trunk for Force II					
< 1 - 2 years	20	2	12	2	4
3 - 4 years	16		9	3	4
≥ 5 or more years	24		10	10	4

[a]NA = not applicable. Step 4 not hypothesized.

As shown in Table 10, the trend toward performing at higher developmental levels with more experience appeared in all components except the Preparatory Backswing, Preparatory Trunk I, and the Trunk for Force I in which an approximately equal number of subjects in each experience group were classified at the same step. Step classifications for the body components of Elbow, Forearm/Facket, and Feet/Legs show that experience of five or more years characterizes performers at Steps 3 and 4.

Partial support for experience-related trends for the Preparatory Trunk II and Trunk for Force II sequences is also indicated in Table 10. Although 10 or 11 players in each experience category demonstrated Step 2 of the Preparatory Trunk II, more players had reached Step 3 after five or more years of tennis playing experience than had reached Step 3 after three to four years of experience. Experience related trends also seem evident for the Trunk for Force II sequence as 10 players had reached Step 3 after 5 years of experience as compared to only 2 or 3 players with 4 years or less of experience who were classified at this level. However, Step 4 of the Trunk for Force II component does not seem related to years of playing tennis as the same number of experienced and less experienced players demonstrated this step.

In summary, although comparisons and interpretations about experience-related trends may be limited by the unequal number of subjects represented in each experience category, it would appear that players with 5 or more years of experience functioned at higher steps for the Elbow, Forearm/Racket, Feet/Leg, Preparatory Trunk II, and the Trunk for Force II components than did players with fewer years of tennis experience. Step classifications for the Preparatory Backswing, the Preparatory Trunk I, and Trunk for Force I components did not support the notion of developmental changes in these actions as a function of years of tennis experience.

Question 5

Does the "closeness of fit" between the observed and expected graphs of an hypothesized longitudinal model (Roberton et al., 1980) support validation through longitudinal study?

The hypothesized longitudinal graph presented in Figure 2 served as the model for comparing the "closeness of fit" of the cross-sectional graphs derived in this study.

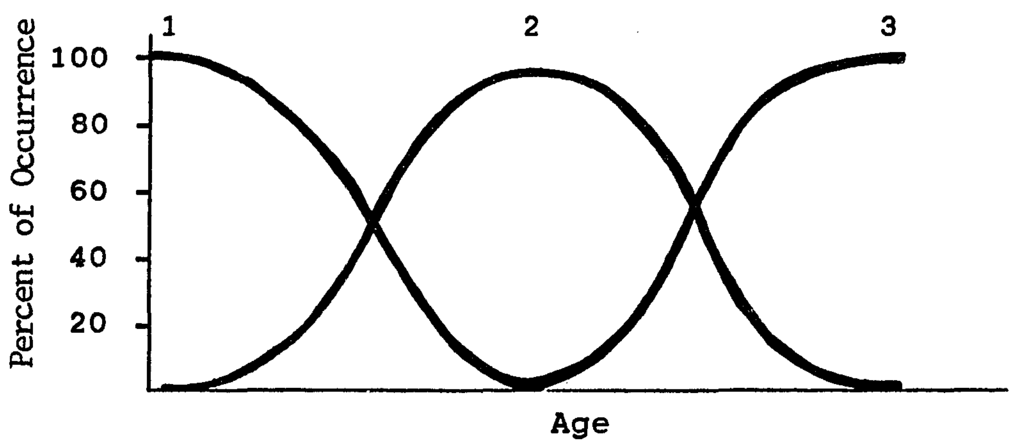


Figure 2. Hypothesized Longitudinal Curves for a Three Step Sequence

Note. Adapted from "Prelongitudinal screening of motor development sequences" by M. A. Roberton, K. Williams, and S. Langendorfer, 1980, Research Quarterly for Exercise and Sport, 51, p. 727. Copyright 1980 by American Alliance for Health, Physical Education, Recreation, and Sport. Adapted by permission.

The Roberton et al. (1980) model was employed to screen the step order of the hypothesized sequences by comparing the percentage of subjects in different age groups classified at each step. Although the model was generated originally to apply to time or age, it may accommodate experience also. Therefore, the same model was used to compare the percentage of subjects in different experience categories classified at each step. To examine experience, the experience factor was substituted for the age factor in the Roberton et al. model.

To consider age and experience-related differences in body component actions, the Roberton et al. (1980) screening criteria of step order and sign of the slope were applied. The step order criterion requires that higher steps not precede the occurrence of lower steps across the age and experience groups sampled. The sign of the slope criterion determines that the curves rise or fall as predicted. For example, the curves generated for the three step sequence in Figure 2 illustrate that as age increases, the percentage of Step 1 actions decreases and, in turn, Step 2 actions increase. Among the oldest subjects, the probability of observing Step 2 diminishes as Step 3 actions are observed more frequently.

The extent to which curves generated from a cross-sectional sample match the expected longitudinal curves should be used with the across-trials screening criteria to determine the feasibility of longitudinal study of the hypothesized sequences (Roberton et al., 1980). To examine the "closeness of fit" of the graphs generated for this study to the hypothesized longitudinal graph, each body component was graphed separately for age and experience. Given the number of graphs to be presented, an interpretation of and conclusions about the step order and sign of the slope associated with each set of curves accompany each figure. An overall summary of conclusions is provided at the end of the text pertaining to Question 5.

Preparatory Backswing

Age. Figure 3 illustrates the approximate percentage of subjects in each age group who were classified at each step of the Preparatory Backswing of the tennis serve.

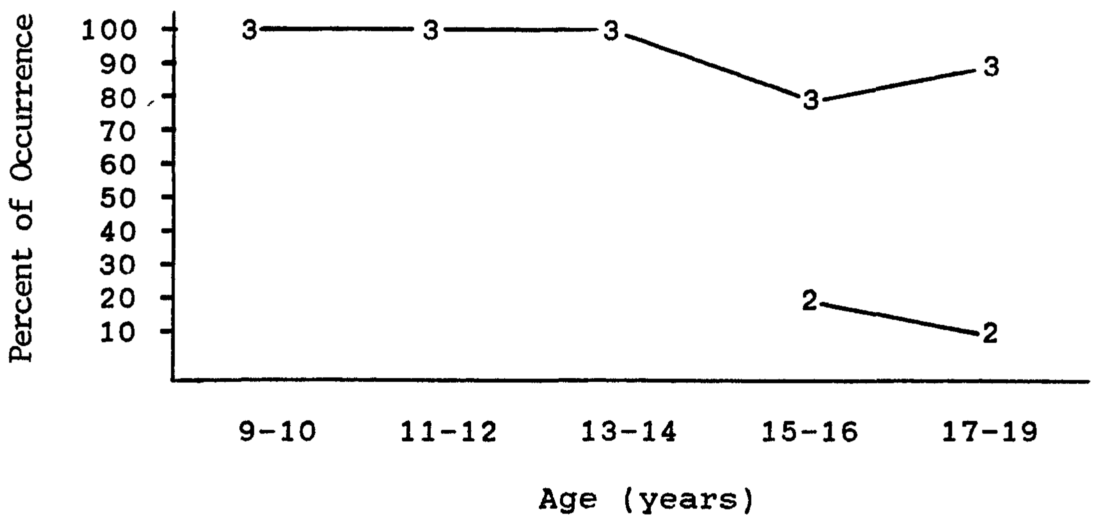


Figure 3. Percentage of step classifications across age groups for the Preparatory Backswing component. (For exact percentages, see Appendix H.)

According to the hypothesized longitudinal curves of Roberton et al. (1980), Step 3 would be expected for the older age groups. As shown in Figure 3, Step 3 was observed most frequently as 80 - 100% of the subjects, regardless of age, functioned at that level. In contrast, Step 2 appeared infrequently and only among 10 - 20% of the older subjects.

The curves in Figure 3 do not approximate the Roberton et al., (1980) hypothesized longitudinal model.

The Preparatory Backswing actions do not seem to be age-related as players of all ages were classified at Step 3. In addition, the step order criterion is not met as Step 3, the highest step appears prior to Step 2.

Experience. Curves generated for the Preparatory Backswing across the three experience categories are displayed in Figure 4.

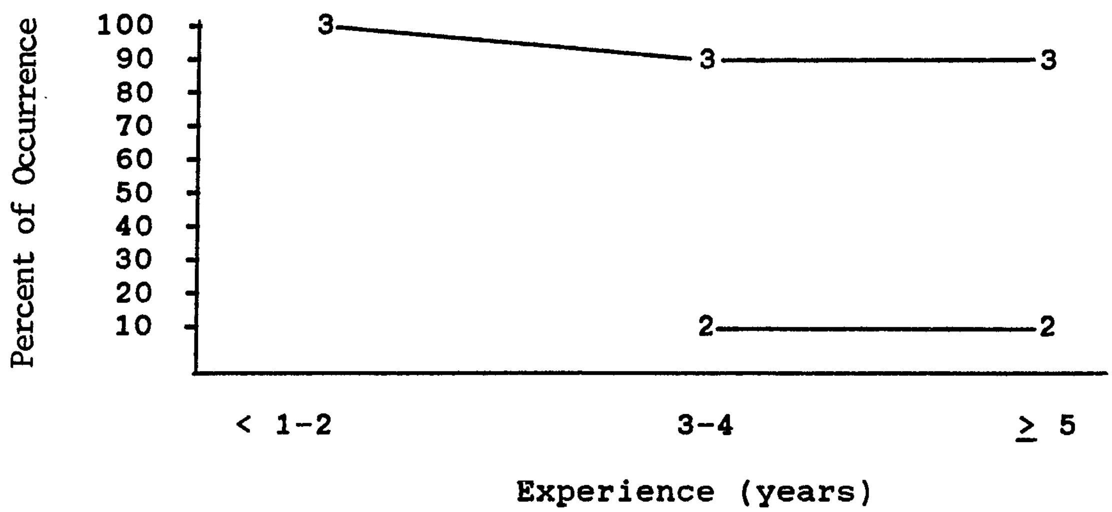


Figure 4. Percentage of step classifications across experience groups for the Preparatory Backswing component. (For exact percentages, see Appendix H.)

Step 3, as shown in Figure 4, was exhibited by 90% or more of the players, regardless of tennis playing experience. In contrast, Step 2 was demonstrated infrequently and only among subjects with 3 or more years of experience. The curves in Figure 4 do not reflect the differences expected in the Preparatory Backswing actions of players with varying tennis playing experience. Rather than illustrating a relationship between years of tennis experience and level of preparatory actions, most players, regardless of experience, were classified at Step 3. The pattern of the curves in Figure 4 does not "closely fit" the expected longitudinal model (Roberton et al., 1980).

Preparatory Trunk I

Age. Age-related curves for the Preparatory Trunk I sequence appear in Figure 5.

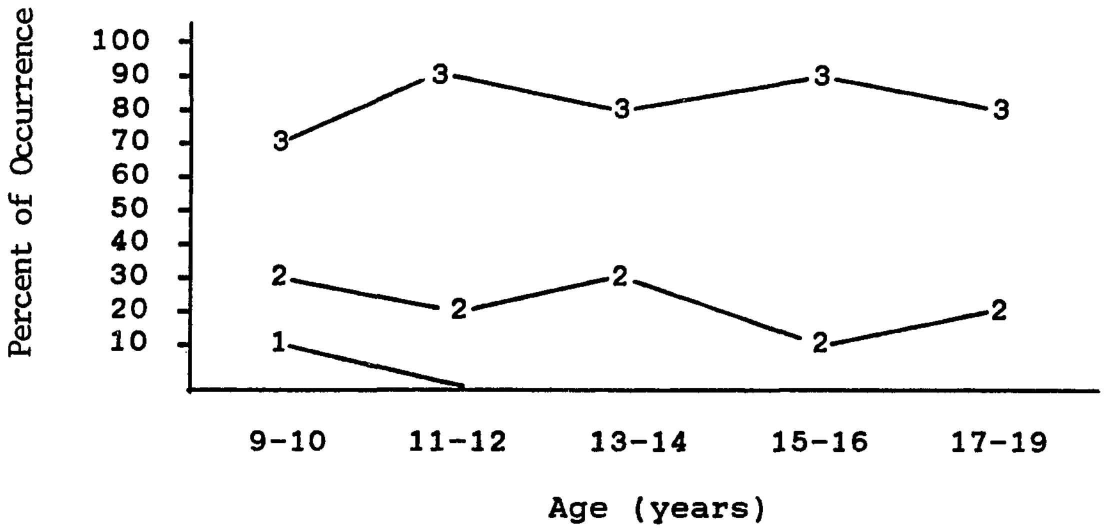


Figure 5. Percentage of step classifications across age groups for the Preparatory Trunk I component. (For exact percentages, see Appendix H.)

Although both Steps 2 and 3 continued to appear across all age categories in Figure 5, Step 3 was observed in a larger percent (70 - 90%) of subjects than was Step 2 (10 - 25%). Step 1 occurred infrequently and only among the youngest players.

As illustrated in Figure 5, the overall positive slope of Step 3 and the concomitant negative slope of Steps 1 and 2 partially support the longitudinal model which states that the developmental function is related to the chronological age of the subject and differences observed in the level of body component actions used to perform the motor skill. However, the fact that Step 3 occurs in 70% or more of the subjects in each age group brings into question the developmental nature of the steps as hypothesized originally for the Preparatory Trunk I component.

Experience. The curves in Figure 6 illustrate the occurrence of Preparatory Trunk I actions across the three experience groups.

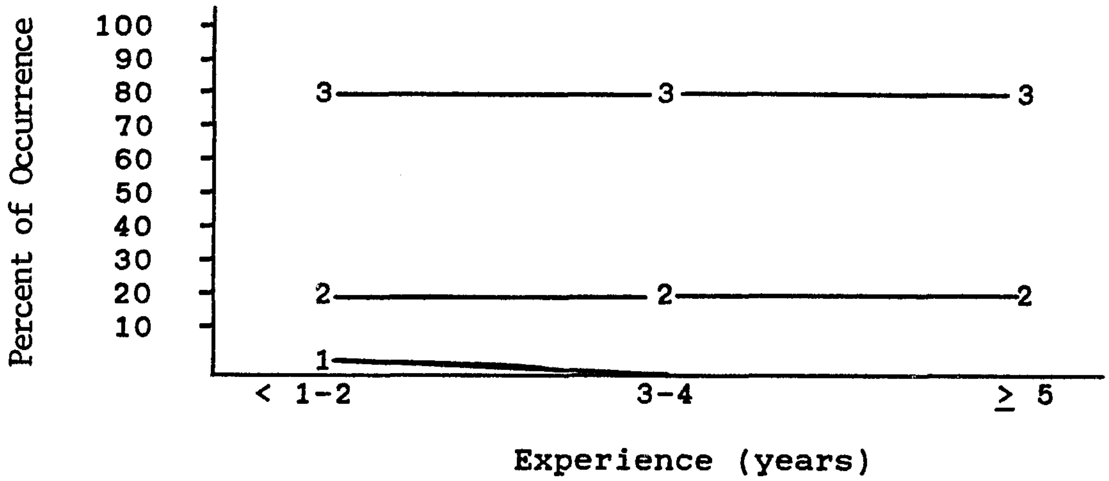


Figure 6. Percentage of step classifications across experience groups for the Preparatory Trunk I component. (For exact percentages, see Appendix H.)

Both Steps 2 and 3, as shown in Figure 6, appeared across each experience category; however, it may be seen that Step 3 was present in all categories to a greater degree than Step 2. Approximately 80% of the players functioned at Step 3 and only 20% functioned at Step 2. Curves for Steps 2 and 3 do not approximate the hypothesized experience-related model (Roberton et al., 1980). The relatively fixed percentage of occurrence of Steps 2 and 3 does not support the notion that developmental changes in these component actions are a function of years of tennis experience.

Trunk for Force I

Age. Figure 7 illustrates the age-related curves generated for the Trunk for Force I sequence.

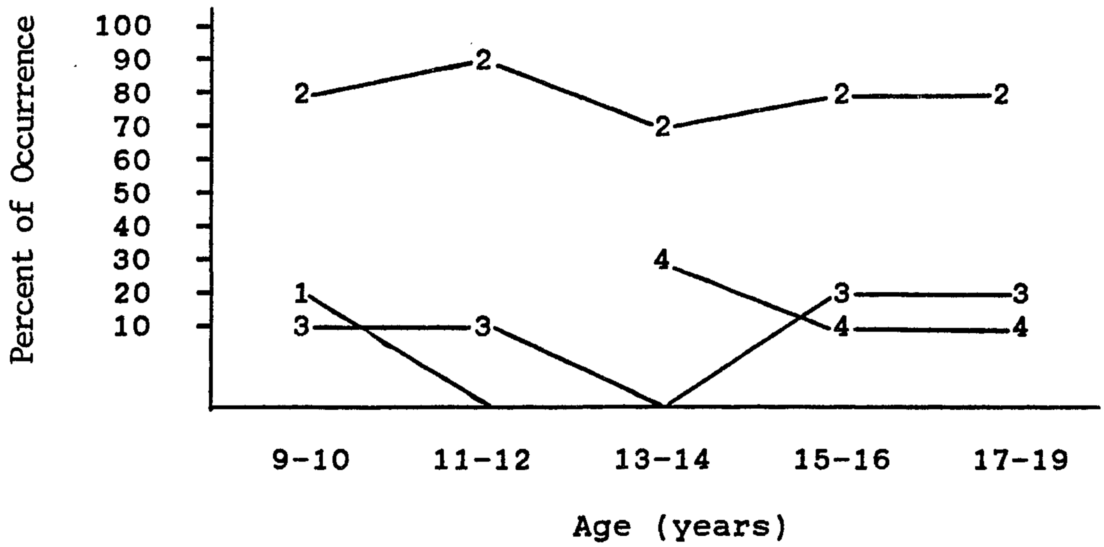


Figure 7. Percentage of step classifications across age groups for the Trunk for Force I component. (For exact percentages, see Appendix H.)

As illustrated in Figure 7, each component step of the Trunk for Force I component was demonstrated; however, 70% or more of the subjects in each age category were classified at Step 2. Steps 3 and 4 occurred among only 30% or fewer of the subjects with no players younger than 13 years functioning at Step 4.

The curves in Figure 7 do not meet the criteria suggested for matching the longitudinal model (Roberton et al., 1980). The preponderance of Step 2 actions among approximately 75% of the players, regardless of age, and the scant occurrence of Step 3 and 4 trunk actions do not support the notion of developmental change over time in this component as hypothesized. Furthermore, the sign of the Step 4 curve diverges from the expected model in that approximately 30% of the 13-14 year olds demonstrated Step 4; however, only one player, represented by 10% in each of the two older age categories, was classified at the highest step.

Experience. The percentage of step classifications in each experience category for the Trunk for Force I sequence are arrayed in Figure 8.

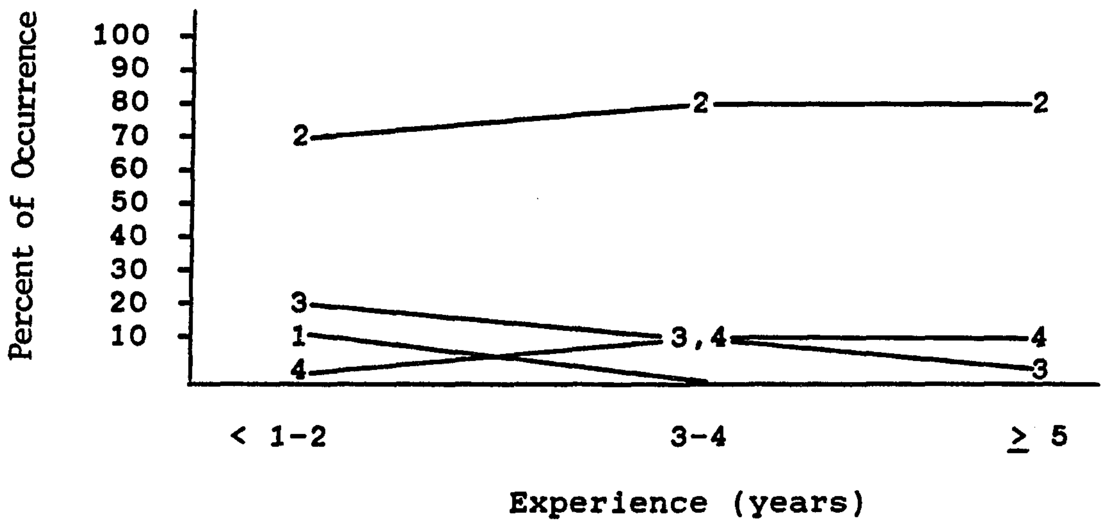


Figure 8. Percentage of step classifications across experience groups for the Trunk for Force I component. (For exact percentages, see Appendix H.)

As illustrated in Figure 8, each step hypothesized for the Trunk for Force I component appeared; however, most players, 70 - 75%, regardless of experience, were classified at Step 2. The other steps were displayed by only 5 - 15% of the players across the experience groups sampled.

The order of the Step 3 and Step 4 curves in Figure 8 approximate the expected model as Step 3 decreases as Step 4 increases slightly for the more experienced players; however, the prevalence of Step 2 actions among 70% or more of the subjects in each experience category brings into question the order of the Trunk for Force I sequence in its present form.

Elbow Component

Age. Figure 9 illustrates the curves produced from the age-related categorizations for the Elbow component.

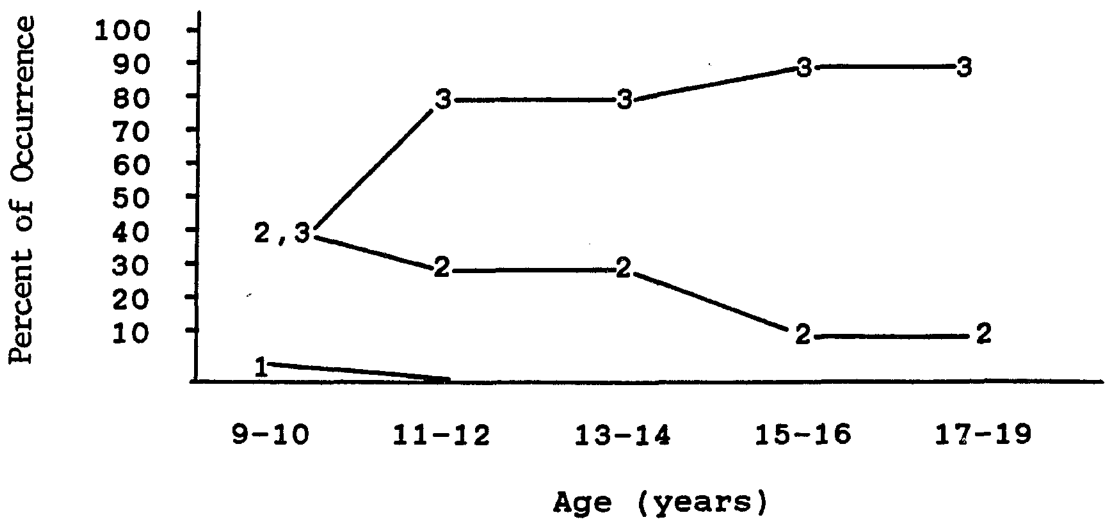
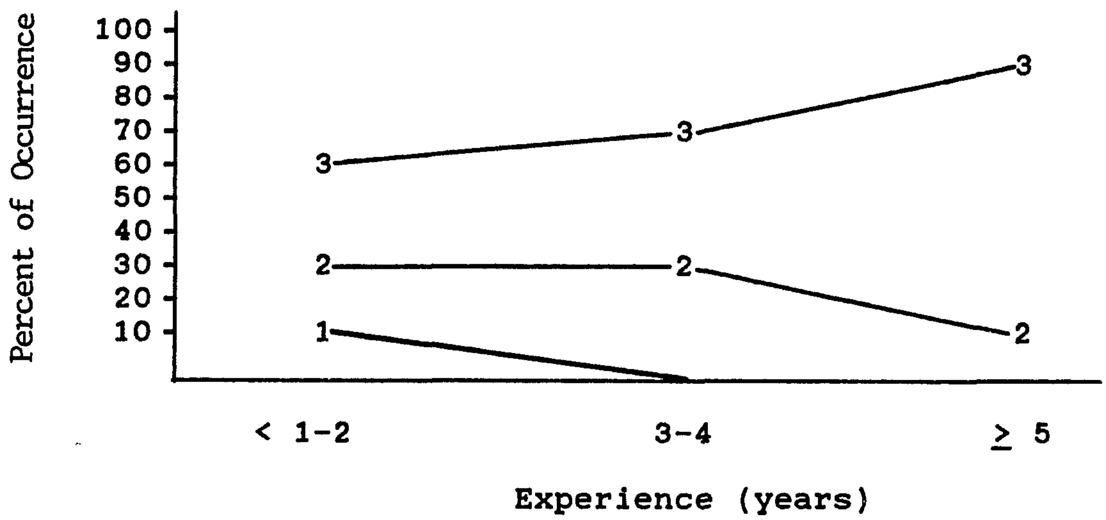


Figure 9. Percentage of step classifications across age groups for the Elbow component. (For exact percentages, see Appendix H.)

The curves in Figure 9 show that approximately 40% of the 9-10 years functioned at either Steps 2 or 3 in the Elbow component. However, the number of Step 2 classifications declined from 40% to 10% and the number of Step 3 classifications increased from 40% to 90% as the age of the subjects increased.

The curves in Figure 9 show time or age-relatedness. That relatedness is reflected in the overall negative slope of the Step 2 curve and the positive slope of the Step 3 curve across the five age groups represented. The curves generated for the Elbow component when age was considered demonstrated "closeness of fit" as proposed by the Roberton et al. (1980) model.

<u>Experience</u>. Experience-related curves for the Elbow component are presented in Figure 10.



<u>Figure 10</u>. Percentage of step classifications across experience groups for the Elbow component. (For exact percentages, see Appendix H.)

As shown in Figure 10, Step 3 was demonstrated by a higher percentage of players in each experience category than Steps 1 or 2. As the years of experience increased, more players, 60 - 90%, were classified at Step 3 and fewer, 10 - 30%, were classified at Step 2.

The shape of the curves in Figure 10 show experience-related trends for the Elbow component as the incidence of observing the more mature Step 3 actions increased as the years of tennis experience increased. The negative slope of the Step 1 and 2 curves as compared to the positive slope of the Step 3 curve across the three experience categories supports the Roberton et al. (1980) longitudinal model.

Forearm/racket

Age. Figure 11 shows the rise and fall of curves depicting the observed frequency of Steps 1, 2, and 3 of the Forearm/Racket sequence across the five age groups sampled.

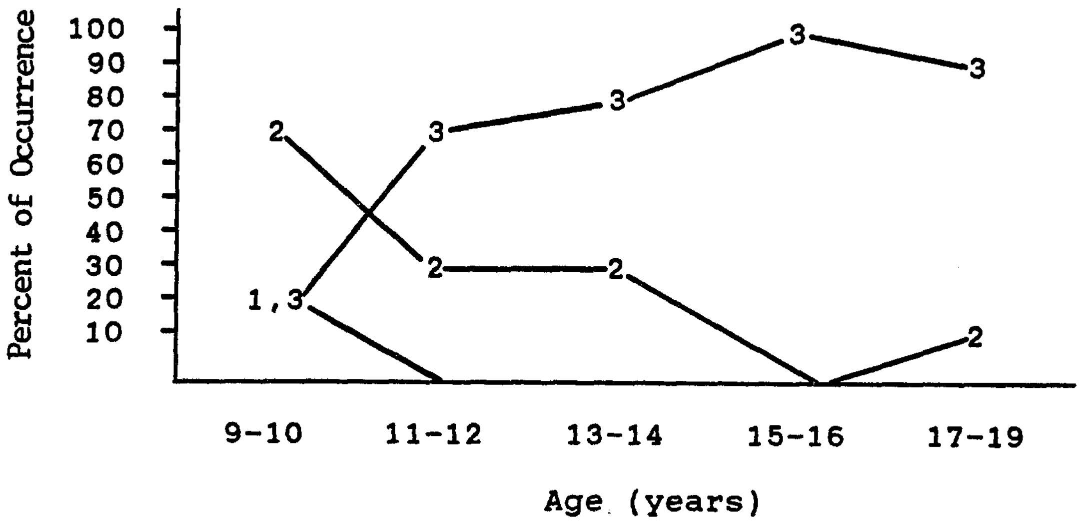


Figure 11. Percentage of step classifications across age groups for the Forearm/Racket component. (For exact percentages, see Appendix H.)

The curves in Figure 11 show that with increases in age, Step 2 classifications diminished and Step 3 classifications increased. Whereas 70% of the 9-10 year old players functioned at Step 2 and 20% at Step 3, among the older players, 90% or more demonstrated the higher Step 3 actions.

The curves in Figure 11 follow the hypothesized longitudinal graph of an ideal, three step developmental sequence. The negative slope of Curves 1 and 2 and the positive slope of Curve 3 indicate that differences observed in the Forearm/Racket actions may be age-related. The order and sign of the curves for Steps 1, 2, and 3 approximate the expected model (Roberton et al., 1980)

Experience. The curves in Figure 12 illustrate the occurrence of Steps 1, 2, and 3 of the Forearm/Racket among the experienced and less experienced tennis players.

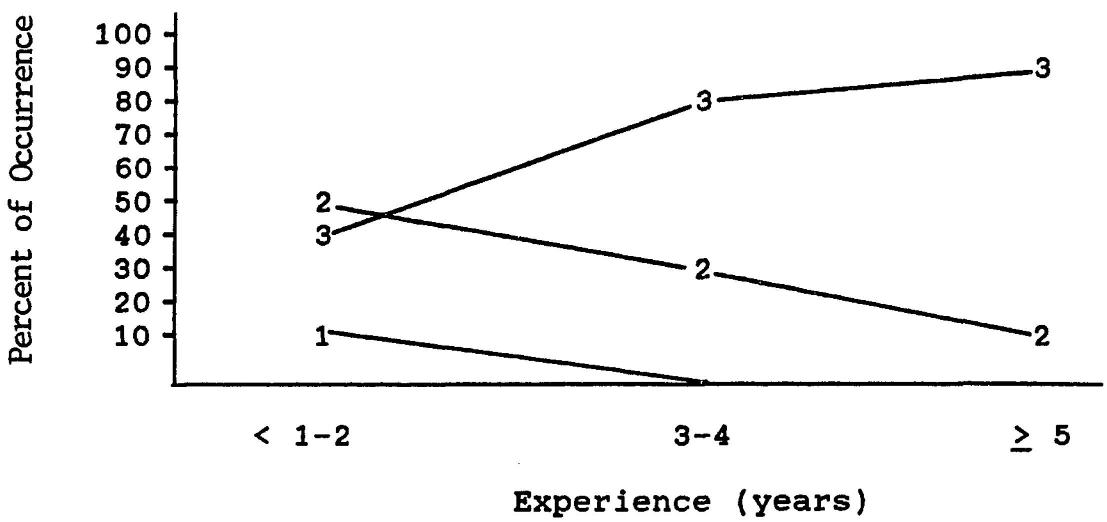


Figure 12. Percentage of step classifications across experience groups for the Forearm/Racket component. (For exact percentages, see Appendix H.)

As shown in Figure 12, an almost equal percentage, 40 - 50%, of the least experienced players functioned at either Steps 2 or 3. However, as the years of experience increased, the percentage of Step 2 classifications declined from 50% to 10% and the percentage of Step 3 classifications increased from 40% to 90%.

The curves in Figure 12 provide a close match of the probability curves hypothesized in the longitudinal model (Roberton et al., 1980). The positive slope of the Step 3 curve and the negative slope of curves for Steps 1 and 2 suggest experience-related trends for the Forearm/Racket component.

Feet/Legs

Age. The cross-sectional curves generated for the Feet/Legs component are presented in Figure 13.

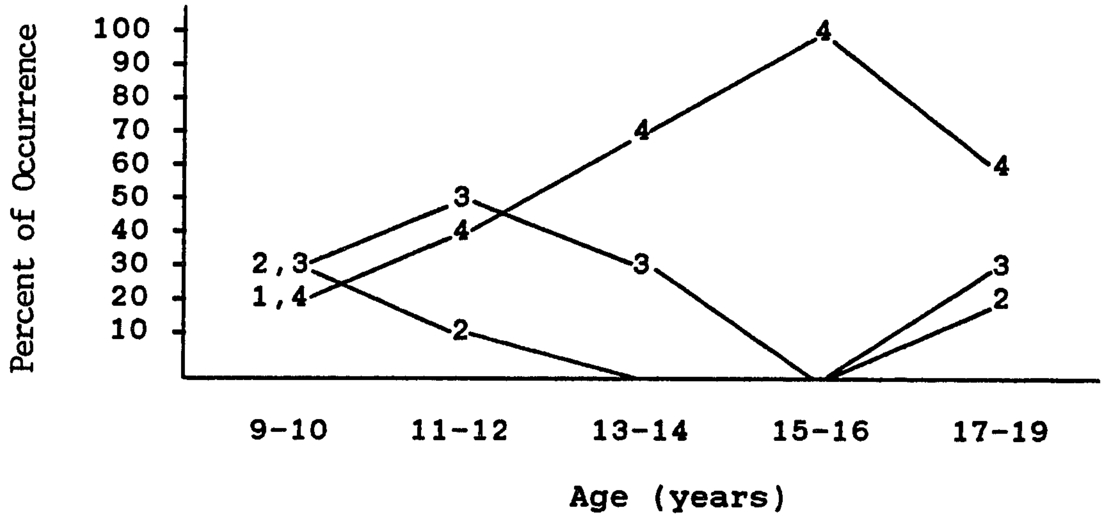
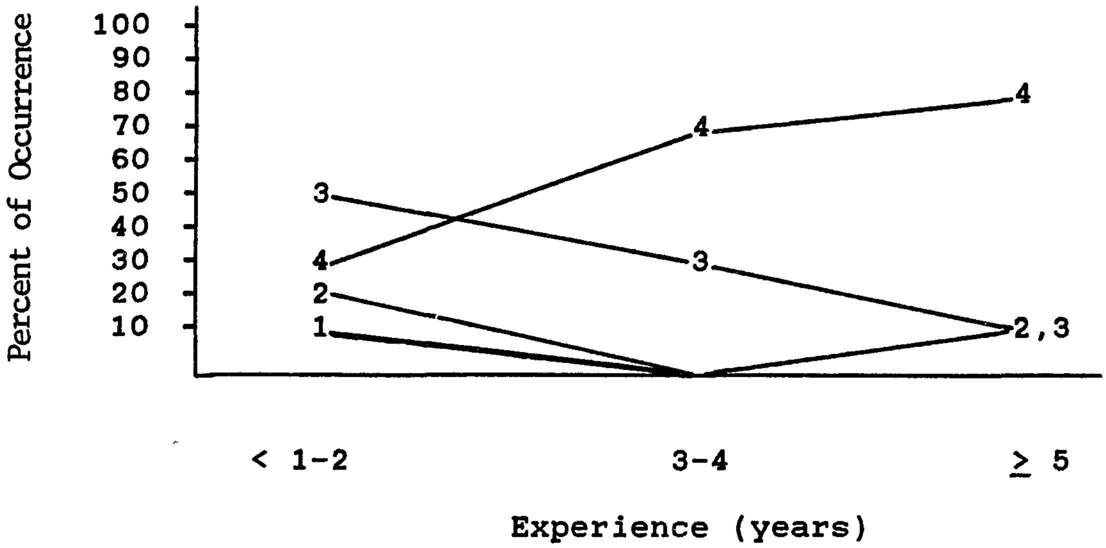


Figure 13. Percentage of step classifications across age groups for the Feet/Legs component. (For exact percentages, see Appendix H.)

The curves illustrated in Figure 13, show that Steps 1 and 2 occurred predominantly among the younger players and that Steps 3 and 4 increased as the age of the players increased. Among the players, 13 years and older, 60% or more were classified at Step 4 with 30% or less exhibiting Steps 2 and Step 3.

Curves in Figure 13 for Steps 1, 2, 3, and 4 suggest age-related, developmental trends across the age ranges included in the 9 to 16 year span. Among the four groups represented in this age span, the two criteria of sequence order and sign of the functions were met. The percentage of Step 1 and 2 classifications decreased, the frequency of Step 3 actions increased and then decreased, and finally, the number of Step 4 classifications increased among the older subjects. These graphically illustrated age differences match the expected pattern; however, the re-emergence of Steps 2 and 3 among the oldest subjects, ages 17-19, does not follow exactly the longitudinal model. Despite the re-emergence of Steps 2 and 3 among the oldest subjects, the shape of the curves in Figure 13 approximate the Roberton et. al. (1980) longitudinal model.

<u>Experience</u>. Experience-related curves drawn for the Feet/Legs component actions are shown in Figure 14.



<u>Figure 14</u>. Percentage of step classifications across experience groups for the Feet/Legs component. (For exact percentages, see Appendix H.)

As shown in Figure 14, Step 3 classifications steadily declined from 50% to 20% or less as the years of experience increased among the players sampled. In turn, Step 4 actions increased from 30% to 70% or higher. Steps 1 and 2 were demonstrated infrequently.

The sign and step order of the curves drawn in Figure 14 for Steps 1, 3, and 4 indicate experience-related trends. The decrease in Step 1 and Step 3 Feet/Leg actions and the increase in Step 4 actions among the more experienced players follow the expected pattern. Although the Step 2 curve deviates slightly from the expected model in that no player with 3-4 years of experience displayed this action, the overall shape of the curves supports the notion of experience-related trends for the Feet/Legs component.

Preparatory Trunk II

Age. Curves generated for the Preparatory Trunk II sequence are displayed in Figure 15.

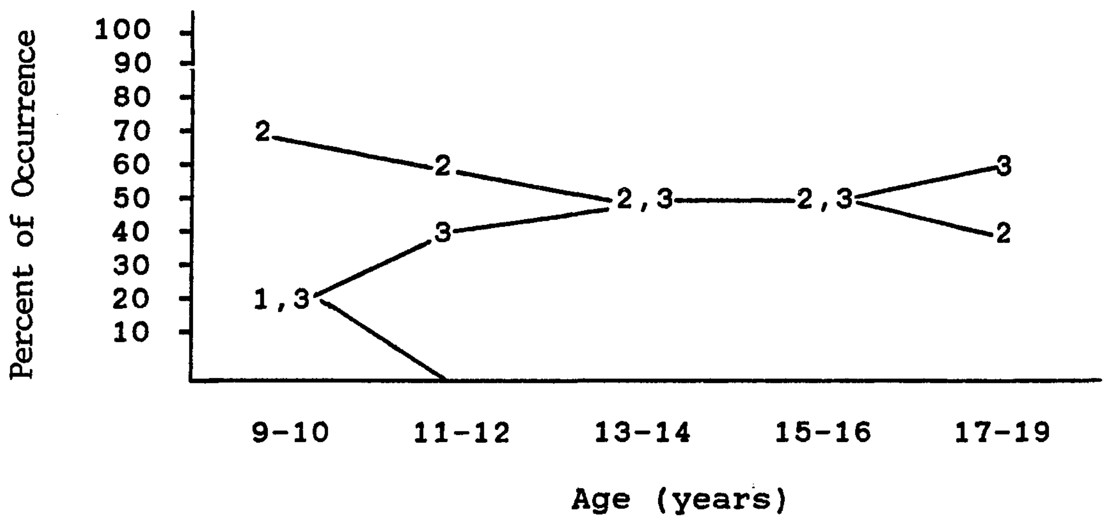


Figure 15. Percentage of step classifications across age groups for the Preparatory Trunk II component. (For exact percentages, see Appendix H.)

The curves in Figure 15 show a decline in Step 2 actions and concomitant increase in Step 3 actions as the age of the subjects increased. Whereas only 20% of the younger players functioned at Step 3, approximately 60% of the older players were at this level. Fifty percent of players, ages 13-16, demonstrated Steps 2 and 3;

however, among the oldest players, a slight increase in the percentage of Step 3 actions occurred as 60% functioned at this level.

The shape of the curves in Figure 15 follows the expected age or time-related trends. The negative slope of the Step 2 curve and the positive slope of the Step 3 curve across the five age groups appear to "closely fit" the model (Roberton et al., 1980).

Experience. The experience-related curves for the Preparatory Trunk II sequence are presented in Figure 16.

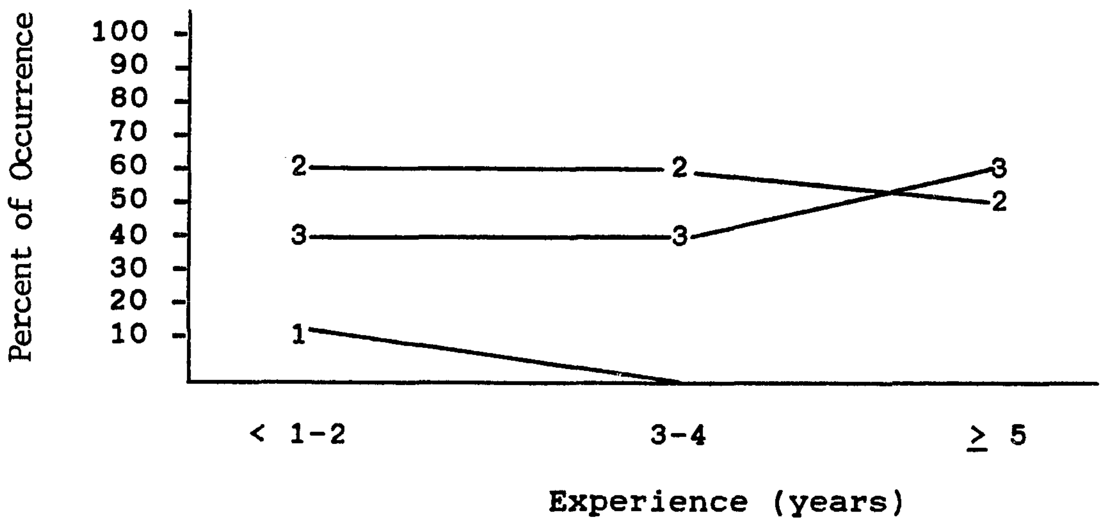


Figure 16. Percentage of step classifications across experience groups for the Preparatory Trunk II component. (For exact percentages, see Appendix H.)

As displayed in Figure 16, 60% of the players with less than 5 years of experience were classified at

Step 2 and 40% at Step 3. However, among players with five or more years of experience, an increase in Step 3 actions and subsequent decrease in Step 2 occurred.

The relative positions of the three curves in Figure 16 appear to support the notion of experience-related trends for the Preparatory Trunk II steps. The cross-sectional curves satisfy the two criteria of sequence order and sign of the slope expected in an ideal, longitudinal graph (Roberton et al., 1980).

Trunk for Force II

Age. The cross-sectional curves for the Trunk for Force II sequence are illustrated in Figure 17.

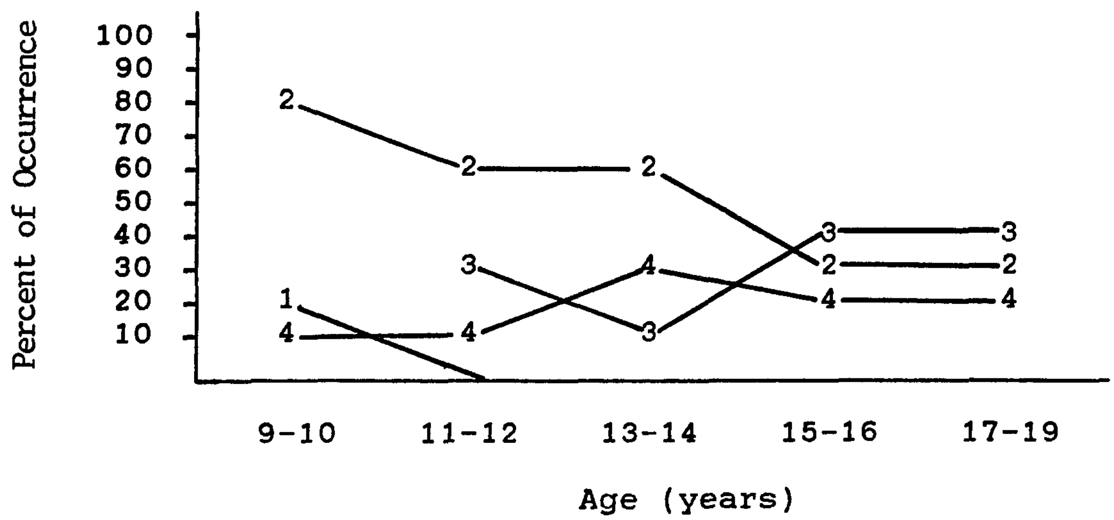


Figure 17. Percentage of step classifications across age groups for the Trunk for Force II component. (For exact percentages, see Appendix H.)

The curves in Figure 17 show that the percentage of players demonstrating Step 2 decreased from 80% to 30% as the age of the players increased. Step 3 actions appeared only among players 11 years and older with 40% of the players, ages 15-19 years, functioning at this level. Step 4 was demonstrated by a few players of all ages with the highest percentage, 30%, of classifications among 13-14 year olds.

The Step 2 curve in Figure 17 follows the expected model across the ages sampled; however, curves for Steps 3 and 4 fail to meet the recommended criteria of sequence order and slope of the expected curves among the older age groups. Close examination of the frequency of Steps 3 and 4 among players, ages 13-14 years, shows that approximately 30% demonstrated the most mature Step 4 trunk action; however, only 8% of the 13-14 years olds were classified at Step 3. In contrast, the sequence order of Steps 3 and 4 is reversed for players 15 years of age and older. Among the older players, a higher percentage, 40%, of Step 3 actions were observed. The Step 3 and Step 4 curves of the Trunk for Force II component do not "closely fit" the expected longitudinal curves (Roberton et al., 1980) across the five age groups.

Experience. Experience-related curves for the Trunk for Force II sequence appear in Figure 18.

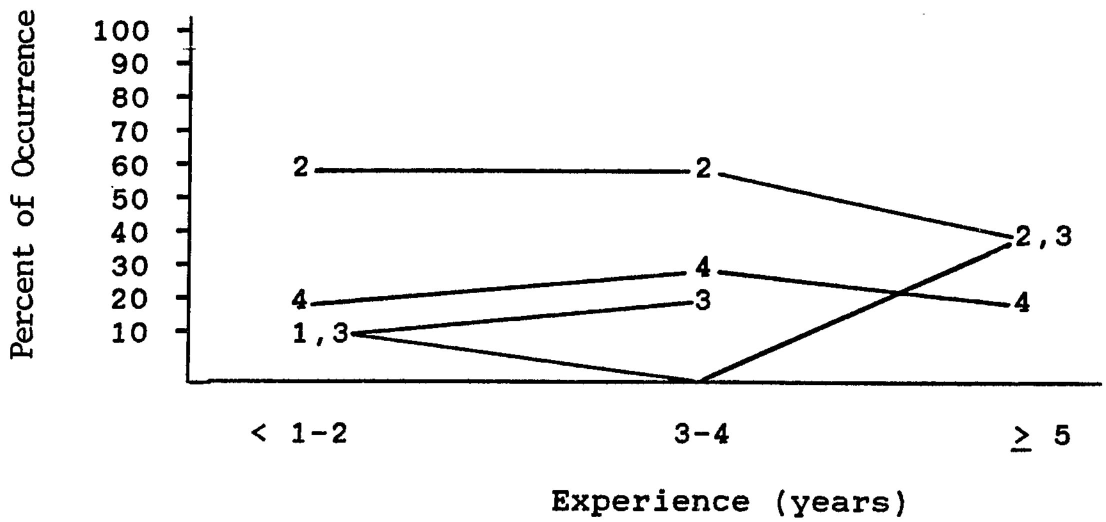


Figure 18. Percentage of step classifications across experience groups for the Trunk for Force II component. (For exact percentages, see Appendix H.)

The curves in Figure 18 show that Step 2 actions appeared most often. Whereas, Step 3 was observed among only 10% the least experienced players, the percentage of Step 3 classifications increased steadily from 10% to 40% as the experience of the players increased. Step 4 was demonstrated by approximately 20% of the players in each experience category.

The shape of the curves in Figure 18 for Steps 1, 2, and 3 of the Trunk for Force II component adhere to the two criteria of step order and sign of the slope; however, Step 4 does not satisfy these criteria. Whereas the slope of the curves for Steps 2 and 3 follow the expected directional trends, the slope of the Step 4 curve neither rises nor declines. Instead, the percentage of players who exhibited Step 4 actions fluctuates from 20% to 25% to 17% across the least experienced to the most experienced players. In addition, the sequence order of Step 3 and Step 4 deviates from the expected model as 20% of the less experienced players demonstrated Step 4 with only 10% categorized at Step 3. The cross-sectional curves in Figure 18 show "closeness of fit" to the expected longitudinal model (Roberton et al., 1980) only in part.

Summary of the Prelongitudinal Screening

To provide an overall picture of the results of the application of the prelongitudinal screening criteria, summary tables were developed. Displayed in Table 11 are the results of the across-trials screening of the comprehensiveness, stability, and adjacency criteria.

Table 11

<u>Summary of the Across-Trials Screening of Hypothesized Sequences for the Tennis Serve</u>

	Prelongitudinal Screening Criteria		
Component	Comprehensivenss	Stability	Adjacency
Preparatory Backswing	No[a]	Yes[b]	Yes
Preparatory Trunk I	Yes	Yes	Yes
Trunk Force I	Yes	Yes	Yes
Elbow	Yes	Yes	Yes
Forearm/Racket	Yes	Yes	Yes
Feet/Legs	Yes	Yes	No
Preparatory Trunk II	Yes	Yes	Yes
Trunk Force II	Yes	Yes	Yes

[a]No - The prelongitudinal screening criterion was not met.

[b]Yes - The prelongitudinal screening criterion was met.

As shown in Table 11, Roberton's (1977, 1978a) across-trials screening criteria were satisfied for all components except the Preparatory Backswing and the Feet/Legs. Screening of the comprehensiveness criterion provided evidence that the actions demonstrated actually fell within one of the steps hypothesized. Furthermore, it was determined that each hypothesized step appeared in the serving patterns of the subjects sampled. Examination of the stability criterion showed consistency was present in body component actions of the subjects. Finally, the adjacency of non-modal steps for each component except the Feet/Legs indicated the invariance or intransitivity of the sequences as hypothesized.

A summary of the across-ages and experience screening of hypothesized component steps is arrayed in Table 12.

Table 12

Summary of the Across-Ages and Experience Screening of Hypothesized Sequences for the Tennis Serve

Component	Mean Age Increased	Experience Increased
Preparatory Backswing	No[a]	No[a]
Preparatory Trunk I	Yes[b]	No
Trunk for Force I	Yes	No
Elbow	Yes	Yes[b]
Forearm/Racket	Yes	Yes
Feet/Legs	Yes	Yes
Preparatory Trunk II	Yes	Partial[c]
Trunk for Force II	Partial[c]	Partial[c]

[a]No - The age or experience criterion was not met.

[b]Yes - The age or experience criterion was met.

[c]Partial - The age or experience criterion was met in part.

As shown in Table 12, with the exception of the Preparatory Backswing and the revised Trunk for Force II sequences, components showed increases in the level of step classifications as the mean age of the players increased. General age trends, as recommended by Langendorfer (1982), were observed across the Preparatory

Trunk I, Trunk for Force I, Elbow, Forearm/Racket, Feet/Legs, and Preparatory Trunk II components.

Experience-related trends displayed in Table 12 appeared to be supported for the Elbow, the Forearm/Racket, and the Feet/Leg components while trends for the Preparatory Trunk II and Trunk for Force II sequences were only partially confirmed. The Preparatory Backswing, Preparatory Trunk I, and Trunk for Force I sequences did not show that increases in the level of step classifications were a function of years of tennis experience.

A summary of the "closeness of fit" between the cross-sectional curves generated in this study and the expected longitudinal curves (Roberton et al., 1980) when age and experience factors were considered appears in Table 13. A summary of "yes" indicates that the age or experience-related curves met the recommended criteria of step order and sign of the slope; however, a summary of "no" reveals that one or both criteria were not met.

Table 13

Summary of the "Closeness of Fit" Between Observed and Expected Age and Experience-Related Curves

Component	Age-Related Related Trends	Experience-Related Trends
Preparatory Backswing	No	No
Preparatory Trunk I	Yes[a]	No
Trunk for Force I	No	No
Elbow	Yes	Yes
Forearm/Racket	Yes	Yes
Feet/Legs	Yes[a]	Yes
Preparatory Trunk II	Yes	Yes
Trunk for Force II	No	Yes[a]

[a]"Closeness of fit" shown only in part.

Age-related trends. As shown in Table 13, three of the eight hypothesized sequences appeared to closely fit the Roberton et al. (1980) longitudinal model and two partially fit the model. Curves generated for the Elbow (Figure 9), Forearm/Racket (Figure 11), and Preparatory Trunk II (Figure 15) seemed to follow the expected curves in the longitudinal model. In part, age-related trends were observed for the Feet/Leg sequence across the ages of 9-16 years; however, slight deviations from the expected age model emerged among the oldest players, ages 17-19 years. Curves drawn for Preparatory Backswing (Figure 3), Trunk for Force I (Figure 7), and Trunk for

Force II (Figure 17) components did not closely fit the longitudinal model.

Particular attention is called to the Preparatory Trunk I (Figure 5) and Preparatory Trunk II (Figure 15) graphs. The Preparatory Trunk sequence was revised to describe more accurately the differences observed in the preparatory trunk actions of players of varying age and experience in performing the tennis serve. It appears that the revised sequence provided a picture more closely resembling age-related trends proposed by the "closeness of fit" model than did the steps included originally in the sequence.

Experience-related trends. Cross-sectional curves for four of the eight sequences met the "closeness of fit" model criteria when experience was considered. The sequence order and sign of the slope for each curve for the Elbow (Figure 10), Forearm/Racket (Figure 12), Feet/Leg (Figure 14), and Preparatory Trunk II (Figure 16) components followed the longitudinal model. Support was given for experience-related trends for the Trunk for Force II sequence across Steps 1, 2, and 3. However, questions regarding Step 4 of the Trunk for Force II sequence permitted only partial support for this hypothesized sequence in its present form. Curves for the Preparatory Backswing (Figure 4), Preparatory Trunk I

(Figure 6), and Trunk for force I (Figure 8) sequences did not closely fit the Roberton et al. (1980) hypothesized longitudinal model when experience was considered.

Analysis of Sex, Experience, and Age Differences

Descriptive Analysis

In order to analyze the data for younger and older female and male subjects, only the 9-12 year olds and 15-19 year olds were considered. In this study those groups represented the extremes of the ages included.

Question 6

Do younger female and male tennis players demonstrate the same developmental steps for body component actions in serving?

To determine the existence of sex differences, if any, in the data, consideration was made of the dominant step classifications of the males and of the females in each component. The dominant step was identified as the step or steps achieved by 50% or more of the males and of the females. If 50% or more of the males and of the females functioned at the same dominant step or steps, no sex differences were determined to exist. In those instances in which the dominant step or steps for the males was different from those of females, it was concluded that differences did exist.

The number and sex of younger subjects classified at each component step are presented in Table 14.

Table 14

Number and Sex of Younger Subjects Classified at Each Component Step

			Steps			
Component/Age Group	Sex	n	1	2	3	4
Preparatory Backswing						NA[a]
9-10	m	6			6	
	f	6			6	
11-12	m	6			6	
	f	6			6	
Total	m	12			12	
	f	12			12	
Preparatory Trunk I						NA[a]
9-10	m	6			6	
	f	6	1	3	2	
11-12	m	6		1	5	
	f	6		1	5	
Total	m	12		1	11	
	f	12	1	4	7	
Trunk for Force I						
9-10	m	6		5	1	
	f	6	2	4		
11-12	m	6		6		
	f	6		5	1	
Total	m	12		11	1	
	f	12	2	9	1	

[a]NA = not applicable. Step 4 not hypothesized.

Table 14 continues

Component/Age Group	Sex	n	Steps			
			1	2	3	4
Elbow						NA[a]
9-10	m	6		1	5	
	f	6	2	4		
11-12	m	6		3	3	
	f	6			6	
Total	m	12		4	8	
	f	12	2	4	6	
Forearm/racket						NA[a]
9-10	m	6		4	2	
	f	6	2	4		
11-12	m	6			6	
	f	6		4	2	
Total	m	12		4	8	
	f	12	2	8	2	
Feet/Legs						
9-10	m	6		3	2	1
	f	6	2	1	2	1
11-12	m	6		1	1	4
	f	6			5	1
Total	m	12		4	3	5
	f	12	2	1	7	2
Preparatory Trunk II						NA[a]
9-10	m	6		4	2	
	f	6	2	4		
11-12	m	6		2	4	
	f	6		5	1	
Total	m	12		6	6	
	f	12	2	9	1	

[a]NA = not applicable. Step 4 not hypothesized.

Table 14 continues

Component/Age Group	Sex	n	Steps 1	2	3	4
Trunk for Force II						
9-10	m	6		5		1
	f	6	2	4		
11-12	m	6		2	4	
	f	6		5		1
Total	m	12		7	4	1
	f	12	2	9		1

[a]NA = not applicable. Step 4 not hypothesized.

In Table 14, a comparison of the table totals indicates that the dominant steps of the males and of the females for five components, namely, the Preparatory Backswing, Preparatory Trunk I, Trunk for Force I, Elbow, and Trunk for Force II were the same for both sexes. Within each of these components, most of the males and most of the females were classified at the same step. For example, within the three steps of the Trunk for Force I component, most of the males (n=11) and most of the females (n=9) functioned at Step 2. Based on the dominant step classifications, it would appear that no sex differences were present for the Trunk for Force I component. A comparison of the dominant step classifications of the males and of the females for the Preparatory Backswing, Preparatory Trunk, Trunk for

Force I, Elbow, and Trunk for Force II components also reveals no sex differences.

Although most of the males and of the females functioned at the same developmental step for five components, as may be seen in Table 14, sex differences appeared in the dominant step classifications for two components, namely, the Forearm/Racket and Preparatory Trunk II. Most of the males demonstrated a higher developmental step for these two components than did most of the females. For example, within the Forearm/Racket component, most of the males (n=8) were classified at Step 3 and most of the females (n=8) were classified at Step 2. Within the Preparatory Trunk II component, although an equal number of males (n=6) exhibited Steps 2 and 3 of the Preparatory Trunk II component, sex differences were present as most of the females (n=9) functioned at Step 2.

Although the focus was upon the dominant step classifications of the males and of the females, of interest is the fact that Step 1 was demonstrated exclusively by females for all components except the Preparatory Backswing in which no players performed at that level. Further study would be needed, however, to substantiate this observation as a developmental sex difference.

Whether sex differences appear in the step classifications for the Feet/Leg component is not readily apparent. Although most of the females (n=7) functioned at Step 2, the number of males operating at Steps 2, 3, and 4 varied from 4 to 3 to 5 with the highest number represented at Step 5. Some sex differences may be present within this component as more males than females functioned at the highest step.

Although primary consideration was given to the results of the 9-12 year group as a whole, of interest were the findings when the group was divided into 9-10 and 11-12 year olds. A close examination of Table 14 of the number of males and females, first, in the 9-10 year old group and then, in the 11-12 year old group, was made to determine whether the sex differences which appeared in the table totals for the Forearm/Racket and Preparatory Trunk II components indicated any further developmental patterns with respect to sex and age. For each of these two components, few sex differences were present among the 9-10 year olds as most of the males and of the females were classified at the dominant Step 2. However, among the 11-12 year olds, most of the males were classified at Step 3 and most of the females were classified Step 2. For example, an equal number of males and females (n=4), ages 9-10, demonstrated Step 2 of the

Forearm/Racket; yet, among 11-12 year olds, all of the males (n=6) functioned at Step 3 whereas most of the females (n=4) functioned at Step 2. A similar pattern, favoring higher developmental step classifications for males, ages 11-12, is present for the Preparatory Trunk II.

Overall, the results of the analysis of the 9-12 year old group showed that most of the males and of the females demonstrated the same developmental steps in the body components studied for the tennis serve except for the Forearm/Racket and Preparatory Trunk II. It may be that the picture of different developmental steps for these two components that emerged when the full 9-12 year span was considered, was affected primarily by the step levels of the 11-12 year olds with the 9-10 year olds more similar than different.

<u>Question 7</u>

Do older female and male tennis players demonstrate the same developmental steps for body component actions in serving?

The number and sex of older subjects years are arrayed in Table 15.

Table 15

Number and Sex of Older Subjects Classified at Each Component Step

Component/Age Group	Sex	n	Steps 1	2	3	4
Preparatory Backswing						NA[a]
15-16	m	6		2	4	
	f	6			6	
17-19	m	6			6	
	f	6		1	5	
Total	m	12		2	10	
	f	12		1	11	
Prepratory Trunk I						NA[a]
15-16	m	6			6	
	f	6		1	5	
17-19	m	6			6	
	f	6		2	4	
Total	m	12			12	
	f	12		3	9	
Trunk for Force I						
15-16	m	6		4	1	1
	f	6		5	1	
17-19	m	6		4	1	1
	f	6		5	1	
Total	m	12		8	2	2
	f	12		10	2	

[a]NA = not applicable. Step 4 not hypthesized

Table 15 continues

Component/Age Group	Sex	n	Steps 1	2	3	4
Elbow						NA[a]
15-16	m	6		1	5	
	f	6			6	
17-19	m	6			6	
	f	6		1	5	
Total	m	12		1	11	
	f	12		1	11	
Forearm/Racket						NA[a]
15-16	m	6			6	
	f	6			6	
17-19	m	6			6	
	f	6		1	5	
Total	m	12			12	
	f	12		1	11	
Feet/Legs						
15-16	m	6				6
	f	6				6
17-19	m	6			2	4
	f	6		2	1	3
Total	m	12			2	10
	f	12		2	1	9
Preparatory Trunk II						NA[a]
15-16	m	6		2	4	
	f	6		4	2	
17-19	m	6		2	4	
	f	6		3	3	
Total	m	12		4	8	
	f	12		7	5	

[a]NA = not applicable. Step 4 not hypthesized

Table 15 continues

Component/Age Group	Sex	n	Steps 1	2	3	4
Trunk for Force II						
15-16	m	6		1	3	2
	f	6		3	2	1
17-19	m	6		1	3	2
	f	6		3	2	1
Total	m	12		2	6	4
	f	12		6	4	2

[a]NA = not applicable. Step 4 not hypothesized.

From the table totals in Table 15, it appears that the older male and females players demonstrated the same dominant steps for all components except the Preparatory Trunk II and Trunk for Force II. A comparison of the table totals indicates that most of the males and of the females functioned at the same developmental step for the Preparatory Backswing, Preparatory Trunk I, Trunk for Force I, Elbow, Forearm/Racket, and Feet/Legs.

Differences in the dominant step classifications of the males and of the females are shown in the table totals in Table 15 for steps within the Preparatory Trunk II and Trunk for Force II components. In the Preparatory Trunk II actions most of the males (n=8) displayed Step 3; yet, most the females (n=7) exhibited Step 2. Examination of the Trunk for Force II component reveals that the number of males and females classified at Steps

2, 3, and 4 varied. However, the highest number of males (n=6) across the steps operated at Step 3 whereas the highest number of females (n=6) across the steps functioned at Step 2. These differences, seen in the dominant step classifications of the males and of the females, ages 15-19, indicate different developmental levels for these two components.

Following the examination of the 15-19 year old group as a whole, of interest were the sex differences when the group was divided into 15-16 and 17-19 year olds. A comparison of the dominant steps of the males and of the females in these two older age groups was made to determine whether the differences which appeared within the older group as a whole were reflected in only one or both of the older age brackets. The differences that were present in Table 15 totals for the Preparatory Trunk II component reflect sex differences primarily in the 15-16 age group. For example, most of the males (n=4), ages 15-16, were classified at Step 3. In contrast, most of the females (n=4) in this same age category were classified at Step 2. The picture of sex differences among the 17-19 years olds for the Preparatory Trunk II actions is not the same as among the 15-16 year olds. Most of the males (n=4) functioned at Step 3, however, an equal number of females (n=3) functioned at Steps 2 and Step 3.

Sex differences appeared to be present in both age categories of 15-16 and 17-19 years when the number of males and of females were compared for the Trunk for Force II component. In each of these age groups, although some males and females functioned at Steps 2, 3, and 4, the highest number of males (n=3) were at Step 3 and the highest number of females (n=3) were at Step 2.

Overall, the results of the analysis of the 15-19 year old group revealed that most of the older male and female players performed at the same developmental steps for all body components except the Preparatory Trunk II and Trunk for Force II. Most of the males functioned at higher steps than did most of the females for these two components. The different developmental level of the males and of the females for these two components was attributed to higher step classifications for males than for females primarily in the 15-16 age bracket; however, some differences, favoring higher step classifications for the males, were also present in the 17-19 age groups.

Summary of Sex and Age Differences

A summary of the step classifications of the males and females in the younger and older age groups is presented in Table 16.

Table 16

Summary of Sex Differences Observed in the Step Classifications of Younger and Older Males and Females

	Step Classifications		Sex Differences
Component	Males	Females	
Preparatory Backswing			
9-10 years	3	3	no
11-12 years	3	3	no
15-16 years	2,3	3	no
17-19 years	3	2,3	no
Preparatory Trunk I			
9-10 years	3	1,2,3	yes
11-12 years	2,3	2,3	no
15-16 years	3	2,3	no
17-19 years	3	2,3	no
Trunk for Force I			
9-10 years	2,3	1,2	no
11-12 years	2	2,3	no
15-16 years	2,3,4	2,3	no
17-19 years	2,3,4	2,3	no
Elbow			
9-10 years	2,3	1,2	yes
11-12 years	2,3	3	no
15-16 years	2,3	3	no
17-19 years	3	2,3	no
Forearm/Racket			
9-10 years	2,3	1,2	no
11-12 years	3	2,3	yes
15-16 years	3	3	no
17-19 years	3	2,3	no

Note. Dominant step(s) underlined.

Table 16 continues

	Step Classifications		Sex Differences
Component	Males	Females	
Feet/Legs			
9-10 years	<u>2</u>,3,4	1,2,3,4	no
11-12 years	2,3,<u>4</u>	<u>3</u>,4	yes
15-16 years	<u>4</u>	<u>4</u>	no
17-19 years	3,<u>4</u>	2,3,<u>4</u>	no
Preparatory Trunk II			
9-10 years	<u>2</u>,3	1,<u>2</u>	no
11-12 years	2,<u>3</u>	<u>2</u>,3	yes
15-16 years	2,<u>3</u>	<u>2</u>,3	yes
17-19 years	2,<u>3</u>	<u>2</u>,<u>3</u>	no
Trunk for Force II			
9-10 years	<u>2</u>,4	1,<u>2</u>	no
11-12 years	2,<u>3</u>	<u>2</u>,4	yes
15-16 years	2,<u>3</u>,4	<u>2</u>,3,4	yes
17-19 years	2,<u>3</u>,4	<u>2</u>,3,4	yes

<u>Note</u>. Dominant step(s) <u>underlined</u>.

In Table 16, "yes" denotes sex differences in the step classifications of the males and females. "No" refers to no sex differences. In addition to that summary, a listing of all steps demonstrated by the males and females within each group is given. Within that listing, the dominant step or steps which were demonstrated by 50% or more of the males and of the females in each age category are underlined. For example, most females, ages 11-12, were classified at Step 3 of the Elbow component; however, an equal number of males (n=3) were classified at Steps 2 and 3 of this component.

Overall, the data in Table 16 indicate that although sex differences were present in some age categories, the tendency toward no differences was greater than the tendency toward differences in all components except the Preparatory Trunk II and Trunk for Force II. For example, the number of "no's" is more than twice the number of "yes's", indicating greater similarities in developmental levels of the males and females than differences. In age categories where differences were present, as indicated by the "yes" summaries, most of the males performed at higher steps than did most of the females. Furthermore, with the exception of the Preparatory Trunk II and the Trunk for Force II components in which differences were present among both younger and older players, sex differences appeared more often among the younger players in the Preparatory Trunk I, Elbow, Forearm/Racket, and Feet/Leg components than among the older players.

In summary, despite the fact that the data for questions on age and developmental level appeared to support no sex differences for most of the body components studied, when age groups were considered separately, it appeared that differences did exist at the younger ages. These differences favored higher step classifications for males than for females.

Question 8

Do less experienced female and male tennis players demonstrate the same developmental steps for body component actions in serving?

Displayed in Table 17 are the number and sex of the less experienced players classified by developmental steps achieved in each body component. Only players with 1-2 years or less of experience were studied to address Question 9. These players represented the least experienced subjects included in this study.

Table 17

Number and Sex of Players with 1-2 Years or Less of Experience Classified at Each Component Step

Component	Sex	n	Steps 1	2	3	4
Preparatory Backswing						NA[a]
	m	11			11	
	f	9			9	
Preparatory Trunk I						NA[a]
	m	11		1	10	
	f	9	1	2	6	
Trunk for Force II						
	m	11		8	2	1
	f	9	2	6	1	
Elbow						NA[a]
	m	11		4	7	
	f	9	2	2	5	
Forearm/Racket						NA[a]
	m	11		4	7	
	f	9	2	6	1	
Feet/Leg						
	m	11		4	4	3
	f	9	2		5	2
Preparatory Trunk II						NAa
	m	11		5	6	
	f	9	2	6	1	
Trunk for Force II						
	m	11		6	2	3
	f	9	2	6		1

[a]NA = not applicable. Step 4 not hypothesized.

The data in Table 17 illustrate that few sex differences were present in the dominant step classifications of players with less than 1-2 years of experience. Differences appear only for the Forearm/Racket and Preparatory Trunk II components in which most of the males functioned at higher steps than did most of the females. For example, 7 of 11 males were classified at Step 3 and 6 of 9 females were classifed at Step 2 of the Forearm/Racket. Within the Preparatory Trunk II component, 6 of 11 males were classified at Step 3 and 6 of 9 females were at Step 2.

Overall, the results of the analysis of the players with 1-2 years or less of experience showed that most of the males and of the females demonstrated the same developmental steps for all components except the Forearm/Racket and Preparatory Trunk II. Most of the males functioned at higher steps than did most of the females for these two components.

<u>Question 9</u>

Do experienced female and male tennis players demonstrate the same developmental steps for body component actions in serving?

Only males and females with 5 or more years of experience were considered. These subjects represented the extreme of the most experienced players included in the study. Arrayed in Table 18 are the number and sex of the players classified by developmental steps demonstrated in each component.

Table 18

Number and Sex of Players with 5 or More Years of Experience Classified at Each Component Step

Component	Sex	n	Steps 1	2	3	4
Preparatory Backswing						NA[a]
	m	12		1	11	
	f	12		1	11	
Preparatory Trunk I						NA[a]
	m	12		1	11	
	f	12		4	8	
Trunk for Force I						
	m	12		9		3
	f	12		11	1	
Elbow						NA[a]
	m	12		1	11	
	f	12		2	10	
Forearm/Racket						NA[a]
	m	12			12	
	f	12		2	10	
Feet/Legs						
	m	12			1	11
	f	12		3	2	7
Preparatory Trunk II						NA[a]
	m	12		3	9	
	f	12		8	4	
Trunk for Force II						
	m	12		3	6	3
	f	12		7	4	1

The data in Table 18 show that most of the male and of the female tennis players with 5 or more years of experience demonstrated the same body component actions; however, differences were present for Preparatory Trunk II and Trunk for Force II. Most of the males were classified at Step 3 and most of the females at Step 2 for these two components. For example, 9 of 12 males were classifed at Step 3 and 8 of 12 females were classified at Step 2 of the Preparatory Trunk II. Similarly, the highest number of males (n=6) were classified at Step 3 and most of the females (n=7) were classified at Step 2 of the Trunk for Force II component.

Overall, most of the male and of the female players with 5 or more years of tennis experience demonstrated the same developmental levels for all body components studied except the Preparatory Trunk II and Trunk for Force II. Most of the males demonstrated higher developmental steps for these two components than did most of the females.

Summary of Experience and Sex Differences

A summary of the step classifications of the males and females in the least and most experienced groups is presented in Table 19.

Table 19

Summary of Sex Differences in the Step Classifications of Less Experienced and More Experienced Tennis Players

Component	Step Classifications		Sex Differences
	Males	Females	
Preparatory Backswing			
< 1-2 years	3	3	no
≤ 5 years	2,3	2,3	no
Preparatory Trunk I			
< 1-2 years	2,3	1,2,3	no
≥ 5 years	2,3	2,3	no
Trunk for Force II			
< 1-2 years	2,3,4	1,2,3	no
≥ 5 years	2,4	2,3	no
Elbow			
< 1-2 years	2,3	1,2,3	no
≥ 5 years	2,3	2,3	no
Forearm/Racket			
< 1-2 years	2,3	1,2,3	yes
≥ 5 years	3	2,3	no
Feet/Leg			
< 1-2 years	2,3,4	1,3,4	no
≥ 5 years	3,4	2,3,4	no
Preparatory Trunk II			
< 1-2 years	2,3	1,2,3	yes
≥ 5 years	2,3	2,3	yes
Trunk for Force II			
< 1-2 years	2,3,4	1,2,4	no
≥ 5 years	2,3,4	2,3,4	yes

Note. Dominant step(s) underlined.

In Table 19, "yes" denotes differences in the dominant step classifictions of most of the males and of the females. "No" refers to no differences. In addition to that summary, a listing of all steps demonstrated by the males and females within each experience groups is given. The dominant step which was demonstrated by 50% or more of the males and of the females in each experience groups is underlined.

The data in Table 19 show that few sex differences appeared among the least and most experienced players when the dominant steps of the males and females were compared. Only within three components, namely, the Forearm/Racket, Preparatory Trunk II, and Trunk for Force II, did a summary of "yes" indicate the presence of sex differences in the dominant step classifications of the males and of the females.

Overall, the results of the analysis indicated that males and females with 1-2 years or less and 5 or more years of tennis experience tended to demonstrate the same developmental steps in most of the body component actions. Sex differences among players with 1-2 years or less favored higher developmental steps for males than females for two components, namely, the Forearm/Racket and Preparatory Trunk II. Among the most experienced players, sex differences appeared only in the Preparatory

Trunk II and Trunk for Force II components with males tending to demonstrate higher developmental steps than females for these two components.

Discriminant Analysis

In addition to the descriptive analysis of age, sex, and experience with regard to the tennis serve, a SAS statistical program for the discriminant analysis of the effect of those variables on the developmental level of the body component actions in serving was employed. The size of the subject sample (N=60) and the number of hypothesized sequences (n=8) permitted analysis of only two components, namely the Forearm/Racket and the Trunk for Force II. Furthermore, only Steps 2 and 3 of the Forearm/Racket component and only Steps 2, 3, and 4 of the Trunk for Force II component were analyzed. Those limits were necessary to establish because (a) the Forearm/Racket component did not contain a Step 4 as did the Trunk for Force II and (b) Step 1 occurred rarely in either of the components. A significance level of .05 was selected for decisions about the effect of the independent variables on the dependent ones.

Each of the two components was analyzed separately. First, stepwise procedures were applied to determine the significance of the effect of the variables of sex, experience, and age on the step level observed in the components, and then, the procedures for classification were completed.

Stepwise Discriminant Analysis

Forearm/racket analysis. In Table 20 the results of the effect of each independent variable on the developmental step of the Forearm/Racket are displayed.

Table 20

Individually Calculated R^2's and F Values for Sex, Age, and Experience in the Forearm/Racket For Entry into the Discriminant Model

Variable	R^2	F
Sex	.0640	3.826*
Age	.2898	22.856***
Experience	.1944	13.517**

*$p \leq .05$ **$p < .001$ ***$p \leq .0001$

As shown in Table 20, age accounted for approximately 29% of the total variance observed in the Forearm/Racket actions, F (1,56) = 22.856, $p \leq .0001$. Sex and experience accounted for 6% and 19% of the variance, respectively.

To establish whether sex and experience added significantly to the effect of age, further stepwise analysis was completed. The results are presented in Table 21.

Table 21

Partial R^2's and F Values for Sex and Experience with Age Entered into the Discriminant Model for the Forearm/Racket

Variable	Partial R^2	F
Sex	.1157	7.193*
Experience	.0181	1.012

*$p < .01$

From Table 21 it may be seen that sex accounted for approximately 12% of the variance, $F\ (1,55) = 7.193$, $p < .01$, while experience did not significantly contribute to the model $F\ (1,55) = 1.012$, $p < .3187$.

Continuing to apply the stepwise procedure, sex and age were retained in the model. In Table 22 the results of the effect of sex and age on developmental step are displayed.

Table 22

Partial R^2's and F Values with Sex and Age Entered into the Discriminant Model for the Forearm/Racket

Variable	Partial R^2	F
Sex	.1157	7.193*
Age	.3291	26.976**
Total Variance	.4448	

*$p < .01$ **$p \leq .0001$

The figures in Table 22 show that age accounted for approximately 33%, F (1,55) = 26.976, $p \leq .0001$, and sex accounted for 12%, F (1,55) = 7.193, $p < .01$, of the total variability. Together, age and sex accounted for approximately 45% of the variance observed across developmental levels in the Forearm/Racket actions. The contribution of experience was not significant in the presence of age and sex.

Trunk for force II analysis. The contribution of each independent variable alone to the variance in the Trunk for Force II step classifications is shown in Table 23.

Table 23

Individually Calculated R^2's for Sex, Age, and Experience in the Trunk for Force II for Entry into the Discriminant Model

Variable	R^2	F
Sex	.1233	3.868*
Age	.1236	3.878*
Experience	.0912	2.761

*$p < .05$

Although the figures in Table 23 show that sex and age each accounted for approximately 12% of the total variability among groups, age was selected as the first variable for entry into the model. With age entered into the model, stepwise procedures determined the amount of additional variance accounted for by sex and experience. The results of this stepwise procedure are presented in Table 24.

Table 24

Partial R^2's and F Values for Sex and Experience with Age Entered into the Discriminant Model for the Trunk for Force II

Variable	Partial R^2	F
Sex	.1618	5.213*
Experience	.0503	1.429

*$p < .01$

The figures in Table 24 show that approximately 16%, F (2,54) = 5.213, $p < .01$, of the variance was accounted for by the sex of the subjects, whereas only 5%, F (2,54) = 1.429, $p < .2458$, of the variance was attributed to experience after age was entered into the model.

Having determined that age and sex should remain in the model, Partial R^2's were calculated to determine the contribution of these two variables to the total variance. The results of this procedure are presented in Table 25.

Table 25

Partial R^2's and F Values with Age and Sex Entered into the Discriminant Model for the Trunk for Force II

Variable	Partial R^2	F
Age	.1621	5.224*
Sex	.1618	5.213*

*$p < .01$

The figures in Table 25 show that age acounted for approximately 16%, F (2,54) = 5.224, $p < .01$, and sex accounted for an almost equal percentage of the variance, F (2,54) = 5.213, $p < .01$. The contribution of experience was not significant in the presence of age and sex.

Having identified the set of predictor variables which contributed most significantly to developmental levels in the Forearm/Racket and Trunk for Force II actions, the accuracy of the discriminant analysis was determined by using the derived functions to identify the actual errors of classification. This procedure permitted the evaluation of the discriminant functions by identifying the number and type of errors made in classifying the Forearm/Racket and Trunk for Force II actions.

Classification Procedures

Forearm/racket. By assigning discriminant weights to the age and sex variables, the following Step 2 and Step 3 functions were derived for the Forearm/Racket component:

Step 2: $D = -13.954 + .141Age + 4.929Sex$

Step 3: $D = -19.808 + .196Age + 2.953Sex$

To interpret the discriminant weights, it should be pointed out that age was measured in months and sex was quantified by assigning males a numerical value of 1 and females a value of 2. For example, in examining the Step 2 function, the seemingly small discriminant weight assigned to age as compared to the larger weight assigned to sex is explained by the large number of months represented by age (i.e., 111 months to 237 months) as compared to the smaller value associated with the sex variable.

Cutoff scores for assigning subjects to either Step 2 or Step 3 were determined by calculating the difference between the discriminant functions derived for each of these steps. This difference is shown as:

Step 3:	$D = -19.808 + .196Age + 2.953Sex$
Step 2:	$D = -13.954 + .141Age + 4.929Sex$
Difference	$D = -5.854 + .055Age - 1.976Sex$

The function, D = -5.854 + .055Age - 1.976Sex, derived from the difference of the Step 3 and Step 2 functions, was used to discriminate Step 2 and 3 classifications. A positive difference predicted the subject would be classified at Step 3 and a negative difference predicted the subject would be classified at Step 2. Applying the discriminant function to calculate each subject's predicted classifications in the Forearm/Racket actions, a comparison of the percentage of correct and incorrect classifications was made. Table 26 displays the number and percentage of subjects classified correctly and incorrectly into Steps 2 and 3.

Table 26

Number and Percentage of Correct and Incorrect Classifications for Steps 2 and 3 of the Forearm/Racket Component

Actual Step	Number Correct	Percentage Correct	Number Incorrect	Percentage Incorrect
Step 2	14	87.50%	2	12.50%
Step 3	31	73.81%	11	26.19%
Total	45	77.59%	13	22.41%

As shown in Table 26, correct Step 2 classifications were made in 14 of 16 observations and correct Step 3 classifications were made in 31 of 42 observations. In total, 45 of 58, or an overall percentage of 78% correct classifications, were made for the Forearm/Racket actions.

The high percentage, 78%, of correct classifications for the Forearm/Racket actions indicates that the sex and age variables accurately predicted developmental levels in the Forearm/Racket actions at Steps 2 and 3. The discriminant function predicted that males, ages 9-11, would demonstrate Step 2, whereas males, 12 years of age and older would demonstrate Step 3. For the females, unlike the males, the lower Step 2 Forearm/Racket actions were predicted across a wider age range. Females, ages 9-14, were predicted to use Step 2 actions and those, 15 years old and older, were expected to use Step 3 actions.

Of the six males who were misclassified, five of them in the 9-11 year age span exhibited Step 3 when expected to demonstrate Step 2. One male, age 13, used the lower Step 2 Forearm/Racket action when predicted he would demonstrate the higher level. Of the seven females misclassified, six of them in the 11-14 age span used Step 3 actions when predicted to demonstrate Step 2. One older female, age 17, was classified at the lower Step 2 action when it was expected she would be classified at Step 3.

Trunk for force II. Having determined that age and sex contributed significantly to explaining the differences observed in the Trunk for Force II actions, the accuracy of the discriminant analysis was determined by using the derived discriminant functions to identify actual errors of classification. The following discriminant functions for Steps 2, 3, and 4 were calculated:

Step 2: $D = -14.706 + .132\text{Age} + 5.147\text{Sex}$

Step 3: $D = -17.091 + .164\text{Age} + 3.031\text{Sex}$

Step 4: $D = -16.185 + .156\text{Age} + 3.438\text{Sex}$

Cutoff scores for assigning subjects to either Step 2, 3, or 4 were determined by calculating the differences between the individual discriminant functions derived for each of these three steps. For example, the function obtained from the difference between the Step 4 and Step 3 discriminant functions is given as:

Step 4: $D = -16.185 + .156\text{Age} + 3.438\text{Sex}$

Step 3: $D = -17.091 + .164\text{Age} + 3.031\text{Sex}$

Difference $D = .906 - .008\text{Age} + .407\text{Sex}$

The difference between the Step 3 and Step 2 functions is shown as:

Step 3:	D = −17.091 + .164Age + 3.031Sex
Step 2:	D = −14.706 + .132Age + 5.147Sex
Difference	D = − 2.385 + .032Age − 2.116Sex

The discriminant function derived from the difference between the Step 4 and Step 3 functions was calculated for each subject. A positive difference score predicted the subject would be classified at Step 4 and a negative score predicted the subject would be classified at either Step 3 or Step 2. To determine whether Step 3 or Step 2 was the more accurate step classification, the difference between the Step 2 and Step 3 discriminant functions was computed. Using zero again as the cutoff score, a positive score predicted the subject would be classified at Step 3 and a negative score predicted the subject would be classified at Step 2.

Applying these discriminant functions to calculate the predicted classification of each subject in the Trunk for Force II sequence, a comparison of the percentage of correct and incorrect classifications was made. In Table 27 the number and percentage of subjects classified correctly and incorrectly into Steps 2, 3, and 4 are displayed.

Table 27

Number and Percentage of Correct and Incorrect Classifications for Steps 2, 3, and 4 of the Trunk for Force II Component

Actual Step	Number Correct	Percentage Correct	Number Incorrect	Percentage Incorrect
Step 2	22	70.97%	9	29.03%
Step 3	7	46.67%	8	53.33%
Step 4	2	16.67%	10	83.33%
Total	31	53.45%	27	46.55%

As shown in Table 27, correct Step 2 classifications were made in 22 of 31 observations; however, only 7 of 15 Step 3 classifications were correct and, even fewer, only 2 of 12 Step 4 classifications were correct. Overall, 54% of the actual classifications were the same as the predicted classifications. The type of misclassifications are arrayed in Table 28.

Table 28

Number of Correct and Incorrect Classifications for Steps 2, 3, and 4 of the Trunk for Force II Component

	Actual Step		
Predicted Step	2	3	4
Step 2	22	4	5
Step 3	3	7	5
Step 4	4	6	2

Examination of the data arrayed in Table 28 shows that the least number of correct classifications were made in classifying Step 4 actions. Of the 14 players expected to demonstrate to Step 4, 4 were classified at Step 2, 6 at Step 3, and only 2 at Step 4. Of the 15 players expected to demonstrate Step 3, only 7 did while 3 were classified at Step 2 and 5 at Step 4. Among the subjects expected to demonstrate Step 2, 22 did with 9 actually classified at higher steps. Of these 9 players, 4 exhibited Step 3 and 5 used Step 4 actions.

The low percentage, 54%, of correct classifications indicate that the sex and age variables did not accurately discriminant developmental steps in the Trunk for Force II actions. A comparison of the ages of subjects misclassified and, in turn, the range of ages predicted for each step revealed deviations from the expected developmental model. The ages of subjects expected to demonstrate Steps 2, 3, and 4 are given in Table 29.

Table 29

Age Range and Sex of Subjects Predicted to Demonstrate Steps 2, 3, and 4 of the Trunk for Force II Component

Males		Predicted Step
Age	n	
9.04 - 10.07	6	Step 2
11.04 - 13.07	15	Step 4
14.03 - 19.09	9	Step 3
Total	30	
Females		**Predicted Step**
Age	n	
9.04 - 17.00	23	Step 2
17.06 - 18.01	2	Step 4
18.07 - 19.06	3	Step 3
Total	28[a]	

Note. Age is given in years and months.

[a]*n* = 28; Step 1, for two female subjects, not entered into analysis.

The data in Table 29 indicate that younger males were expected to demonstrate more mature developmental Trunk for Force II actions than the older males. For example, males, ages 11.04 - 13.07, should have been classified at Step 4 whereas males, ages 14.03 - 19.09, should have been classified at Step 3. This deviation from the expected developmental model also occurs in the age span of the females predicted to demonstrate Steps 3 and 4. Females, ages 9.04 - 17.00, were expected to exhibit Step 2; however, the predicted age span of females expected to function at Steps 3 and 4 was limited to only a few months. For example, 3 females, ages 18.07 - 19.06, were predicted to function at Step 3; however, 2 females, ages 17.06 - 18.01, were expected to function at Step 4. Overall, the deviations in the ages of the males and of the females predicted to demonstrate Steps 3 and 4 of the Trunk for Force II bring into question the validity of the sequence as presently ordered.

Although questions surround the sequential ordering of Steps 3 and 4 of the Trunk for Force II component, the data arrayed in Table 29 indicate similarities and differences in the step classifications predicted for the males and females. The youngest males and females, ages 9-10, were expected to demonstrate Step 2; however, differences in the predicted step classifications of male and females, ages 11-12, are shown. The males were expected to function at Step 4 and the females at Step 2.

The picture of different developmental step classifications of the older males and of the females for the Trunk for Force II are also shown in Table 29. The narrow age span and relatively small number of females predicted to exhibit Steps 3 and 4, however, limits the comparison and interpretation of sex differences, if any, in the step classifications of the oldest players.

Summary of Discriminant Analysis and Classification Results

The results of the stepwise discriminant procedures revealed that sex and age together accounted for approximately 45% and 32% of the total variance observed across developmental levels in the Forearm/Racket and Trunk for Force II component actions, respectfully. The relatively high percentage, 78%, of Step 2 and 3 classifications for the Forearm/Racket actions indicate that sex and age were accurate predictors of developmental levels for this component. In contrast, the relatively low percentage, only 54%, of correct classifications brings into question sex and age as accurate predictors of developmental levels for the Trunk for Force II component.

SUMMARY OF RESULTS

Prelongitudinal Screening Analysis

The application descriptively of the criteria of comprehensiveness, stability, and adjacency as defined by Roberton (1977, 1978a) resulted in the comprehensiveness criterion being met in all hypothesized steps except Step 1 of the Preparatory Backswing. No performers demonstrated that step on any trial. The criterion of stability was upheld also. Each subject demonstrated the same step action on 57% or more of the trials for each body component. Adjacency was demonstrated for all components except the Feet/Legs. According to the criterion of adjacency, if there is only one case in which non-modal steps are not adjacent to the modal step, the criterion is not satisfied. Two cases of non-adjacent Feet/Leg actions were noted.

Analysis of increases in developmental levels as the mean age and experience increased, as recommended by Langendorfer (1982), showed that except for the Preparatory Backswing component, and, to a lesser extent, the Trunk for Force I and Trunk for Force II components, the mean age of the subjects increased across the sequential steps hypothesized for the remaining five sequences studied. In addition, the trend toward performing at higher developmental levels with additional years of experience appeared for all components except the Preparatory Backswing, the Preparatory Trunk I, and the Trunk for Force I.

Age-related curves drawn for the actions of the Elbow, Forearm/Racket, and Preparatory Trunk II components closely fit the hypothesized longitudinal model of Roberton et al., (1980). Age curves drawn for the Preparatory Trunk I and Feet/Legs only partially fit the model as one or more step curves failed to meet the criteria of step order or sign of the slope. Cross-sectional curves for the Preparatory Backswing, Trunk for Force I, and Trunk for Force II did not approximate the hypothesized longitudinal model when age was considered.

Four of the eight sequences, namely, the Elbow, Forearm/Racket, Feet/Leg, and Preparatory Trunk II, closely fit the longitudinal model when experience was considered. Deviations were noted in the expected step order or sign of the slope for one or more steps of the remaining sequences.

In summary, sequences hypothesized for the Elbow, Forearm/Racket, and Preparatory Trunk II components satisfied each of the criteria applied in the prelongitudinal screening. Sequences for the remaining components failed to meet one or more of the prelongitudinal screening criteria (Langendorfer, 1982; Roberton, 1977, 1978a; Roberton et al., 1980).

Age, Sex, and Experience Analysis

More sex differences were noted in body component actions of younger players, ages 9-12, in serving than were observed in the actions exhibited by the older players, ages 15-19. Among the younger players, most of the males, ages 9-12, were classified at higher steps for the Forearm/Racket and Preparatory Trunk II components than were most of the females of the same ages. In addition, comparison of the differences within the ages of 9-12 revealed that more differences, favoring higher step classifications for males, occurred among players, ages 11-12, than among players, ages 9-10. Few sex differences appeared among players, ages 15-19, with the exception of the Preparatory Trunk II and Trunk for Force II components. Most of the older males demonstrated higher developmental steps for these two components than did most of the older females. Differences which appeared in the 15-19 age group as a whole were attributed to higher step classifications of males than females primarily within the 15-16 age group.

Most of the males and of the female subjects with 1-2 years or less of tennis experience demonstrated the same developmental steps for each body component studied with the exception of the Forearm/Racket and Preparatory Trunk II. Most of the males exhibited higher step actions for these two components than did most of the females.

Most of the male and of the female subjects with 5 or more years of tennis experience demonstrated the same developmental step for all body components studied except the Preparatory Trunk II and Trunk for Force II. Most of the males demonstrated higher step actions than did the most of the females for these two components.

Results of the discriminant analysis of the effect of sex, experience, and age on developmental levels in the Forearm/Racket and Trunk for Force II components revealed that sex and age accounted for a significant percentage of the variance observed within groups. The effect of experience was not significant when age and sex were considered. The classification procedures, based upon the discriminant analysis, supported the descriptive analysis for the Forearm/Racket. Younger males and females, ages 9-10, were predicted to function at the lower Step 2 level. Sex differences were revealed, however, as males were predicted to demonstrate Step 3 Forearm/Racket actions at a younger age (12 years) than the females (15 years). No sex differences in this component were present among the older players. The most mature Step 3 actions were predicted for males and females, ages 15 years and older.

The discriminant analysis for the Trunk for Force II component identified sex and age differences, favoring higher developmental levels for males at younger ages than could be expected for females. The relatively low percentage (54%) of correct classifications for this component, however, did not permit an accurate profile of the expected age and sex differences.

DISCUSSION

In the sections that follow, the results of the prelongitudinal screening criteria are discussed initially, then results from the descriptive analysis and the statistical analysis of the sex, experience, and age factors are considered. Emphasis is placed on those components and variables that appeared not to support the criteria and models applied; however, points of support are noted.

Across-Trials, Prelongitudinal Screening

Comprehensiveness. The comprehensiveness criterion was applied with the belief that if the steps hypothesized for each component appeared sequentially over time as the serving pattern was adapted, then the probability of observing each step in the cross-sectional sample would be relatively high. The comprehensiveness criterion was met for all steps hypothesized with the exception of Step 1 of the Preparatory Backswing. No player functioned at Step 1 and all but three players functioned at Step 3 for the Preparatory Backswing.

The failure of Step 1 to appear and for Step 2 to be exhibited infrequently, may have been due to the fact that Roberton's (1983) three step Preparatory Backswing sequence for the overarm throw was used to analyze the preparatory backswing actions of players in the delivery of the tennis serve. Within theories in motor development and motor learning, dealing with motor stage theory and schema formation, it is often suggested that the fundamental motor skill of overarm throwing forms the foundation upon which more advanced motor skills, such as serving in tennis, are developed (East & Hensley, 1985). It may be speculated that Steps 1 and 2 of the Preparatory Backwing may appear generally as young performers develop the schema for overarm throwing and striking; however, young performers with a keen interest in tennis may have moved on in skill development to the more advanced Step 3 Preparatory Backswing actions; therefore, by age 9, the probability of observing Steps 1 and 2 would be relatively low for performers such as those included in the study. The players selected for this study, although they varied in years of tennis participation, were "experienced" tennis players. All but five had participated in USTA sanctioned tournaments, 34 were ranked at the state level, and all had taken tennis lessons.

The unexpected prevalence of Step 3 Preparatory Backswing actions could be explained further by noting from demographic information that all players had received instruction and had observed the serving patterns of instructors and other players. According to Bernstein (1967), the establishment of a visual-motor image is essential to the performance of a motor skill. In the instance of the experienced subjects of this study, the visual-motor image for how the racket should be placed initially to contact the ball probably had been well established through observing instructors and other players and by learning through practice. To determine whether the three step Preparatory Backswing sequence actually characterizes the developmental process of positioning the forearm and racket for serving in tennis, the analysis of younger players or of older players who have not received instruction is recommended. It is possible that the sequence, as presently hypothesized, does exist; however, through instruction, facilitation of the developmental process may have have occurred, thus, overriding the appearance of the less mature actions.

Stability. The criterion of stability was met for each component as all subjects demonstrated four or more trials within the same step. The consistency of body component actions displayed by most players in this study reflects not only their ability to repeat the actions required but possibly their satisfaction in the product of their performance. The notion of stability as applied in motor stage theory is addressed within several motor learning theories. For example, the ability to repeat a motor act is possible as recall and recognition schemata are strengthened through practice (Schmidt, 1975). Furthermore, the motor programs responsible for initiating the actions as well as the lower level processes and mechanisms responsible for adjusting the resulting actions when external or internal demands deviate from the expected, are modifiable yet thought to become "automated" through practice (Higgins, 1972). As subroutines comprising the total motor act become automated, one would expect a high degree of consistency in performance. Within these theories of motor development and motor learning, the stability of component actions, at least as observed among the older, more experienced players, would be anticipated. For example, close examination of the data revealed that the players who demonstrated more than one step across trials were the younger players, ages 9-12. That the younger players showed greater instability in component actions used than did the older players was not unexpected. According to Bernstein (1967), effective solutions to motor problems require mastery of the degrees of freedom involved in the motor act. The tennis serve may be considered as a complex motor problem that would require the control of many degrees of freedom. It may be that the older players, through years of practice, had mastered more degrees of freedom than had the younger players.

Within motor stage theory, the younger players who demonstrated inconsistency across trials would be "in transition" from one step to the next higher step (Roberton, 1978a). Through practice and the conscious attention of the individual to effecting the change (Sage, 1977), the neural structures and processes responsible for the overt motor actions would undergo reorganization. In turn, fluctuations in the level of body component actions would be observed. Within motor stage theory, although more than one step may be observed as the player is "in transition", the strength of one level over an adjacent level should be observable even across as few as seven trials (Roberton, 1977).

Adjacency. The criterion of adjacency was achieved for all components except the Feet/Legs in which two subjects demonstrated non-adjacent steps. Roberton (1977), based on the work of Pinard and Laurendeau (1969), recommended that the presence of even one negative case would bring into question the hierarchical nature of the sequence as ordered. A negative case would require additional prelongitudinal screening and, in turn, modifications in the sequence prior to longitudinal study. To understand the nature of the non-adjacent step actions which appeared in the Feet/Legs actions of two subjects, the context in which the actions occurred must be considered. The process of motor skill development is an adaptive process in which movements are adapted to accomplish a motor task the goal of which is directed by the environment (Bernstein, 1967; Gentile, 1972; Higgins, 1972; Spaeth, 1972). It has often been suggested that serving in tennis involves the development of two skills, one of tossing the ball and the other of contacting the ball with the racket. In addition, the moving ball, its height, and its location in relation to the server must be considered as part of the environmental contingencies. It is possible that the height and location of the ball in serving are external factors which direct the adaptation of the motor skill pattern over time. For example, each player who demonstrated the non-adjacent Step 3 Feet/Leg actions had performed four or more trials at Step 1. The Step 3 actions, no movement of the feet, seemed to occur when the ball was tossed slightly behind the player, forcing the player to adjust the feet to accommodate the different location of the ball in relation to the body/racket.

The appearance of non-adjacent step actions may be further speculated upon by applying several other motor learning theories. Perhaps, as the developing player, intentionally or unintentionally, changes the height and location of the ball, the mechanisms by which the motor skill pattern is adapted are triggered. Through continued adjustments to different locations of the ball, the perceptual and motor images for future motor responses are established (Bernstein, 1967). When these expected images match past motor responses (Schmidt, 1975), then the motor pattern is adapted. In turn, through this adaptive process, environmental demands shape and condition the organization and structure of the movement pattern (Higgins, 1972); therefore, the fact that the environment changed, and, in turn, a different action resulted does not necessarily negate the order of the Feet/Legs sequence as hypothesized. Had the non-adjacent Step 3 actions occurred under the same environmental conditions, that is, a consistent ball toss, then perhaps the step order as hypothesized should be questioned.

Analysis of Sex, Experience, and Age Factors

Age. The fact that the data showed age-related trends was not unexpected given the ages of the players sampled. It was difficult to locate players younger than 9 years who were "experienced" tennis players; therefore, it may be that the age of the youngest players sampled represented fairly accurately the youngest age at which players have acquired the fundamental skills and abilities needed to begin developing the highly complex skills called for in tennis. As pointed out earlier, had the sample included younger, less experienced players, perhaps a higher incidence of Step 1 actions would have been present still in the serving patterns of the players. Overall, the across-ages screening and cross-sectional graphs supported the notion of age-related changes in several body component actions and thereby may well comply with the idea that time should be considered a critical factor in motor skill development.

The notion that the developmental level of body components actions used in the delivery of a tennis serve were age-related yet may not be age-determined was also supported by examining each player's overall component profile. Although some of the youngest players, ages 9-12, had developed the highest developmental steps for some components, none had developed the most mature actions for each component studied. Several of the older players, ages 15 and older, functioned at the highest developmental level across each of the components; however, many, particularly the females, were functioning at intermediate steps for one or more components. Furthermore, it should be pointed out that although many of the older players displayed intermediate steps for some components, three players, ages 13-14, functioned at the highest level for each component analyzed. Interestingly, these three players were ranked very high in their age groups. It should be pointed out that although the most mature steps for each component studied were observed in the serving patterns of two males and one female, ages 13-14, it seems that their advanced motor skill development in serving was the exception rather than the expected. The data in the study tended to show that the development of mature body component actions may not be complete among most experienced tennis players even after four years of tennis participation.

Experience. Just as the experience factor may have contributed to the high percentage of Step 3 classifications in the Preparatory Backswing component, so that factor should be considered in examining those component sequences which showed prelongitudinal support for systematic change as a function of time. The purpose of selecting only players who were "experienced tennis players" was to determine if the component steps appeared among players who had taken lessons, who had practiced regularly, and who had received incentives such as awards and rankings for their efforts to develop their tennis skills. Although no attempt was made to determine the type of instruction received, the underlying assumption was that "experienced tennis players" would have received instruction about the "proper service technique." It was postulated that if the less mature component actions appeared frequently among players despite instructions received, then support for the developmental nature of the actions observed would be warranted. The presence and distribution of the step classifications for the Elbow, Forearm/Racket, and Preparatory Trunk II components seemed to support the notion that the different actions observed in the serving patterns of the players of varying age and experience may be part of a developmental process. That process appeared to be functioning as the incidence of observing lower level steps was higher among the younger, and, often times, less experienced players than among the older, more experienced players. In turn, the notion of a developmental process underlying the adaptation of these body component actions in serving gained support.

Much of the discussion so far has centered upon the fact that the players selected for study were "experienced." The descriptive and statistical analysis, however, indicated that greater differences were observed when age and sex rather than experience were considered. Despite the statistically non-significant effect of years of tennis experience upon developmental levels in the Forearm/Racket and Trunk for Force II components, the role of experience as a factor of change in the development of a sport skill must still be considered. Whereas, previous findings in motor development have shown that changes in fundamental motor skill patterns and body component actions were age-related yet not age-determined, the role of experience in sport skill development was sought in this study. The data indicated, at least for the Forearm/Racket and Trunk for Force II components, that age accounted statistically for more of the variance across step classifications than did experience. The discriminant analysis of each of these components and, particularly, the "closeness of fit" graphs for all components indicated that age and experience were related; that is, the youngest players were the least experienced and the oldest players were the most experienced. Although the overlap of age and experience was anticipated given the range of ages and players sampled, it was possible that some of the older players could have initiated tennis at older ages and some of the younger players could have started at very young ages. The age and experience of a few players deviated from the expected model; however, even among these players, age was apparently the stronger indicator of developmental level.

Intuitively, it would be expected that experience should play a critical role as the change factor responsible for the adaptation of sport skill patterns over time. And yet, the question must be raised, "What constitutes 'experience' of the experienced tennis player?" It could be that years of tennis participation should reflect a player's experience and that perhaps, in this study, the self-report of the players did not accurately reflect their years of participation in tennis. For example, although the players were asked whether they practiced every day, every other day, three or four times per week, or only in the summer, their responses were not considered in the statistical analysis. Similarly, other information about type and years of tennis lessons taken was collected but not analyzed. Had this type of data been included in the analysis, perhaps experience would have accounted for a significant percentage of the variability observed in the serving patterns of the players. These findings and questions indicate that a more complete picture is needed to uncover the factors or combinations of factors that best explain the role of experience in the development of component actions in the delivery of a tennis serve. Whereas East and Hensley (1985) investigated the role of sociocultural factors upon fundamental skill proficiency through multivariate analysis, more complete models are needed to identify the experiential variables which account most significantly for the differences observed in component actions of performers in developing the overhead tennis serve.

Sex. The data indicated that the younger males tended to demonstrate higher developmental steps than did the younger females for several of the components studied. Even across components in which most of the males and females functioned at the same level, a few males functioned at the higher steps and a few females functioned at the lowest step. However, with the exception of the revised trunk actions, few sex differences were noted among the older players. This finding, although not generalizable beyond the subjects sampled in this study, is interesting in that sex differences reported in the overarm throwing literature suggest that females show an inability to maintain or achieve the highest levels of arm and pelvic-spinal actions (Roberton & Langendorfer, 1980) and that the developmental rate of females lags 5-6 years behind the males across the years from kindergarten to the seventh grade in overarm throwing (Halverson et al., 1982).

The data in this study showed that more sex differences existed among the younger players than among the older players. A comparison of the sex differences displayed across components revealed several developmental trends when the step classifications of the youngest players, ages 9-11, were compared independently of the classfications of the 11-12 year olds. For example, most of the males and females, ages 9-11, functioned at the same level in the Forearm/Racket, and Preparatory Trunk II actions. However, among the 11-12 year olds, most of the males exhibited higher step actions than did most of the females. The sex differences disappeared among the older players as most of the males and of the females were classified at the highest step for each of these components. Although males achieved the most mature Forearm/Racket actions at an earlier age than females, of interest, is the fact that few sex differences appeared among the older players. Such a result may indicate that given an adequate amount of practice and the appropriate incentives for continued participation in tennis, males and females will develop similar motor skill patterns. Although this finding is not supported generally in the research about fundamental skill development as the skills studied often reflect gender differences, it may be speculated that complex skills, because they require higher order of information processing, do not differentiate the males and females in the execution of the skills.

Statistical Analysis

The purpose of conducting the statistical analysis was to identify differences, if any, in the developmental levels of the males and females when age and experience were considered. The results of the discriminant analysis indicated that age and sex accounted for a greater percentage of the variablity observed in the Forearm/Racket and Trunk for Force II components than did experience. Based upon these findings, it was predicted that males at younger ages would function at higher, more mature levels than females in the Forearm/Racket and Trunk for Force II components.

Although the statistical analysis was completed to gain a picture of the relationship of sex, experience, and age to the developmental level of selected body component actions in serving, perhaps as Hair, Anderson, Tathum, and Grablowsky (1979) pointed out, the results of the discriminant analysis should be used to profile the subjects studied rather than to predict developmental levels of experienced tennis players.

Several reasons for confining the statistical results to a profile analysis rather than to a predictive interpretation are suggested. First, an understanding of the procedures employed in the discriminant analysis should reveal several limitations to extending the results beyond the descriptive analysis of the players studied. For example, the results of the discriminant analysis and classification procedures indicated that age and sex were relatively accurate predictors of developmental levels for the Forearm/Racket as 78% of the classifications were correct when only these factors were considered. However, it should be pointed out that although 78% of correct classifications indicates a relatively high accuracy rate, an upward bias may be present due to the procedures employed in classification. Upward biasing occurs when the subjects used in computing the function are the same as those used in developing the classification matrices (Hair et al., 1979). Rather than using a split-sample or cross-validation approach to derive and test the validity of the discriminant functions, the entire sample in this study was used for both the stepwise and classification procedures. This procedure was recommended when the sample size is too small to justify a split-sample (Hair et. al. 1979). The relatively high percentage of correct classifications permitted a clearer understanding of the sex and age differences of the players actually involved in this study rather than providing a model for predicting the motor skill development of experienced tennis players in general.

Stepwise procedures, in which each independent variable was entered into the discriminant analysis one at a time on the basis of their discriminating power, were followed in this study. Given the exploratory nature of the statistical analysis, stepwise rather than simultaneous or forced procedures were applied. The stepwise procedures were instrumental in discriminating the combination of variables which accounted for the most significant percentage of the variance observed within groups; however, future applications of discriminant procedures in developing multivariate models for the study of changes in motor skill development may need to incorporte alternative discriminant procedures as more information becomes known about the factors which influence the developmental process of acquiring complex sport skills.

Interpretations about the statistical significance of the sex, experience, and age factors should also be made within the context of the developmental theories and models presented within this study. For example, Wohlwill (1973) recommended multivariate approaches to study age changes in behavioral development. He, however, identified the initial steps in the research process as (1) determining the presence and direction of developmental change and (2) determining the shape of the developmental function. According to Wohlwill, the discovery and synthesis of the developmental dimension and the descriptive study of "age changes" along the developmental dimension should precede the specification of mathematical models (p. 40). Furthermore, the form of the developmental function as "the relationship between the chronological age of the individual and the changes observed to occur in his responses over the course of his development", may only be determined through longitudinal study (p. 32). Based upon these guidelines, the intended predictive interpretation of the results of this study may be inappropriate for at least two reasons. First, the data were derived from differences observed at a single point in time rather than from changes observed over time. Secondly, statistical notions of prediction as related to motor skill development are not consonant with the notion that changes in motor skill development are age-related yet not age-determined. Thus, although statistical procedures such as discriminant analysis may permit and actually achieve success in predicting some behavior patterns, the use of similar procedures for predicting levels of motor skill development may be premature and purely speculative in the exploratory phase of this study. It is noteworthy, also, that models applied in this study depended still upon descriptive data.

Although the limitations of the results of the discriminant analysis have been discussed, the merits of the statistical procedures employed should also be noted. The discriminant analysis complemented yet extended the results of the descriptive analysis. For example, the descriptive analysis identified differences in the forearm/racket actions of males and females of varying ages and experience; however, through the discriminant analysis a greater percentage of the differences was attributed to sex and age than to experience. Although the cross-sectional graphs for age and experience were similar when closely compared, through stepwise analysis, the stronger of the two variables, age, was identified as the more accurate discriminator of developmental level.

The discriminant analysis also supported the prelongitudinal screening criteria applied to the Forearm/Racket and Trunk for Force II sequences. Both the screening and discriminant procedures supported the validity of the Forearm/Racket sequence as hypothesized. In contrast, weaknesses in the Trunk for Force II sequence which were identified in the screening procedures were further accentuated in the classification procedures. In conclusion, the discriminant analysis identified not only the relationship of sex, experience, and age upon the developmental levels in the Forearm/Racket and Trunk for Force II components but also added to the prelongitudinal screening procedures by permitting a more complete picture to aid in determining the feasibility of longitudinal study of these two components.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The primary purpose of this study was to determine whether the broad criteria of stability and intransitivity, applied in motor stage theory, characterized the body component actions of performers in the execution of an overhead serve in tennis. The specific criteria of comprehensiveness, stability, and adjacency were employed to ascertain whether the hypothesized steps and sequences for a tennis serve met the requirements of an across-trials, prelongitudinal screen test as proposed by Roberton (1977, 1978a). In addition, the effects of sex, experience, and age upon the hypothesized developmental skill level of performers in the tennis serve were examined.

Tennis players, 30 males and 30 females, of varying age and experience, were selected for participation in the study. Only those players were included who held a 1986 North Carolina State ranking, were recommended by teaching professionals, or were experienced in tournament competition. In addition, only players between 9-19 years of age with 1-2 years or less and up to 10 or more years of experience were studied.

The performance of each player was videotaped from the side and rear viewing angles. Each player performed seven trials of a forceful overhead serve. Right handed players served from the right service court and left handed players served from the left service court.

Developmental sequences, comprised of three or four step actions, were hypothesized to describe changes in the preparatory and force production phases of the tennis serve to be expected in selected body components as the serve developed over time and with experience. Drawing primarily upon Langendorfer's (1982) comparison of developmental sequences for throwing and striking and upon weaknesses and errors identified in the literature, the components selected for study during the preparatory phase of the tennis serve were the backswing and trunk actions. During the force production phase of the serve, the elbow, forearm/racket, feet/legs, and trunk actions were considered.

The videotapes were analyzed by two observers, one of whom was the investigator and the other, an experienced tennis teacher trained by the investigator. The two observers sought to arrive at an 80% or higher agreement as advised by Langendorfer (1982) and Williams (1980). In order to achieve that goal, several steps were taken. First the observers analyzed independently all trials of the 60 players and arrived at an 80% or higher agreement for three of the six components; then, a second independent analysis was completed with a result of an 80% or higher agreement for five components. Finally, to finish the analysis, the observers together viewed the tapes and decided upon the appropriate classifications where necessary.

The initial analysis of the data consisted of the prelongitudinal screening of the hypothesized sequences according to several recommended criteria. Roberton's (1977, 1978a) across-trials screening criteria of comprehensiveness, stabilty, and adjacency were applied to the data. Langendorfer's (1982) recommended across-ages screening and the Roberton et al. (1980) hypothesized longitudinal model were used to analyze the data further.

Descriptive and statistical analyses were employed to determine the role and effect of sex, experience, and age in the developmental level of males and females in the delivery of tennis serve. Description was used first to identify step classifications associated with the variables of sex, experience, and age; then further study of the effect of those variables on the body component actions in the Forearm/Racket and the Trunk for Force II was completed through stepwise discriminant procedures.

MAJOR RESULTS

The primary results of the study were:

1. Sequences hypothesized for three components identified as the Elbow, Forearm/Racket,and Preparatory Trunk II components satisfied the prelongitudinal screening criteria recommended by Roberton (1977, 1978a), Langendorfer (1982) and Roberton et al. (1980).

2. Sequences hypothesized for five components identified as the Preparatory Backswing, Preparatory Trunk I, Trunk for Force I, Feet/Legs, and Trunk for Force II components did not satisfy one or more of the prelongitudinal screening criteria recommended by Roberton (1977, 1978a), Langendorfer (1982), and Roberton, et. al. (1980).

3. Most of the males, ages 9-12, demonstrated higher step actions for the Forearm/Racket and Preparatory Trunk II components than did most of the females of the same age. Although most of the younger males and females functioned at the same developmental level in the Preparatory Trunk I, Feet/Leg, and Trunk for Force II components, some sex differences were present as more of the males than of the females were classified at higher steps. Few sex differences were found among the younger players for the Preparatory Backswing, Trunk for Force I, and Elbow components.

4. Most of the males and of the females, ages 15-19, demonstrated the same developmental levels for each component, with the exception of the Preparatory Trunk II and Trunk for Force II. Males demonstrated higher developmental levels for these two components than did the females.

5. Most of the males and of the females with 1-2 years or less of experience demonstrated the same developmental levels for each component, with the exception of the Forearm/Racket and Preparatory Trunk I. Males demonstrated higher developmental levels than did females for these two components.

6. Most of the males and most of the females with 5 or more years of experience demonstrated the same developmental level for each component, with the exception of the Preparatory Trunk II and Trunk for Force II components. Males demonstrated higher developmental levels than did females for these two components.

7. Sex and age, together, accounted for approximately 45% of the total variance observed across developmental levels in the Forearm/Racket component. The contribution of experience was not significant when sex and age were considered.

8. Age and sex were accurate predictors of Forearm/Racket actions as shown by the high percentage (78%) of correct Step 2 and 3 classifications. Males and females, ages 9-11, were predicted to demonstrate Step 2 Forearm/Racket actions. Step 3 Forearm/Racket actions were predicted to appear among males, ages 12 and older, and among females, 15 years and older. Although males were predicted to demonstrate Step 3 Forearm/Racket actions at a younger age than females, no differences were predicted in the Forearm/Racket actions of males and females ages 15 years and older.

9. Sex and age, together, accounted for approximately 32% of the total variance observed across developmental levels in the Trunk for Force II component. The contribution of experience was not significant when sex and age were considered. However, sex and age were not accurate predictors of Trunk for Force II actions as shown by the low percentage (54%) of correct classifications.

CONCLUSIONS

Within the limits and data of the study, the following conclusions seem warranted:

1. The criteria of stability and intransitivity, applied in motor stage theory, appear to characterize body component actions of the Elbow, Forearm/Racket, and Preparatory Trunk II in the development of an overhead serve in tennis.

2. Males, ages 9-12, tend to function at higher developmental levels in the Forearm/Racket and Preparatory Trunk II actions than females of the same age in the delivery of an overhead tennis serve.

3. Males and females, ages 15-19, tend to function at the same developmental levels in all body component actions, except the trunk, in the delivery of an overhead tennis serve.

4. Sex and age are accurate discriminators of developmental levels in forearm/racket actions used in the overhead serve in tennis.

5. Experience, as measured in years of tennis participation, does not distinguish developmental levels in the Forearm/Racket and Trunk for Force II components in the delivery of the overhead tennis serve as well as do sex and age factors.

RECOMMENDATIONS

Based upon the results of the investigation and insights gained during the course of the study, the following recommendations for further study are made:

1. Sequences for the Elbow, Forearm/Racket, and Preparatory Trunk II actions should be validated through longitudinal study.

2. The Feet/Leg and Trunk for Force II sequences hypothesized in this investigation should be modified and re-examined prior to longitudinal study.

3. The age range of the tennis players in future studies should be extended to include younger players. Such inclusion may provide a more complete description of the motor skill development of serving in tennis than was possible in this study.

4. Study of other body component actions used in the delivery of a tennis serve, such as the humerus and the tossing arm, should be completed to understand more completely the development of the skill.

5. In conjunction with the continued study of experienced tennis players, longitudinal study of individuals with less experience than those subjects sampled in this study should be undertaken to validate the sequences hypothesized for the tennis serve.

6. Changes in component actions of males and females who begin the sport of tennis at older ages should be studied to determine if the order of change and rate of change follows the same pattern of players who take up the sport at younger ages.

7. The criteria applied in motor stage theory should be used to examine the process of motor skill development in a variety of sport skills.

8. The use of digital analysis and computer simulation of body component actions should be explored to enhance observation and classification of developmental levels in executing motor skills.

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APPENDIX A

A-1: Initial Letter to Subjects

A-2: Questionnarie

A-3: Consent Forms

A-4: Follow-up Letter to Subjects

A-5: Player Profile

Appendix A-1

Initial Letter to Subjects

May 14, 1986

HPERD
Forney Building
UNCG
Greensboro, NC 27403

Dear ,

I am a graduate student in physical education at UNCG. For my dissertation, I plan to analyze the serving patterns of advanced tennis players, ages 8-18. Your name and address were provided by the North Carolina Tennis Association and by teaching professionals in the area.

I am writing to request your participation in my study. If you volunteer, you will be asked to participate as follows:

1. Complete and return the enclosed Human Subject Consent Forms. You and your parents must sign the forms.

2. Attend one, 1 hour videotaping session. You will be asked to serve and throw several times. Ample practice time will be allowed prior to taping. (The dates and sites are listed on the enclosed questionnaire.)

3. Please wear white or light colored shirt and shorts for videotaping. Adhesive strips will be placed on selected body joints (i.e., wrist, elbow, knee, ankle) and across the hips and chest). The adhesive strips will aid in identifying the actions of these body parts in serving and throwing.

Upon completion of the study, you will receive a profile of your serve. The results of the study will be shared with you if you so request. Hopefully, the analysis of your serving and throwing patterns will contribute new information for improved teaching of these skills.

Appendix A-1 continues

I look forward to hearing from you. If you decide to participate, I will contact you to verify your videotaping date, time, and site. If you would like to participate yet are unable to attend one of the scheduled sessions, please indicate your interest when you return the consent forms and questionnaire. If you have any questions, I may be reached at the following telephone number: (919) 379-3024.

Sincerely,

Jo Ann Messick

Appendix A-2

Questionnaire

Name ________________________ Date of Birth ____________

Address ______________________ Male _____ Female _____

____

1. Which of the following videotaping sessions could you attend? Please indicate a specific time if you are available for only part of a three hour session.

_____ June 1, 3:00 - 6:00 p.m., UNCG Tennis Courts, Greensboro, NC

_____ June 2, 3:00 - 6:00 p.m., UNCG Tennis Courts, Greensboro, NC

_____ June 3, 3:00 - 6:00 p.m., UNCG Tennis Courts, Greensboro, NC

_____ June 4, 3:00 - 6:00 p.m., Oak Hollow Tennis Center, High Point, NC

_____ June 5, 3:00 - 6:00 p.m., Olde Forest Racket Club, Elon College, NC

_____ June 7, 3:00 - 6:00 p.m., UNCG Tennis Courts, Greensboro, NC

_____ June 8, 3:00 - 6:00 p.m. Wake Forest University Tennis Courts, Winston-Salem, NC

2. How many years have you played tennis?

_____ less than a year
_____ 1 - 2 years
_____ 3 - 4 years
_____ 5 - 6 years
_____ 7 - 9 years
_____ 10 or more years

Appendix A-2 continues

3. How often do you practice tennis?

_____ Almost every day
_____ Almost every other day
_____ Three or four times each week
_____ Almost every day during the summer

4. Have you taken tennis lessons?

_____ yes
_____ no

5. Describe the type of tennis lessons which you have taken.

_____ group
_____ private
_____ group and private

6. How long have you taken tennis lessons?

_____ less than a year
_____ 1 - 2 years
_____ 3 - 4 years
_____ 5 - 6 years
_____ 7 - 9 years
_____ 10 or more years

7. Please list your current NC ranking(s).

____

____

____

8. Please list any other current USTA rankings.

____

____

____

9. Do you serve with your right or left hand?

_____ right

_____ left

Appendix A-3

Subject Consent Form

THE UNIVERSITY OF NORTH CAROLINA AT GREENSBORO

SCHOOL OF HEALTH, PHYSICAL EDUCATION & RECREATION

SCHOOL REVIEW COMMITTEE

INFORMED CONSENT FORM*

I understand that the purpose of this study is to investigate changes in motor skill development as performers of different ages and experience learn to serve in tennis.

I confirm that my participation is entirely voluntary. No coercion of any kind has been used to obtain my cooperation.

I understand that I may withdraw my consent and terminate my participation at any time during the project.

I have been informed of the procedures that will be used in the study and understand what will be required of me as a subject.

I understand that all of my responses, written/oral/task, will remain completely anonymous.

I understand that a summary of the results of the project will be made available to me at the completion of the study if I so request.

I wish to give my voluntary cooperation as a participant.

____
Signature

____
Address

____

____
Date

*Adopted from L.F. Locke and W.W. Spirduso. (1976). Proposals that Work, New York: Teachers College, Columbia University.

Appendix A-3 continues

Appendix A-3

Parental Consent Form

I understand that the purpose of this study is to investigate changes in motor skill development as performers of different ages and experience learn to serve in tennis.

I confirm that my son or daughter's participation is entirely voluntary. No coercion of any kind has been used to obtain my cooperation.

I understand that my son or daughter may withdraw at any time during the study.

I have been informed of the procedures that will be used in the study and understand what will be required of my son or daughter as a participant.

I understand that data derived from analysis of my son's or daughter's serving pattern will remain completely anonymous.

I understand that a summary of the results of the project will be made available to me at the completion of the study if I so request.

I wish to give my voluntary cooperation as a parent of a subject in this study.

____
Signature

____
Address

____

____
Date

*Adapted from L.F. Locke and W.W. Spirduso. (1976). Proposals that Work, New York: Teachers College, Colombia University, p. 237.

Appendix A-4

Follow-up Letter to Subjects

January 17, 1987

School of HPERD
Forney Bldg.
UNCG
Greensboro, NC 27412

Dear ,

Thank you again for participating in my study. You were one of 75 experienced tennis players, ages 9-19, who volunteered to participate in the study. Since June, I and another tennis expert have studied the videotapes, looking for differences in the serving patterns. I would like to share our findings as related to your serve.

We analyzed your serve by looking for very specific actions in different parts of the body. To understand what actions we considered, study the enclosed profile of your serve. For example, you will notice that under the category "Trunk Action During Force Production," there are four steps. After carefully observing your serve in slow motion, we classified the action of your trunk into one of these four steps.

As you study your profile, you may discover that some parts of your serve are at a higher step than other parts. This is possible as we hypothesize that different parts of the body develop at different rates as the tennis player develops an effective serving pattern.

How can you use the profile to improve your serve? If you are comfortable and effective with your serve, you may not want to make any changes. You may have already adapted your serve since we met last summer. If, however, you are still interested in improving your serve,

Appendix A-4 continues

consider practicing the next higher step within each category. For example, if we classified your elbow action at Step 2, try to bend your elbow more so that the racket is positioned farther behind your head prior to extending upward to contact the ball. If your trunk action was classified at Step 2, try to shift you hips toward the net before you extend your racket and serving shoulder to contact the ball.

As you work to improve your serve, realize that as you make a change in one body action, all other parts of the serve may have to be altered slightly to accomodate the change. In addition, time will be needed to practice the changes. We recommend that you work on the changes during months when you are not playing tournaments so that you will have time to practice the changes in a non-competitive situation. Understand that it is impossible to think about more than one or two changes at the same time. We suggest that you concentrate only on one body part until the change has become a natural part of your serving pattern. Finally, realize that some changes may take years to develop to the most advanced step. For example, to be able to delay extending your racket and shoulder as your hips begin to rotate forward, probably requires several years of practice. Do not become discouraged if you are unable to make the suggested changes immediately.

Thank you for your assistance. If you have any further questions, please give me a call (370-1095). I enjoyed working with you, and I congratulate you on your continued successes in tennis.

Sincerely,

Jo Ann Messick

Appendix A-5

Player Profile

TENNIS SERVE: PLAYER PROFILE

Name ______________________ Date ______________________

Preparatory Backswing

Step 1. Elbow and humeral flexion. The arm and racket move to a position behind or alongside the head by lifting the arm and bending the elbow. The elbow points to the net as the racket is placed in position to contact the ball.

Step 2. Circular, upward backswing. The arm and racket move to a position behind the head by a circular overhead motion with the elbow extended or by a vertical lift from the hip.

Step 3. Circular, downward backswing. The arm and racket move to a position behind the head by a circular, down and back motion, which carries the racket below the waist.

Preparatory Trunk

Step 1. No trunk action or forward/backward movement of the trunk. The player faces the net and uses only the arm to place the racket in the preparatory position. The player may bend forward and then backward at the waist to position the racket in the preparatory position.

Step 2. Minimal trunk rotation. The player initiaties the serve by partially turning sideways to the net as the racket is positioned behind the head. The player may combine forward/backward movement of the trunk with minimal shoulder rotation to position the racket in the preparatory position.

Step 3. Total trunk rotation. The player turns the shoulders and the hips completely away from the net as the racket is positioned behind the head. The serving shoulder continues to rotate back such that the arm and racket appear outside of the line of the body from the rear viewing angle.

Appendix A-5 continues

Trunk Action during Force Production

Step 1. Minimal trunk action or forward/backward movement. Only the arm and racket are active in force production.

Step 2. Upper trunk or total trunk rotation. The shoulders and hips simultaneously begin forward rotation. Foward flexion often occurs prior to contact.

Step 3. Lateral shift of the hips prior to total trunk rotation. The player shifts the hips toward the net then rotates the hips and shoulders simultaneously. Foward flexion may occur prior to contact.

Step 4. Differentiated trunk rotation. The player begins to rotate the hips forward as the shoulders continue to rotate backward. Hyper-extension away from the ball may be followed by extension of the trunk to contact the ball. However, forward flexion may still occur prior to contact.

Elbow Action

Step 1. Elbow flexes and extends. The elbow points toward the net throughout the serving motion.

Step 2. Elbow partially flexes and extends. The elbow only partially flexes to form an angle greater than or equal to 90 degrees with the upper part of the arm.

Step 3. Elbow flexes and extends. The elbow flexes as the racket is positioned behind the head to form an angle less than 90 degrees with the upper arm. The elbow extends to contact the ball.

Appendix A-5 continues

Forearm and Racket Action

Step 1. No forearm/racket lag. The racket and forearm move steadily forward to contact the ball throughout the serving motion.

Step 2. Forearm/racket lag. The racket and forearm appear to remain stationary behind the player as the shoulders begin to rotate forward. However, by contact, the elbow has moved ahead of the racket and forearm.

Step 3. Delayed forearm/racket lag and upward extension. The racket and arm appear to remain behind the player as the shoulders rotate forward. The shoulder, racket, and forearm extend upward to contact the ball.

Feet and Leg Action

Step 1. Homolateral step. The player steps forward with the foot on the same side as the racket arm prior to contact.

Step 2. Contralateral step. The player steps or repositions the foot on the opposite side as the racket arm prior to contact.

Step 3. No step. The player shifts the weight from the back foot to the front foot or pivots on the forward foot prior to contact.

Step 4. No step or repositioning of the back foot toward the front foot prior to contact. The knees and ankles flex and then extend to project the player forward and upward.

SUGGESTIONS:

____

____

____

____

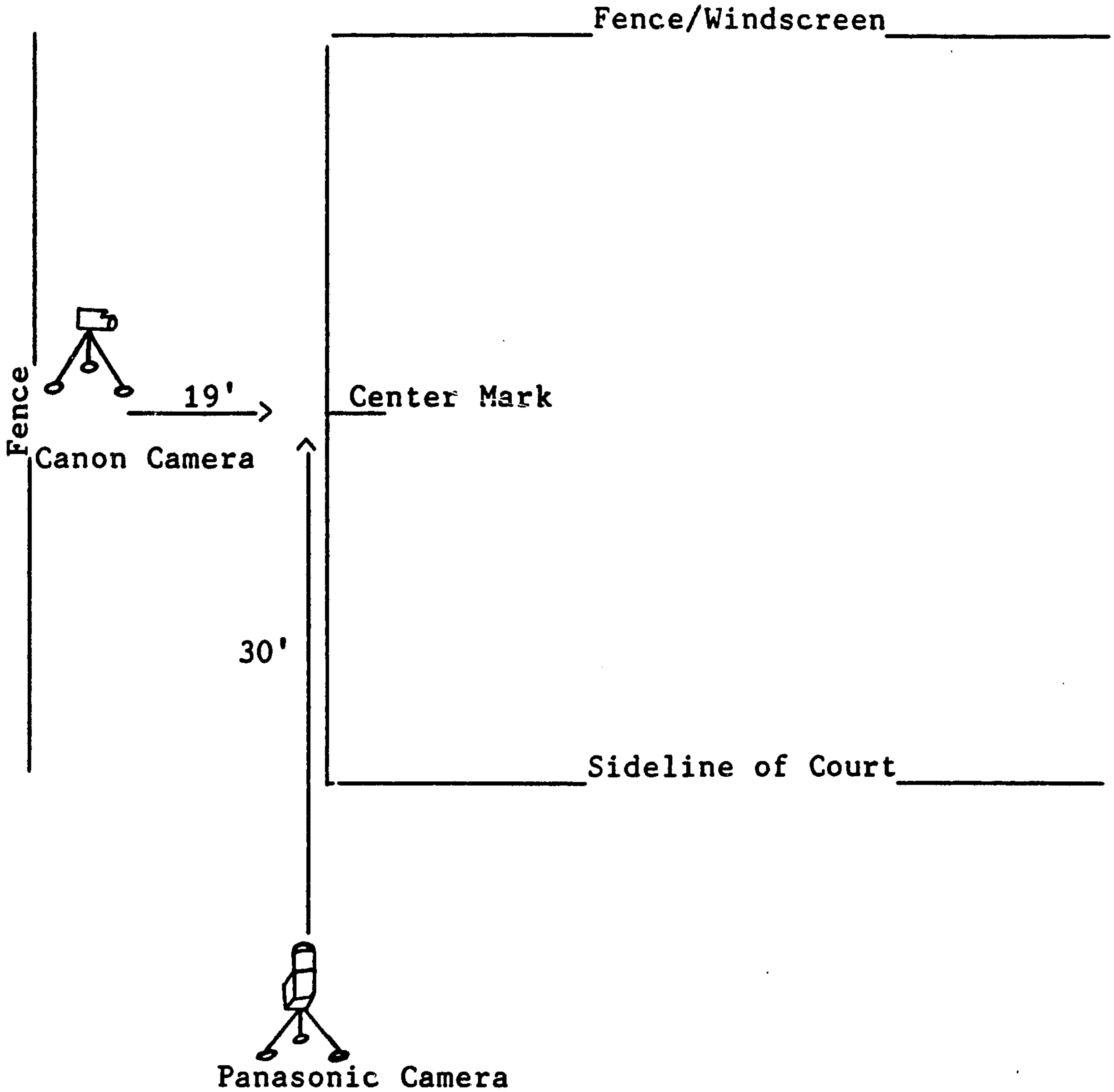
____

APPENDIX B

Layout of the Video Cameras

Appendix B

Layout of the Video Cameras



APPENDIX C

C-1: Original Sequences Hypothesized for Tennis Serve

C-1: Revised Sequence Hypothesized for Preparatory Trunk II Component

C-2: Revised Sequence Hypothesized for Trunk for Force II Component

Appendix C-1

Original Sequences Hypothesized for Tennis Serve

Preparatory Phase
Preparatory Backswing
Step 1. Elbow and Humeral Flexion. The arm and racket move to a position behind or alongside the head by upward flexion of the humerus and concomitant elbow flexion.
Step 2. Circular, Upward Backswing. The racket moves away from the intended line of flight to a position behind the head via a circular overhead movement with elbow extended, or an oblique swing back, or a vertical lift from the hip.
Step 3. Circular, downward backswing. The racket moves away from the intended line of the flight to a position behind the head via a circular, down and back motion, which carries the racket below the waist.
Preparatory Trunk Action
Step 1. No trunk action. Only the arm is active in placing the racket in the preparatory position.
Step 2. Forward flexion and backward extension of the trunk as the racket is positioned in the preparatory position.
Step 3. Total trunk rotation. Hips and shoulders rotate away from the intended target as the ball and racket are positioned in the preparatory position.

Appendix C-1 continues

Elbow Action

Step 1. Elbow flexed and extended. The elbow points toward the net throughout the motion.

Step 2. Elbow partially flexed and extended. The elbow partially flexes to form an angle $\geq$ 90 degrees prior to extension.

Step 3. Elbow flexes and extends. The elbow flexes as the racket is positioned behind the head to form an angle < 90 degrees with the humerus. The elbow extends to contact the ball.

Force Production Phase

Forearm/racket Action

Step 1. No forearm/racket lag. The racket and forearm move steadily forward to contact the ball throughout the serving motion.

Step 2. Forearm/racket lag. The forearm/racket appear to "lag", i.e., to remain stationary behind the individual as the shoulders begin to rotate forward. By contact, the humerus has moved ahead of the lagging forearm/racket.

Step 3. Delayed forearm/racket and extension. The forearm/racket and humerus appear to lag as the shoulders begin to rotate forward. The forearm/racket extends upward in line with the humerus to contact the ball.

Appendix C-1 continues

Trunk Action

Step 1. Minimal trunk action or forward-backward movement. Only the arm and racket are active in force production.

Step 2. Upper trunk or total trunk rotation. The spine and pelvis both initiate or turn away from the intended line of flight and then simultaneously begin forward rotation, acting as a unit or block prior to contacting the ball. Forward flexion of the upper trunk occurs prior to contacting the ball.

Step 3. Differentiated trunk rotation with forward flexion of the upper trunk prior to contacting the ball.

Step 4. Differentiated trunk rotation with hyper-extension away from the ball followed by extension toward the ball prior to contact. Lateral flexion of the upper trunk away from the ball occurs prior to contact.

Feet/Leg Action

Step 1. Homolateral step. The individual steps with the foot on the same side as the racket arm.

Step 2. Contralateral step. The individual steps with the foot on the opposite side as the racket arm or repositions the forward foot to face in direction of the intended hit prior to contact.

Step 3. No step. The individual shifts the weight from the back foot to the front foot by pivoting on the forward foot prior to contact.

Step 4. No step or a homolateral step toward the contralateral foot prior to contact. Deep knee and ankle flexion and extension occur prior to contact to project the player forward and upward.

Appendix C-2

Revised Sequence Hypothesized for Preparatory Trunk II Component

Preparatory Trunk Action

1. No trunk action or forward/backward movement of the trunk. The player faces the net and uses only the arm to place the racket in the preparatory position. The player may bend forward then backward at the waist to position the racket in the preparatory position.

2. Minimal trunk rotation. The player initiates the serve by partially turning sideways to the net as the racket is positioned behind the head. The player may combine forward/backward movement of the trunk with minimal shoulder rotation to position the racket in the preparatory position.

3. Total trunk rotation. The player rotates the shoulders and hips completely away from the net as the racket is positioned behind the head. The serving shoulder continues to rotate backward such that the arm and racket appear outside of the line of the body from the rear viewing angle.

Appendix C-3

Revised Sequence Hypothesized for Trunk for Force II Component

Trunk for Force II Actions

1. Minimal trunk action or forward/backward movement. Only the arm and racket are active in force production.

2. Upper trunk or total trunk rotation. The shoulders and hips simultaneously begin forward rotation. Forward flexion may occur prior to contact.

3. Lateral shift of the hips prior to total trunk rotation. The player shifts the hips toward the net then rotates hips and shoulders simultaneously. Forward flexion may occur prior to contact.

4. Differentiated trunk rotation. The player begins to rotate the hips forward as the shoulders continue to rotate backward. Hyper-extension away from the ball is followed by extension of the trunk to contact the ball. Forward flexion may still occur prior to contact.

APPENDIX D

D-1: Training Session I: Inter-observer Percentage of Agreement

D-2: Training Session II: Inter-observer Percentage of Agreement

Appendix D-1

Training Session I: Inter-observer Percentage of Agreement

Body Component Action	Percentage of Agreement
Preparatory Backswing	100%
Preparatory Trunk I	100%
Trunk for Force I	59%
Elbow	100%
Forearm/Racket	100%
Feet/Legs	88%

Appendix D-2

Training Session II: Inter-observer Percentage of Agreement

Body Component Action	Percentage of Agreement
Preparatory Backswing	100%
Preparatory Trunk I	100%
Trunk for Force I	100%
Elbow	80%
Forearm/Racket	83%
Feet/Legs	94%

APPENDIX E

Viewing Order of Subjects by Observers

Appendix E

Viewing Order of Subjects by Observers

Observer	Viewing Order	Subject Order
Trained Observer	Group A	1,3,4,13,16,17, 18,21,22,24,26, 27,30,31,34,39 43,44,47,48,52, 63,64,65,67,69, 70,71,72,75.
	Group B	2,5,6,7,9,10, 11,12,14,15,19, 23,25,28,32,35, 36,38,40,41,42, 45,49,50,54,55, 56,58,59,74.
Investigator	Group B	74,59,58,56,55, 54,50,49,45,42, 41,40,38,36,35, 32,28,25,23,19, 15,14,12,11,10, 9,7,6,5,2.
	Group A	75,72,71,70,69, 67,65,64,63,52, 48,47,44,43,39, 34,31,30,27,26, 24,22,21,18,17, 16,13,4,3,1.

Note. Following subjects not selected for analysis: 8, 20, 29, 33, 37, 46, 51, 53, 57, 60, 61, 62, 66, 68, 73

APPENDIX F

F-1: Independent Analysis I: Inter-observer Percentage of Agreement

F-2: Independent Analysis II: Inter-observer Percentage Agreement

Appendix F-1

Independent Analysis I:

Inter-observer Percentage of Agreement

Body Component	Number of Trials	Exact Agreement	% of Agreement
Preparatory Backswing	419	419	100%
Preparatory Trunk I	419	345	82%
Trunk for Force I	420	263	63%
Elbow	419	353	84%
Forearm/Racket	420	337	80%
Feet/Legs	420	269	64%

Appendix F-2

Independent Analysis II:

Inter-observer Percentage of Agreement

Body Component	Number of Modal Steps	Exact Agreement	% of Agreement
Preparatory Backswing[a]			
Preparatory Trunk I	54	46	85%
Trunk for Force I	54	43	80%
Elbow	54	44	82%
Forearm/Racket	54	49	91%
Feet/Legs	54	37	69%
Preparatory Trunk II	54	42	78%
Trunk for Force II	54	37	69%

[a] 100% agreement after Independent Analysis I

APPENDIX G

Step Classifications of Subjects

Appendix G

Step Classifications of Subjects

Data for each subject appear in Appendix G. The subject number/initials, sex, age, experience, and step classifications for each component for each trial are arrayed. To read the data, the following guidelines are given:

Row 1, Column 1: Subject number and initials
Row 1, Column 2: Sex of Subject
1 = Male; 2 = Female
Row 1, Column 3: Age of subject in years and months
Row 1, Column 4: Experience of subject

1 = 1-2 years or less
2 = 3-4 years
3 = 5 or more years

Row 1, Column 5: Preparatory Backswing
Row 1, Column 6: Preparatory Trunk I
Row 1, Column 7: Trunk for Force I
Row 1, Column 8: Elbow
Row 1, Column 9: Forearm/Racket
Row 1, Column 10: Feet/Legs
Row 2, Column 6: Preparatory Trunk II
Row 2, Column 7: Trunk for Force II

01LB	2	0904	1	3333333	1111121	1111111	2222222	2222222	3333333
01LB					1111111	1111111			
02CD	2	1304	2	3333333	2222222	2222222	2222222	2222222	3333333
02CD					2222222	2222222			
03CD	2	1002	1	3333333	3333333	2222222	2222222	2222222	4444444
03CD					2222222	2222222			
04TD	2	1200	1	333333	333333	2222222	3333333	2222222	3333333
04TD					222222	2222222			
05TF	1	1208	3	3333333	3333333	2222222	3333333	3333333	4444444
05TF					3333333	2222222			
06ZM	1	1604	5	3333333	3333333	2222222	3333333	3333333	4444444
06ZM					3333333	3333333			
07AM	2	1708	5	3333333	3333333	2222222	3333333	3333333	2222222
07AM					2222222	2222222			
09SH	1	1107	1	3333333	3333333	2222222	3333333	3333333	2222323
09SH					3333333	3333333			
10JW	2	1203	1	3333333	2222222	2222222	3333333	2222222	3333333
10JW					2222222	2222222			
11RW	1	1307	3	3333333	2222222	4444444	3333333	3333333	4444444
11RW					3333333	4444444			
12SW	1	1007	1	3333333	3333333	2222222	3333333	2222222	2222222
12SW					2222222	2222222			
13JM	1	1604	2	3333333	3333333	3333333	3333333	3333333	4444444
13JM					3333333	4444444			
14FR	1	0904	1	3333333	3333333	3333333	3333333	3333333	3343334
14FR					3333333	4444444			
15RC	1	1003	1	3333333	3333333	2222222	3333333	2222222	2222222
15RC					2222222	2222222			
16CM	1	1403	2	3333333	3333333	4444444	2222222	3333333	4444444
16CM					2222222	4444444			
17CM	1	1509	2	2222222	3333333	2222222	3333333	3333333	4444444
17CM					2222222	2222222			
18TH	1	1504	1	3333333	3333333	4444444	2222222	3333333	4444444
18TH					3333333	4444444			
19MF	1	1909	3	3333333	3333333	2222222	3333333	3333333	3333333
19MF					2222222	3333333			
21KI	2	1306	2	3333333	2222222	2222222	3333333	3333333	3333333
21KI					2222222	2222222			
22SM	2	1100	2	3333333	3333333	3333333	3333333	3333333	4444444
22SM					3223323	4444444			
23YM	2	1107	1	3333333	3333333	2222222	3333333	2222222	3333333
23YM					2222222	2222222			
24JJ	1	0910	1	3333333	3333333	2222222	3333333	2223333	2223332
24JJ					3333333	2222222			
25MK	2	1300	2	3333333	3333333	2222222	3333333	2222222	3333333
25MK					2222222	2222222			
26RS	2	1406	2	3333333	3333333	4444444	3333333	3333333	4444444
26RS					3333333	4444444			

27PW	2	1510	1	3333333	3333333	3333333	3333333	3333333	4444444
27PW					3333333	4444444			
28JQ	1	0903	1	3333333	3333333	2222222	3322222	2222222	4444444
28JQ					2222222	2222222			
30JM	1	1502	4	2222222	3333333	2222222	3333333	3333333	4444444
30JM					2222222	3333333			
31MH	1	1701	1	3333333	3333333	3333333	3333333	3333333	3333333
31MH					3333333	4444444			
32BB	1	1301	3	3333333	3333333	4444444	3333333	3333333	4444444
32BB					3333333	4444444			
34KW	2	1211	2	3333333	3333333	2222222	3333333	3333333	3333333
34KW					2222222	2222222			
35BC	1	1704	4	3333333	3333333	2222222	3333333	3333333	4444444
35BC					2222222	2222222			
36BS	1	1610	3	3333333	3333333	2222222	3333333	3333333	4444444
36BS					3333333	3333333			
38JM	1	1707	4	3333333	3333333	2222222	3333333	3333333	4444444
38JM					3333333	3333333			
39AW	1	1208	2	3333333	3333333	2222222	3333333	3332333	4444444
39AW					3333333	3333333			
40DP	1	1104	2	3333333	3333333	2222222	222222	3333333	4444444
40DP					2222222	3333333			
41HS	2	1310	3	3333333	3333333	2222222	3333333	3333333	3333333
41HS					2222222	2222222			
42CM	2	1801	4	3333333	2222222	2222223	3333333	3333333	4444444
42CM					3333333	3333334			
43BO	1	1305	2	3333333	3333333	2222222	2222222	2222222	4444444
43BO					3333333	2222222			
44BC	1	1111	1	3333333	2222222	2222222	2222222	3333333	3333333
44BC					2222222	2222222			
45BM	1	1703	2	3333333	3333333	2222222	3333333	3333333	4444444
45BM					3333333	3333333			
47DA	2	1109	1	3333333	3333333	2222222	3333333	2222222	3333333
47DA					2222222	2222222			
48BR	1	1106	1	3333333	3333333	2222222	2222222	3333333	4444444
48BR					3333333	3333333			
49AM	2	1502	4	3333333	2222222	2222222	3333333	3333333	4444444
49AM					2222222	3333333			
50DT	1	1406	4	3333333	3333333	2222222	2222222	3333333	4444444
50DT					3333333	2222222			
52PM	1	1805	5	3333333	3333333	4444444	3333333	3333333	4444444
52PM					3333333	4444444			
54SH	2	1608	3	3333333	3333333	2222222	3333333	3333333	4444444
54SH					2222222	2222222			
55SP	1	1410	4	3333333	3333333	2222222	3333333	3333333	4444444
55SP					3333333	3333333			
56JR	1	1006	1	3333333	3333333	2222222	3333333	2222222	3333333
56JR					2222222	2222222			

58JM	2	1007	2	3333333	2222222	2222222	2222222	2222222	3333333
58JM					2222222	2222222			
59AS	2	1011	1	3333333	2222222	1111111	1111111	1111111	3131111
59AS					1111111	1111111			
63SC	2	1408	2	3333333	3333333	2222222	3333333	3333333	4444444
63SC					2222222	2222222			
64EM	2	1007	1	3333333	3333333	2222222	1111111	1111111	3111111
64EM					2222222	2222222			
65EB	2	1004	3	3333333	2222222	2222222	2222222	2222222	2222222
65EB					2222222	2222222			
67KC	2	1605	2	3333333	3333333	2222222	3333333	3333333	4444444
67KC					2222222	2222222			
69SS	2	1606	4	3333333	3333333	2222222	3333333	3333333	4434444
69SS					3333333	3333333			
70CK	2	1607	4	3333333	3333333	2222222	3333333	3333333	4444444
70CK					2222222	2222222			
71JB	2	1706	5	3333333	2222222	2222222	2222222	2222222	4444444
71JB					2222222	2222222			
72KD	2	1906	5	3333333	3333333	3333333	3333333	3333333	4444444
72KD					3333333	4444444			
74MW	2	1700	5	2222222	3333333	2222222	3333333	3333333	3333333
74MW					3333333	3333333			
75EH	2	1807	5	3333333	3333333	2222222	3333333	3333333	2222222
75EH					2222222	2222222			

APPENDIX H

H-1: Exact Percentage of Subjects in Each Age Group Classified at Each Component Step

H-2: Exact Percentage of Subjects in Each Experience Group Classified at Each Component Step

Appendix H-1

Exact Percentage of Subjects in Each Age Group

Classified at Each Component Step

Preparatory Backswing		Steps			
Age	n	1	2	3	4
9-10	12			12 (100%)	NA
11-12	12			12 (100%)	
13-14	12			12 (100%)	
15-16	12		2 (17%)	10 (83%)	
17-19	12		1 (8%)	11 (92%)	
Preparatory Trunk I					
9-10	12	1 (8%)	3 (25%)	8 (67%)	NA
11-12	12		2 (17%)	10 (83%)	
13-14	12		3 (25%)	9 (75%)	
15-16	12		1 (8%)	11 (92%)	
17-19	12		2 (17%)	10 (83%)	
Trunk for Force I					
9-10	12	2 (17%)	9 (75%)	1 (8%)	
11-12	12		11 (92%)	1 (8%)	
13-14	12		8 (67%)		4 (33%)
15-16	12		9 (75%)	2 (17%)	1 (8%)
17-19	12		9 (75%)	2 (17%)	1 (8%)
Elbow					
9-10	12	2 (17%)	5 (42%)	5 (42%)	NA
11-12	12		3 (25%)	9 (75%)	
13-14	12		4 (33%)	8 (67%)	
15-16	12		1 (8%)	11 (92%)	
17-19	12		1 (8%)	11 (92%)	

Appendix H-1 continues

Forearm/Racket					
9-10	12	2 (17%)	8 (67%)	2 (17%)	NA
11-12	12		4 (33%)	8 (67%)	
13-14	12		3 (25%)	9 (75%)	
15-16	12			12 (100%)	
17-19	12		1 (8%)	11 (92%)	
Feet/Legs					
9-10	12	2 (17%)	4 (33%)	3 (33%)	2 (17%)
11-12	12		1 (8%)	6 (50%)	5 (42%)
13-14	12			4 (33%)	8 (67%)
15-16	12				12 (100%)
17-19	12		2 (17%)	3 (25%)	7 (58%)
Preparatory Trunk II					
9-10	12	2 (17%)	8 (67%)	2 (17%)	NA
11-12	12		7 (58%)	5 (42%)	
13-14	12		6 (50%)	6 (50%)	
15-16	12		6 (50%)	6 (50%)	
17-19	12		5 (42%)	7 (58%)	
Trunk for Force II					
9-10	12	2 (17%)	9 (75%)		1 (8%)
11-12	12		7 (58%)	4 (33%)	1 (8%)
13-14	12		7 (58%)	1 (8%)	4 (33%)
15-16	12		4 (33%)	5 (42%)	3 (25%)
17-19	12		4 (33%)	5 (42%)	3 (25%)

Appendix H-2

Exact Percentage of Subjects in Each Experience Group Classified at Each Component Step

Preparatory Backswing		Steps			
Experience	n	1	2	3	4
< 1-2 years	20			20 (100%)	NA
3-4 years	16		1 (6%)	15 (94%)	
≥ 5 years	24		2 (8%)	22 (92%)	
Preparatory Trunk I					
< 1-2 years	20	1 (5%)	3 (15%)	16 (80%)	NA
3-4 years	16		3 (19%)	13 (81%)	
≥ 5 years	24		5 (21%)	19 (79%)	
Trunk for Force I					
< 1-2 years	20	2 (10%)	14 (70%)	3 (15%)	1 (5%)
3-4 years	16		12 (75%)	2 (12.5%)	2(12.5%)
≥ 5 years	24		20 (83%)	1 (4%)	3(12.5%)
Elbow					
< 1-2 years	20	2 (10%)	6 (30%)	12 (60%)	NA
3-4 years	16		5 (31%)	11 (69%)	
≥ 5 years	24		3 (12%)	21 (88%)	
Forearm/Racket					
< 1-2 years	20	2 (10%)	10 (50%)	8 (40%)	NA
3-4 years	16		4 (25%)	12 (75%)	
≥ 5 years	24		2 (8%)	22 (92%)	

Appendix H-2 continues

Feet/Legs					
< 1-2 years	20	2 (10%)	4 (20%)	9 (45%)	5 (25%)
3-4 years	16			5 (31%)	11(69%)
≥ 5 years	24		3 (12.5%)	3 (12.5%)	18(75%)
Preparatory Trunk II					
< 1-2 years	20	2 (10%)	11 (55%)	7 (35%)	NA
3-4 years	16		10 (62.5%)	6 (37.5%)	
≥ 5 years	24		11 (46%)	13 (54%)	
Trunk for Force II					
< 1-2 years	20	2 (10%)	12 (60%)	2 (10%)	4 (20%)
3-4 years	16		9 (56%)	3 (19%)	4 (25%)
≥ 5 years	24		10 (42%)	10 (42%)	4 (16%)