The development of movement effectiveness in children - a qualitative analysis

by

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Dedications

To Lyly

Though human ingenuity may make various inventions which, by the help of various machines, answer the same end, it will never devise any invention more beautiful, nor more simple, nor more to the purpose than nature does.

Leonardo da Vinci (1452-1519)

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Abstract

The development of movement effectiveness in children – a qualitative analysis

Qualitative biomechanical analysis of movement effectiveness can be proposed as an innovative approach to oversee motor skill development in boys and girls of school age, since it permits an appreciation of how effective the movement is in attaining the performance criterion. Analysis of *movement effectiveness* involves establishing, first, the *technical level* of the child and, second, the *mechanical effectiveness* of the movement performed by the child. The assessment of *technical level* involves basic analysis of the main form of the movement and provides an initiation to biomechanical analysis; whereas, analysis of *mechanical effectiveness* consists of a follow-up comprehensive analysis. The present research aimed to qualitatively determine, and study gender differences in the development of, movement effectiveness in children.

The research included both cross-sectional (N = 187 children) and longitudinal (N = 55 children) studies. A group of adults (N = 31) were used as controls. The subjects were asked to perform two consecutive trials of the soccer kick, the overarm throw and the standing broad jump, all for maximum distance, which were recorded on videotape. In **Study 1**, hierarchical models were developed to qualitatively establish the technical level of the subjects and to study the development of technical level in children. In **Study 2**, a model for the qualitative analysis of mechanical effectiveness was constructed. The model allows the integration of phase analysis and mechanical analysis using movement principles in order to select important variables for the analysis. Rating scales for each variable of the three motor skills were outlined and, then, fine-tuned using tests of rater accuracy and intra-rater reliability, in order to create scoring references. Inter-rater reliability in the use of the scoring references was acceptable. In **Study 3**, the development of mechanical effectiveness in children was examined, and the relative contribution of specific variables to performance was assessed.

Generally, in the cross-sectional studies male children showed a higher technical level and higher mechanical effectiveness, and also a faster rate of development, in the soccer kick and the overarm throw. However, male and female children were better matched in the standing broad jump. The longitudinal studies were inconclusive. Not all adult subjects, particularly females, had reached maturity of movement patterns. The knowledge gained in the research may be used to guide effective progression in coaching and curriculum development in education.

Key words: Motor skill development, movement effectiveness, technical level, qualitative model, mechanical effectiveness, gender differences, school-aged children.

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Chapter I - Introduction

The qualitative biomechanical analysis of fundamental motor skills has traditionally been used in Physical Education (PE) and sports coaching to oversee motor development in children. The simplest test to monitor a child's state of motor performance consists of measuring the outcome of performance, *the product*; for example, the distance jumped in a standing broad jump. However, observation of the movement of the child, *the process*, is more meaningful since it also enables technical faults to be identified. Diagnostic analysis typically involves describing and classifying the movement pattern of the child and, then, comparing it to those of normal children of a similar age and to the mature form of the movement. Normative data for comparisons derives from studies on motor development. For example, the *fundamental stages* model of motor development (e.g., Shirley, 1931; Halverson, 1937; Wild, 1937) consists of initial, elementary and mature stages. More accurate in representing developmental change is the *intra-task component stages* model (Roberton, 1977, 1978), which purports that the actions of different body segments develop independently. The *kinematic continuum stages* model (Adrian, Toole and Randall, 1984) is based on a more detailed biomechanical analysis of the movement.

However, it can be suggested that the sports coach and PE teacher may benefit from using a method of qualitative biomechanical analysis that allows, not just the description of the movement of the child, but to appreciate the mechanical nature of the movement and determine how effective the movement is in attaining the performance criterion (for example, *maximum distance* in an overarm throw for maximum distance). Such **movement effectiveness** (definitions of operational terms appear in the Glossary; p. 6) may be determined using two levels of analysis. The *first* involves basic analysis and consists of establishing the **technical level** of the child. The *second* involves a more comprehensive biomechanical analysis to establish the **mechanical effectiveness** of the movement performed by the child. The determination of *technical level* is similar to the traditional classifications of movement used for the study of motor development in past research (e.g., Wild, 1937; McClenaghan, 1976; Bloomfield *et al.*, 1979) and focuses on the main form of the movement. Therefore, such analysis would provide the uninitiated PE teacher or coach with some experience in technique analysis before progressing to the analysis of *mechanical effectiveness*; which is a more complex biomechanical analysis that requires examination of all the performance factors (mechanical variables) that are directly related to the performance criterion. Knowledge of movement effectiveness, and of gender differences in the development of movement effectiveness, in school-aged children may be used to guide effective progression in coaching and curriculum development in education (Horn and Williams, 2003).

In the last few decades, various **qualitative models** have been developed that facilitate the process of qualitative biomechanical analysis. These include the models of Norman (1975), Arend and Higgins (1976), Brown (1982), Hay and Reid (1982), Hoffman (1983), Gangstead and Beveridge (1984), Hudson (1985, 1995), McPherson (1990), Dunham (1994), Abendroth-Smith, Kras, and Strand (1996), Knudson and Morrison (1996), Kreighbaum and Barthels (1996) and Lees (1999b). The models encourage some form of description and simplification of the movement, and aim to find an explanation as to why the movement looks the way it does. However, such models have a number of limitations. The models differ in terms of the extent to which movement description, simplification and identification of the mechanical principles that underlie effective movement are carried out. It seems, therefore, that the majority of models available are incomplete, and the use of a single model is not sufficient. Most models do not make it explicit whether their aim is in the analysis of technique or performance, or how these two may interrelate. While some authors have suggested procedures for the observation of movement (e.g., Brown, 1982; Knudson and Morrison, 2002), most omit an evaluation of human visual perception and the sensory limitations during the process of subjective movement analysis (e.g., Arend and Higgins, 1976; Hay and Reid, 1982). Also, most methods of qualitative analysis encourage the search for critical or essential features of the movement (e.g., Arend and Higgins, 1976; McPherson, 1990). However, very few studies have provided some sort of guidance as to how to select those variables that are related to performance (almost exclusively by Hay and Reid, 1982; Lees, 1999b; and Sanders, 2004). Even fewer studies have put forward qualitative descriptors that may be used to subjectively quantify mechanical parameters such as force or impulse. It seems, therefore, that a qualitative model that overcomes the shortcomings of existing models needs to be developed in order to be able to use qualitative analysis effectively to assess the mechanical effectiveness of the movements performed by children.

Embedded in the existing analytical models is the use of classical Newtonian mechanics. Broer (1966) and Bunn (1972) stated generalized **mechanical principles** based on Newton's Laws and applied these principles to the analysis of different sports techniques. Bunn (1972; p. 11) suggested that the use of mechanical principles is *"the* *only sound basis for developing the correct mechanical methods for all sports techniques."* However, Adrian and Cooper (1995; p. 106) have stated that *"Although it* (the human body) *acts according to Newtonian mechanics, it has the ability to dampen and dissipate forces, transfer forces from one body part to another, and to add nonlinear forces to the system in motion".* Accordingly, various authors (e.g., Sprigings, Marshall, Elliott and Jennings, 1994; Winter, 1997; Lees, 1999a) have warned that the application of Newton's laws for the study of human movement should be approached with caution since, in fact, mechanical principles of rigid bodies are applied to living, anisotropic, deformable bodies; namely, to the human body. Nonetheless, a number of researchers have identified several **bio-mechanical principles** (e.g., Bunn, 1972; Wang and Wiese-Bjornstal, 1994; Kreighbaum and Barthels, 1996; Lees, 1999b) that include, for example, stretch-shortening cycle and force-velocity relationships. Recently, Lees (1999b) presented a classification of **movement principles** (mechanical and biomechanical) in a format where the principles are easily identifiable and ready to apply by the sports coach. There is a strong rationale, therefore, for the use of movement principles to help assess movement effectiveness in children.

In summary, establishing both movement effectiveness (technical level and mechanical effectiveness) and gender differences in the development of movement effectiveness, in school-aged children may be invaluable to guide successful progression of this age group. However, a suitable model for the qualitative analysis of mechanical effectiveness, based on the rational application of movement principles, needs to be developed. Therefore, the **aim** of the present research was to qualitatively determine, and study gender differences in the development of, movement effectiveness in selected skills representing common sports activity (the soccer kick -a lower limb asymmetrical activity, the overarm throw -an upper limb asymmetrical activity, and the standing broad jump –a whole body symmetrical activity, all for maximum distance) in a group of school-aged children. The specific **objectives** of the research were: 1) to establish the *technical level* of the children, 2) to study the development of technical level in children, 3) to construct an integrated *model* for the qualitative analysis of mechanical effectiveness, 4) to establish the *mechanical effectiveness* of the movements performed by the children, and 5) to study the development of mechanical effectiveness in children. Further, the **general hypotheses** underpinning the research were formulated around the logical assumptions that: GH_1 - the *performance* (distance attained) and *technical level* of children and the *mechanical effectiveness* of the movements performed by children increase with age; and GH_2 - children of school age show distinct gender differences in *performance* and in *movement effectiveness*, and in the rate of development of these. Therefore, this thesis contains the following three studies:

Study 1: A qualitative analysis of the development of technical level in children.
Study 2: A construction of a model for the qualitative analysis of mechanical effectiveness.
Study 3: A qualitative analysis of the development of mechanical effectiveness in children.

More specifically, **experimental hypotheses** that apply to different tests in the three studies were stated as follows (null hypotheses not included):

Study 1:

H_1 - There is a significant association between technical level and age of the children (cross-sectional study).

H_2 – There are distinct gender differences in technical level and its rate of development in children (cross-sectional study).

H_3 – There are significant differences between the technical level of a group of children in test 1 and their technical level in test 2 (longitudinal study).

H_4 - There is a significant correlation between measures of the performance criterion and age of the children.

H_5 - There is a significant association between technical level of the children and the performance criterion.

Study 3:

H_6 – There is a significant association between mechanical effectiveness and age of the children (cross-sectional study).

H_7 – There are distinct gender differences in mechanical effectiveness and its rate of development in children (cross-sectional study).

H_8 – There are significant differences between the mechanical effectiveness of the movement of a group of children in test 1 and the mechanical effectiveness in test 2 (longitudinal study).

H_9 - There is a significant association between mechanical effectiveness and the performance criterion.

Glossary of operational terms

Biomechanical model – A model that focuses on the mechanical aspects of the performance.

Biomechanical principle – A description of how human movement occurs based on biomechanics; that is, based on the analysis of the actions of forces on living mechanical systems (adapted from Hall, 2003).

Comprehensive model – A model that presents a summary of the components necessary for qualitative analysis and provides information on *"movement goals, preparation for observation, stages of motor development, observation, evaluation, diagnosis of errors, and appropriate feedback"* (Knudson and Morrison, 2002; p. 16).

Critical feature – An observable component of the movement that is essential for optimal performance (McPherson, 1990).

Fundamental motor skill - also categorised as a 'basic' or 'gross skill'. A motor skill that provides the foundations for more complex skills (Ulrich, Ulrich and Branta, 1988).

Mature – also appearing as 'mature form'. In this thesis the term 'mature' is used to refer to the highly-skilled form of the movement.

Mechanical analysis – Refers to the use of a deterministic mechanical model to establish the factors that determine the performance criterion.

Mechanical effectiveness – Refers to how effective the movement of the child is in attaining the performance criterion. Assessment of mechanical effectiveness involves examination of the performance factors (mechanical variables) that are directly related to the performance criterion.

Mechanical principle – A description of how movement occurs based on mechanics; that is, based on the analysis of the actions of forces on mechanical systems (adapted from Hall, 2003).

Movement effectiveness - In this thesis the term 'effectiveness' conveys the idea of being effective in achieving the performance goal; whereas, 'effective' is analogous to *"producing the desired result"* (Longman Dictionary of Contemporary English, 1989; p. 326). Assessment of movement effectiveness involves determining the *technical level* of the child and the *mechanical effectiveness* of the movement performed by the child.

Observational model – A model whose main role is to aid in the observation of human movement.

Performance variable - A variable that consists of magnitudes for speed, velocity, acceleration and force in a spatio-temporal framework (based on Lees, 2002).

Phase analysis – or '*movement simplification*'. *"... the descriptive process of dividing up a movement into relevant parts so that attention can be focused on the performance of each part"* (Lees, 2002; p. 816).

Technical level – A measure that quantifies the technique used by the child according to how effective the technique is in attaining the performance criterion.

Technique variable – A variable that is used to describe either body posture or direction and range of movement in a spatial framework (based on Lees, 2002).

Chapter 2 - Review of literature

This review contains the following four parts: **1-** a review of research on **motor development** of the soccer kick, the overarm throw and the standing broad jump for maximum distance, and of general factors affecting motor development in children; **2-** identification of the **movement principles** that underlie effective kicking, throwing and jumping, and a review of the principal kinematic and kinetic **variables** that determine the performance criterion in the three motor skills; **3-** critical appraisal of existing **models** for the qualitative analysis of human movement; and **4-** a review of aspects of human **visual perception** and the **observation** of human movement. Thus, the review provides a basis for *the construction of a qualitative model for the analysis of mechanical effectiveness, and for the study of the development of movement effectiveness in children.*

Part 1 – A review of previous research on motor development of the soccer kick, the overarm throw and the standing broad jump for maximum distance, and of general factors affecting motor development in children

A number of previous studies have described the movements used by children in performing basic motor skills and documented the developmental pattern of such movements. However, the study of gender differences in development has only been carried out with regard to the overarm throw and the standing broad jump. Other research has outlined general factors that affect motor development in children.

1.1 The soccer kick - Descriptive studies

The skilled form of kicking has been described in the literature. Following cinefilm analysis, Plagenhoef (1971) produced a kinetogram (strobe-effect diagram) that represents the lower limb movement of proficient soccer players (Figure 2.1).

Figure 2.1: Kinetogram of the soccer kick (Plagenhoef, 1971; taken from Lees and Nolan (1998), p. 212).

Wickstrom (1975) observed that the mature form of kicking consisted of placing the supporting leg by the side of the ball and a certain distance behind it. The kicking leg produces a counter-movement by extending at the hip and flexing at the knee. The actual kicking action is initiated by rotation around the hip and bringing the upper leg of the kicking leg forwards. While the knee is still flexing at this stage, knee extension only occurs when the upper leg is decelerating towards the instant of ball contact. At contact the knee remains in a flexed position. The leg extends further throughout ball contact and flexes again during the follow through. Lees (1996) has suggested that, based on the descriptions by Wickstrom (1975), the mature form of the soccer kick skill may be divided into four distinct phases: the backswing, the forward rotation of the whole leg, the movement sequence during which the upper leg decelerates and the lower leg accelerates as a reaction, and the follow through. Descriptions of highly skilled performance have been used in sports technique analysis for comparative purposes (e.g., Arend and Higgins, 1976; Hay, 1993).

The developmental pattern of kicking has also been described in previous research. Barfield (1998) reported that kicking skill develops rapidly between the ages of 4 and 6 years in boys and girls, at which ages the relationship between age and kicking skill development for boys and girls shows a linear relationship (Butterfield and Loovis, 1993). Bloomfield, Elliott and Davies (1979) carried out cinematographical analysis of soccer kicking skill in 2-12 year olds; therefore, including both children who were in their early childhood, 'fundamental movement phase', and children in their later childhood, or 'sport skill' phase of motor behaviour (see Figure 2.2). Following comparisons to a form of mature kicking, subjects were classified into 6 groups. Table 2.1 summarises the main characteristics of the kicking action for the 6 groups identified.

Figure 2.2: The 'sport skill' phase of motor development (from Gabbard, 1992; p. 312).

Table 2.1: Classification and description of the soccer kick skill (Bloomfield *et al.*, 1979).

Elliott, Bloomfield and Davies (1980) grouped 2-12 year olds in terms of punt kicking skill level. The children were classified in 5 groups (5 developmental levels). Level 1 was characterised by the absence of run up. Backswing of the kicking leg was first observed at level 3 (mean children's age = 4 years, 8 months). Velocity of approach at ball contact increased from 0.35 m/s at level 1 to 1.78 m/s at level 5 (mean age at level 5 was 9 years and 9 months). Trunk angles changed from 'vertical' (level 1) to 'inclined backwards' (level 5) showing a progressive development across levels. Movement of the arm in opposition to the kicking leg was not seen until level 3. However, both Bloomfield *et al.*, (1979) and Elliott *et al.*, (1980) observed that not all children progress predictably through set levels of development. Gallahue and Ozmun (1995) have also outlined different stages in the development of the soccer kick (Figure 2.3).

Figure 2.3: Stages in the development of kicking (from Gallahue and Ozmun, 1995; p. 273).

Barfield (1998) stated that in unskilled players the action is dominated by the approach phase; while skilled players perform longer strides and show defined phases throughout the kick, and then temporal proximity of maximum hip extension and maximum knee flexion is closer. Children under 3 years of age tend to walk into the ball and at ages between 3 and 5 years do not perform any steps towards the ball. A paced run up is observed in children over 5 years of age, who start to produce a more diagonal approach. In the preadolescent years, maximum knee extension velocity increases progressively with age and the peak angular velocity corresponds more closely with ball contact. The facts that not all children follow fixed patterns of development and that there is intra-group variability in similar age groups have been confirmed by Barfield (1998), although most children follow a general developmental trend.

To sum up, descriptions of the mature form of kicking (i.e., Plagenhoef, 1971; Wickstrom, 1975) have been provided which may help to create idealised models of sound technique for comparative biomechanical analysis. The studies on the development of kicking by Bloomfield *et al.* (1979) and Elliott *et al.* (1980) are descriptive in nature and provide a good indication of expected stages in the development of the kicking movement in normal children. However, such developmental studies have relied heavily on mature models, which implies that children have been considered adults in miniature (Abernethy, Kippers, Mackinnon, Neal and Hanrahan, 1997), and were limited to a cross-sectional design, therefore presenting no longitudinal data. Also, the studies lack analysis of intra-subject variability in the execution of the kicking movement and of gender differences in the development of kicking. Most importantly, no comprehensive biomechanical analysis has been carried out to determine how effective the different kicking movements used by children are in attaining the performance criterion.

1.2 The overarm throw - Descriptive studies

1.2.1 The mature throwing action and the throwing action of adult females

The throwing action of proficient throwers has been described by a number of authors (Toyoshima, Hoshikawa, Miyashita, and Oguri, 1974; Hay, 1993; Haywood and Getchell, 2001). During the back swing the trunk rotates so that the throwing shoulder moves backwards, the throwing arm follows a circular downward trajectory. Body weight is shifted to the back leg. Then, there is a forward contralateral step, which is followed by sequential rotation of the trunk; whereby the pelvic girdle commences forward rotation while the shoulder girdle is still rotating backwards. The trunk flexes laterally to the side opposite to the throwing arm; such action increases the distance of force application. The humerus rotates forward at an angle of 90° to the trunk. The forearm is held at a 90° angle to the humerus during the swing, and it first lags behind the shoulder. When the shoulders reach the front-facing position the elbow is extended towards ball release. Following ball release, the force-generating movement is dissipated in the follow through. In contrast, Atwater (1970) observed that the average throwing pattern of adult females is similar to the less mature patterns seen in children. Generally, women moved more slowly and through a smaller range of movement (ROM) than skilled men. Notice the differences in step length, counter-rotation, lateral humeral rotation and elbow extension in Figure 2.4 below. In agreement, Leme and Shambes (1978) determined the degree of immaturity in the throwing action of adult women. The women participating in their study could not throw with a velocity higher than 15 m/s. These authors used a 1-10 stage-scale based upon previous models by Wild (1937). They found that 14.8 % of occurrences were at stage 3 of development and 81.5 % were at stage 7 of throwing development in adult women of average skill.

Figure 2.4: Movie film sequences of skilled man (left column), skilled woman (middle column) and average-skill woman (right column) at the end of back swing, 25 ms before release and just after release (Atwater, 1970; taken from Adrian and Cooper (1995), p. 356).

1.2.2 The development of the overarm throw in children

Various authors have described the developmental sequence of the overarm throw development (e.g., Wild, 1937, 1938; Roberton, 1978; Langendorfer; 1980). Wild (1938) first described the development of throwing behaviour in children using a whole-body approach and using age and gender characteristics as a reference. She observed 32 (2-12 year old) children and proposed four stages in the development of throwing:

Stage 1 - The throwing action is arm-dominated. The feet remain stationary. Sometimes the child may attempt to walk or step forward prior to the throwing action. Propulsion of the thrown object is achieved by lifting the arm either sideways or forwards. There are no rotational movements of the trunk or hips. Such throwing pattern was typical of 2 and 3 year old children.

Stage 2 – The child is able to integrate rotational movements in the transverse plane. The trajectory of the throwing arm is either horizontal or oblique above the shoulder. Propulsion is initiated by elbow extension, however rotary movements of the trunk are present. Stage 2 was observable in children of ages between 3.5 and 5 years.

Stage 3 - The child uses contralateral forward step (therefore with the foot opposite to the throwing arm). The direction of arm movement during the back swing is oblique and upward. During propulsion the arm movement is forward and downward, accompanied by forward trunk flexion. Stage 3 was observed in 5 and 6 year olds.

Stage 4 – This was the most proficient throwing stage in the children observed. The arm moves back and down during the preparatory phase. There is a forward step with the contralateral leg, and extensive trunk rotation and arm adduction prior to ball release. This stage was observed in most boys who were over 6.5 years of age. Comparatively, girls of the same age showed more immature throwing patterns. A similar whole-body classification of throwing based on three stages of development appears in Figure 2.5.

Figure 2.5: Three stages in the development of the overarm throw (Gallahue and Ozmun, 1995; p. 269).

In contrast, Roberton (1978) used a component approach and found that development may occur at a different rate for individual body segments (humerus, forearm and trunk). For example, arm action could be at stage 3 while trunk movement might still be at stage 2 in the same child. Subsequent studies have been carried out in order to validate this component theory (Langendorfer, 1980, 1987; Roberton and Langendorfer, 1980). More recently, Yan, Payne and Thomas (2000) evaluated the throwing performance of 3-6 year old girls using Roberton's component model (Roberton, 1977, 1978). Three-year-olds showed Level 1 in all movement components (i.e., no step, no backswing, no trunk rotation and only flexing the trunk, and no forearm lag and humerus oblique). The 6-year-olds showed Level 2 with trunk 'block' rotation, little trunk flexion, flexed elbow, humerus aligned but independent, and lack of forearm lag. However, Langendorfer (1980) found gender differences in development, whereby boys were generally at a more advanced stage than girls. The most recent research on throwing development (Langendorfer and Roberton, 2002) is concerned with the study of 'profiles', or the study of how the combinations of developmental levels that are observed across components change in the same children across trials within a single day and over time. Such type of analysis revealed both common and individual developmental pathways in the development of the overarm throw and it appears that *"within-person constraints eliminated certain movement relationships while encouraging others"* (p. 245). Some children followed common paths of development, while other children showed fairly unique paths. Langendorfer and Roberton (2002) found 13 distinct whole-body throwing patterns and their findings challenged the validity of Wild's (1938) developmental sequences.

1.2.3. Gender differences in the development of the overarm throw

No other motor skill shows greater gender differences in performance and rate of development than the overarm throw (Halverson, Roberton and Langendorfer, 1982; Hardin and Garcia, 1982; Nelson, Thomas and Nelson, 1991; Thomas and Marzke, 1992). These differences are not limited to children but persist into adulthood (see Figure 2.6). Halverson *et al.* (1982) estimated that girls in seventh grade lagged 5-6 years behind the throwing development of boys, and commented on the fact that boys reported greater participation and practice in throwing events. A detailed study on this topic is that of Nelson *et al.*, (1991), who analysed the longitudinal development in throwing performance for 52 boys and 48 girls. Subjects threw a small beanbag and the rating of trunk rotation was based upon a 1 (low)-to-3 (high) scale. At age 5 years, boys could throw the beanbag 8.4 m away and girls 4.8 m. Trunk rotation was 1.7 for boys and 1.1 for girls. The children were re-examined at age 8 years. Distance thrown had increased to 18.7 m for boys and to 8.8 m for girls. The boys's trunk rotation had increased to 2.9 and the girls's to 1.5. In terms of distance thrown, girls's performance was 31 % less than that of boys, when adjusting biological characteristics.

Figure 2.6: The overarm throw – Development and gender differences (from Thomas and Marzke, 1992; p. 64).

The descriptive studies on the overarm throw above have provided knowledge regarding gender differences in both the throwing performance and the development of the throwing action in normal children. The component approach to movement analysis has revealed the complexity of the developmental patterns in children. However, some studies have limited their analysis to measures of range of motion of selected body segments and have used product of performance, distance thrown, for the study of throwing development. Generally, the literature provides little information regarding the biomechanical nature of the movements performed by children. This calls on analysis of the link between the movement patterns observed in children and performance through biomechanical analysis of movement effectiveness.

1.3 The standing broad jump - Descriptive studies

The pattern of horizontal jumping has been extensively studied (Seefeldt and Haubenstricker, 1976; Wickstrom, 1983; Roberton and Halverson, 1984; Clark and Phillips, 1985; Keogh and Sugden, 1985). Gallahue and Ozmun (1995) stated that such complex movement requires coordination of all body parts and it is difficult for young children to constrain the tendency to step forward as in leaping. A developmental 3-stage sequence of horizontal jumping has been proposed by McClenaghan (1976; Figure 2.7).

Initial Stage - The arms fail to initiate the jump and there is limited swing. The amount of leg flexion during the preparatory crouch is inconsistent. During the flight phase the arms move in directions other than the sagittal plane to ensure balance. The trunk travels vertically rather than horizontally. The two feet do not produce a symmetrical movement/force-production pattern. The ankles, knees and hips are not extended fully at take-off. The child may fall or move backwards at landing.

Elementary Stage – The arms initiate the action, although they do not swing back during the preparatory phase. The preparatory crouch is deeper and more consistent. The arms still move laterally during the flight. There is larger extension of lower limbs at take-off. During the flight the hips and knees remain flexed in a fixed position.

Mature Stage – The arms swing backwards and upwards during the preparatory crouch, and forwards and upwards during the take-off. The preparatory crouch is deep and consistent. The arms remain high throughout the flight. The angle of take-off is of about 45° and the emphasis on distance rather than height. The lower limbs extend fully at take-off. During the flight the thighs travel parallel to the ground and the shank is perpendicular to the ground. After landing the centre of gravity moves forward.

Figure 2.7: The three stages in the development of the standing broad jump suggested by McClenaghan (1976); taken from Gallahue and Ozmun (1995; p. 252).

It is useful to note the developmental difficulties as listed by McClenaghan (1976), which include: improper use of the arms (particularly poor coordination with lower limb movement); twisting of the body; inability to perform a two-footed take-off; poor preliminary crouch; limited range of motion of arms and legs; too high an angle of take-off; incomplete extension of ankles, knees and hips at take-off; failure to extend the legs forward at landing, and backward movement of body weight on landing. 'Winging' action is a direct consequence of threatened balance, and being the most primitive arm action it can be seen in younger children (Hellebrandt, Rarick, Glassow and Crans, 1961). Some erroneous movement associated with normal development can be observed in Figure 2.8 below.

Figure 2.8: Differences in movement mechanics for three different children (A, B and C) (from Keogh and Sugden, 1985; p. 63).

Clark and Phillips (1985) hypothesised a developmental model for the arm and leg components of the standing broad jump. They tested the performance of 110 children aged between 3 and 7 years against a probabilistic model. Most children had more advanced leg action than arm action by one stage, although some children were two stages more advanced in one component. Gender differences in jumping performance have been reported by Hensley, East and Stillwell (1982), Morris, Williams, Atwater and Wilmore, (1982) and Davies (1990); although these studies found no significant differences between males and females's performance when adjusting biological characteristics. Finally, in a study of motor performance status in 10 to 17-year-old girls, increased standing broad jump performance was most pronounced between age groups 11 to 12 years; when mean length of the jump increased from 160 cm to 175 cm. Performance status stabilised from age 12 years (Loko, Aule, Sikkut, Ereline and Viru, 2000).

The descriptive studies on the standing broad jump reviewed above have suggested different stages in the development of jumping. Specifically, Clark and Phillips (1985) examined development using a component approach, revealing independent development for different body segments. However, only a few studies have examined gender differences in the normal development of this fundamental motor skill.

Moreover, no developmental study has been found in the literature that conducted detailed biomechanical analysis and commented on the effect specific movement patterns may have on the jumping performance of children.

1.4 General factors affecting motor development in children

In the study of motor development in children one must consider related developmental factors and not just the technical aspects of the movement. Such factors include the effects of somatotype, alteration of movement patterns due to practice, the changes in body dimensions throughout childhood, chronological and biological age, and the biomechanical changes associated with growth and development. According to Abernethy *et al.* (1997), children of the ectomorph and ecto-mesomorph type show greater participation in physical activity. Such extra participation results in the acquisition of movement patterns that show greater mechanical effectiveness compared to the movements of other children. For example, in throwing and striking activities children use greater back swings. This can be translated as larger distance over which the child performs work and, therefore, greater velocity of release. There is also greater pre-stretching of muscles and greater storage of elastic energy/pre-activation.

Abernethy *et al.* (1997) suggested that not all body dimensions change at the same rate, nor are the changes in body size during growth constant (Figure 2.9). For example, the arms, legs and trunk do not grow at the same rate. From birth to maturity the height of the head doubles, the height of the trunk increases by 3 times, that of the upper limbs by 4 times, and that of the lower limbs by 5 times. The growth of some limbs at different rate than others can cause technical disturbances in performing motor skills. As with body segments, body tissues do not grow at the same rate. The relative amount of muscle tissue increases during growth, indicating that the amounts of other tissues decrease.

Figure 2.9: Height and weight gain per year for normal children (Abernethy *et al.*, 1997; p. 81).

In addition, Clegg (1998) suggested that while bones and muscles are still growing they are mechanically inefficient, making it difficult for the child to perform motor skills. Females are likely to show signs of growth spurt, or phases in which the growth of the child speeds up for a while, earlier than males. As they reach the growth spurt, previously well-coordinated children may show poorer coordination at performing motor skills (Davis, Bull, Roscoe and Roscoe, 1994). In contrast, Leon-Pérez (1984) has pointed out that phases of fast physical growth (weight and height) of the child can provide a temporary advantage in sports situations (greater strength), although children may also show phases of retardation in development. In any case, chronological age is a convenient reference in the study of motor development. However, using chronological age can conceal individual characteristics regarding the functional and morphological development of the child. Rapid changes in the size and strength of bones and muscles during growth spurts result in declines in motor performance requiring strength, power and co-ordination (Abernethy *et al.,* 1997). There are two reasons for the temporary decrease in performance. The *first* is that the increase in moment of inertia of segments causes clumsiness; and the *second* is that increases in muscle size and strength are often delayed relative to skeletal growth, therefore making it difficult to perform in activities that require strength and power.

In sum, the studies included in Part 1 of this review have described the mature kicking, throwing and jumping actions observed in proficient performers and the patterns of motor development of these three motor skills observed in children. Generally, the developmental patterns are characterised by non-linear development, since children show periods of rapid development as well as periods of delayed development. Not all children develop predictably at the same rate, and different components of the movement may develop at different rates in the same child. A few studies have used, almost exclusively, measures of the performance criterion as indicators of motor development, while other studies have provided key kinematics that may be associated with the performance criterion and that can be used for the study of motor development. Moreover, little is known about the development of the soccer kick in girls, whereas considerable gender differences in throwing performance and development, that persist into adulthood, have been reported. Gender differences in standing broad jump performance are virtually non-existent when adjusting biological characteristics. Further, previous research presents very limited longitudinal data; where the experimental designs are usually cross-sectional. Similarly, little assessment of intra-subject variability has been carried out that may provide an insight into the variability of the movement patterns in children. Therefore, the review of literature above suggests that a greater understanding of the mechanical nature of kicking, throwing and jumping can be attained by conducting biomechanical analysis of the effectiveness of the movements in attaining the performance criterion. Assessment of gender differences in development necessitates the use of both cross-sectional and longitudinal experimental designs. Also, assessment of within-day intra-subject variability can be used to explore the fluctuations in the motor development of individual children. Such knowledge may be of use to the coach and PE teacher to understand the performance capabilities of children and help identify erratic movement or abnormal development in children. Notwithstanding, general factors that affect motor development in children including the effects of somatotype, amount of practice, biological age, and the biomechanical changes associated with growth need to be considered in the interpretation of developmental findings. A review of the movement principles and variables pertinent to the three motor skills follows.

Part 2 – Movement principles, kinematics and kinetics of the three basic motor skills

This section incorporates descriptions of the mature form of the movement for each of the three motor skills using movement principles. A review of controversial aspects of biomechanical principles is also included, as well as the identification of variables that are directly related to performance in the three motor skills.

2.1 The movement principles associated with the 'mature' forms of kicking, throwing and jumping

The term *movement principle* encompasses both mechanical and biomechanical principles. Definitions of the terms *mechanical principle* and *biomechanical principle* have been provided in the Glossary (p. 6). In the past, movement principles had been outlined using generalised theoretical statements that describe optimum movement patterns so that the principles could be applied for coaching purposes. In their groundbreaking work, Broer (1966) and Bunn (1972) listed generalised mechanical principles and suggested that optimum performance arises from the application of such principles. The list of principles is extensive and includes statements such as: *"In throwing, jumping, or kicking activities where the horizontal distance is the goal, the body or the object should be projected at an angle of approximately, but not greater than 45°."* (Bunn, 1972; p. 37) and *"In general, force should be applied as directly as possible in the direction of intended motion so that as much of the force as possible can be utilized as effective force (parallelogram of forces)."* (Bunn, 1972; p. 71). While there is a great deal of logic behind such statements, detailed analysis of the techniques used by athletes reveals that, for example, discus throwers and long jumpers use angles of release and takeoff, respectively, well below 45° (Hay, 1993). Although, Bunn (1972) acknowledges the limitations of using mechanical principles, more recent research (Putnam, 1983; Sprigings *et al.*, 1994; Winter, 1997; and Lees, 1999a) suggests that the application of mechanical principles for the study of human movement requires experimental testing to determine the mismatch between predictable rigid body mechanics and human movement biomechanics. Another criticism of the work of Broer (1966) and Bunn (1972) is that they often provide examples of sound technique based on the observation of proficient performers, however explanations as to how the 'transfer of momentum' or 'conservation of momentum' principles are carried out by such performers during the actual movement are rather limited. Nevertheless, an in-depth understanding of the principles underlying optimum movement is invaluable for the analysis of movement effectiveness. Recently, Lees (1999b) provided a classification of movement principles (mechanical and biomechanical) and presented them in a user-friendly format for their use by sports coaches.

2.1.1 The soccer kick

According to Bunn (1972), in the kicking action, the forward momentum of the body develops from the step or run up. This momentum is transferred to the ball (Bunn presumably refers here to the impulse-momentum relationship and conservation of momentum principle; while the main advantage of a run up may lie in facilitating the opening out of the hip). The leg is swung in a line that corresponds to the desired flight of the ball (this would not apply during a curved approach). The foot is held at right angles to the shin (but this would not apply in an instep kick) to prevent any recoil action (Newton's 3rd law) and related loss of force. Placing the non-kicking foot about 15 cm back and to the side of the ball allows motion of the kicking leg in the direction of the kick and a desired angle of ball projection. Keeping the head down or forward allows the momentum of the body to continue through the kick (Bunn (1972) does not explain the mechanisms that enable the body to continue through the kick; although one can speculate that the head merely reacts to the forward-upward swing of the kicking leg).

The explanations of Bunn (1972) regarding why the kicking action of proficient soccer players looks the way it does can be challenged through more detailed knowledge of the kicking action. More recent research represents a departure of the generalised application of mechanical principles and provides greater detail of analysis. Kreighbaum and Barthels (1996) stated that each part or phase of the movement has its own mechanical purpose that may be different to the overall performance objective. Therefore, mechanical purposes "*usually involve the identification of what one wants to achieve during that phase of the performance*" (p. 305). Wang and Wiese-Bjornstal (1994) and Wang and Griffin (1997) have explained the mechanical principles underlying effective kicking for each phase of the soccer kick. The purpose of the approach is to increase running speed, and therefore forward momentum. During this phase the player should adopt normal steps, however the last step of the approach should be very long to enable the kicking leg to swing over a large range of motion. The underlying principle is 'duration of force application'; whereby the foot develops greater acceleration as the distance over which muscle forces are applied increases. Nonetheless, Wang and Wiese-Bjornstal (1994) have stated that *"a smooth and flowing kicking action will produce a greater final momentum than a jerky swing because there is less inertia against the action"* (p. 35). The supporting foot should be placed by the side of the ball. This distance is usually 5-15 cm depending on how tall the player is. Regarding forward or backward distance to the ball, *"if the foot is too far forward, there is no sufficient time to build momentum before making contact with the ball. If it is too far back, the peak force of the kick will be spent before contact is made"* (p. 35). The sequential movement of the kicking leg segments results in the summation of forces and optimal angular velocity of the foot at contact. For optimum transfer of momentum the foot should contact the ball when it is at the bottom of the arc. This can be accomplished by a correct position of the support leg; whereby the foot is planted by the ball, the knee remains flexed, and body weight is shifted onto the support leg for stability.

Further, according to Wang and Griffin (1997) lateral inclination of the body contributes to balance and allows the leg *"to have a smooth swinging motion"* (p. 55). The muscles of the support hip, knee, and ankle co-contract to provide stability and balance. Further stability can be achieved by lowering the centre of gravity. During the swing phase, the principle is to develop large momentum of the leg; however, while the velocity factor can be manipulated by the player, the mass of the leg does not change. For effective transfer of momentum the kicking force should be applied, as much as possible, in the intended direction of the motion, *"with the kicking leg swinging from straight back to straight forward"* (Wang and Wiese-Bjornstal, 1994; p. 36). During the follow through the player should avoid the tendency to decelerate the leg abruptly before the kicking action is completed, otherwise the consistency of muscular contractions during the swing phase and the direction of the ball after impact will be negatively affected.

Further, Lees and Nolan (1998) explained that three mechanisms can affect performance during the kicking movement. The **first** involves the *"use of interacting segments to aid the end-point velocity of the system (the foot)"* (p. 217). Therefore, during the backswing the knee is restrained from extending. When the lower leg is released it starts rotating forward resulting in a large radius of rotation of the foot. This translates into increased tangential or linear velocity of the distal segment (the foot). Lees and Nolan

(1998) highlighted the importance of timing or movement co-ordination in this action in order to produce a well-executed kick, since the angular velocity of the shank can be enhanced by slowing down or even reversing the movement of the thigh. Similarly, Barfield (1998) stated that good coordination differentiates skilful from unskilled players, and that as skill develops the greater foot velocity is due to increases in knee extension velocity without similar increase in hip flexion velocity. Barfield (1998) has explained the traditional belief that decreased angular velocity of the thigh during the swing results in acceleration of the shank and foot due to a momentum shift and the active role of elastic and contractile knee extensor components. However, such a claim has not been confirmed and the decrease in thigh angular velocity may be caused by the actual shank motion (based on Dunn and Putnam, 1988, and Putnam, 1991). More recently, DeWitt (2002) has suggested that it is possible that both mechanisms occur. The **second** mechanism that may lead to increased angular velocity of the shank is the stretch-shortening action which, compared to using concentric muscular contraction alone, can increase rotational velocity of the lower leg by 21% (Bober, Putnam and Woodworth, 1987). The collision or impact between the foot and ball is the **third** mechanism identified by Lees and Nolan (1998) as important to performance. The effective striking mass, or rigidity of the limb during ball contact, may contribute to the effectiveness of the kicking movement. However, mechanical characteristics of the foot and ball (foot deformation and coefficient of restitution, respectively) need also to be considered. Whether such parameters, foot and ball deformation, can be measured qualitatively from video recordings is a matter for consideration.

Finally, good coordination (a term not easily defined; Hudson and Hills, 1991) in any movement, including the soccer kick, has been linked to optimum performance: *"An individual is said to show good coordination when he moves easily and the sequence and timing of his acts are well controlled. This essential element of motor performance is not readily measured objectively although high achievement in any event implies good coordination."* (Espenschade and Eckert, 1967; p. 165). Coordination has occasionally been determined quantitatively in past research (e.g., Marqués-Bruna and Grimshaw, 2000).

The studies above have outlined some of the movement principles that underlie effective kicking and provide an understanding of the logic and mechanical make up of proficient movement. Nonetheless, Lees (1999a) and Hong, Cheung and Roberts (2001) have warned against the application of traditional principles of mechanics formulated before the advent of 3-dimensional high-sampling-rate biomechanical analysis. Also, Viitasalo (2003) (personal communication) pointed out that the application of mechanical principles for improved sports performance can only be carried out within the anatomical and biomechanical constraints of the individual.

2.1.2 The overam throw

In the present research, special attention is given to the motor skill of kicking in order to demonstrate how a qualitative model for the analysis of mechanical effectiveness can be used for the analysis of motor skills. Consequently, less detail of the throwing and jumping skills is presented in this review. Bunn (1972) has explained that throwing involves linear and angular motion. Examples of linear movement include forward steps, forward trunk lean, and forward forearm and wrist movement. Rotations occur along the trunk and about the throwing shoulder. The overall mechanical principles are range of motion and end-point speed. Rhythmic co-ordinated movement of body segments must be performed optimally. As the thrower steps forward, the backward rotation of the throwing arm begins. The further the arm goes back the longer will the arc of movement be (Plagenhoef (1971) had also explained that maximal velocity of throwing involves a full motion of body segments). The speed developed during the final steps serves to generate forward momentum of the thrower, under the principle of 'whole-body running speed' (principle outlined by Lees, 1999b). Such momentum is transferred to the ball in a series of sequential movements following final forward-foot plant. Body segments rotate in sequence in a way that distal segments first lag behind with respect to proximal body segments. The result is a gradual increase of velocity culminating with the wrist snap at release. In fact, Atwater (1979) reported that the sequence of segments reaching peak angular velocity in skilled throwers was pelvis, upper trunk, upper arm, forearm and hand (see also Figure 2.10). Since the hand remains behind the elbow during most of the propulsive phase, the ball is in reality being pulled during the movement. Release occurs when the hand reaches a position forward and above the head. During the follow through phase forces are no longer applied to the ball, although a proper follow through allows the development of maximum force during the previous phases of the throw and also the application of force in the right direction to increase accuracy. The follow through is carried out by applying relatively small forces over a long time (according to Newton's 2^{nd} law, in this case deceleration, and the impulse-momentum relationship) in order to allow for the dissipation of forward momentum and, therefore, avoid strain and injury to the elbow joint.

Figure 2.10: The summation-of-speed principle in the overarm throw (taken from Abernethy *et al.*, 1997; p. 171).

In summary, the aforementioned authors have described the throwing action with reference to movement principles that allow effective overarm throwing. However, although well-coordinated linear and angular motions over a large range of movement are a necessity for an explosive throwing action, identification of the movement principles alone does not help to determine what are the optimum kinematic and kinetic values for individual performers or, in the case of the present research, children of different ages for the study of the development of throwing.

2.1.3 The standing broad jump

According to Bunn (1972) the initial back swing serves to attain a rhythm of movement before the jump. Most importantly, the preliminary swing places the arms in a position that allows a forward swing through as large an arc as possible, allowing greater momentum from the arms motion to be transferred to the body (here Bunn (1972) may be referring to the increased impulse of the ground reaction force the forwards and upward swing of the arms produces prior to takeoff). At the instant of take off the arms are held high above the head so that a maximum effective arc of arm swing is attained. The amount of crouch before takeoff should be proportional to muscle strength. The take off should be at 45° allowing the highest position of the body's centre of gravity. Taking off from the toes permits application of force for the greatest possible distance. In mid flight the legs should be bent with the heels almost touching the buttocks, therefore creating minimum moment of inertia for a fast forward rotation of the legs. Near touchdown the arms should be brought down and back with the effect of elevating the feet a bit further as a reaction (Newton's 3rd law) for a maximum forward reach. At landing, the arms should come forward to provide forward momentum to the rest of the body and keep the centre of gravity travelling along the arc of flight. This landing pattern helps to dissipate the shock of landing by increasing the distance over which forces act. All movements need to be performed in the sagittal plane, since movement in any other direction dissipates force and reduces the length of the jump. Studies on the vertical jump have emphasised the importance of arm countermovement in order for the performer to apply the maximum impulse principle (Chen, Liu, Huang, Lin and Chen, 1999). Greater velocity of takeoff is attained by greater peak ground reaction force and a higher rate of ground reaction force development, rather than a longer takeoff phase. Arm countermovement and swing may play a similar role in the standing broad jump.

The standing broad jump has received less attention than the study of the soccer kick and the overarm throw, despite being considered a basic motor skill and its popularity as a test of motor performance. However, Bunn (1972) has explained the actions and the mechanisms that allow highly-skilled performers to attain maximum-distance jumps. Therefore, any movements associated with the jumping action observed in children that represent a considerable deviation from the proficient jumping action can be assessed with reference to appropriate movement principles.

2.1.4 Particularities of biomechanical principles

The research above has outlined the mechanical and biomechanical principles that apply to the three motor skills. However, while Newtonian principles of mechanics describe a predictable behaviour, some studies have discussed the idiosyncrasies of biomechanical principles. One such set of biomechanical principles is that regarding the different **acceleration patterns**. From empirical analysis (Hochmuth, 1960) it is clear that maximal force can be developed by the performer for only a short time and cannot be maintained from the beginning to the end of the acceleration path. Hochmuth (1960) highlighted the biomechanical principles involved in accelerating an object in two different ways. According to Figure 2.11, acceleration will be small initially and fast later in no-rebound jumps. However, in rebound jumps the greater acceleration is expected at the beginning of the positive work phase.

Figure 2.11: Ground reaction forces during rebound (RJ) and no-rebound (NRJ) jumps (Hochmuth, 1960; in Asmussen and Jorgensen (1977), p. 97).

Also, when projecting a light object the faster acceleration of countermovement action may have a more appropriate result. For example, baseball pitchers use a countermovement while shot putters do not (Hof, 1997). Such principles of acceleration suggest, however, that each individual performer needs to fine-tune their technique to attain their optimum acceleration pattern. For example, Aragón-Vargas and Gross (1997a) reported kinesiological factors involved in the standing vertical jump. Jumpers could maximize take off velocity by maximizing average force applied to the centre of mass, by maximizing the distance over which force is applied, or by finding a compromise between these two. Since jumpers show differences in body mass, the performer could maximise average vertical acceleration, they could maximize the time over which acceleration is maintained, or again could find a compromise. Such technical differences are due to the differences between individuals to develop force (Figure 2.12).

Figure 2.12: Force-time histories of two different performers, A and B (from Zatsiorsky, 1995; p. 36).

A second biomechanical principle presenting specific peculiarities is that of **stretch-shortening cycle**. Winter (1997) discussed the role of the three stretch-shortening mechanisms to improve concentric contraction as a result of prior eccentric contraction. The *first* and most important mechanism is that preceding eccentric movement allows more time for muscle activation before the actual concentric movement occurs. For example, the counter-movement action of a jump can be enhanced by the active state of the cross-bridges at the beginning of positive work (Bosco, 1997). It must be noted that activation, as indicated by electromyographical activity, is different to muscle tension (there is a 80-100 ms electromechanical delay). The *second* mechanism is known as reflex facilitation. Reflex delays or latencies need to be of the right duration to recruit extra muscle fibres when the muscle changes from eccentric to concentric action. The *third* mechanism involves the storage of elastic energy. However, it is possible that after the first 100 ms of the eccentric movement the cross-bridges start shortening the elastic components of the muscle. This will happen before the concentric phase. Only if the elastic elements remain stretched will they have the potential to transfer energy during the concentric phase. In any case, energy is lost through elastic hysteresis and the muscles must regain the elastic energy that has been lost as heat (Ingen Schenau, Bobbert and Haan, 1997).

Thus, according to Winter (1997) the storage and utilization of elastic energy are not the only factors that enhance skeletal muscle performance during stretch-shortening cycle movements, but pre-activation and reflex facilitation too. Komi and Gollhofer (1997) outlined the requirements for effective stretch-shortening cycle activity:

1. a well timed preactivation of the muscles before the concentric action
2. a short and fast eccentric movement
3. an immediate transition between the stretching phase and the shortening phase

The work of Ingen Schenau *et al.* (1997) concluded that countermovements most benefit persons with a high percentage of slow twitch fibers. However, Goubel (1997) considered the role of muscle fiber type more complex, and suggested that the precise amount of energy stored is directly related to the stiffness of the elastic elements, where fast-twitch and slow-twitch fibers may have difference elasticity. Some authors (e.g., Wilson, Wood and Elliott, 1991) have highlighted the benefits of flexibility training to enhance elastic energy storage. However, an increase in muscle stiffness is beneficial for two reasons: 1- during stretching, more potential energy can be stored since force will rise rapidly; and 2- during shortening, the shortening component is not affected by a compliant elastic component.

A third biomechanical principle showing oddities is that of **force-velocity relationship.** Bosco and Komi (1979) suggested that individuals may not be limited by fibre type but they may use different coordination strategies that allow them to act at a more advantageous section of the force-velocity curve (Figure 2.13; notice also that peak power occurs at around 30% of maximum shortening velocity). This permits producing in fact a lower muscle-fiber shortening velocity for a given joint angular velocity, therefore allowing the muscle to generate more force. For example, it has been highlighted by Bobbert and Ingen Schenau (1988) that subjects use different techniques to perform the vertical jump. This leads to differences in peak mechanical power developed, while the actual jump height and external work done remain unchanged. Therefore, it is reasonable to suggest that adjustments in vertical jump technique can make up for decreased power output. Similar adjustments may take place in the standing broad jump.

Figure 2.13: Relationships between force, velocity and power (from Newton and Kraemer, 1994; p. 21).

Fourth, the singularities of the **proximal-to-distal activation** of muscle groups and sequence of joint reversal have been discussed by a number of authors. Bobbert and Ingen Schenau (1988) reported that not all individuals display a proximal-to-distal sequence of muscle activation and joint reversal. Later, Aragón-Vargas and Gross (1997b) found that in some trials of the vertical jump a pattern of hip-ankle-knee sequence of joint reversal was observed. With regard to the peak velocity differences between proximal and distal ends for each segment, the worst subject and average subject showed a proximal-to-distal pattern. Comparatively, the best jumper did not display this pattern. The results of the study by Aragón-Vargas and Gross (1997b) suggest that the ideal sequence is not necessarily a proximal-to-distal sequence but that in which hip joint reversal occurs before other joints reversals. A reasonable mechanism has been proposed that involves co-contraction of the flexors and extensors in a position that locks the leg in place and allows for maximal tension. Such tension is suddenly released by the relaxation of the flexor muscles. In the vertical jump, it is possible that when the trunk and hip extend upwards their large mass places a load on the knee extensors and ankle plantar flexors. This allows a static development of tension at the knee and ankle extensors. Such tension is released suddenly when actual extension occurs. This mechanism may also be present in the standing broad jump.

In the context of proximal-to-distal activation it is worth reviewing the **role of bi-articulate** or **two-joint** muscles in the development and transfer of power. Proper application of the proximal-to-distal activation principle involves optimum concurrent activation of single- and two-joint muscles. Enoka (2002) has outlined the advantages of two-joint muscles in musculo-skeletal control, and thus the redistribution of muscle torque and joint power across adjacent joints. First, two-joint muscles produce concurrent motion at the two joints they cross and this is useful to refine the coordination of movement. Second, when two-joint and single-joint muscles act synergistically, the shortening velocity of the bi-articulate muscle is less than that of the single joint muscle. *"For example, the shortening velocity of rectus femoris (two joint) during concurrent hip and knee extension is less than the shortening velocity of the vasti (one joint)"* (p. 318). Such lower velocity of the two-joint muscle allows greater application of force according to the force-velocity relationship. Third, the role of two-joint muscles in redistributing muscle torque and joint power between two adjacent joints is beneficial to reduce net torque at one joint (co-activation with an antagonist) but to increase net torque (concurrent activation with a synergist) at the other joint for different phases of the movement. For example, in Figure 2.14 activation of the hamstrings (muscle 6), together with activation of the gluteus (1) and vasti (3) fixates the knee and increase the net torque at the hip. This facilitates a sequence of proximal-to-distal muscle activation in a closed-kinetic chain typical of the standing broad jump.

Figure 2.14: A leg model showing muscles around the hip and knee (adapted from Ingen Schenau, Bobbert and Soest, 1990; in Enoka (2002), p. 318).

Another characteristic of two-joint muscles that has implications for the refinement of technique in sports movements is the fact that two-joint muscles, unlike single-joint ones, may stretch beyond 160% of their resting length. Certain body postures result in greater muscle length and, therefore, greater muscle tension can be developed (McGinnins, 1999).

To sum up, section 2.1 of the review of literature provides an explanation of why the mature forms of kicking, throwing and jumping look the way they do through the application of movement principles. A review of the particularities of biomechanical principles has been included that puts in evidence the complexity and individuality of human performance. Analysis of mechanical effectiveness in children requires, ultimately, the identification and observation of the critical features (observable kinematic and kinetic variables) of the movement in order to evaluate to what extent the movement of the child conforms to the underlying movement principles.

2.2 Kinematics and kinetics of the kicking, throwing and jumping movements

In order to gain an in-depth understanding of the biomechanical nature of the three fundamental motor skills included in the present research it is necessary to review the kinematics and kinetics from previous studies. In addition, typical kinematic and kinetic values, not only from proficient performance but also from children of different ages, can be used as a guide in the construction of rating scales for the purposes of qualitative biomechanical analysis and the study of motor development.

Identifying which variables need to be measured in order to carry out diagnostic analysis and help athletes improve their performance has been described as *"probably the most difficult task for the biomechanist"* (Lees, 1999a; p. 300). Three approaches have been used to identify the key movement variables that are directly related to performance which, according to Lees (1999a), include: **1-** relationships between measurement variables and performance; **2-** relationships with performance using a theoretical framework; and, **3-** association between movement variables and performance by means of statistical analysis. Moreover, the issue of relative importance amongst selected variables has been addressed in numerous studies (i.e., Hay, Miller and Canterna, 1986; Takei, 1992; Sanders, 1999; Greig and Yeadon, 2000). Greig and Yeadon (2000) and Knudson and Morrison (2002) commented that the correlation values obtained from studies that use a large number of athletes fail to represent any one individual athlete and this makes it impossible to determine an ideal form of movement. However, Knudson and Morrison (2002) put forward that biomechanical research might be able to determine a range of desirable form, or "*range of correctness for the critical features*" (p. 81).

2.2.1 The soccer kick

The review of key kinematic and kinetic variables below helps to gain a detailed understanding of the soccer kick movement. The first consideration to bear in mind is that the soccer kick is a 3-dimensional movement; as shown in Figure 2.15 below taken from Levanon and Dapena (1998; p. 920).

Figure 2.15: Sequence of the mature full kick action from 3 viewing positions (sequence is from toe off (a) to impact (i)).

Stationary vs. running approach

The differences between a stationary and a running approach in the maximal instep kick were investigated by Opavsky (1988). When using a stationary approach, maximum ball velocities were 23.5 m/s compared to mean velocities of 30.8 m/s achieved when using a 5-to-8-stride running approach. Lees and Nolan (2002) reported mean approach speeds for two professional soccer players of 3.32 and 3.46 m/s under speed kicking conditions. The relevance of measuring speed of approach is evident from the study by Opavsky. What the optimal speed and distance of approach are, appear to be questions not yet addressed by sports biomechanists (DeWitt, 2002).

Straight vs. angled approach

Highly-skilled soccer goalkeepers may prepare to produce a long distance kick by allowing for an angled approach to the stationary ball. Isokawa and Lees (1988) studied the effects of using different angles of approach to the ball using a one-step approach from angles of 0, 15, 30, 45, 60 and 90°. The trend of the data showed that an angled approach of 30° produced the greatest maximum swing velocity of the leg, whereas an angle of 45° resulted in the maximum ball velocity attained. Isokawa and Lees (1988) attributed the faster ball velocity when using a 45° approach to the increased striking mass this approach enables, or the greater fixation of the knee and ankle joints of the support leg. Plagenhoef (1971) had earlier observed that a diagonal approach resulted in greater ball velocity than a straight approach. The balancing effect created by the active torque of the leg and that of the body that results in increased leg and foot momentum in an angled approach of between 40° and 60° has been explained by Barfield (1998).

The length of the last step

According to Wang and Wiese-Bjornstal (1994), "*a large and speedy final approach step is the central mechanism for the approach phase*" (p. 35). A long last step allows a large range of motion of the kicking leg and, therefore, a large distance over which force can be applied. Lees (2000) explained that a long last stride facilitates the opening out of the hips near the instant of foot placement. Other authors have also associated a long last step with large range of motion and optimum placement of the support foot (Opavsky, 1988; Hay, 1993; Wang and Wiese-Bjornstal, 1994). From a developmental point of view, Bloomfield *et al.* (1979) reported the onset of a curved approach, which incorporates a long jumping step and a complete backswing, at age 9 years in children. Nonetheless, the literature provides no data regarding this important kinematic variable.

What happens during the backswing phase?

Barfield (1998) stated that during the backswing the kicking foot reaches hip level, and Robertson and Mosher (1985) had earlier reported that the hip flexors and knee extensors showed negative power to halt the backswing, therefore becoming eccentrically stretched. In proficient performers, the opposite arm produces horizontal abduction followed by horizontal adduction across a large arc during the backswing and swing phases, respectively. However, very few studies have paid attention to this technical component of the kick, although the contribution of the opposite arm to kicking effectiveness has been described by Lees (1999a). The horizontal abduction of the opposite arm balances the backswing action of the kicking leg according to the mechanical principle of action-reaction (a coordination principle). Typical angular displacements of the kicking knee and hip in highly-skilled performers have been provided by Plagenhoef (1971). But more recently, Browder, Tant and Wilkerson (1991) and Levanon and Dapena (1998) reported 3-dimensional kinematics of the hip and knee joints (Figure 2.16; sequence shown is from take off of the kicking foot to ball contact).

Figure 2.16: Angular displacement in 3 directions of the pelvis, hip and knee. For the pelvis, negative values correspond to external rotation; for the hip, positive values correspond to flexion; and for the knee, negative values correspond to flexion (adapted from Levanon and Dapena, 1998; p. 924).

Foot placement

Descriptions of the mature form of the soccer kick have indicated that the supporting leg should be at the side and a certain distance behind the stationary ball (Wickstrom, 1975). Bloomfield *et al.* (1979) reported foot placements of between 14 and 38 cm behind the ball in children of ages 2-12 years, although there was no relationship between foot placement distance and age of the children. Wang and Wiese-Bjornstal (1994) have suggested that the supporting foot should be placed 5-15 cm depending on how tall the player is. Lees and Nolan (1998) have explained that the distance of foot placement is dependent on the type of kick and also whether the trajectory of the ball is intended low or high. Bunn (1972) had earlier stated that placing the non-kicking foot about 6 inches back and to the side of the ball allows motion of the kicking leg in the direction of the kick and a desired angle of ball release. Further, the kicking leg contacts the ball after passing the shank vertical position, therefore when the foot velocity is greatest. Barfield (1998) pointed out that most research considers an optimum foot position 5 to 10 cm to the left of the ball, and that unskilled players tended to place the support foot behind the ball, perhaps due to task and environmental constraints. Nonetheless, Lees and Nolan (1998) pointed out the need for further research in this area.

Inclination of the trunk and body

Extension and flexion of the trunk in the sagittal plane is an observable component of the mature kicking action. Back trunk lean has been associated with a high trajectory of the ball after contact (Parassas, Terauds and Nathan, 1990). Bunn (1972) stated that after ball contact the head is kept down and the trunk flexes forward in order to continue the momentum of the body into the follow through. *"If the head is raised, some force is lost, ..."* (p. 162). Wang and Wiese-Bjornstal (1994) and Wang and Griffin (1997) have explained the role of the lateral body inclination in enhancing balance. Lees and Nolan (2002) have reported backward trunk inclination of up to 25.9° and lateral, to support foot side, trunk inclination of up to 16.4° in two professional soccer players, although the kicks performed were not for maximum distance.

Opposite arm and kicking leg motion during the swing phase

Horizontal adduction of the opposite arm and adduction velocity may be regarded as important aspects of effective kicking technique (based on Lees, 1999a). The opposite arm balances the forward swing of the kicking leg according to the principle of action-reaction. Similarly, forward trunk flexion during the swing phase is thought to also balance the leg swing, although in the sagittal plane (Bunn, 1972). The importance of the sequential timing of segmental movement has for long been recognised (Zernicke and Roberts, 1978; Aitcheson and Lees, 1983; Bober *et al.*, 1987; Luhtanen, 1988, Putnam, 1991; Lees, 1996). However, while the kinetics of opposite arm horizontal adduction have been documented, no kinematics have been reported in the literature. The angular velocity pattern of the kicking leg segments is shown in Figure 2.17. However, whether critical variables of the swing phase can be perceived by the observer during qualitative analysis and subjectively quantified using qualitative descriptors is a matter of concern. The importance of pelvic rotation in producing high-speed kicks has also been emphasised (Browder *et al.*, 1991). Lees and Nolan (2002) have explained that opening out of the hips increases hip-to-shoulder separation angle conforming to the principle stating that *"increased end-point speed of a limb (e.g., the foot) can be achieved by using a greater range of motion at the joints"* (Lees and Nolan, 2002; p. 20).

Figure 2.17: Angular velocity of the leg segments at four different stages of the swinging action (from Reilly, 1996; p. 126).

Related to ball velocity, the angular velocity of knee extension has been a matter for research. Elliott *et al.* (1980) reported values of 17.7 rad/s at age 4.6 years, which increased to 28.0 rad/s at age 9.9 years (punt kicking). For boys aged 8 years the mean value recorded was 17.6 rad/s (Day, 1987). Maximum angular velocity of the shank at impact in adult male soccer players was 30.5 rad/s, which yielded a maximum linear speed of the foot of 20.3 m/s (Dorge, Andersen, Sorensen and Simonsen, 2002).

At ball contact

A number of authors have described the contact technique of proficient soccer players (e.g., Levanon and Dapena, 1998; Lees and Nolan, 2002). The kicking knee remains in a flexed position at contact in order to prolong contact time and, therefore, the impulse applied to the ball. Rodano and Tavana (1991) reported angular positions of the lower limb at ball contact in professional football players as follows: hip flexed at 8.6° ± 7.1; knee flexed at 41.1° ± 8.6; and ankle plantar flexed at 27.1° ± 10.2 (angles represent deviations from standard anatomical position). Actual contact time (between 6 and

16 ms) has also been measured in previous research (e.g., Asami and Nolte, 1983; Tsaousidis and Zatsiorsky, 1995) in relation to impulse. Placement of the non-kicking foot may influence the configuration of the kicking thigh and lower leg at the point of ball contact and also the magnitude and timing of power flow from the upper to the lower leg segment (Aitcheson and Lees, 1983).

The follow through action

The velocity of the ball and flight trajectory are observable after impact, and therefore may be analysed within the follow-through phase. Lees and Nolan (1998) have reported that for experienced soccer players maximum velocity of ball release is in the range of 20-30 m/s. When devising a rating scale to measure the movement of children, one needs to be aware of the kinematics obtained from children of various ages. For example, the maximum velocities of ball release in children aged 8-14 years was between 12.0 and 12.5 m/s (Day, 1987). Bunn (1972) and, later, Parassas *et al.* (1990) suggested that the trajectory of the ball flight might be related to the amount of backward inclination of the trunk, where trunk inclination allows a higher trajectory due to a lower placement of the boot under the ball. Wang and Wiese-Bjornstal (1994) have suggested that the follow through allows accuracy of the shot by achieving desired direction, whilst maintaining full kicking force. Tsaousidis and Zatsiorsky (1995) have also provided support for the use of a follow through since it increases the mechanical work of the muscles during ball contact. When the follow through is restricted a 'chopping' or 'punching' action results. The follow through action has been described by Lees and Nolan (1998) as one of hip flexion and thigh elevation; where, eccentric knee flexor activity is already present before ball contact which acts mainly as an injury-prevention mechanism (Robertson and Mosher, 1985).

The most influential kinetic variables

Although kinetics do not lend themselves very well to subjective qualitative analysis, it is important for the analyst to have a general understanding of how forces are applied, and of their magnitude and direction during the soccer kick. Studies of kicking kinetics have helped to understand the intricacies of the kicking movement (e.g., Luhtanen, 1988; Barfield, 1995; Nunome, Asai, Ikegami and Sakurai, 2002). Luhtanen (1988) explained that the linear velocity of the rotating foot is a function of the angular velocity and the radius of rotation, where the leg segments show resistance to rotation in proportion to their moment of inertia. Luhtanen (1988) depicted the direction of joint forces at three specific instants of the kick (Figure 2.18). The impulse-momentum relationship is the mechanism that allows transferring linear momentum from the kicking leg to the ball. Changes in joint torque and angular velocity in the kicking leg have been reported by Nunome *et al.* (2002) (Figures 2.19–2.21). Further, Luhtanen (1988) reported that back swing of the kicking leg followed by a well-coordinated open kinetic chain sequence was observed in children as young as 8 years. In an analysis of the influence of selected variables on ball velocity Barfield (1995) identified maximum linear toe velocity, maximum knee flexion torque and hip extension torque as those with highest correlation.

Figure 2.18: Direction of joint forces about the hip and knee joints at the instants of support foot contact, maximum knee flexion and ball contact (Luhtanen, 1988; in Reilly, Lees, Davids and Murphy (1988), p. 446).

Figure 2.19: Changes in joint torque and angular velocity at the hip in the instep kick (adapted from Nunome *et al.*, 2002; p. 2032).

Figure 2.20: Changes in joint torque and angular velocity at the knee in the instep kick (adapted from Nunome *et al.*, 2002; p. 2033).

Figure 2.21: Changes in joint torque and angular velocity at the ankle in the instep kick (adapted from Nunome *et al.*, 2002; p. 2033).

To sum up, the kinematics and kinetics of the soccer kick movement of children and adults reported in other researcher provide an understanding of the biomechanical nature of this motor skill. Unlike movement principles alone, kinematics and kinetics throw light into the issues of optimal performance for groups of individuals and the biomechanical limitations of the performer. Unavoidably, different researchers obtain somewhat different mean kinematic and kinetic values from samples of proficient soccer players and children, although such variability constitutes a range of optimum (proficient players) and typical (children) performance for specific groups of subjects. Such kinematics and kinetics provide invaluable data for the construction of rating scales for the qualitative analyses of mechanical effectiveness. However, the question of whether all kinematic and kinetic variables identified in previous research as relevant for a biomechanical analysis of the kick can be assessed subjectively and with acceptable accuracy still remains.

2.2.2 The overam throw

A review of research on the kinematics and kinetics of the overam throw is presented in this section. A cross-sectional study by Marqués-Bruna and Grimshaw (1997) using 7 young children (aged 15-30 months) showed that the children performed either a static or a dynamic (step or run up) throwing action. The older children in the group performed dynamic action and showed higher velocity of the ball at release. In a case study, Marqués-Bruna and Grimshaw (1998) studied the development of the overarm throw in a young child over a period of 6 months. The child's throwing action was inconsistent displaying arm-dominated and sequentially-linked throws, homolateral and contralateral forward steps, and right-handed and left-handed throws. Sequentially-linked throws were interrupted, whereby the child allowed a small pause at the end of the back swing. Angles of ball release varied from 2.2 to 28.0 degrees, and velocity of ball release from 2.1 to 4.3 m/s. Height of ball release varied from 91.5 to 103.3 % of the child's height. Such kinematics showed no clear pattern of development in this child.

Toyoshima and Miyashita (1973) measured velocity of ball release in tests of maximum-effort throwing (maximum speed). The 6-year-old subjects used in the study threw a 60-g ball overhand with a mean velocity of 13.4 m/s and a 500-g ball with a mean velocity of 8.5 m/s. The highest velocity of release of 30.3 m/s was achieved by two adult subjects when using a 100-g ball. Additional research using balls of different proportions (Burton, Greer and Wiese, 1992 and Burton, Greer, Wiese and Bjornstal, 1993) reported that changes in the components of overarm throwing patterns might be elicited by variations in the diameter of the ball. Another study has examined gender differences in overhand throwing kinematics, motor performance and muscle strength in 8-year-old children (Raudsepp and Paasuke, 1995). The boys surpassed the girls in all parameters measured. In the overhand throwing test, children threw a tennis ball that weighed 150 grams and throwing kinematics for boys and girls, respectively, were: distance thrown = 23.3 m and 17.5 m; velocity of ball release = 16.3 m/s and 13.3 m/s; angle of ball release = 28.2° and 24.9°; throwing time = 1.32 s and 1.21 s; back swing-phase time = 0.92 s and 0.73 s; and throwing-phase time = 0.38 s and 0.48 s. Research carried out by Yan (1993) showed that age was the major factor affecting the kinematics at the point of release in the overarm throwing performance of a group of girls aged 2 to 7 years. The parameters measured included spatial position of release point, and velocity and acceleration at release. Later Yan *et al.* (2000) evaluated the throwing performance of 51 girls of ages 3 to 6 years. Mean (± SD) velocity of release for the 3-, 4- and 6-year-olds was 5.3 m/s (± 2.6), 7.8 m/s (± 2.1), and 10.2 (± 2.2), respectively. The timing of peak ball velocity relative to the point of release was significantly different ($F(2,48) = 21.47$, $p < 0.01$) and was interpreted as a developmental feature, whereby 6- and 4-year-olds released the ball closer to the point of peak ball velocity. Mean elbow extension at release was greater in 6-year-olds (112° ± 9°), compared to 3-year-olds (79° ± 13°) and 4-year-olds (90° ± 12°); and trunk flexion at release was less in 6-year-olds (23° ± 11°), in contrast to 3-year-olds (54° ± 20°) and 4-year-olds (49° ± 18°). Other joint angles, including shoulder horizontal adduction, humeral internal rotation and trunk rotation showed no significant age-related differences. Elbow extension velocity and shoulder horizontal adduction velocity at release showed significant differences between age groups, while the velocities of humeral internal rotation, trunk rotation and trunk flexion at release did not. It is important to note, however, that the detailed study by Yan *et al.* (2000) was limited to female children only.

The following studies have thrown some light into the kinetics of the overarm throw. Tarbell (1971) explained the effect of elbow flexion in reducing the radius of rotation of the throwing arm with implications for arm moment of inertia and throwing velocity. Toyoshima *et al.* (1974) reported that 46.9 % of throwing velocity derived from the step and trunk action, whilst the remaining 53.1 % was attributable to the arm action. Similar findings were reported by Broer and Zernicke (1979). Cooper, Adrian and Glassow (1982) explained that contraction of the muscles responsible for the forward arm swing is initiated before the arm reaches the limit of the backswing, suggesting the presence of a stretch-shortening mechanism of muscle contraction. Herring and Chapman (1992) simulated throwing action and associated torques and torque reversal during overarm throwing and found support for the proximal-to-distal sequence employed and the use of antagonistic muscle groups during the execution of this type of throw. Finally, the work of Hong *et al.* (2001) revealed similarities in the kinetic control of trunk rotation (longitudinal axis) amongst professional baseball players, but variability in the control of lateral and forward trunk flexion. Further, the contribution of the non-throwing arm was described as minimal and variable. Temporal activation of muscle torques was *"not in a strictly successive proximal to distal sequence"* (Hong *et al.*, 2001; p. 95); therefore, in disagreement with Herring and Chapman (1992).

Of the three motor skills in this thesis, the overarm throw has been studied from the widest number of perspectives that include kinematic analysis of early child development, the size and mass of the ball, gender differences in motor development, kinetic analysis and the contribution of individual body parts to the throw, and other. Unfortunately, previous studies have focused the analysis of throwing on specific age groups to solve specific research problems and fail, therefore, to provide data across the age spectrum that may include children form early to later childhood in the same study. Even fewer studies have included longitudinal designs to assess the course of development of individual children.

2.2.3 The standing broad jump

It seems, from an extensive search on the literature of the standing broad jump, that a great deal of research remains in the form of unpublished doctoral theses that are less accessible. However, a limited number of published studies have reported the kinematics (mostly performance measures) and kinetics of this motor skill. Important takeoff parameters and body configuration that may contribute to age-related differences in the distance jumped were investigated by Phillips, Clark and Petersen (1985). The study included 102 children aged between 3 and 7 years. Angles of ankle, knee and hip joint at takeoff showed no differences with age. The shoulder showed increasing flexion with increasing age. Three-year-olds differed significantly from other age groups in all segmental angles of inclination at takeoff. There was a tendency for the mass centre to be located horizontally farther from the toes and the angle of takeoff tended to decrease with age of the children. The authors highlighted the difficulty younger children experience in maintaining dynamic stability while generating sufficient horizontal velocity at takeoff. In terms of absolute performance, Merriman, Barnett and Kofka (1993) reported jumped distances of 50.8, 61.0 and 86.4 cm for children aged 3, 4 and 5 years, respectively. Clark and Phillips (1985) measured the following distances for the age groups specified in brackets (the children's groups included both boys and girls): 44.7 ± 18.5 cm (3-year-olds), 69.0 ± 23.0 cm (4-year-olds), 89.9 ± 12.2 cm (5-year-olds), 109.0 ± 14.7 cm (6-year-olds), 110.3 ± 16.9 cm (7-year-olds), and 281.7 ± 10.6 cm (adults). In older children, 23 girls and 19 boys aged between 11.6 and 13.2 years (Davies, 1990), the absolute performances of the boys were superior to those of the girls (153 and 134 cm, respectively). However, when jumping performance was normalised to body mass there were no significant gender differences. Differences between girls and young adult females were not significant, whereas the differences between the boys and young adult males were significant. Kokubun (1999) reported mean performance for 12- to 18-year-old children with intellectual disability of 108 ± 46.6 cm. The study by Reilly, Atkinson and Coldwells (1991) reported a mean standing broad jump performance in adult males of 220 ± 16 cm, which was positively related to isokinetic peak torque ($r = 0.56$).

In terms of kinetic analysis, Robertson and Fleming (1987) reported that the respective contributions of the hip, knee, and ankle muscles to the external mechanical work were 45.9 %, 3.9 % and 50.2 %. Therefore, emphasising the importance of the hip extensor and ankle plantar-flexor muscles in the standing broad jump. They also revealed that *"all three extensor moments of force summate... but the sequence of contractions was not from proximal muscles to distal as it is stated by the continuity principle. Instead all three extensor movements act simultaneously to produce leg extension."* (p. 19). Non-compliance with the principle of proximal-to-distal sequence in jumping has also been reported by Aragón-Vargas and Gross (1997b). Moreover, Dowell and Lee (1991) investigated the effects of transferring momentum in the standing broad jump. When testing 31 male physical education students these authors observed that leg production, or jumping without the use of the arms, accounted for 1.99 m in the standing broad jump (84 % of maximum distance). However, using the arms, and therefore transferring momentum, allowed an additional 0.48 m in the distance jumped (16 %). In terms of motor development, no effective arm action was observed in children at level 1 of development (Clark and Phillips, 1985); whereby the arms remain immobile throughout the propulsive phase, and may exhibit shoulder girdle retraction ('winging') close to take off. McClenaghan (1976) had reported that at the initial stage in the development of jumping the two feet do not produce a symmetrical force production pattern. Later, a study by Horita, Kitamura and Kohno (1991) compared the body configurations and joint function during the standing broad jump between adult males and 6-year-old children (1 male, 7 females). Adults displayed a wider range of motion of the legs during flight. In the crouch phase, joint muscle power peaks appeared in the same order for children and adults. Joint contribution to total work done showed almost identical values in both adults and children. However, hip joint work was much better in adults, since they showed higher negative work from the onset of preparatory movement to the point of maximum crouch. The study of Horita *et al.* (1991) concluded that the children had neither fully developed hip negative work during the crouch nor body configuration during the flight. However, gross motor pattern prior to take off in the 6-year-olds did not differ to that of adults.

The authors above have reported kinematics and kinetics of the standing broad jump, where variable selection appears to have often been guided by non-explicit mechanical principles. A large number of studies have used measures of the performance outcome as sole indicators of the motor ability of the child. Kinematic analysis has allowed highlighting technical errors that are typical of children and has shown how girls can perform this movement as effectively, if not better, than boys after adjusting anthropometrics. Kinetic studies have focused on the role of the movement of the arms to increase jumping performance. However, the kinematic and kinetic data available for a comparative phase-by-phase analysis of the jump is very limited.

The review of the kinematics and kinetics for the three motor skills carried out in this section provides a foundation for the analysis of mechanical effectiveness in children, however whether such variables can be estimated accurately and reliably during subjective analysis needs investigating. Further, there seems to be a certain mismatch in the literature between the critical features identified by some researchers and the choice of kinematic and kinetic variables selected by other researchers for analysis. Essentially, a number of critical features derived from theoretical models have not been considered for inclusion in kinematic and kinetic studies (e.g., *forward trunk flexion* and *lateral body inclination* in the soccer kick); therefore, affecting the capability of sports analysts to integrate critical features, the associated movement principles, and measures of optimal performance that can be typically derived from kinematic and kinetic studies. Nonetheless, a number of strategies designed to enhance qualitative analysis of human movement are presented in Part 3 of the review of literature.

Part 3 – Review of existing models for the qualitative analysis of human movement

The **principal comprehensive models** are reviewed in this section, which can be synthesised in order to construct an integrated model for the qualitative analysis of mechanical effectiveness in children. In fact, the different models available have been classified by Knudson and Morrison (2002) into two categories. The *first* is *comprehensive models*, which present a summary of the components necessary for qualitative analysis and provide information on *"movement goals, preparation for observation, stages of motor development, observation, evaluation, diagnosis of errors, and appropriate feedback"* (p. 16). The *second* category comprises *observational models*, which fit within comprehensive models and their main role is to aid in the observation of human movement. Comprehensive models can be further classified as either **pedagogical comprehensive** (e.g., Arend and Higgins, 1976) or **biomechanical comprehensive** (e.g., Hay and Reid, 1982; McPherson, 1990; Kreighbaum and Barthels, 1996; and Lees, 1999b). Pedagogical comprehensive models have been designed to assist teachers in the analysis of sports movements, whereas biomechanical comprehensive models focus on the mechanical aspects of the performance.

Nevertheless, in order to aid observation, phase analysis at an early stage of the analysis has been recommended by many authors (e.g., Bartlett, 1997; Knudson and Morrison, 2002) on the basis that it is *"... the descriptive process of dividing up a movement into relevant parts so that attention can be focused on the performance of each part"* (Lees, 2002; p. 816). Phase analysis may, therefore, identify a minimum of three phases in discrete skills, or those that show a definite beginning and end (Kreighbaum and Barthels, 1996). Phase analysis requires a basic knowledge of the skill been analysed and is often used due to its simplicity, but not always (e.g., Hay and Reid's (1982) movement simplification method consists of dividing the performance variable into component parts).

Arend and Higgins (1976) put forward a strategy for the subjective analysis of human movement. Their approach comes under the category of pedagogical comprehensive models for the qualitative analysis of movement. The strategy consists of three stages of pre-observation, observation and post-observation (see Figure 2.22). Of these, the first stage, pre-observation, aims to synthesise prerequisite information and is further divided into three levels of movement decomposition. The *first* order of decomposition aims to provide a general description of the movement followed by a simplification of the movement by dividing it into arbitrarily-defined phases and sub-phases. Generally, a movement sequence or skill can be divided into preparatory phase, action phase, and follow through phase. The *second* order of decomposition consists of a qualitative and/or quantitative description of each phase of the movement. This is carried out by describing the movement kinematics, kinetics, temporal factors and effort/shape factors. In terms of kinematics, all displacements, velocities and accelerations require quantitative calculation; whereas joint ranges of motion, limb/trunk relationships, body position and posture can be easily described in a qualitative manner. Nevertheless, the kinetics of the movement can also be studied by qualitative means. This consists of describing how the forces are produced and applied; reporting, in other words, the magnitude, point of application, direction, and distance over which forces act. Temporal factors of the movement can also be assessed qualitatively. These include speed of the movement, rhythm, co-ordination, and other. Effort/shape constructs have been described as factors that provide the same information as kinematics and kinetics of the movement but from a purely qualitative perspective. For example, a force can be perceived as 'delicate' or 'forceful', time as either 'sustained' or 'sudden'. The *third* order of decomposition in Arend and Higgins's (1976) model aims to explain why each phase of the movement looks the way it does by using biomechanical correlates such as laws of motion, relationships between force and motion, principles of leverage, path of the centre of gravity, and other. It is this third order of movement decomposition that allows the coach or biomechanist to identify critical features of the movement, or those *"parts or phases of the movement that can be least modified by the performer in order to achieve the goal* (movement outcome)" (p. 45).

Figure 2.22: The strategy for the subjective analysis of human movement developed by Arend and Higgins (1976; p. 38).

It is evident from the work of Arend and Higgins (1976) that their analytical model can be used to describe and simplify the movement, and subjectively measure the kinematics, kinetics, temporal factors, and shape/effort characteristics of the movement through qualitative analysis and using qualitative descriptors. An obvious advantage of Arend and Higgins' (1976) movement analysis strategy is that it aims to explain why the movement is performed the way it is by considering biomechanical correlates, although this has only been outlined in general terms. However, these authors do not show an example of how to measure kinematics and kinetics of the movement in practical terms, and imply that their approach is descriptive in nature. Further, their analytical strategy is based on idealised models of sound technique and assumes, therefore, the observer's knowledge of the intricacies and mechanical aspects of the skill.

One of the most widely used tools for the qualitative analysis of motor skills is the hierarchical deterministic model of Hay and Reid (1982), a biomechanical comprehensive model. The practical implementation of this theoretical framework is demonstrated by Hay (1983), where an example is given on how to identify, evaluate and correct technical faults in a long jumper using a photographic sequence of the athlete's performance. The model requires having a thorough knowledge of the skill being analysed. The basic steps of the qualitative analysis process involve, first, observing the performance and identifying technical faults; second, prioritising the faults that need correction; and finally, instructing the performer. Nonetheless, the interesting aspects of Hay and Reid's (1982) systematic approach reside in the logic of its theoretical framework. The procedure of identifying technical faults requires developing a hierarchical deterministic model that shows the relationship between the performance criterion and the factors that produce such performance criterion. This is needed in order to supplement any prerequisite knowledge of the motor skill the analyst may posses. The deterministic mechanical model is constructed as follows: 1- identification of the criterion measure; 2- division of the criterion measure into distinct consecutive parts; and 3- identification of the factors that produce the criterion measure. An example of division of the criterion measure in the long jump into parts appears in Figure 2.23 below, and an incomplete deterministic mechanical model for the analysis of the high jump is shown in Figure 2.24.

Figure 2.23: Parts that make up the distance jumped in the long jump (Hay and Reid, 1982; p. 268).

Figure 2.24: An 'incomplete' deterministic model for the analysis of high jump performance (Hay and Reid, 1982; in Hay (1993), p. 448).

When identifying the subordinate factors two rules must be obeyed. The *first* rule demands the use of mechanical quantities, where possible. Hay and Reid (1982) suggested that the first rule could be disregarded when an alternative term that summarises the meaning of a particular mechanical quantity can be used. For example, in the model the term 'body position' could be used to summarise the kinematics of the movement/technique of the performer. The *second* rule requires that each of the factors included be determined by those subordinate factors that appear immediately below it. This second rule can be observed by 'simple addition' of the consecutive parts into which the criterion measure is divided and also by using a 'known mechanical relationship'. Hay (1983) explained that the model should be developed up to a point at which *"further development seems likely to be unrewarding"* (p. 106). However, the model does not aim to describe the kinematics and kinetics of the movement or describe the technique used by the performer in any level of detail, as in other skill analysis methods (e.g., Arend and Higgins, 1976). The model proposed by Hay and Reid (1982) is being used increasingly widely in biomechanical analysis. Nonetheless, the procedures of addition or use of known mechanical relationships malfunction at certain levels of the model, and some expressions vaguely suggest that aspects of technique should be incorporated (Lees, 2002).

Knowledge of the skill and innate perceptual ability are essential requirements to effectively evaluate movement (McPherson, 1990). From McPherson's (1990) point of view, qualitative analysis is based on knowledge of mechanical principles while, at the same time, requires an awareness of the *"limitations on the perceptual processes as well as constraints on the athlete's performance"* (p. 1). McPherson's (1990) approach to skill analysis consists of four distinct parts: **1-** pre-observation, **2-** observation, **3-** diagnosis, and **4-** remediation (Figure 2.25). The pre-observation part is divided into two steps; the *first* step involves movement analysis and leads to the identification of critical features, and the *second* step requires designing an observation plan. Further, the *first* step, movement analysis, consist of the following stages: **1-** determination of the performance criterion, **2-** breaking of the skill into phases (e.g., preliminary movements, back swing, force producing movements, the critical instant, and the follow through), **3-** determination of the mechanical factors affecting performance, and **4-** identification of critical features. Here, stages 2 and 4 show important deviations from Hay and Reid's (1982) approach. Stage 2 aims to simplify the skill by dividing it into distinct phases, as in Arend and Higgins's (1976) model above. Stage 4 takes Hay and Reid's (1982) deterministic model a bit further, into a level in which the actual critical features of the movement are identified. Critical features are observable components of the movement that are essential for optimal performance (McPherson, 1990; Kreighbaum and Barthels, 1996). In McPherson's (1990) model such critical features are descriptions of specific body or segment movements (the technical aspects) that may be observed, and may indicate whether the mechanical factors immediately above in the hierarchical order have been performed effectively (see Figure 2.26). With regard to the determination of mechanical principles (stage 3 of movement analysis), McPherson (1990) pointed out that *"technique is largely determined by mechanical factors"* and that the identification of critical features (stage 4) *"is the most difficult, as it requires the synthesis of all fundamental principles of mechanics"* (p. 4).

Figure 2.25: McPherson's (1990; p. 2) model of skill analysis.

Figure 2.26: Identification of critical features by extension of a basic deterministic mechanical model (from McPherson, 1990; p. 3).

The observation part in McPherson's (1990) skill-analysis strategy involves paying attention to visual stimuli for the actual perception of critical features. Incidentally, McPherson (1990) suggested that *"critical features are observable, whereas* *mechanical quantities such as impulse and momentum are not"* (p. 2). This author explained that a number of cues and body movements such as arm range of motion or leaning forward during the takeoff phase of a jump (the critical features) might indicate that impulse and momentum (the mechanical quantities) have taken place. While mechanical quantities, such as force, may not be observable McPherson (1990) suggested that watching for specific body movements such as rapid extension (here McPherson (1990) implies that speed is observable) of the hip, knee and ankle through a large range of motion in a sprinter unequivocally indicate that ground reaction force is being developed. To provide more examples, descriptors of movement and observable critical features that include 'legs abducted', 'sequential extension of the knee and ankle with forward displacement of the body's CG at approximately 45°', and 'range of motion from initial flexion to final extension' can be used to indicate whether the mechanical factors of 'body position', 'magnitude and direction of force application', and 'time', respectively, have been optimised. This is similar to describing the kinematics, kinetics, temporal factors, and shape/effort characteristics of the movement by means of qualitative analysis in the way suggested by Arend and Higgins (1976). McPherson (1990) further clarified that the movements performed (the technique used by the performer) to accomplish the outcome of a motor skill contain observable critical features, whilst individual modifications within a given technique, what is known as individual style, contain movement components that are not critical to the outcome of the motor skill. Ultimately, observation, or attention to sensory input, requires *"methodical search for the relevant features of a performance"*, since *"there is a limit to our ability to observe and accurately record the movements of the human body"* (p. 6).

McPherson's (1990) approach to skill analysis consists of the use of an extended deterministic mechanical model that involves the difficult task of identifying critical features of the movement. Further, the author recognises the limitations to perceive kinematic and kinetic variables and provides examples of qualitative descriptors that can be used to indicate whether optimum performance has taken place. Nonetheless, McPherson's (1990) approach assumes knowledge of mechanical principles and of a model of sound technique by the observer. In addition, no examples of selected critical features and specific perceptual difficulties from real sport situations were provided.

A comprehensive tool for the analysis of technique in sport has been developed by Lees (1999b). This systematic approach to technique analysis involves the use of movement principles to explain why the movement is performed the way it does. Knowledge of the skill (or sport), good observational skills, ability to simplify the movement, and ability to identify movement principles for each phase of the skill are essential characteristics of a successful coach. Of course, the coach must also be able to implement strategies to correct technical faults. The method of technique analysis suggested by Lees (1999b) involves breaking down the skill into phases, identifying critical features of the movement (these must be observable), and comparing the performance to models of sound technique. Typically, skills are broken down into the four phases of movement initiation, preparation, execution, and follow through; although, in some sports, the transition from one phase to the next may not be clearly distinct. Occasionally, there is more than one important observational feature, or *"the things to look out for in an individual's performance"* (p. 14), within a phase of the movement. In this case it may be useful to break down the movement a bit further into sub-phases. With regard to mature models of technique, the purpose is to compare *"what is observed with what is expected"* (p. 19). However, it must be taken into account that the level of performance, and physiological and musculoskeletal characteristics render each athlete a unique performer. That is why it is important to consider a range of optimum performance. In the context of inter-subject variability, it needs also to be considered that 'technique' has been described as "*a pattern of movement*" (McPherson, 1990; p. 3) while style, comparatively, has been described as the *"individual adaptations of a technique"* (Kreighbaum and Barthels, 1996; p. 300). Moreover, Lees (2002) pointed out the need to differentiate between technique variables and performance variables during the process of movement analysis, despite the strong link between these; whereby technique variables may include those variables that report either body posture or describe the direction and range of movement in a spatial framework. Comparatively, variables that consist of magnitudes for velocity, acceleration and force in a spatio-temporal framework may be classified as performance-related variables.

Lees (1999b) classified movement principles into those of speed, force and movement co-ordination. He also identified specific performance principles that are responsible for optimal movement in specific sports. The first group of principles, speed principles, includes 'whole body running speed', 'whole body rotational speed', 'limb rotational speed', and 'end point speed'. An important aspect to consider in complex and/or high force skills is that the performer needs to control the amount of speed, and therefore, although high speed at release or takeoff may be the performance criterion the actual speed of approach is kept sub-maximal. Force principles often used to explain movement patterns include those of 'force production', 'range of motion', 'change of direction', 'impact (stationary ball or object)', 'impact (moving ball or object)', 'stability', 'resistance to motion in fluids', and 'propulsion in fluids'. In this group of principles, force production refers to the ground reaction force elicited by the athlete. Often, the preparatory phase allows large range of motion later in the execution phase of the movement. Impacting a stationary object involves the striking limb or object moving in the same direction of the impacted object. Co-ordination principles include 'using action-reaction to make simultaneous movements of opposing limbs', 'proximal-to-distal sequence of movements', 'simultaneous joint movements for force/power production', and 'stretch-shortening cycle'. It is not uncommon to encounter phases of the skill in which the movement is first simultaneous for force production and, then, sequential for speed generation. In a stretch-shorten sequence, the underlying principle involves facilitating high muscle force at the beginning of the movement. Recurring specific performance principles include 'a pivot is used when running and jumping for height', 'flight and projectile motion', and 'speed-accuracy trade-off'. Thus, in certain sports a blocking front leg often allows the body to pivot over the foot, and by so doing, gain vertical velocity. Finally, height, angle and velocity of release are determinant parameters in projectile motion.

Lees (1999b) provided practical examples in the analysis of technique in sport that involve dividing the movement into phases, identifying deviations from a model of technique in relation to underlying movement principles, and suggesting recommendations for improved performance. Although the procedure outlined by Lees (1999b) is based on a hierarchical deterministic structure (Hay and Reid, 1982), and aims to simplify and describe the technique of the athlete and identify critical features (as in Arend and Higgins, 1976 and McPherson, 1990) the most significant breakthrough in the model is, perhaps, the classification and description of specific principles of movement underlying performance. The advantages of Lees's (1999b) approach, to sum up, include phase division, identification of underlying movement principles and critical features, consideration of a range of optimum performance and the provision of practical examples. However, the approach is mainly biomechanical and no evaluation of the perceptual limitations involved in the analysis is provided. A summary of the above evaluation of the principal comprehensive models available for the qualitative analysis of human movement appears in Table 2.2. Part 4 of the review of literature is concerned with the visual perceptual and observational aspects of qualitative analysis.

Table 2.2: Summary and evaluation of the principal comprehensive models for the qualitative analysis of human movement.

Author(s)	Type of model	Advantages of the model	Disadvantages of the model
Arend and Higgins (1976)	Pedagogical comprehensive	Allows initial movement simplification using phase analysis. Enables describing kinematics and kinetics using qualitative descriptors. Allows analysing movement using biomechanical correlates (laws & principles of motion). Allows identification of critical features or observable aspects of technique.	It is descriptive in nature and does not allow obtaining measures or scores. Relies on the observer's knowledge of the mechanical aspects of the skill and of sound technique. Authors do not provide practical examples so as how to implement the model in sport.
Hay and Reid (1982)	Biomechanical comprehensive	It is based on sound mechanical relationships. Permits to focus the analysis on the mechanical aspects of the skill. Authors provide examples of application of the model in sport.	Movement simplification is limited to division of the performance criterion. It relies on prior thorough knowledge of the skill by the analyst. It is esentially complimentary to other technique analysis models and therefore practical application of the model is limited. Procedures of addition or use of mechanical relationships malfunction at certain levels of the model. Vague expressions suggest that aspects of technique need to be incorporated in the analysis. It does not indicate how to measure kinematics and kinetics of the movement qualitatively. Authors use vague qualitative descriptors to provide examples of technique analysis.

Table 2.2 (cont.): Summary and evaluation of the principal comprehensive models for the qualitative analysis of human movement.

Author(s)	Type of model	Advantages of the model	Disadvantages of the model
McPherson (1990)	Biomechanical comprehensive	Allows movement simplification using phase analysis. Analysis is based on the use of movement principles. Involves indentifying critical features. Authors raise awareness regarding limitations on the perception of critical features. Authors provide examples of qualitative descriptors to substitute kinematic and kinetic measures.	Assumes observer's knowledge of movement principles. Assumes observer's familiarisation with models of proficient performance. Authors provide no practical examples on the use of the analytical approach.
Kreighbaum and Barthels (1996)	Biomechanical comprehensive	Allows movement simplification using phase analysis. Analysis is based on the use of movement principles. Allows identification of critical features.	Authors do not indicate how to measure or rate critical features of the movement. Authors provide no practical examples of technique analysis in sport.
Lees (1999b)	Biomechanical comprehensive	Allows movement simplification using phase analysis. Analysis is based on the use of movement principles to help understand how to attain optimum performance. Author lists specific movement principles to guide the analist. Allows identification of critical features. It encourages consideration of 'range of optimum performance'. Author provides practical examples of technique analysis in sport.	It is based on the performance of high-standard athletes that may not always comply to movement principles. It is mainly biomechanical and no evaluation of perceptual limitations is provided.

Part 4 – Review of aspects of human visual perception and the observation of human movement

This section presents a review of previous research on the capabilities and limitations of the **human eye** to perceive spatial changes associated with human movement. It also includes a review of the existing **observational models** that have been developed in order to facilitate the process of observation and of the use of different **video playback speeds and conditions** to improve accuracy of analysis. Finally, a review of studies on the **validity and reliability** of qualitative analysis and a review of the use of **qualitative descriptors** and **measuring scales** in this type of analysis are presented.

4.1 The sense of vision and eye movements

The senses and perception, according to Knudson and Morrison (2002), are *"... to qualitative analysis of movement what biomechanical instruments are to the quantitative analysis of movement"* (p. 40); whereas perception can be described as the organisation and interpretation of, in this case, visual stimuli from the surrounding environment. While different senses provide unique information about a performance, vision is the most sensitive to spatial changes in the position of the human body. Nonetheless, with the advent of videography the limitations of human visual perception of motion have been drastically reduced. An understanding of the functions of the human eye may be useful for the biomechanist to get an insight into the capabilities and limitations of human visual perception to conduct qualitative video analysis of human movement.

Apart from static visual acuity, other factors affecting vision in qualitative analysis include: dynamic visual acuity, perception of colour, contrast, accurate eye movements, eye dominance, and peripheral vision. Viewing time affects static visual acuity, so that the longer the viewing time available the easier it is to make visual discriminations. When observing human movement, dynamic visual acuity determines the visual discrimination of the performer's movements. Interestingly, dynamic visual acuity deteriorates rapidly when the eye is required to turn at speeds above 60 to 70 deg/s (Knudson and Morrison, 2002). However, in high speed movements and events, for example the collision of the ball and the bat in baseball lasts 1 or 2 ms, the player uses cues to track the ball movement (Watts and Bahill, 1990). The previous information helps to explain why the human eye may not be reliable in the qualitative analysis of human movement.

Kluka (1991) outlined the four eye movements that are important in the analysis of human movement. These include saccadic, vestibulo-ocular, vergence, and smooth-pursuit eye movements. Saccadic eye movements allow scanning rapidly and jumping from point to point in the visual field. Saccadic suppression or omission is the 'turning off' of the eyes as they rotate to the next fixation. This occurs in order to prevent blurring of light and images as the eye moves. Vestibulo-ocular movements occur in unison with head motion to follow the movement of the performer. Vergence eye movements permit focusing on objects that are at different distances, and smooth pursuit eye movements are those movements we use to follow slow-moving objects. Other eye movements, convergence and divergence, reflect the eye's ability to focus quickly when objects close up and then increase the distance away from the observer, respectively. Fixation takes place when something has our visual attention, and both eyes focus on the object. The focus of visual field during fixation is very limited. Kluka (1991) stated that this is limited to 3 degrees. This is approximately the area of the thumb when the arm is held extended in front of the body. The selective nature of visual attention can be both an advantage and a drawback in movement analysis. In Johnsson's (1975) view, the eyes act like *"motion detection systems"* (p. 76). The eyes will have tendency to move to unusual or quickly moving objects. This may be in some cases disrupting or in other situations may help to perceive unusual and, therefore, erroneous movement.

Moreover, related to visual perception of the movement is the concept of imagery, which forms part of the information-processing model suggested by O'Donnell, Moise, Warner and Secrist (1994). Imagery has been described as template matching (Anderson, 1990), as the observer compares observed performance to a mental image of skilled technique. However, in her review of related literature, Carnegie (1997) found support for using both skilled and unskilled models of performance for modelling purposes. This finding suggests that those involved in the analysis of sports technique in children may benefit from being familiarised with the different developmental levels observed in children of different ages.

The limitations of eye movements, as outlined by Knudson and Morrison (2002), have important implications for direct visual observation. Some high-speed movements cannot be observed. Saccade may render a key instant of the movement imperceptible. However, observational strategies often increase visual discipline, so that the eye does not fix on extraneous movements. Observation from a distance, for example, may help to reduce the angular velocities of the eye required to track the object or performer. Peripheral vision refers to our ability to see around the point of visual focus; this is useful in qualitative analysis to orientate the objects relative to the background. Nonetheless, a review of existing observational models follows.

4.2 Existing pedagogical and biomechanical observational models

A number of strategies have been developed to facilitate the perception of critical features during movement in sport. However, while some models involve breaking down the skill into phases, others use a more 'gestalt' approach whereby the analyst gets "*an overall feeling about the quality of the movement before observing specific components.*" (Knudson and Morrison, 2002; p. 29). Aimed to improve the qualitative analysis skills of teachers, pedagogical observational models include the following: Hoffman's model (1983) uses a mental image of what the performance should look like; Gangstead and Beveridge's (1984) model consists of temporal foci (phases of the movement) and spatial foci (path and position of body segments); and Dunham's (1994) model uses the gestalt impression, or "*general feeling approach*" as expressed by Knudson and Morrison (2002; p. 98). In order to translate abstract movement principles into observable features, biomechanical observational models have been developed. These include the models of Brown (1982), containing 19 visual evaluation techniques, and Hudson (1985) in which the purpose of the movement is associated to visual variables that are important and observable (such variables "*must distinguish between skill levels, be observable qualitatively by the naked eye, and be subject to change by the performer*"; Knudson and Morrison (2002, p. 22)). Hudson's (1985) model involves focusing on the whole-body (somatic approach) and the body segments (sectional approach); see Table 2.3.

Table 2.3: The purpose underlying the direction of force application is linked to the visually observable variable of initial path of projection in Hudson's (1985) model (taken from Knudson and Morrison, 2002; p. 22).

Pedagogical and biomechanical observational models are often used as part of comprehensive models for the analysis of human movement. Pedagogical observational models aim to facilitate the description of the performance for comparative analysis. In contrast, biomechanical observational models have the added advantage of guiding the analyst in the observation of specific technique and performance variables that are both mechanically related to performance and observable. In any case, when using direct visual observation the performance may need viewing over a number of consecutive trials. However, when using video analysis, viewing conditions may also limit, and not always enhance, observation of the true characteristics of the movement.

4.3 Normal-motion and slow-motion video replay of the activity

It has been suggested that slow-motion video replay is a more effective means of showing correct action than slow-motion demonstration of the activity by the coach or instructor (Hupprich, 1941). However, Ragsdale (1930) had highlighted that slow-motion demonstration was better at showing fine movements, while the whole body action can be easily picked up using normal speed viewing. Williams (1986) found support for these ideas and suggested later that,

> " *...'real' time display of the required movement is important because of the fundamental nature of 'timing' in effecting movement of the limbs. Slowed displays are probably most effective for presenting 'superficial' aspects of movement such as the order and direction in which the limbs are to be moved."* (p. 57)

Accordingly, Carnegie (1997) established that novice observers were more accurate at obtaining kinematic information (angular displacement of the hip, knee and ankle joints) when viewing slow-motion video demonstrations of a dance step than when using normal-speed demonstrations. The observers were also able to accurately obtain information related to the timing of the movement (absolute and relative timing of action patterns) when using slow motion. However, observers exposed to slow-video demonstration tended to speed up the action when attempting to replicate the movement; although relative timing of the movement of segments seemed unaffected.

The capabilities and limitations of the human eye to perceive movement in sports have been outlined in this section. To overcome the limitations of naked-eye observation, observational models have been developed with either a pedagogical or a biomechanical emphasis according to purpose. It seems from the studies reviewed above that when attempting to estimate the kinematics of the movement from video the observer should use both slow-motion (including frame-freeze) and normal-motion video replay to increase the accuracy of the estimated displacement, time and velocity measurements. This is when validity and reliability in qualitative analysis must be considered.

4.4 Validity and reliability in qualitative analysis

Qualitative analysis must possess logical validity, which is based on consensus of the literature and expert opinion. In practice, assessing criterion-referenced validity is a suitable approach that may involve, for example, comparing visual estimations to digitised data or to angles measured using a goniometer (Knudson and Morrison, 2002). Ergonomics studies have provided measures of the validity of visual observation. For static posture or slow movements accuracy of visual ratings has been reported from poor to good (e.g., Bernhardt, Bate and Matyas, 1998; Knudson, 2000). The studies of Douwes and Dul (1991) and Ericson, Kilbom, Wiktorin, and Winkel (1991) revealed that visual estimation of static body-segment angles during the assessment of posture are accurate within 3-5° and concluded that visual observation of trained operators can be considered generally valid and reliable. Juul-Kristensen, Hansson, Fallentin, Andersen, and Ekdahl (2001) reported accuracy within 4-13% for posture at the work place. However, in dynamic work situations direct visual observation was acceptable for gross body posture only and the use of video analysis was recommended (Looze, Toussaint, Ensink and Mangnus, 1994). Fast movements are not rated as accurately and only well-trained observers are considered able to estimate discrete body angles

(Knudson, 1999). For example, a mean absolute error of 30.1° and a constant overestimation error of 21.8° in maximum knee flexion when using video replay of the vertical jump have been reported (Knudson and Morrison, 2000). Some authors have carried out assessment of visual perception of human locomotion (Johansson, 1973; Cutting and Kozlowski, 1977) and other authors have evaluated accuracy of observation in sports specific movements, including gymnastics (Frederick, 1977) and overarm throwing (Wilkinson, 1996). However, Knudson and Morrison (2002) have suggested that criterion-referenced validity may exist for some variables but not for others. Michelitsch and Sinclair (1980) reported that repeated viewing, 2-4 times, improved scoring accuracy in gymnastics judges since repeated viewings *"reduce the limiting effects of human information processing capacities on judges' scoring accuracy"* (p. 59). In physical therapy, observers were able to estimate step length in walking at slow-to-normal speeds to within 3–7 cm. The use of fast walking speeds or observation from over 3 m away led to increased errors in distance estimation (Stuberg, Straw and Deuine, 1990).

A sound approach to qualitative analysis aims for intra-rater and inter-rater reliability; or consistency within one analyst and agreement within several raters (sometimes referred to as 'objectivity'), respectively. General conclusions reached by Knudson and Morrison (2002) contended that qualitative analysis has shown to have content validity; however, experimental studies showed moderate validity, and poor-to-moderate reliability. Knudson (1999) reported that assistant collegiate basketball coaches were unable to rate discrete body angles in the vertical jump accurately or consistently, 60 % of college students could rate accurately and consistently overall range of motion, and only 1 of 6 kinesiology professors could rate range of motion accurately and consistently, demonstrating that professional experience did not increase the ability to rate range of motion in the vertical jump. Observational gait assessment has had low-to-moderate reliability with correlations between 0.6 and 0.7 (Krebs, Edelstein and Fishman, 1985; Eastlack, Arvidson, Snyder-Mackler, Danoff, and McGarvey, 1991).

In their evaluation of throwing performance, Yan *et al.* (2000) reported a within-observer reliability of 0.88 and Merriman *et al.* (1993) reported inter-rater reliability coefficients of between 0.97 and 0.98 in experienced physical therapists when performing qualitative video analysis of the standing broad jump. Similarly, Ulrich (1984) found an acceptable reliability in the assessment of 12 motor skills. However, Ulrich, Ulrich and Branta (1988) suggested that reliable assessment of the horizontal jump developmental level required three observers and three trials. They also pointed out that bias might introduce error in qualitative analysis, for example rating younger subjects lower than older ones. Painter (1990) demonstrated that focusing on components resulted in greater reliability than using a whole-body approach, whereas subjects were able to reliably identify developmental level by focusing on, for example, the arm or leg action. Slow components of the overarm throw (foot placement and body rotation) could be reliably observed in one trial by one observer. However, this is different when observing fast and complex movements. Painter (1990) found that the action of the arms in the overarm throw was difficult to observe reliably. This author suggested that a single observer would need at least 5 trials to reliably observe and rate the arm action in hopping, whereas a single observer will have to observe 10 trials to reliably rate the whole-body developmental level of hoping. To compensate for the limited reliability the solution is to increase the number of observers or the number of trials observed. Another approach consists of increasing specificity of the system or model by analysing discrete events and providing a simple rating for them (as proposed by Kerner and Alexander, 1981). Identifying specific critical features and defining a system on how they will be evaluated can also help increase reliability. In any case, a compromise must be reached between the depth and complexity of any human motion analysis model and the simplicity of its use, in order to reduce the perceptual demands on the observer and therefore improve reliability. Simplicity in subjective analysis is often achieved by using qualitative descriptors of the movement and reference rating scales.

4.5 The use of qualitative descriptors of movement and measuring scales

While attempting to estimate the magnitude of force in standard units of Newtons during direct visual observation can be regarded as an impossible task, certain postural positions can be reliably estimated within 3-5° (Douwes and Dul, 1991; Ericson *et al.*, 1991). In other research, a number of descriptive expressions have been used to report the developmental sequence for kicking. For example, these appear in the text by Gallahue and Ozmun (1995; p. 272) as follows: *'movements are restricted during the kicking action'*, *'trunk remains erect'*, *'a pushing rather than a striking action'*, *'kicking leg tends to remain bent'*, *'one or more deliberate steps'*, and other. The deterministic model of Hay and Reid (1982) has enjoyed great popularity for the qualitative analysis of technique in sports. However, in their application of the model to the analysis of sports events there is only a vague attempt to subjectively quantify the range of motion and the magnitude of forces from photosequences of athletic performance. Some descriptive statements extracted from the work of Hay and Reid (1982) include: *"strange manner in which the first part of the backswing was performed"*; *"the player's efforts to swing the racket"* (p. 347); *"the apparently close-to-the-side position of the right elbow"*; *"the lack of extension of the leg at contact"*; and, *"the very long follow through of the racket after impact"* (p. 348). Nonetheless, Adrian and Cooper (1995) put forward that qualitative analysis could be expressed in relative terms. This consists in comparing the performance of an individual to a standardised model of performance (descriptors include: *'faster/slower', 'at an angle to the vertical'*, and other). Adrian and Cooper (1995) have defined relative qualitative analysis as "*non-precise quantification of movement performance*" (p. 153). For example, time can be described and measured as 'irregular', 'slow', and '0.2 seconds', using the behavioural qualitative, relative qualitative and quantitative approaches, respectively. Space can be described and measured as 'curved', 'large' and '2 m radius'; force as 'exists in legs', 'strong tension' and '80% of maximum isometric force'; and so on.

In terms of tools for subjective analysis, Gabbard (1992) advised that when selecting an instrument for the assessment of motor development the examiner should consider whether the instrument is norm-referenced or criterion-referenced. This author also commented on the feasibility of the instrument, where time, cost and equipment may be decisive factors. Of these, time is often the most critical factor when assessing large groups. Instruments that have received great recognition are those based on product-oriented assessment. An example of such instrument is the component of neuromuscular maturity assessment of the Gestational Age Assessment instrument developed by Ballard, Novak and Driver (1979). The rating scale ranges from 0-5 based on principles of motor development that are evident in the criteria. The interesting aspects about this tool are the use of stick figures to guide the rater and the use of scale intervals as small as 15° (see Table 2.4). Nonetheless, Ballard *et al.* (1979) have pointed out that extensive practice is needed to use this instrument accurately.

Table 2.4: Rating neuromuscular maturity (Ballard *et al.*, 1979; p. 368).

Finally, Adrian and Cooper (1995) have suggested that, in order to be consistent and reliable in evaluating motor skills, an analyst must adopt an observational plan. This plan involves preparing a checklist. This is followed by a list of the actions that differentiate skilled and unskilled performers. The actual description or measuring of the performance is done by devising a scale on the basis of '*exists or does not exist*', or the scale could be based on a numerical/continuum ranking such as '*0-4*'. Typical factors included in check lists are: location of the centre of gravity of the body, range of motion and path of movement of different body segments, sequence of movement of body segments, angle of projected implements, and "*total perception of the movement's effectiveness, rhythm, awkwardness, ...*" (p. 156). An example of checklists for the analysis of throwing appears in Table 2.5. Although most of the variables shown are kinematic variables, some kinetic variables have also been included.

Table 2.5: Checklist and rating scale for the analysis of throwing (from Adrian and Cooper, 1995; p. 157).

Nicholls, Fleisig, Elliott, Lyman and Osinski (1999) validated a biomechanical qualitative analysis of baseball pitching that involved using a 24-item checklist of mechanics developed using published biomechanical data and laboratory tests using 20 youth pitchers. Kappa coefficients were calculated for 17 kinematic variables. From these, 11 variables showed acceptable relationships between digitised quantitative data and qualitative data that consisted of ratings of Low, Correct and High. The study concluded that using a single camera and observation with a three-choice qualitative checklist provides information that is compatible with that obtained using a three-dimensional analysis system and is, therefore, a valuable field procedure. Useful substitutes of checklists are templates, which consist of *'a number of critical angles sequentially placed for the observer's convenience'* (Frederick, 1977; p. 28).

In sum, the sense of vision is highly sensitive to spatial changes during sports activity, where such spatial changes are perceived using different eye movements. However, saccade and deterioration of dynamic visual acuity limit the capability of the human eye to perceive movements occurring at high speed. To overcome such limitations, observational models have been developed that allow estimating almost any variable, kinematic or kinetic, using video analysis; although a combination of normal speed and slow speed video replay is required to increase accuracy of estimation. Qualitative analysis of human movement has been found to have only moderate validity and reliability in previous research, although the observational conditions have varied considerably from study to study and only a few studies have assessed validity and reliability in dynamic sports situations. Finally, the use of rating scales containing relative qualitative descriptors can be used to increase intra-rater and inter-rater agreement.

Summary of the review of literature

Previous research has described the kicking, throwing and jumping actions observed in skilled adult performers and the development of such motor skills in children. Past research has also reported measures of performance, and kinematic and kinetic data, which have been used for the study of the development of motor skills in children. However, it is evident from the literature that a further understanding of motor development in children may be attained by studying the development of movement effectiveness. Analysis of movement effectiveness is based on movement principles and would allow not only description of the movement and the measurement of relevant performance factors, but also an appreciation of how effective the movement is in attaining the performance criterion. Analysis of ***movement effectiveness*** may be carried out using qualitative biomechanical video analysis, and two levels of analysis. The *first* level involves basic analysis and consists of establishing the ***technical level*** of the child. The *second* level requires comprehensive biomechanical analysis to determine the ***mechanical effectiveness*** of the movement of the child. Based on the literature, the study of the development of movement effectiveness needs to include both cross-sectional and longitudinal designs, and also address issues of reliability, primarily, the assessment of within-day intra-subject reliability in technical level.

The existing comprehensive and observational models available for the qualitative analysis of human movement have been evaluated. Most models use some form of movement simplification that consists of either phase analysis or the division of the criterion measure into its mechanical parts. A number of researchers have encouraged an understanding of why the movement looks the way it does by using movement principles which also aid the search for the critical features of the performance. However, most models give the impression of being incomplete, interdependent, and provide only general guidance to the sports analyst. Consequently, there is need for a ***model*** that incorporates the desirable features of existing models and facilitates the qualitative analysis of the *mechanical effectiveness.*

Chapter III - Study 1

A qualitative analysis of the development of technical level in children

Introduction

The movement patterns used by children when performing basic motor skills and the typical age at which such movements emerge have been extensively documented in the literature (e.g., Wild, 1938; Seefeldt and Haubenstricker, 1976; Roberton, 1978; Elliott *et al.,* 1980; Wickstrom, 1983). However, an examination of how effective these movements are in attaining the performance criterion is required in order to establish **technical level** and to study the **development of technical level** in children. Therefore, the **aims** of Study 1 were: **1-** to establish and classify the techniques used by a group of boys and girls of school age, **2-** to determine the technical level of the children, and **3-** to identify gender differences in the development of technical level in children.

Initial pilot work (**Pilot Study 1**) was carried out to establish the techniques used by a sample group of 45 children and a control group of 31 adults. Subsequently, the techniques were classified according to mechanical effectiveness using movement principles (e.g., Bunn, 1972; Lees, 1999b), in order to develop hierarchical models for the determination of technical level in children. Further, from a methodological viewpoint, it was crucial to be aware of the reliability of the observer in establishing technical level (e.g., Merriman *et al.*, 1993; Yan *et al.*, 2000), and also to determine how many trials per child would be required for analysis (Painter, 1990). For the study of the development of technical level in children, it was important to differentiate between within-day intra-subject variability and true developmental change (e.g., Langendorfer and Roberton, 2002). These methodological concerns regarding reliability were addressed in preliminary pilot work (**Pilot Study 2**). The study of the development of technical level in children was carried out in the **main body of Study 1**, which consisted of 4 parts: **1 -** a **cross-sectional study** of the development of technical level; **2-** a **longitudinal study** of the development of technical level; **3-** a **regression analysis** of the association between measures of the performance criterion and age of the children for a product-related assessment of motor development; and **4-** an **analysis of the association** between technical level and measures of the performance criterion to test the effect of technique on performance. These studies were approved by the Ethics Committee of Liverpool John Moores University.

Pilot Study 1: Classification of the techniques used by children and adults, and development of hierarchical models for the determination of technical level.

The purpose of this pilot study was to qualitatively establish and classify the techniques used by a group of school-aged children and adults, in order to develop hierarchical models that can be used to determine and interpret technical level in children.

Method

Subjects, equipment and data collection

Forty-five children (31 males and 14 females) from the Liverpool area, who participated regularly in extra-curricular sports activities (soccer and athletics), were asked to perform two consecutive trials of the soccer kick, the overarm throw and the standing broad jump, all for maximum distance. The parents or guardians of the children were asked to provide written informed consent for testing, according to the specifications of the Liverpool John Moores University Ethics Committee (see Appendix 1). Descriptive statistics of the children were (mean ± SD): age = 9.2 ± 2.11 years; height = 134.6 ± 14.69 cm; mass = 28.2 ± 8.60 kg. The children's age ranged from 5–11 years. Thus, children attending Primary school and in their 'sport skill' phase of motor development were targeted, since PE teachers usually need to monitor state of motor development in this age group. The children performed the three motor skills in an open sports ground or school playground, used a stationary standard-size soccer ball and threw a tennis ball. A Panasonic M10 video camera was used to record the movement of the children. The camera was placed with its axis perpendicular to the intended direction of the ball (or body in the case of the standing broad jump) and at about 6-8 m from the performer, with a field of view of approximately 5-6 m in the centre of the action. The exposure time was 1/500th second to avoid blurring of the image.

The children were explained the task briefly using verbal instructions (e.g., '*throw as far away as possible from that mark on the ground*'). In the cases of throwing and jumping, the generalised overarm throwing action and standing broad jump required from the children were demonstrated momentarily using body gesticulations. However, exposure to this was minimised in order to avoid their performance being influenced by demonstration (Brown, 1994). The children were required to throw and jump from a mark on the ground (a line) and there was sufficient space behind the mark to perform a run up. A run up prior to kicking and throwing was encouraged (by positioning the child

4-5 metres behind the mark) but not imposed upon the children, and no special instructions were given as to the way the three activities should be performed. Therefore, it was assumed that the children kicked the soccer ball, threw the tennis ball and jumped in their most natural manner to achieve the specific objective (maximum distance of the ball or jump). One trial per child was selected for analysis subjectively as an example of the child's best performance (i.e., most effective technique based on models of mature performance and/or greatest effort produced).

A control group of 31 adult subjects, also from the Liverpool area, was used to examine the techniques used by adults when performing the three basic motor skills and to help interpret the development of technical level in the children. The adult group was composed of recreational soccer players, track athletes and University Sports Science students, who also gave their informed consent. There were 20 males and 11 females with a mean age of 21.5 years (± 5.9), a mean height of 167.8 cm (± 17.6), and a mean mass of 64.1 kg (± 13.4). All 31 adult subjects performed maximum-distance soccer kicks for analysis; however only 24 of the adults (14 males and 10 females) performed the overarm throw and the standing broad jump. The method of video data collection was identical to that used for the children above.

1. Identification and classification of the techniques used by the children and the adults

Description of the kicking, throwing and jumping actions of the children and adults from video recordings of the performance was carried out by one experimenter in order to establish and classify the techniques used by the subjects. An example of child performance is shown in Figures A2.1-A2.3 (Appendix 2), in which the typical kicking, throwing and jumping actions of a 5-year-old boy are depicted using selected video frames. In order to facilitate the analysis, the three movements were divided into different phases, and key moments were identified, based on traditional descriptions of these motor skills (e.g., Seefeldt and Haubenstricker, 1976; Bloomfield *et al.*, 1979; Knudson and Morrison, 2002). For example, approach phase, back swing phase, last foot plant instant, swing phase, ball contact instant, and follow through phase were used for the soccer kick. The experimenter used combinations of normal video playback speed, slow motion, frame-by-frame video replay, and repeated viewing (2-3 viewings of a video sequence, as required) to view the movement of the subjects. Video playback speeds and conditions were selected based on the literature (e.g., Brown, 1982; Gangstead and Beveridge, 1984; Williams, 1986; Dunham, 1994; Abendroth-Smith *et* *al.*, 1996; Carnegie, 1997) and the requirements of the experimenter to satisfactorily describe the movement. Movement patterns were recorded using descriptive narrative and a number of coding symbols developed in the present research (see Tables A3.1 and A3.2, in Appendix 3). The movements that composed the **soccer kick** varied distinctly from child to child with respect to 5 components of the kicking action. These were: *approach pattern, movement of the opposite arm, placement of the non-kicking foot, pattern of contact with the ball,* and *follow through action.* In the **overarm throw**, the children differed from each other noticeably in their *overall throwing action* and in the *last step pattern.* In the **standing broad jump**, the *action of the arms* during the flight phase was the only component of the movement that was observed to conspicuously vary from child to child. Subsequently, the different movement patterns, within each component specified above, observed in the subjects were grouped into 'specific' techniques using 'common-general-direction-of-movement' as a grouping factor. For example, the actions of the arms associated with the standing broad jump initially labelled as 'Pendulum', 'Pendulum–swing back', 'Pendulum-down', and 'Late pendulum-swing back' were considered individual adaptations of a technique and were grouped under the generic technique of 'Pendulum'.

2. Development of hierarchical models for the determination of technical level

The specific techniques used by the subjects were classified in hierarchical order according to mechanical effectiveness. This was carried out subjectively by the experimenter and done with reference to specific movement principles and examples of proficient performance (e.g., Atwater, 1970; Bunn, 1972; Wickstrom, 1975; Hay, 1993; Gallahue and Ozmun, 1995; Lees, 1999b). For example, mechanical effectiveness of the placement of the support foot in the soccer kick was assessed based on statements such as "*If it* (the foot) *is too far back, the peak force of the kick will be spent before contact is made*" (Wang and Wiese-Bjornstal, 1994; p. 35). The hierarchical classification of the techniques allowed the construction of hierarchical models that can be used to establish technical level.

Results

1. Identification and classification of the movements used by the children

In total, 29 movement patterns were identified within the 5 components of the **soccer kick** (see Table 3.1 below, and Tables A3.3-A3.5 in Appendix 3). Table 3.1 shows the grouping of movement patterns into specific techniques for the soccer kick using a colour system, for example *running action* and *low running action* movements of the opposite arm were grouped under the technique of *running action*. In the **overarm throw**, the children used 8 distinctive throwing actions and 3 different modes of last step pattern (Tables 3.2 and A3.6). In the **standing broad jump**, 12 different patterns of arm motion were identified (Tables 3.3 and A3.7).

Table 3.1: The different actions used by the children in the soccer kick and grouping of these actions under specific techniques. [a]

Approach pattern [b] (3) [c]	Opposite arm movement (10)	Foot placement [d] (3)	Ball contact pattern (5)	Follow through (8)
Straight (42, 64) [e]	Back sail (29, 0)	By ball (55, 29)	Back lean (39, 43)	Static (10, 0)
Curved (45, 29)	Rotational (3, 0)	Behind ball (26, 50)	Weighted (16, 7)	Step ahead (42, 50)
Diagonal (13, 7)	Horizontal (14, 7)	Well behind ball (19, 21)	Sink & rise (16, 0)	Step over ball (6, 8)
	Diagonal (29, 15)		Jumping on (16, 14)	Run over ball (10, 0)
	Diagonal-horizontal (6, 7)		Running through (13, 36)	Running (13, 21)
	Diagonal-rotational (10, 0)			Switch over (3, 0)
	Held up & in front (3, 7)			Right & back (10, 0)
	Held low & behind (0, 7)			Drag & hop (6, 21)
	Running action (0, 7)			
	Low running action (6, 50)			
Grouping of actions under specific techniques (by colour)				
Straight (42, 64)	Rotational (32, 0)	By ball (55, 29)	Back lean (39, 43)	Static (10, 0)
Curved (45, 29)	Horizontal (62, 43)	Behind ball (26, 50)	Weighted (48, 21)	Step (58, 58)
Diagonal (13, 7)	Running action (6, 57)	Well behind ball (19, 21)	Running action (13, 36)	Running (16, 21)
				Rotational (10, 0)
				Drag & hop (6, 21)

[a] **Actions/techniques listed in no particular order that may reflect kicking proficiency.**
[b] **Type of approach is self-explanatory.**
[c] **Number of actions per movement component.**
[d] **Foot placement was classified using coding symbols from Table A3.2, Appendix 3.**
[e] **(% males, % females) using the action.**

Table 3.2: Classification of the different overall throwing actions and last step actions used by the children, and grouping of these actions under specific techniques. [a]

Overall throwing action (8)	**Last step action [b] (3)**
Blocking (35, 7)	Running (10, 21)
Leading opposite arm (13, 7)	Contralateral (87, 36)
Baseballer's (3, 0)	Homolateral (3, 43)
Cricketer's (13, 0)	
Straight (13, 43)	
Wide arc (20, 29)	
Interrupted swing (0, 14)	
Interrupted run up (3, 0)	
Grouping of actions under specific techniques (by colour)	
Blocking (35, 7)	Running (10, 21)
Leading opposite arm (16, 7)	Contralateral (87, 36)
Cricketer's (13, 0)	Homolateral (3, 43)
Straight (13, 43)	
Wide arc (20, 29)	
Interrupted swing (0, 14)	
Interrupted run up (3, 0)	

[a] **Actions/techniques listed in no particular order that may reflect throwing proficiency.**
[b] **Type of step is self-explanatory.**

Table 3.3: The different actions of the arms after takeoff in the standing broad jump used by the children and grouping of these actions under specific techniques. [a]

Action of the arms (12)
Back circle (20, 7)
Late back circle (10, 7)
Pendulum (6, 14)
Pendulum-down (13, 37)
Pendulum–swing back (24, 21)
Late pendulum-swing back (3, 0)
Swing back (6, 0)
Throw-swing back (6, 7)
Throw-down (3, 0)
Diagonal-down (3, 0)
Mature (6, 0)
No swing (0, 7)
Grouping of actions under specific techniques (by colour)
Back circle (29, 14)
Pendulum (52, 72)
Throw (13, 7)
Mature (6, 0)
No swing (0, 7)

[a] **Actions/techniques listed in no particular order that may reflect jumping proficiency.**

2. Development of hierarchical models for the determination of the technical level of the children

Appendix 4 provides descriptions of the mature and less-skilled forms of the movement based on movement principles. The hierarchical models for technique classification are shown in Figures 3.1-3.8. The models consist of 3 or 4 levels, whereby techniques above are considered to be more effective than techniques below, and techniques at the same level are considered to be similar in terms of effectiveness. The different levels in the hierarchical models provide a system to rate the technical level of the child; for example, a *curved* approach to the stationary ball in soccer corresponds to a technical level of 3 in the model shown in Figure 3.1. The pathways between technical levels (shown as lines between boxes) merely indicate the possibility of children changing from a less effective technique to a more effective technique; for example, a child may substitute for a *running* follow through in soccer either a *step* or a *rotational* follow through as a result of the motor development of the child (Figure 3.5).

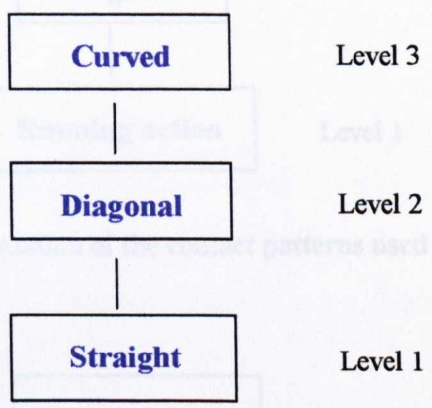


Figure 3.1: Hierarchical representation of the approach patterns used by the children (soccer kick).

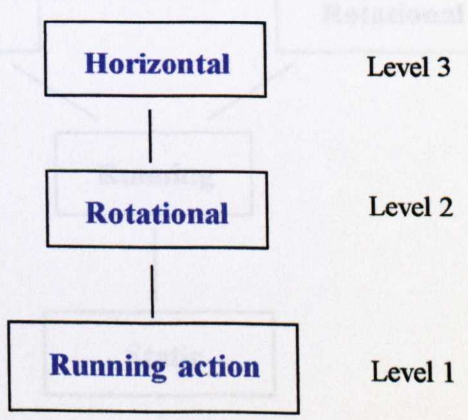


Figure 3.2: Hierarchical representation of the movements of the opposite arm used by the children (soccer kick).

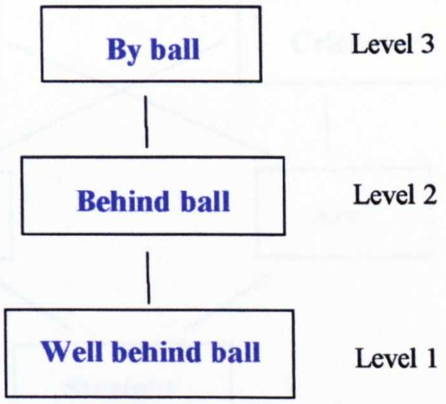


Figure 3.3: Hierarchical representation of the estimated foot placement positions used by the children (soccer kick).

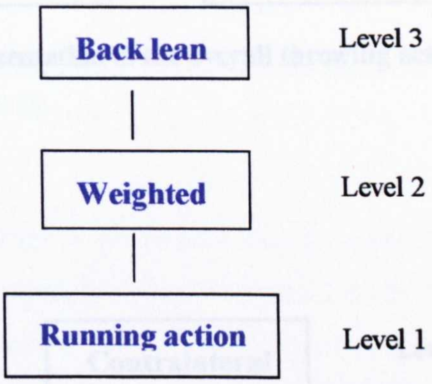


Figure 3.4: Hierarchical representation of the contact patterns used by the children (soccer kick).

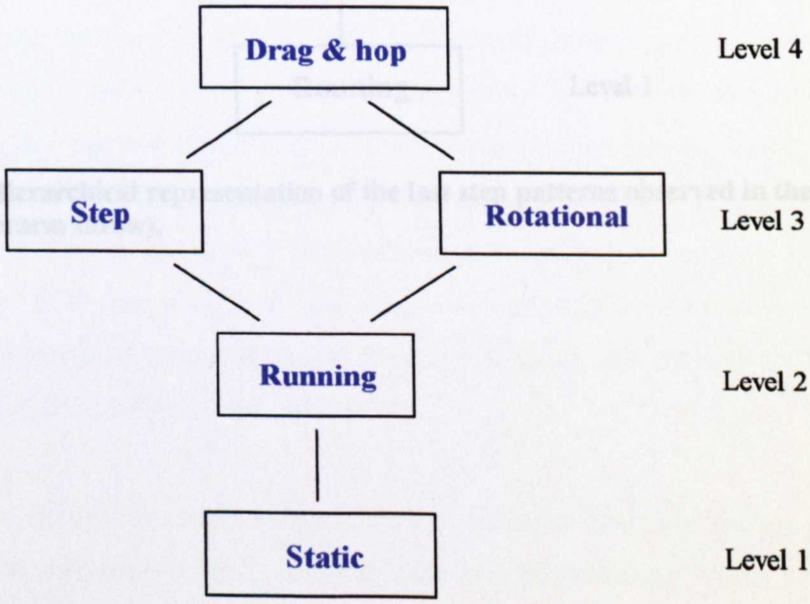


Figure 3.5: Hierarchical representation of the follow through techniques observed in the children (soccer kick).

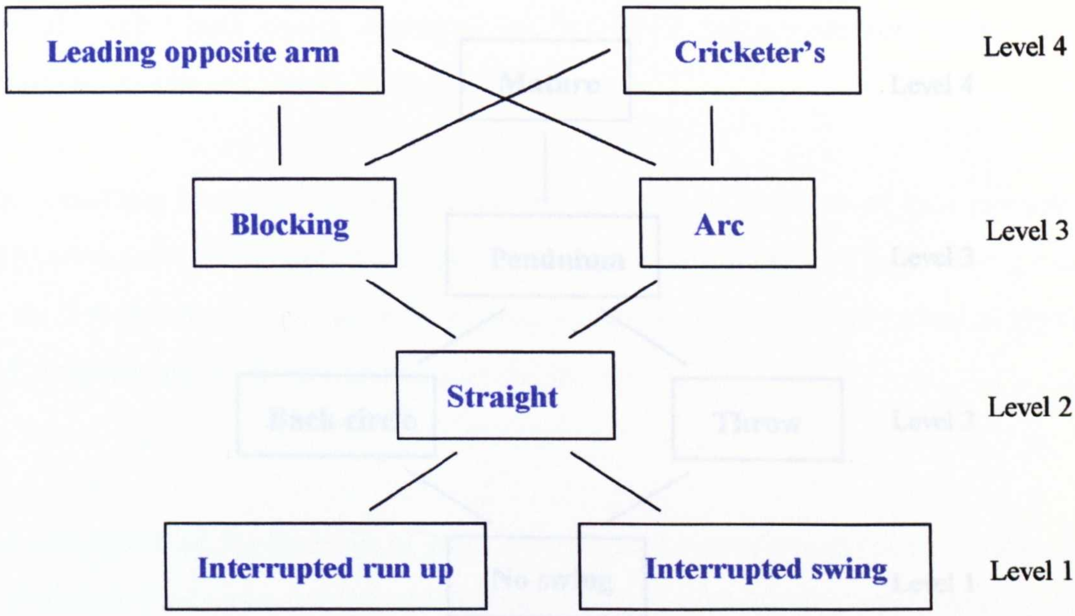


Figure 3.6: Hierarchical representation of the overall throwing actions used by the children (overarm throw).

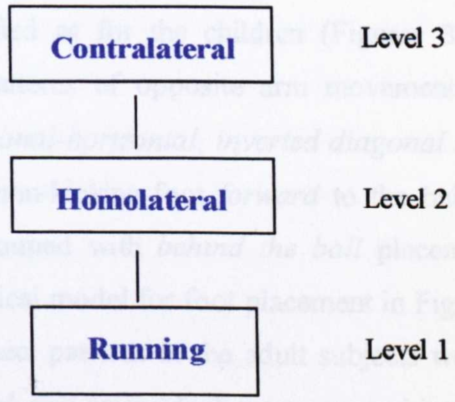


Figure 3.7: Hierarchical representation of the last step patterns observed in the children (overarm throw).

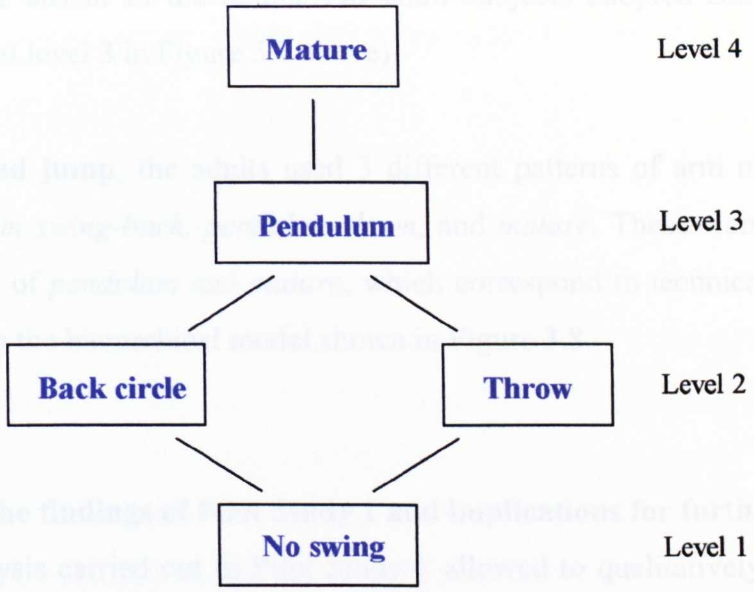


Figure 3.8: Hierarchical representation of the movements of the arms used by the children (standing broad jump).

3. Identification and classification of the movements performed by the adults

In the **soccer kick**, the adult subjects's type of approach to the ball and the movement of the opposite arm were classified as for the children (Figures 3.1 and 3.2 above), although the adults used 3 patterns of opposite arm movement that had not been observed in the children: *rotational-horizontal, inverted diagonal* and *out and across.* One adult subject placed the non-kicking foot *forward* to the ball, however *forward* placement of the foot was grouped with *behind the ball* placement. Only technical levels 2 and 3 (see the hierarchical model for foot placement in Figure 3.3 above) were present in the adults. Ball contact patterns in the adult subjects were of 4 types: *back lean, upright, weighted*, and *sink and raise* which were grouped into the 2 techniques of *weighted* and *back lean* that correspond to technical levels 2 and 3, respectively, in Figure 3.4 above. The adults used 7 follow through techniques including 4 techniques *(drag and jump, short step, long step,* and *jump and step*) that were not observed in the children. The hierarchical model shown in Figure 3.5 above was suitable for the adult subjects, although the adults did not use level 2.

In the **overarm throw**, the adult subjects used 5 different throwing actions including *leading opposite arm, baseballer's, straight, wide arc,* and *blocking*. These movements were classified using Figure 3.6 above; thus yielding 3 technical levels, whereby technical level 1 was absent in the adults. All adult subjects adopted *contralateral* forward step (technical level 3 in Figure 3.7 above).

In the **standing broad jump**, the adults used 3 different patterns of arm movement, which were: *pendulum swing-back, pendulum down,* and *mature.* These were grouped into the 2 techniques of *pendulum* and *mature*, which correspond to technical levels 3 and 4, respectively, in the hierarchical model shown in Figure 3.8.

Brief discussion of the findings of Pilot Study 1 and implications for further testing

The descriptive analysis carried out in Pilot Study 1 allowed to qualitatively establish and classify the techniques used by a group of school-aged children and adults. Some of the techniques used by the subjects had already been described in previous research (e.g., Toyoshima *et al.*, 1974; McClenaghan, 1976; Bloomfield *et al.,* 1979; Elliott *et al.,* 1980; Haywood and Getchell, 2001), such as the placement of the foot by the ball or the movement of the opposite arm in the soccer kick. However, the descriptive analysis carried out in this pilot study was somewhat more detailed and included observations such as 'pendulum swing-back' and 'pendulum down' for the standing broad jump. Classification of the techniques used by the children according to mechanical effectiveness allowed developing hierarchical models that can be used to quantify technical level in larger groups of subjects. The hierarchical models are suitable to determine technical level in adult subjects, although the adults in the present pilot study did not generally use the more ineffective movement patterns (low technical level) characteristic of very young children, such as *no arm swing* in the standing broad jump. However, before analysis of a larger group of children could be carried out various issues of reliability needed clarifying. Such issues are addressed in Pilot Study 2.

Pilot Study 2: Assessment of intra-rater reliability in the determination of technical level, and assessment of within-day intra-subject reliability in technical level.

Method

1. Intra-rater reliability in the determination of technical level

Intra-rater reliability was assessed using the video recorded kicking, throwing and jumping performance of a subgroup 15 male children (mean age ± SD of 7.3 ± 1.2 years) from Pilot Study 1. The technical level of the children was determined by one rater, familiarised with the hierarchical models developed in Pilot Study 1, on two separate occasions with a time span between test 1 and test 2 of one month. The period of one month between repeated classification of the same performance recorded on video represented a realistic pace of work for revisiting data analysis by the rater. The view of the performance was in the sagittal plane and the rater used combinations of normal-speed, slow motion, frame-by-frame video replay and repeated viewing, as required (e.g., Dunham, 1994; Abendroth-Smith *et al.*, 1996; Carnegie, 1997). Intra-rater reliability was assessed using percent agreement (exact agreement) between test 1 and test 2, with the acceptable level of agreement set at 70 % (based upon Eastlack *et al.*, 1991 and Knudson and Morrison, 2002). Intra-rater reliability was ascertained using Kappa statistic (*k*) (tendency to agree) to assess strength of agreement (e.g., 'moderate', 'good agreement') and account for agreement due to chance (Altman, 1999; Howitt and Cramer, 2003). Assessment of intra-rater reliability in the determination of last step pattern in the throw was not required since recognition of this pattern is straightforward.

2. Within-day intra-subject reliability in technical level

Within-day intra-subject reliability was assessed in order to determine the number of trials needed for analysis and to help differentiate between within-day variability and true developmental change. A stratified random sample of 70 children (35 males and 35 females) was selected from a group of school-aged children, and within-day intra-subject reliability in technical level was assessed using 2 consecutive trials of each of the three motor skills. There were 5 males and 5 females per age group, in a total of seven age groups that ranged from 5 to 11 years of age. The stratified sample allowed including an equal number of children from each age/gender group. Agreement between technical level in trial 1 and technical level in trial 2 was assessed using percent agreement and Kappa statistic. Brief observation of the adults revealed that the adult subjects used highly repeatable movement patterns over two consecutive trials, which rendered the assessment of intra-subject reliability of adults unnecessary.

Results

1. Intra-rater reliability in the determination of technical level

Percent agreement between test 1 and test 2 was no lower than 73% for any movement component (Table 3.4), and strength of agreement ranged from moderate to very good according to *k* statistic (Altman, 1999; Howitt and Cramer, 2003).

Table 3.4: Results of the tests of intra-rater reliability in the determination of technical level (N = 15).

	Movement component of the motor skill	Agreement between test 1 and test 2 (%)	*k*	Sig.*
Soccer kick	Approach pattern	73.3	0.552	0.004
	Opposite arm movement	80.0	0.602	0.019
	Foot placement	80.0	0.674	0.001
	Contact pattern	73.3	0.583	0.001
	Folllow through	73.3	0.524	0.013
Overarm throwing	Overall throwing action	86.7	0.769	0.001
Standing broad jump	Arms movement	86.7	0.877	0.001

* All Kappa results are significant ($p < 0.05$).

2. Within-day intra-subject reliability in technical level

Results for the within-day intra-subject reliability test appear in Table 3.5. Percent agreement in technical level between consecutive trials ranged from 56.8 to 89.2 %. Thus, children attained only moderate reliability across two trials in some components of the soccer kick. In addition, some of the children used two different techniques in consecutive trials, although these techniques were within the same technical level. Agreement according to *k* statistic was fair to good (Altman, 1999), and all results were statistically significant.

Table 3.5: Results of the tests of within-day intra-subject reliability in technical level (N = 70).

	Movement component of the motor skill	Males			Females		
		Agreement (%)	*k*	Sig.*	Agreement (%)	*k*	Sig.*
Soccer kick	Approach pattern	56.8	0.393	0.001	75.7	0.481	0.001
	Opposite arm movement	62.2	0.468	0.001	59.5	0.513	0.001
	Foot placement	62.2	0.432	0.001	64.9	0.319	0.011
	Contact pattern	62.2	0.427	0.001	62.2	0.438	0.001
	Folllow through	73.0	0.634	0.001	70.3	0.570	0.001
Overarm throw	Overall throwing action	73.0	0.629	0.001	70.3	0.612	0.001
	Last step pattern	89.2	0.793	0.001	62.2	0.475	0.001
Standing broad jump	Arms movement	73.0	0.674	0.001	75.7	0.629	0.001

* All Kappa statistical results are significant ($p < 0.05$)

Brief discussion of the findings of Pilot Study 2 and implications for further testing

1. Intra-rater reliability in the determination of technical level

Agreement between test 1 and test 2 was above 70% for all components of the motor skills, therefore it was concluded that the reliability of the operator in the determination of technical level was acceptable for the purposes of qualitative analysis (based on Krebs *et al.*, 1985; Eastlack *et al.*, 1991; and Knudson and Morrison, 2002). The difficulty in being consistent was attributed to some of the children displaying movement patterns that were a mixture of two distinct techniques and that corresponded to two different technical levels.

2. Within-day intra-subject reliability in technical level

The results of the reliability tests showed inconsistent technical level of the children across two consecutive trials for some movement components. Also, 5 children used different techniques over two trials, although this did not involve a change in technical level. For example, in the overarm throw two male children used *cricketer's* technique and *leading opposite arm* technique in trials 1 and 2, respectively. A few children showed inconsistent technical level by either increasing or decreasing technical level (± 1-3 levels). In the male group, the younger children were generally more variable and the 11-year-olds showed greater reliability. However, there were no obvious gender differences in reliability. The findings suggest that it is important to record at least two trials on video and, if the child displays inconsistent technical level, the trial showing the highest technical level should be used. Finally, the findings of the within-day intra-subject reliability study must be taken into account in the longitudinal assessment of the development of technical level in children (a similar approach has recently been used by Langendorfer and Roberton, 2002).

Main Study: The development of technical level in children.

Introduction

Pilot Studies 1 and 2 permitted developing hierarchical models to determine technical level and addressing methodological concerns regarding issues of reliability, therefore laying the foundations for the study of the development of technical level in children. Such developmental study was conducted in the main body of Study 1, which consisted of 4 parts: **1-** a **cross-sectional study** of the development of technical level; **2-** a **longitudinal study** of the development of technical level; **3-** a **regression analysis** of the association between measures of the performance criterion and age of the children for a product-related assessment of motor development; and **4-** an **analysis of the association** between technical level and measures of the performance criterion to test the effect of technique on performance.

Method

Subjects

A group of 187 normal school children (106 males and 81 females) from the Liverpool area, who participated regularly in PE classes and in extra-curricular sports activities (i.e., athletics, soccer, gymnastics, swimming), were asked to voluntarily participate in a **cross-sectional study** of motor skill development. Children were aged between 5 and 11 years (Figure 3.9 and Table 3.6); where, a minimum number of 10 children per age/gender group were recruited. This age group was targeted since children are in their later childhood and, therefore, in their 'sport skill' phase of motor behaviour (Gabbard, 1992); during which phase PE teachers are more likely to monitor children's development in Primary schools. In selecting this age group it was considered that the 'fundamental movement' (2-5 year olds) and 'growth and development' (12-18 year olds) phases of motor development show specific developmental patterns and may be best studied either independently or within the context of a larger scale study. Thus, the conspicuous effects that growth spurts, physiological changes and environmental influences have on motor development, and which occur at the onset of adolescence, were avoided. The children were grouped according to gender and allocated to absolute age groups; for example, a child aged 5 years and 10 months was placed in the 5-year-old group. In a **longitudinal design**, 55 of those children (28 males and 27 females) were assessed twice (test 1 and test 2), with a mean ± SD of 6 ± 3 months between measures (Figure 3.10, and Table 3.7). The time span between repeated measures was chosen based on preliminary observations of a sample of 11 children of different ages, which showed that changes in the children's use of technique were taking place within periods of 5-7 months. The time between test 1 and test 2 was variable due to difficulties in arranging videoing sessions with the children and guardians of the children. The unequal number of children from each age/gender group included in the study was due to the difficulty in keeping track of the children assessed longitudinally. Thirty-one adult subjects were assessed cross-sectionally and used as a **control group**. The adult subjects were the same as those described in Pilot Study 1. The parents or guardians of the children and the adult subjects were asked to provide written informed consent for testing, according to the specifications of the Liverpool John Moores University Ethics Committee (see Appendix 1).

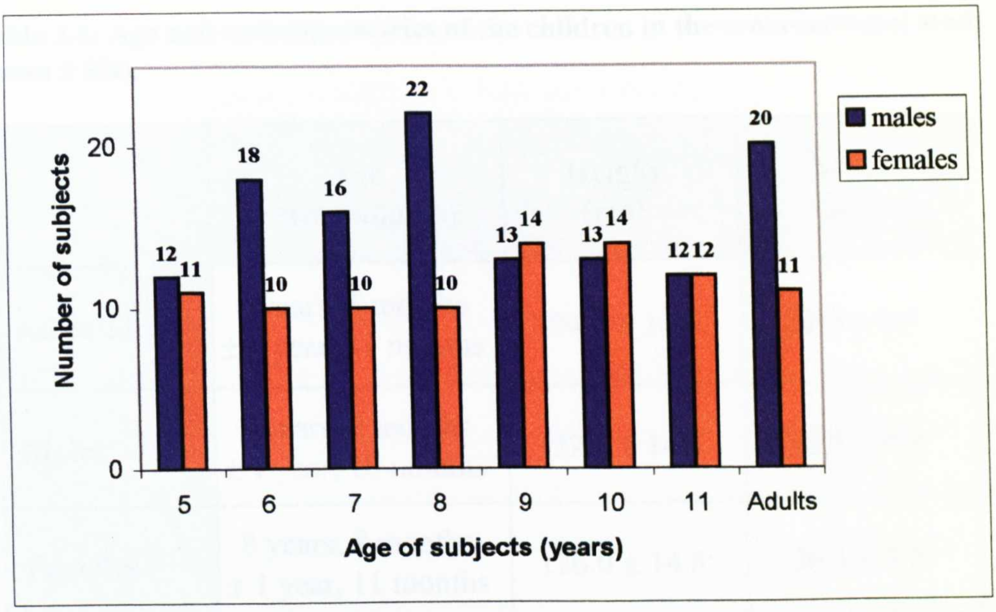


Figure 3.9: Number of children (N = 187; 106 males & 81 females) and adults (N = 31) assessed cross-sectionally

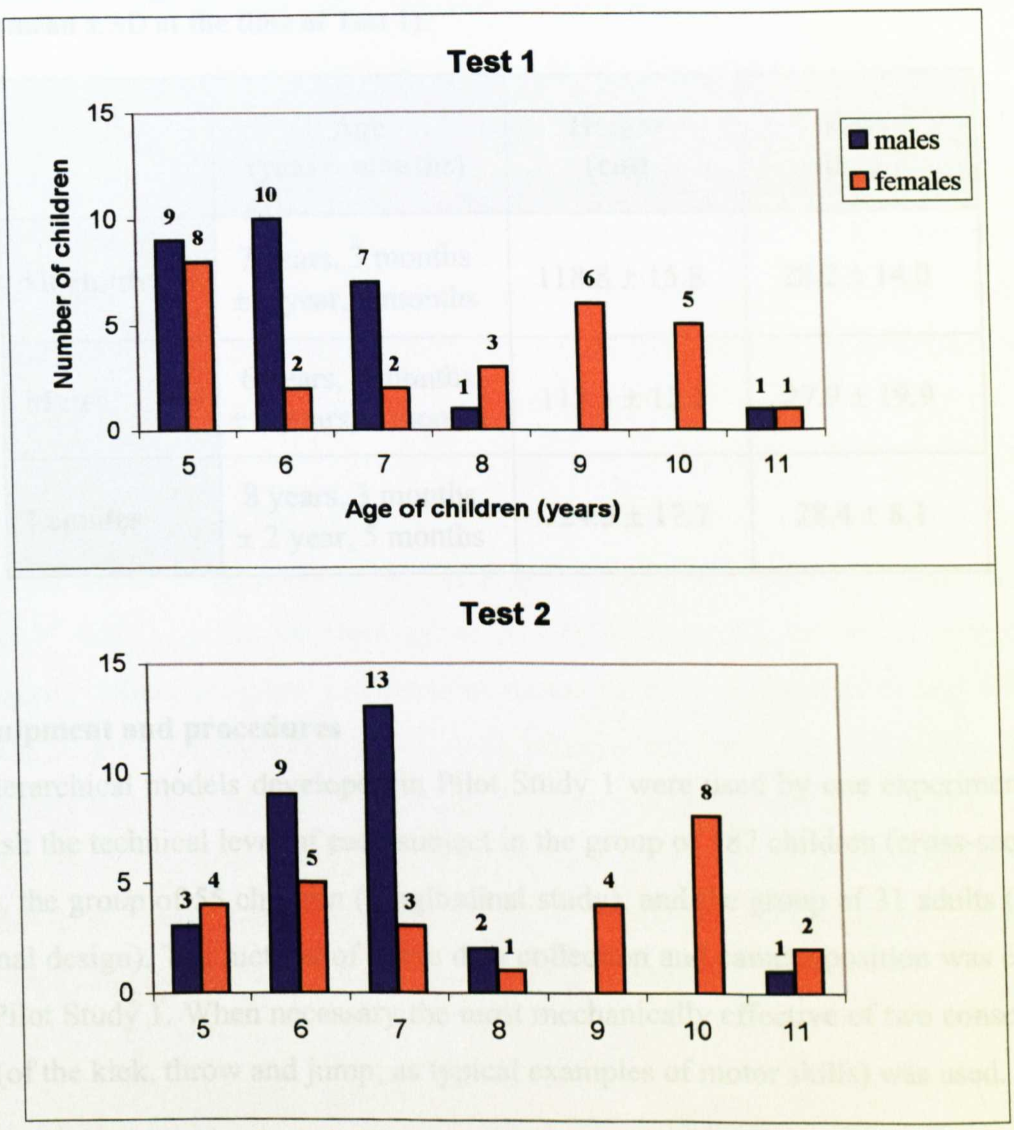


Figure 3.10: Number of children in the longitudinal study (N = 55; 28 males & 27 females).

Table 3.6: Age and anthropometrics of the children in the cross-sectional study (mean ± SD).

	Age (years, months)	Height (cm)	Mass (kg)
All children	8 years, 6 months ± 1 year, 11 months	124.3 ± 14.6	29.3 ± 9.3
Males	8 years, 3 months ± 1 year, 10 months	122.9 ± 14.4	28.5 ± 9.3
Females	8 years, 8 months ± 1 year, 11 months	126.0 ± 14.8	30.3 ± 9.2

Table 3.7: Age and anthropometrics of the children in the longitudinal study (mean ± SD at the time of Test 1).

	Age (years, months)	Height (cm)	Mass (kg)
All children	7 years, 3 months ± 1 year, 8 months	118.8 ± 15.8	28.2 ± 14.0
Males	6 years, 6 months ± 1 years, 3 months	112.3 ± 12.1	27.9 ± 19.9
Females	8 years, 3 months ± 2 year, 5 months	124.3 ± 17.7	28.4 ± 8.1

Equipment and procedures

The hierarchical models developed in Pilot Study 1 were used by one experimenter to establish the technical level of each subject in the group of 187 children (cross-sectional study), the group of 55 children (longitudinal study), and the group of 31 adults (cross-sectional design). The method of video data collection and camera position was exactly as in Pilot Study 1. When necessary the most mechanically effective of two consecutive trials (of the kick, throw and jump; as typical examples of motor skills) was used.

1. Cross-sectional study of the development of technical level

Inspection of the data using Spearman's Rho tests revealed low technical level-age correlation coefficients (e.g., opposite arm movement in the soccer kick, males; rho = 0.137, df = 104, $p = 0.028$ (significant)). Consequently, children were allocated to three age groups, 5 & 6 year-olds (N = 30 males and 21 females), 7 & 8 year-olds (N = 38 males and 20 females), and 9 to 11 year-olds (N = 38 males and 40 females) and a two-tailed X^2 test (suitable for rating scales with a low number of categories; significance set at $p < 0.05$) for each movement component was used to test the significance of the discrepancy between observed and expected results and, thus, infer an association between technical level and age of the children. The X^2 tests were carried out using a contingency table for the 3 independent age groups and multiple technical level categories (e.g., 1-2; 1-4). Males and females were analysed separately to be able to inspect gender differences in the development of technical level. The number of children performing at each technical level, expressed as a percentage due to the unequal number of children in each age/gender group, was displayed graphically using stacked graphs for a visual inspection of gender differences in both technical level and its pattern of development. In the adult subjects, frequency count was used to establish how many of the subjects performed at each technical level. This was also expressed as a percentage, due to the unequal number of males and females, and was used to assess the level of maturation in the movement patterns of the adults to aid interpretation of motor development in the children.

2. Longitudinal study of the development of technical level

Changes in the technical level of the children between test 1 and test 2 were assessed using a X^2 test (significance level set at $p < 0.05$) for each movement component. Contingency tables included 2 dependent measures (test 1 and test 2) and multiple technical level categories (e.g., 1-3; 1-4). Where one or more cells in a 2 x 2 contingency table had an expected frequency of less than 5 a two-tailed Fisher's exact test (Howitt and Cramer, 2003) was used to increase the significance threshold. The technical level of the children at the times of test 1 and test 2 was presented graphically using stacked graphs for a visual inspection of developmental change.

3. Regression analysis: Performance criterion measure – age of the children

Regression analysis of the association between the performance criterion (range of the ball/distance jumped; hereafter referred to as the 'range') and age of the children (cross-sectional group) was carried out as a product-related analysis of the rate of development of the children. Incidentally, measuring the range of the soccer ball and the tennis ball, and the distance jumped with a measuring tape during a typical filming session proved to be time consuming and not always practical to do. Therefore, the range of the ball and the distance jumped were calculated from video. The range was calculated using measures of velocity, angle and height of release of the ball, which were obtained from the video monitor screen using frame-by-frame playback (50 Hz), rulers and a protractor. A vertical calibration tool consisting of a 1-metre ruler positioned at the point of release/takeoff had been previously filmed to allow conversion of monitor screen measures into actual distances. Changes in the position of the ball and time between video fields were measured using video playback at 50 Hz, and were used for the calculation of release velocity. Length of the jump in the standing broad jump was also measured directly from the screen monitor as the distance from toe at takeoff to heel at landing. Height of ball release in the throw and distance jumped were recorded as absolute values, and also expressed as a percentage of the child's height for normalisation of the data.

The range data were inspected for normality using Kolmogorov-Smirnov (KS) and Shapiro-Wilk (SW) diagnostic tests and normality plots (Q-Q plot) (Ntoumanis, 2001), which showed that the data met the assumptions of normality considering that the sample of children was large (e.g., standing broad jump, males; KS = 0.073, df = 99, p = 0.200; SW = 0.961, df = 99, p = 0.005). Range-age scatter plots were used which suggested a positive relationship between range and age, although they revealed heteroscadisticity for the **soccer kick** and the **overarm throw** in both male and in female children. The square of the coefficient of determination (R^2) was used to help interpret the meaningfulness of the correlations since the sample size was relatively large (Thomas and Nelson, 1996). Range-age relationships were displayed graphically using scatter graphs; including regression lines, R^2, prediction equations, 95% confidence intervals for the slope and intercept of the regression lines, and Pearson's Product Moment correlation coefficients (r).

4. Analysis of the correlation between technical level and measures of the performance criterion

The effect of technique on performance was assessed using the correlation between technical level of the children (cross-sectional group) for each movement component and the range; Spearman's Rho test (significance level set at $p < 0.05$). The *overall technical level* (sum of technical levels for all movement components) for the **soccer kick** and the **overarm throw** was also correlated with the range. The range attained by the children was also expressed relative to the height of the child, to eliminate the effects of limb length and stature on the range attained, and plotted against technical level of the children.

Results

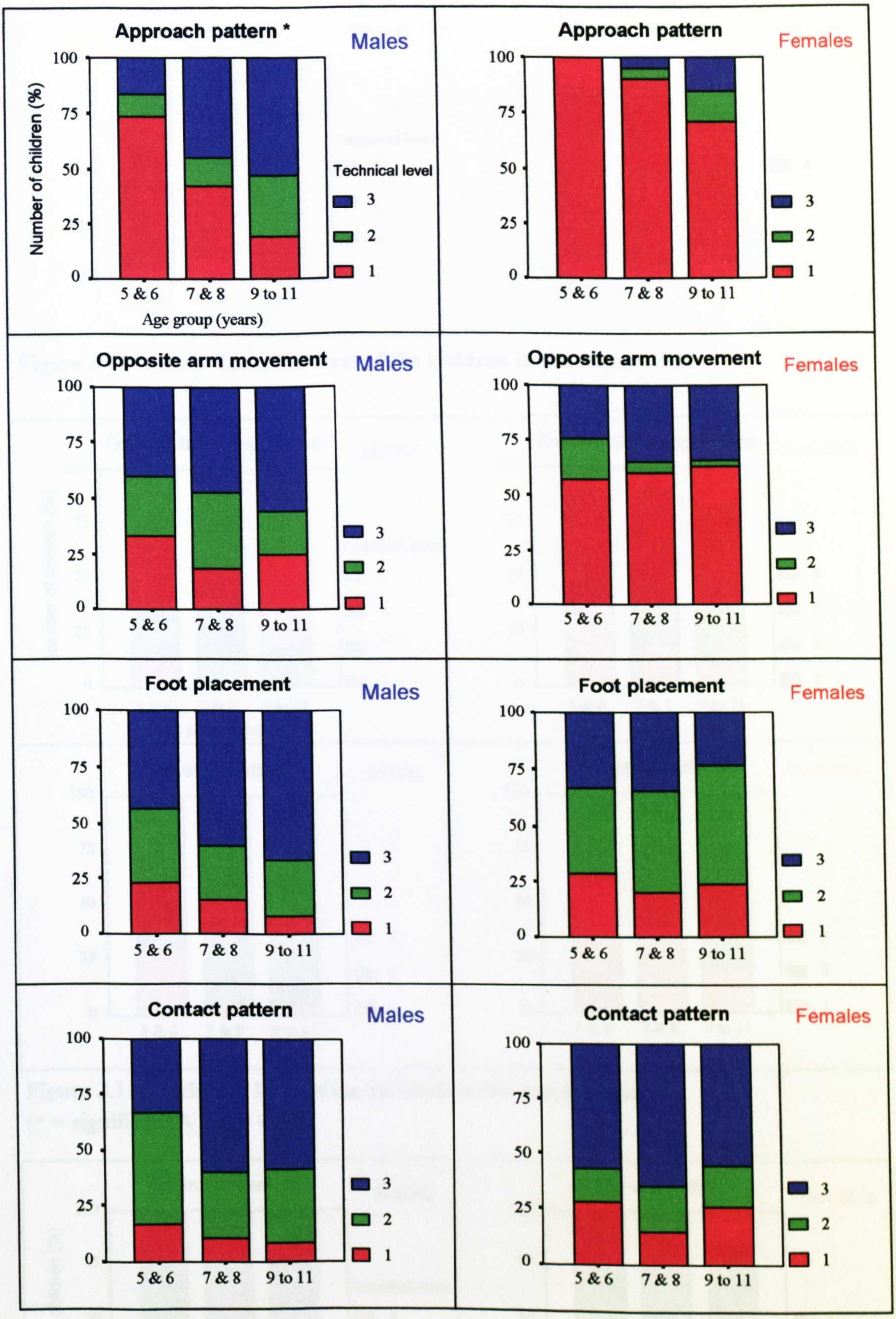
1. Cross-sectional study of the development of technical level

The results of the X^2 tests appear in Table 3.8, and Figures 3.11 – 3.13 show the number of children (as a percentage) performing at each technical level. Generally, male children showed a higher technical level across the age range and a faster rate of development in the **soccer kick** and the **overarm throw** (higher X^2 values), however female children showed supremacy in the **standing broad jump**. The higher technical level of male children was particularly noticeable in the throw. Figure 3.14 shows that, generally, the male adults displayed a higher technical level than the female adults. Notice that in the **standing broad jump** only a small percentage of the adults used a *mature* arm action (technical level 4).

Table 3.8: Results of the X^2 tests for the cross-sectional study of the development of technical level.

	Movement component of the motor skill	Males			Females		
		X^2	*df*	Sig.	X^2	*df*	Sig.
Soccer kick	Approach pattern	20.43	4	**0.001***	9.07	4	0.059
	Opposite arm movement	3.82	4	0.431	5.68	4	0.225
	Foot placement	4.68	4	0.321	1.70	4	0.791
	Contact pattern	6.05	4	0.195	1.37	4	0.850
	Follow through	7.57	6	0.272	4.46	6	0.614
Overarm throw	Overall throwing action	34.67	6	**0.001***	7.84	6	0.250
	Last step pattern	15.61	4	**0.004***	13.88	4	**0.008***
Standing broad jump	Arms movement	6.29	6	0.392	13.53	6	**0.035***

* Significant ($p < 0.05$)



* X^2 was significant at $p < 0.05$.

Figure 3.11: Technical level of the children in the soccer kick.

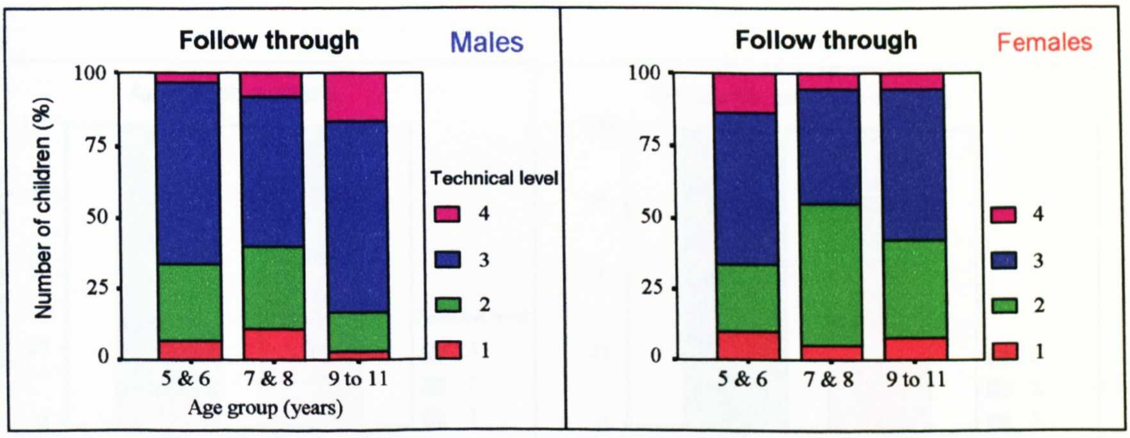


Figure 3.11 (cont.): Technical level of the children in the soccer kick.

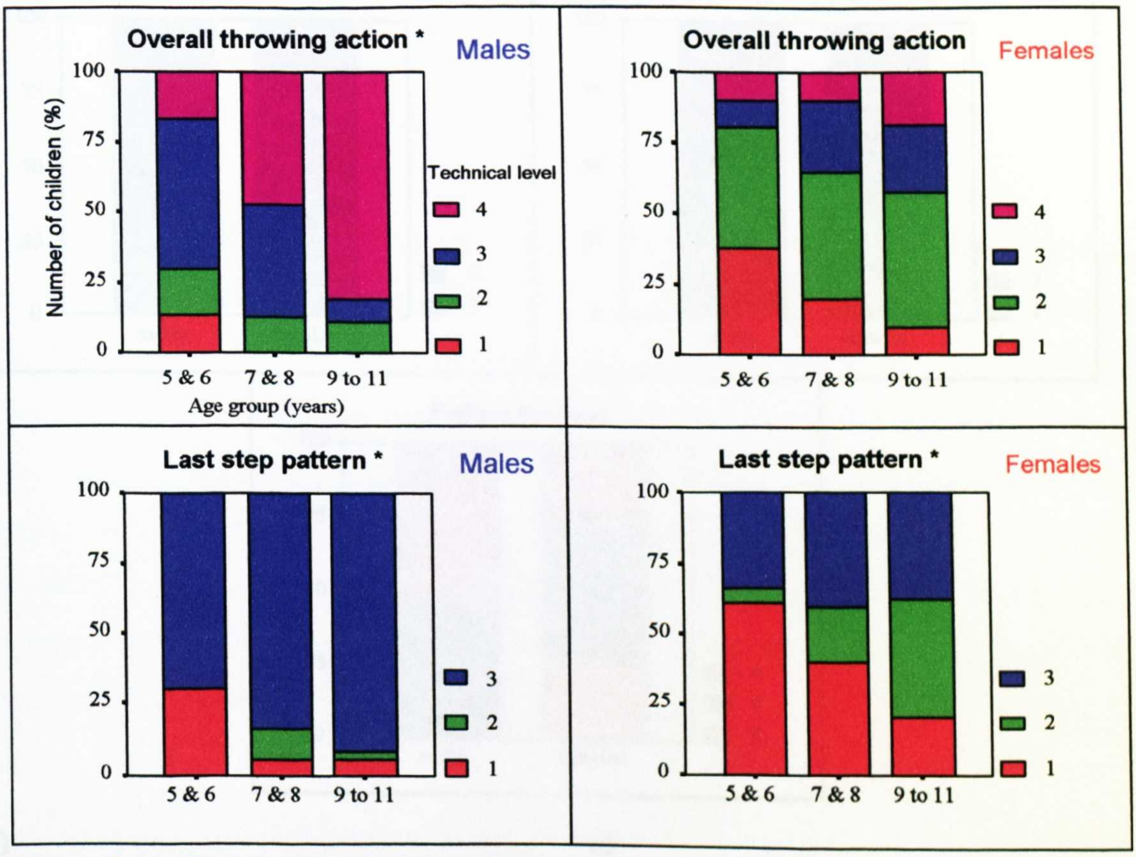


Figure 3.12: Technical level of the children in the overarm throw (* = significant X^2, p < 0.05).

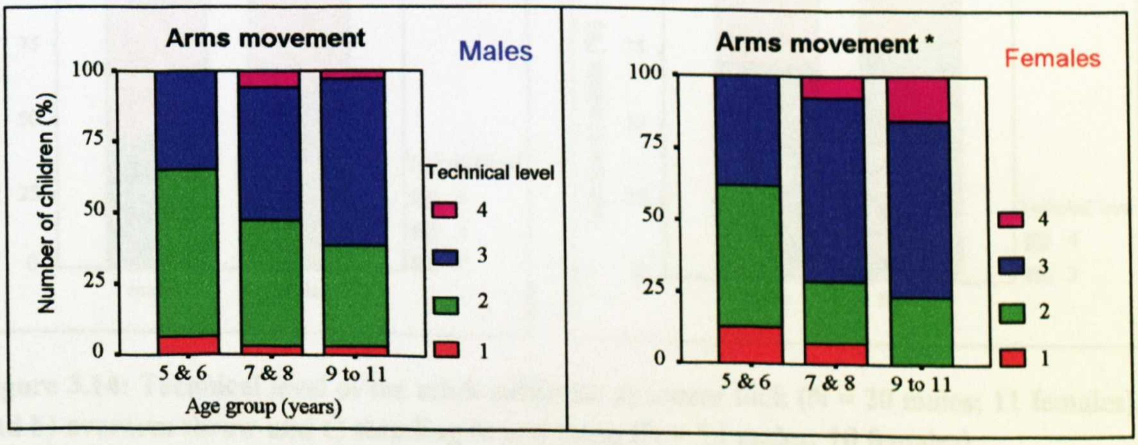


Figure 3.13: Technical level of the children in the standing broad jump (* = significant X^2, p < 0.05).

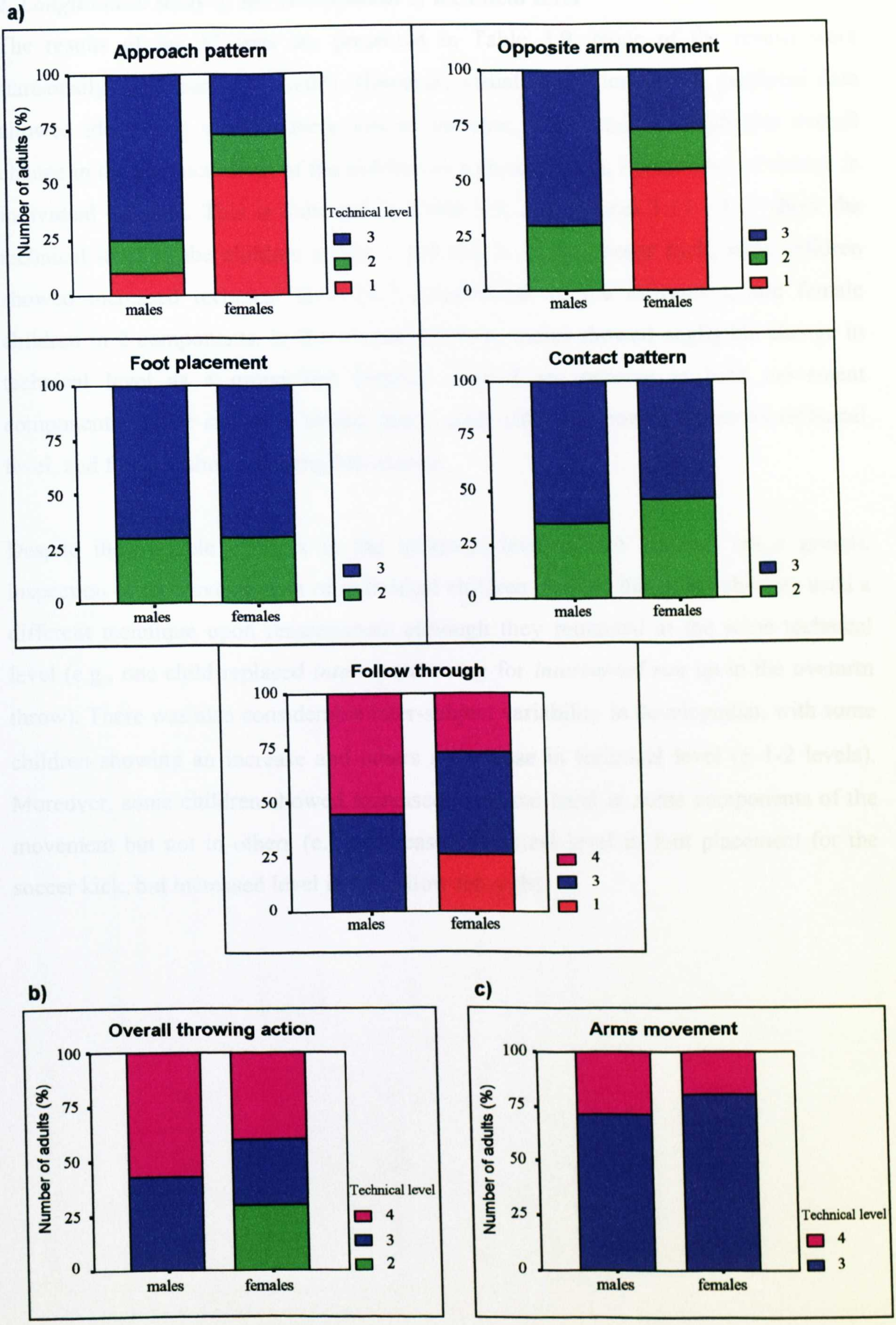


Figure 3.14: Technical level of the adult subjects; a) soccer kick (N = 20 males; 11 females), and b) overarm throw and c) standing broad jump (N = 14 males; 10 females).

2. Longitudinal study of the development of technical level

The results of the X^2 tests are presented in Table 3.9. None of the results were statistically significant ($p < 0.05$). However, visual inspection of the graphical data allowed identifying whether there was an increase, a decrease, or negligible overall change in the technical level of the children as a group; that is, irrespective of change in individual children. This is indicated in Table 3.9, and Figures 3.15 - 3.17 show the technical level of the children at test 1 and test 2. In the **soccer kick**, male children showed increased technical level in 3 components of the movement, and female children in 2 components. In the **overarm throw**, males showed negligible change in technical level as a group and females showed an increase in both movement components. In the **standing broad jump**, male children showed increased technical level, and females showed negligible change.

Despite the variable changes in the technical level of the children (as a group), inspection of the development of individual children showed that some children used a different technique upon reassessment although they remained at the same technical level (e.g., one child replaced *interrupted swing* for *interrupted run up* in the overarm throw). There was also considerable inter-subject variability in development, with some children showing an increase and others a decrease in technical level (± 1-2 levels). Moreover, some children showed increased technical level in some components of the movement but not in others (e.g., decreased technical level in foot placement for the soccer kick, but increased level in the follow through).

Table 3.9: Results of the X^2 tests for the longitudinal study of the development of technical level.

	Movement component of the motor skill	Males			Females		
		X^2	*df*	Sig.*	X^2	*df*	Sig.*
Soccer kick	Approach pattern	0.39 (+)	2	0.824	0.00 (~)	1	1.000 (1.000)**
	Opposite arm movement	1.06 (-)	2	0.589	0.61 (+)	2	0.739
	Foot placement	2.38 (-)	2	0.304	4.90 (-)	2	0.086
	Contact pattern	2.06 (+)	2	0.358	3.15 (-)	2	0.207
	Follow through	3.23 (+)	3	0.357	5.78 (+)	3	0.123
Overarm throw	Overall throwing action	6.50 (~)	3	0.090	5.97 (+)	3	0.113
	Last step pattern	0.57 (~)	2	0.753	4.91 (+)	2	0.086
Standing broad jump	Arms movement	7.72 (+)	3	0.052	2.89 (~)	3	0.409

* None of the results is significant ($p < 0.05$)

** Fisher's exact significance in brackets (two-tailed)

(+) = increase; (-) = decrease; (~) = negligible overall change in the technical level of the children, as a group.

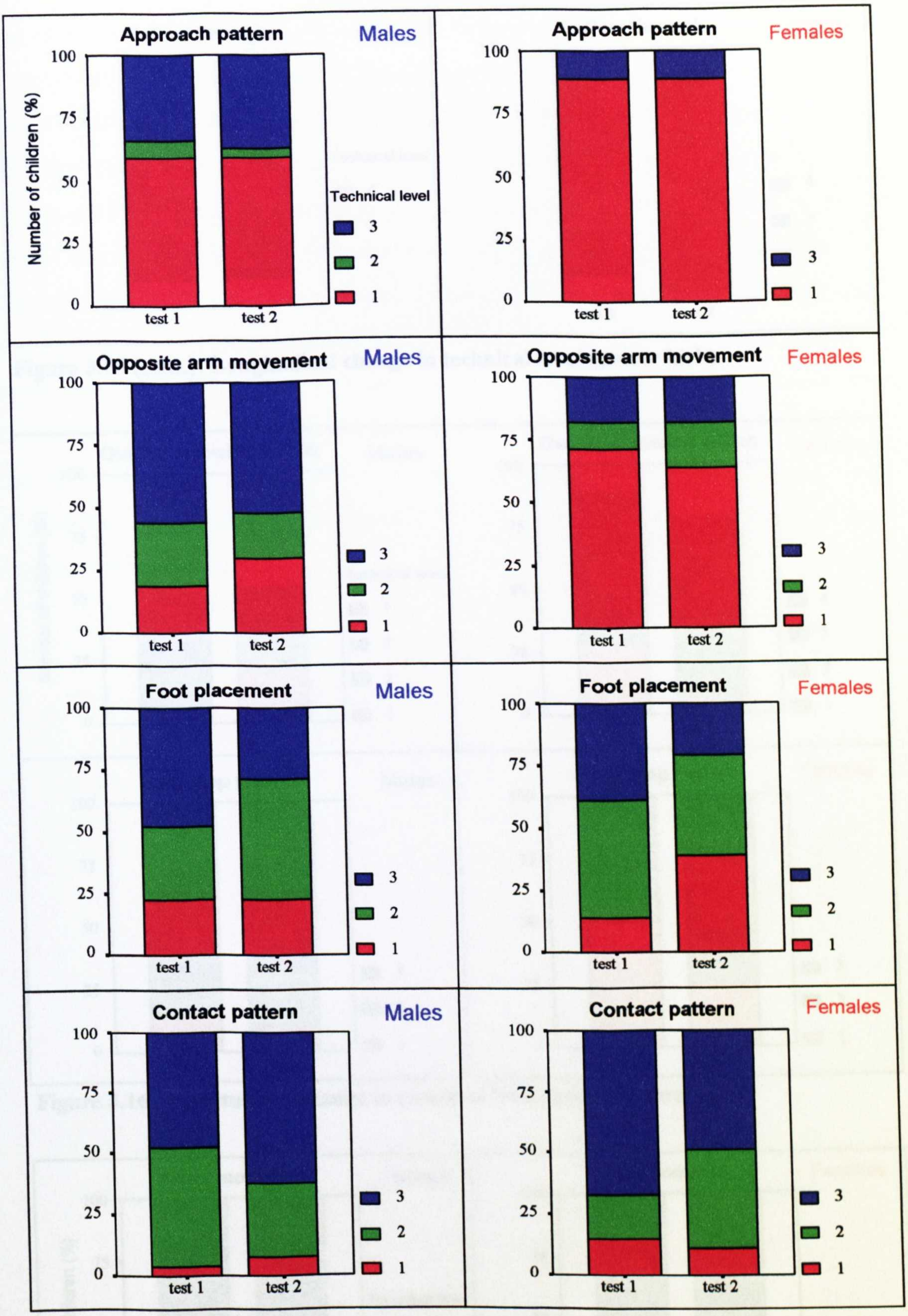


Figure 3.15: Longitudinal change in technical level (soccer kick).

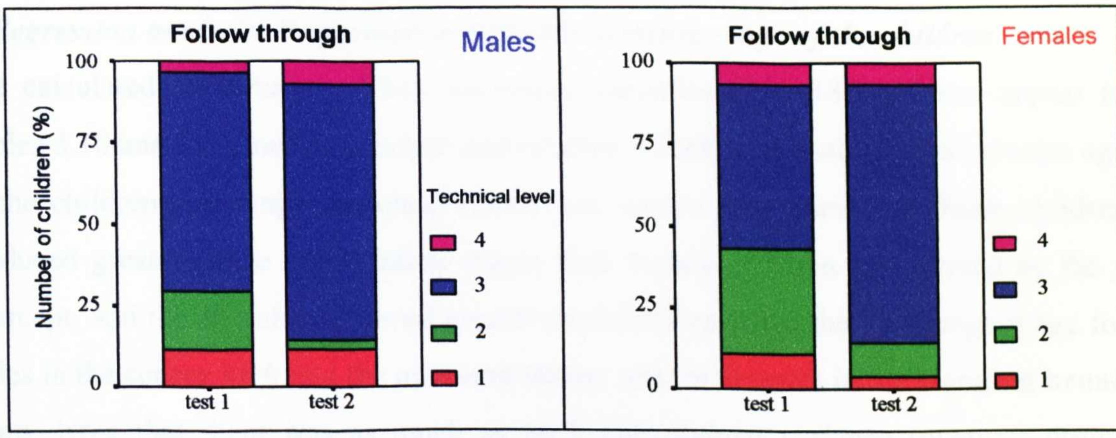


Figure 3.15 (cont.): Longitudinal change in technical level (soccer kick).

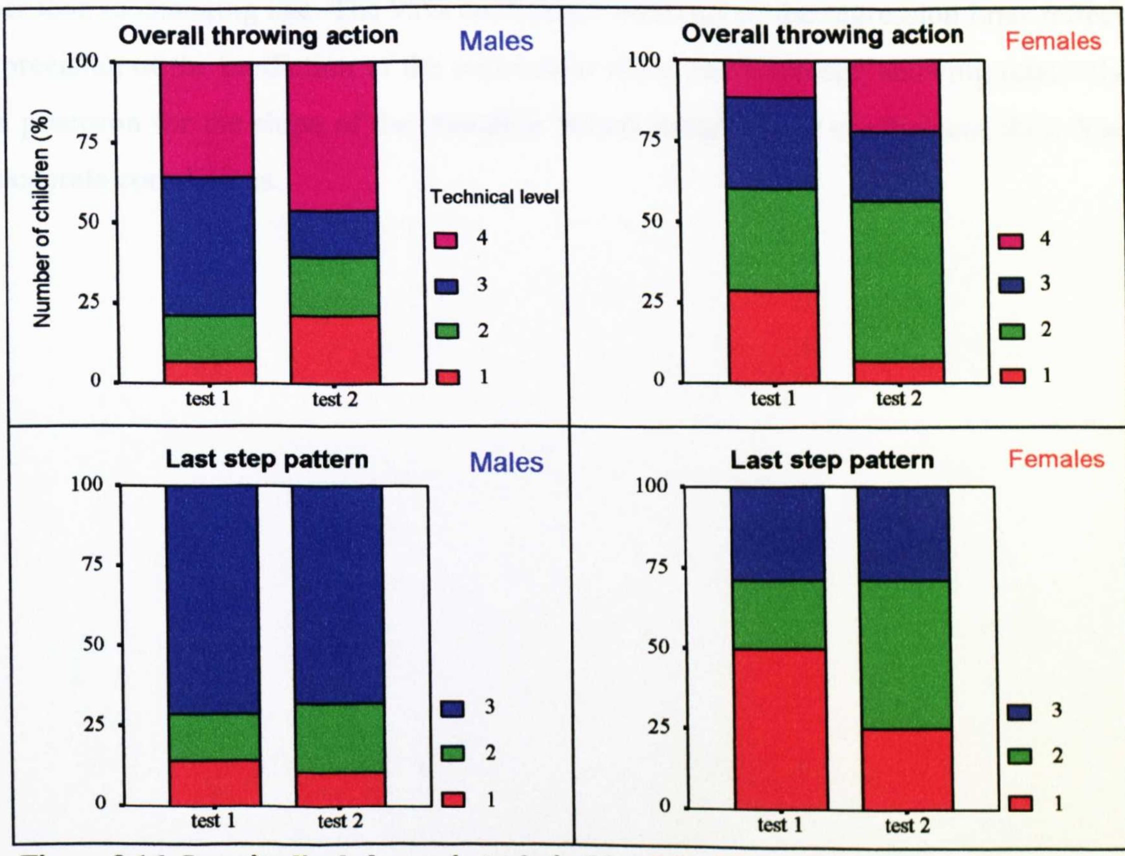


Figure 3.16: Longitudinal change in technical level (overarm throw).

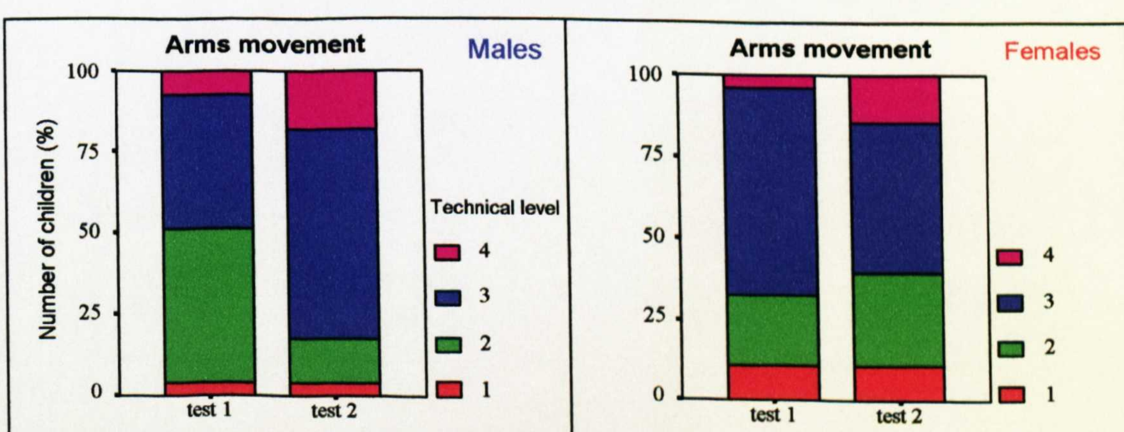


Figure 3.17: Longitudinal change in technical level (standing broad jump).

3. Regression analysis: Performance criterion measure – age of the children

The calculated magnitudes of key kinematic variables from 187 children appear in Tables 3.10 and 3.11; notice absolute and relative values. The scatter plots between age of the children and range (absolute values) are shown in Figure 3.18. Male children produced greater range at the initial stages than female children as revealed by the *y* intercept, and the R^2 values showed greater explained variance due to changing age for males in the **soccer kick** and the **overarm throw** and for females in the **standing broad jump**. Note that there was as much as 86% unexplained variance (overarm throw, females) due to other factors (e.g., relative strength, height of the child, coordination) rather than to changing age. The 95% confidence intervals of the regression lines reflect the precision of the prediction of the population slope and intercept, showing relatively high precision for the slope of the **standing broad jump**. The *r* coefficients show low to moderate correlations.

Table 3.10: Calculated magnitude of key kinematic variables of the soccer kick and the standing broad jump (mean ± SD; by age group).

Age (N,N)*	Soccer kick: Release velocity (m/s) males	Release velocity (m/s) females	Release angle (deg.) males	Release angle (deg.) females	Range (m) males	Range (m) females	Standing broad jump: Range (jump distance) (m) males	(m) females	(%)** males	(%)** females
5 **(12,11)**	8.30 ± 2.01	7.44 ± 1.45	13.42 ± 9.16	8.18 ± 5.25	3.21 ± 2.06	1.56 ± 1.03	.91 ± .24	.83 ± .20	.92 ± .26	.79 ± .20
6 **(18,10)**	11.04 ± 2.16	7.84 ± 1.28	14.72 ± 7.05	11.70 ± 8.26	6.47 ± 4.17	2.52 ± 1.94	.95 ± .11	.92 ± .18	.83 ± .11	.83 ± .16
7 **(16,10)**	11.81 ± 1.95	11.15 ± 2.60	15.38 ± 7.76	14.60 ± 4.16	7.53 ± 4.55	6.28 ± 3.20	1.11 ± .21	1.16 ± .18	.94 ± .18	.97 ± .11
8 **(22,10)**	13.55 ± 2.39	11.13 ± 1.84	16.55 ± 6.19	16.10 ± 6.56	10.39 ± 4.70	6.95 ± 2.79	1.21 ± .27	1.14 ± .20	.98 ± .23	.88 ± .15
9 **(13,14)**	14.70 ± 2.61	10.93 ± 2.69	16.85 ± 6.36	10.50 ± 6.20	12.29 ± 6.18	4.48 ± 3.12	1.26 ± .20	1.24 ± .27	.94 ± .14	.97 ± .21
10 **(13,14)**	13.38 ± 3.29	11.59 ± 3.05	17.54 ± 8.96	12.43 ± 7.27	10.54 ± 7.31	6.02 ± 4.15	1.26 ± .14	1.32 ± .22	.95 ± .14	1.01 ± .12
11 **(12,12)**	15.46 ± 3.31	13.00 ± 2.91	16.10 ± 5.53	13.50 ± 5.68	13.90 ± 7.14	7.30 ± 4.83	1.20 ± .22	1.33 ± .21	.88 ± .17	.99 ± .17
All **(187)**	12.55 ± 3.20	10.32 ± 2.88	15.81 ± 7.21	12.12 ± 6.65	9.04 ± 5.99	4.91 ± 3.75	1.12 ± .24	1.14 ± .28	.92 ± .19	.92 ± .18

* N (males), N (females)

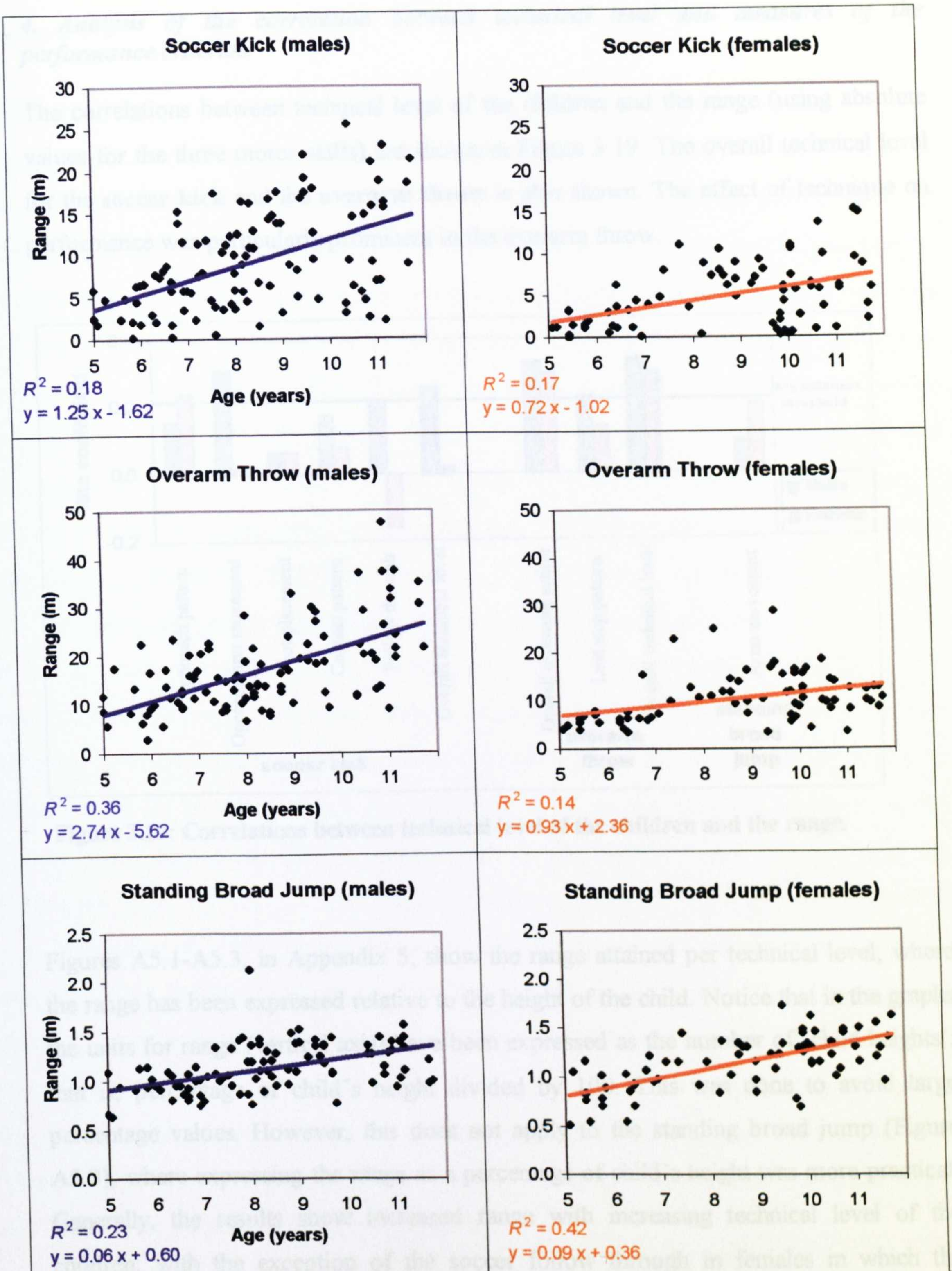
** Relative to the height of the child

Table 3.11: Calculated magnitude of key kinematic variables of the overarm throw (mean ± SD; by age group).

Age (N,N)*	Overarm throw									
	Release velocity (m/s)		Release angle (deg.)		Release height (m)		Release height (%)**		Range (m)	
	males	females	males	females	males	females	males	females	males	females
5 (12,11)	10.33 ± 2.45	8.21 ± 1.27	18.42 ± 14.29	19.73 ± 15.34	1.10 ± .26	1.20 ± .16	106.39 ± 20.13	113.15 ± 12.01	9.58 ± 5.98	5.99 ± 1.34
6 (18,10)	11.79 ± 1.88	8.74 ± 1.65	32.89 ± 15.53	16.50 ± 9.83	1.35 ± .22	1.15 ± .11	118.02 ± 17.27	103.18 ± 7.48	13.45 ± 4.45	6.85 ± 3.30
7 (16,10)	12.05 ± 2.03	11.24 ± 2.21	36.56 ± 13.37	26.00 ± 7.97	1.31 ± .18	1.33 ± .13	111.38 ± 14.33	111.18 ± 5.75	14.61 ± 4.40	12.78 ± 5.98
8 (22,10)	12.42 ± 2.22	11.41 ± 2.17	37.45 ± 16.04	31.40 ± 12.37	1.31 ± .20	1.40 ± .17	106.04 ± 14.74	109.55 ± 11.28	14.87 ± 5.32	13.15 ± 4.96
9 (13,14)	14.55 ± 2.85	11.20 ± 3.18	32.62 ± 9.99	28.93 ± 13.44	1.47 ± .19	1.43 ± .22	110.64 ± 14.11	110.34 ± 12.57	21.06 ± 7.51	12.70 ± 6.55
10 (13,14)	15.96 ± 4.38	10.98 ± 2.17	30.00 ± 11.68	33.43 ± 15.43	1.45 ± .12	1.50 ± .17	111.56 ± 11.91	114.17 ± 9.13	23.89 ± 11.26	11.92 ± 3.80
11 (12,12)	15.87 ± 3.34	10.05 ± 1.02	39.10 ± 8.99	30.70 ± 19.65	1.49 ± .12	1.55 ± .48	109.58 ± 5.07	112.84 ± 22.85	26.54 ± 8.85	10.19 ± 2.90
All (187)	13.05 ± 3.24	10.26 ± 2.37	32.95 ± 14.51	27.11 ± 15.00	1.35 ± .22	1.37 ± .27	110.58 ± 15.00	110.91 ± 13.50	17.00 ± 8.44	10.49 ± 5.04

* N (males), N (females)

** Relative to the height of the child



		95% interval (slope coefficient)	95% interval (intercept)	*r* (Sig.)*
Kick	Males	0.73 - 1.76	-6.08 to 2.85	0.423 (0.001)
	Females	0.38 - 1.05	-4.19 to 2.16	0.413 (0.001)
Throw	Males	2.03 - 3.45	-11.64 to 0.40	0.603 (0.001)
	Females	0.39 - 1.48	-2.49 to 7.29	0.375 (0.001)
Jump	Males	0.04 - 0.09	0.40 - 0.80	0.482 (0.001)
	Females	0.07 - 0.12	0.14 - 0.58	0.651 (0.001)

*** All statistical results are significant at p <0.05 (two-tailed)**

Figure 3.18: Regression analysis (performance criterion - age) in the three motor skills (N = 106 males; 81 females).

4. Analysis of the correlation between technical level and measures of the performance criterion

The correlations between technical level of the children and the range (using absolute values for the three motor skills) are shown in Figure 3.19. The overall technical level for the **soccer kick** and the **overarm throw** is also shown. The effect of technique on performance was particularly prominent in the overarm throw.

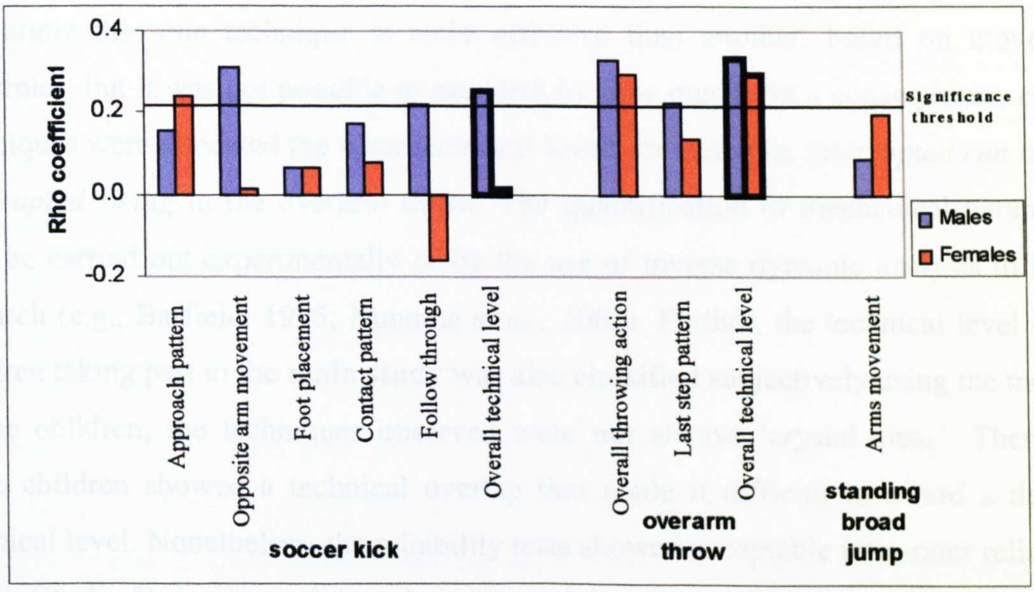


Figure 3.19: Correlations between technical level of the children and the range.

Figures A5.1-A5.3, in Appendix 5, show the range attained per technical level; where the range has been expressed relative to the height of the child. Notice that in the graphs the units for range (vertical axis) have been expressed as the number of 'child heights'; that is, percentage of child's height divided by 100. This was done to avoid large percentage values. However, this does not apply to the standing broad jump (Figure A5.3), where expressing the range as a percentage of child's height was more practical. Generally, the results show increased range with increasing technical level of the children; with the exception of the soccer follow through in females in which the inferred association is negative.

Discussion

1. Some reflections on the development and use of the hierarchical models

The classification of the techniques according to mechanical effectiveness to develop the models **(Pilot Study 1)** was done subjectively. This approach prevented using objective indicators of mechanical effectiveness (such as moment of inertia and angular velocity of body segments). In the absence of precise mechanical quantities one may still argue that one technique is more effective than another, based on movement principles, but it was not possible to establish by how much. As a consequence, certain techniques were allocated the same technical level; for example, *interrupted run* up and *interrupted swing* in the overarm throw. The quantification of mechanical parameters may be carried out experimentally or by the use of inverse dynamic analysis in future research (e.g., Barfield, 1995; Nunome *et al.,* 2002). Further, the technical level of the children taking part in the **main study** was also classified subjectively using the models. In the children, the techniques observed were not always 'crystal clear'. Therefore, some children showed a technical overlap that made it difficult to award a definite technical level. Nonetheless, the reliability tests showed acceptable intra-rater reliability **(Pilot Study 2)** in determining the technical level of the children (Altman, 1999; Knudson and Morrison, 2002), perhaps due to familiarity of the analyst with the techniques used by the children and experience with the classification procedure (e.g., Ballard *et al.*, (1979) has emphasised the importance of experience in qualitative analysis). This indicates that the hierarchical models may be suitable for their use in coaching and teaching environments, where progression and curriculum development may be attuned considering the technical level of the child and the typical rate of development. However, objectivity, or inter-rater reliability, in the determination of technical level was not assessed in the present research, due to the extent of the work, and needs to be addressed in future research.

Only fair within-day intra-subject reliability in the technical level of the children was found for some movement components. At best, variability in children may allow exploration, in order to acquire movement patterns that lead to optimum performance. However, this emphasises the importance of recording at least two trials of the child's performance on video in order to select the most mechanically effective trial as representative of the technical level of the child. Within-day intra-subject reliability needs to be taken into account in the study of the development of motor skills in children, particularly when considering that the adult subjects in the present research showed highly consistent movement patterns across two consecutive trials.

2. The development of technical level in children

2.1 Cross-sectional study

In the **soccer kick**, the pattern of approach to the stationary ball was the aspect that showed the greatest rate of development (based on the results of the X^2 tests; Table 3.8) both in male and female children, even though a large number of girls used the *straight* approach which is associated with a low technical level (Figure 3.11). In fact, the *diagonal* and *curved* approaches were only observed in girls of or above 8 years of age. In contrast, a *curved* approach (technical level 3) was already used by some boys as young as 5 years, while in the work of Bloomfield *et al.* (1979) a *curved* approach is described as typical of 11-year-old boys. Nonetheless, in the present research the majority of 5 and 6 year olds used *straight* approach (Figure 3.11), contrary to the observations of Barfield (1998) who stated that children of these ages start to use a more *diagonal* approach. The approach pattern, opposite arm movement and placement of the support foot relative to the ball presented some technical difficulties to the female children, who may need special direction to improve these aspects of the technique. In contrast, a relatively high number of boys used the effective *horizontal* movement of the opposite arm, which in agreement with Bloomfield *et al.* (1979) can be observed in children from age 5 years, while a comparatively large percentage of girls used *running* arm movement pattern for the kick. As in the study of Bloomfield *et al.* (1979) foot placement was not a developmental feature in this group of children. With regard to the pattern of ball contact, a substantial number of boys used the *weighted* technique, perhaps in an attempt to add more power to the kick. This afforded the girls a temporary advantage in terms of development, since more of the younger girls used the more effective *back lean* technique. This produced a low X^2 value for girls, indicating little developmental change. This lack of development in the contact technique of female children was confirmed in the longitudinal study (Table 3.9). A similar technical level between male and female children was observed for the follow through. Relatively few children used the highly-effective injury-preventing *drag and hop* technique.

The present study confirmed, once more, the noticeable gender differences in the development of the **overarm throw** (Langendorfer, 1980; Nelson *et al.*, 1991; Thomas and Marzke, 1992; Butterfield and Loovis, 1993) (Table 3.8 and Figure 3.12 show a faster rate of development and a higher technical level for males). Despite gender differences in technical level, the results of the X^2 tests (Table 3.8) show that both boys and girls improved their last step pattern with age. While most boys adopted a contralateral forward step (technical level 3), it was clear that most girls needed special coaching arrangements to improve this aspect of the throw (in agreement with Halverson *et al.*, 1982 and Hardin and Garcia, 1982). Both technical level and its rate of development were relatively higher in female children in the **standing broad jump** (Table 3.8 and Figure 3.13). A similarity in performance between males and females in the standing broad jump has been noticed in previous research (Hensley *et al.*, 1982, Morris *et al.*, 1982; Davies, 1990), particularly when adjusting biological characteristics. It is thought that the high degree of coordination required to execute this movement may have brought the technical level of girls above that of boys in this motor skill (Gallahue and Ozmun, 1995). Knowledge of gender differences, in both the technical level and the typical rate of development, is important to the coach and teacher. In fact, the coach or PE teacher may target the specific technical problems identified in the present research that concern female children, such as the pattern of approach and the movement of the opposite arm in the soccer kick. Further, although female children displayed a somewhat higher technical execution of the standing broad jump than male children, the opposite was certainly true in the overarm throw. Finally, **experimental hypothesis** H_1 - There is a significant association between technical level and age of the children (cross-sectional study) – was only accepted with regard to the **throw** in males and the **jump** in females based on the X^2 statistical results (Table 3.8). **Experimental hypothesis** H_2 – There are distinct gender differences in technical level and its rate of development in children (cross-sectional study) – was accepted with regard to the **three motor skills**; where females showed a higher technical level and a faster rate of development in the **jump** (Table 3.8 and Figures 3.11-3.13).

2.2 Longitudinal study

The developmental studies of Bloomfield *et al.* (1979) and Elliott *et al.* (1980) were limited to a cross-sectional design and presented neither longitudinal data nor gender differences in development. The present research attempted to cover this gap in the literature. However, there were few changes in the technical level of the children as a group, whereby none of the X^2 tests were statistically significant (Table 3.9). In fact, based on the results of the X^2 tests **experimental hypothesis** H_3 – There are significant differences between the technical level of a group of children in test 1 and their technical level in test 2 (longitudinal study) – was rejected. Figure 3.15 shows increased technical level in the contact pattern (males), opposite arm movement (females) and follow through (males and females) of the **soccer kick**. The overall **throwing** action and the last step pattern showed negligible change in males as a group, although females improved both components of the throwing movement (Table 3.9 and Figure 3.16). In contrast, male children improved their arms movement in the **standing broad jump**, while females showed little change as a group. This allowed males to catch up with the technical level of female children in this motor skill. Detailed analysis of the developmental change of the children suggests that, in the follow through of the **soccer kick**, most children would progress from a *running* technique to a *step* technique, rather than to a *rotational* technique. In the **overarm throw**, a greater number of children may show a replacement of *interrupted swing* for *straight* action, rather than developing from *interrupted run up* to *straight* action. In the **standing broad jump**, the natural progression seems to be from *back circle* of arm motion to *pendulum* action and from here to *mature* movement of the arms, while the use of *throw* technique is not very common. However, these observations need confirming in larger-scale longer-duration longitudinal research, particularly because the within-day intra-subject reliability study (**Pilot Study 2**) showed inconsistent technical level over two consecutive trials in some individual children. For example, in Pilot Study 2 female children of ages 5-7 years showed high within-day consistency in their use of approach technique in the **soccer kick** (they used *straight* approach), while older females (8-11 years) showed more variability (they used, for example, *straight* approach in trial 1 and *curved* approach in trial 2). This variability may reflect a capacity for within-day adaptation of the approach pattern in older female children to attempt to kick the ball farther away, as children enter the context-specific period of motor development (Horn and Williams, 2003). Such adaptation may have been the result of using kinaesthetic feedback from the first trial to perform the second trial more effectively (a within-test learning effect) (Knudson and Morrison, 2002). Similarly, in the overall **throwing** action and the arms movement of the **standing broad jump** the second trial was performed at a higher technical level than the first by some of the children aged above 7 years. Between-day intra-subject variability needs also to be determined in future research to help interpret longitudinal change in technical level.

3. *The technical level of adult subjects*

Not all adult subjects, particularly females, displayed a high technical level when performing the motor skills (Figure 3.14), in spite of the fact that these subjects originated from a sporting background. For example, only a small percentage of the adults used the *mature* form of arm movement when performing the **standing broad jump**. Therefore, the movement patterns observed in the adult subjects differed from the archetypes of sound technique proposed by Plagenhoef (1971) and Wickstrom (1975). These findings must be taken into account when interpreting the technical level of normal male and female children.

4. *Regression analysis: Performance criterion measure – age of the children*

Measures of the range revealed the performance capabilities of the children, where males not only attained greater ranges in the **kick** and **throw** than females, but there was also a greater percentage of explained variance due to changing age (Figure 3.18). Both the mean values for the range and their dispersion (SD) for children of different ages were similar to measures reported in previous research on overarm throwing and the standing broad jump (e.g., Hardin and Garcia, 1982; Clark and Phillips, 1985; Davies, 1990; Nelson *et al.*, 1991; Barnett and Kofka, 1993; Raudsepp and Paasuke, 1995); while no previous research was found that reported the range attained by children in the soccer kick. The results support the findings of Nelson *et al.*, (1991) who reported that females of school age attained distances in the overarm thrown which were approximately half of the distances achieved by boys of the same age when adjusting biological characteristics. However, performance was better matched in the **standing broad jump**, a motor skill in which females displayed a faster rate of development with age and a greater percentage of explained variance due to changing age (see r and R^2 coefficients in Figure 3.18). Similarly, Hensley *et al.* (1982), Morris *et al.* (1982) and Davies (1990) found no significant differences between males and females's jumping performance even when adjusting for biological characteristics. Despite the findings of the present research regarding gender differences in development, it is important to consider the heteroscadisticity of the data in **soccer** and **throwing** which shows greater inter-subject variability in the performance of the children with age. Heteroscadisticity, unexplained variance and the confidence intervals of the regression lines put in evidence that chronological age is only one of several factors determining the motor performance of school-aged children. Other factors may include technical level, amount of practice, the effects of relative strength, height of the child and physique, and ability to generate explosive force (Abernethy *et al.*, 1997); and also the presence of constraints in development (Langendorfer and Roberton, 2002; Horn and Wiliams, 2003). Considering the results of the Pearson's Product Moment correlation tests (Figure 3.18), **experimental hypothesis** H_4 - There is a significant correlation between performance and age of the children – was accepted. The correlations were significant due perhaps to the large number of children involved, although in reality the correlations were only low to moderate. In fact, it is possible that the children may have attempted to attain a great distance due to roll of the ball in the soccer kick, hence producing a relatively low angle of release and a short range. This may explain the variability in performance in Figure 3.18 and the low *r* values.

5. Analysis of the association between technical level and measures of the performance criterion

While there was a negative correlation between technical level (follow through in **soccer**) and the range for female children (Figure 3.19), technique had an effect on the **throwing** and **jumping** performance of the female children. However, the generally low correlations between technical level of the children and the range indicated that other developmental factors (i.e., hereditary, practice, strength, socio-educational; Thomas and Marzke, 1992 and Thomas and Nelson, 1996), and not just technical level, dictate the performance capabilities of school-aged children. Nonetheless, when the range was normalised to child's height the results showed that technical level was still a determinant of the range attained by the children (Figures A5.1-A5.3). **Experimental hypothesis** H_5 - There is a significant association between technical level of the children and the performance criterion – was only accepted with regard to the **soccer kick** in males, and the **overarm throw** in both males and females.

Limitations of the study and suggestions for further work

In addition to the qualitative nature of the present study regarding both the development of the hierarchical models and the determination of technical level, several limitations were identified in the research. The number of children included in the longitudinal study was limited by the availability of the children. In fact, the present study may be best perceived as a pre-longitudinal study, whereby further understanding of motor development would benefit from following up the technical development of a group of children over several years (e.g., Langendorfer and Roberton, 2002). Although all children included in the analysis participated in regular PE programmes, the amount of practice (a crucial factor as pointed out by Halverson *et al.*, 1982 and Thomas and Marzke, 1992) they were involved in was not recorded. This may have explained the high technical level observed in some of the 5 year old children. The main limitation when obtaining the range was related to the manual on-screen system of measure; however, digitisation of the performance of all the children assessed would have been impractical. Thus, the systematic and random errors associated with the manual calculation of the range were not evaluated, and this needs to be addressed in future studies (Bartlett, 1997). Also, the association between technical level of the children and the range was used to determine the effect of technique on performance, however the results suggested that other factors such as strength development and changes in physique associated with growth and maturation determine the range attained by the child (Thomas and Nelson, 1996; Abernethy *et al.*, 1997). Moreover, the nature of the nominal data in this study and the large sample used limited the accuracy of the statistical analysis, since analysis using conventional parametric statistical tests was not appropriate and using data at yearly intervals was not meaningful (Ntoumanis, 2001; Howitt and Cramer, 2003). Finally, the findings of Study 1 have implications for the quantitative analysis of technical level in children. While higher precision of measure would reduce the methodological limitations of qualitative analysis, the lack of reliability in technical level observed in the children questions the usefulness of quantitative analysis in the assessment of this age group.

Conclusions

In sum, male children showed a higher technical level and a faster rate of development in the soccer kick and the overarm throw, however the opposite was true in the standing broad jump. Initially, descriptions of the movement and the application of movement principles allowed the creation of hierarchical models that can be used to classify the techniques used by children in performing representative basic motor skills, and thus to determine their technical level. In the **cross-sectional study**, the technical level of a group of children and the rate of development of technical level in this group of children were determined. Male children showed higher technical level and a faster rate of development than female children in most movement components of the soccer kick. A higher technical execution by male children was particularly noticeable in the overarm throw. However, girls demonstrated an ability to be ahead in development regarding standing broad jump technique. The majority of male adults displayed high technical levels in the execution of the motor skills, while a relatively large number of female adults showed immature movement patterns. **Longitudinal assessment** of the development of technical level in children revealed improvements in some of the components of the soccer kick in males and females, in the two components of the throwing movement in females and in the jumping technique of males, as a group. The results of the **regression (performance criterion - age) analysis** showed greater explained variance due to changing age for males in the soccer kick and the overarm throw, and for females in the standing broad jump. Finally, **analysis of the association** between technical level and the range showed that throwing technique had a prominent effect on performance.

Chapter IV – Study 2

A construction of a model for the qualitative analysis of mechanical effectiveness

Introduction

The hierarchical models presented in Study 1 allow the determination of *technical level* in children and adults. However, such hierarchical models need only make reference to a limited number of body segments or a particular phase of the movement for their purposes; whereas, the assessment of *mechanical effectiveness* requires a comprehensive analysis of all the relevant performance factors. In addition, the review of literature highlighted the limitations of the different models available for the qualitative analysis of human movement. This calls for the development of an integrated **model** that overcomes the shortcomings of previous models and enables qualitative analysis of mechanical effectiveness.

Therefore, the **aim** of Study 2 was to develop a model for the qualitative analysis of mechanical effectiveness. **First**, the model was outlined as a result of synthesis of existing comprehensive and observational models. **Second**, implementation of the model to draft the analytical components (mechanical and perceptual) and to develop scoring references for the qualitative analysis of motor skills in general was demonstrated using the soccer kick for maximum distance, as an example of fundamental motor skill. **Third**, the model was used to outline the analytical components and to develop scoring references for the analysis of the overarm throw and the standing broad jump. The development of scoring references for the three motor skills included the assessment of the *accuracy* and *intra-rater reliability* of an experienced rater in estimating kinematic quantities from video. *Inter-rater reliability* was also determined to assess the adequacy of the scoring references.

1. Synthesis of existing models for the qualitative analysis of human movement, and construction of a model for the qualitative analysis of mechanical effectiveness

1.1. Synthesis of existing comprehensive models

First, the advantages and limitations of the existing models were identified (the principal models appear in Table 2.2 in the Review of Literature; other models included those of Norman, 1975; Brown, 1982; Hoffman, 1983; Gangstead and Beveridge, 1984; Hudson, 1985, 1995; Dunham, 1994; and Knudson and Morrison, 1996) in order to select desirable features, while at the same time attempt to overcome the disadvantages of such models. The features identified as desirable included: use of phase analysis, analysis with reference to movement principles, identification of critical features, awareness of the visual perceptual limitations when selecting variables for the analysis, consideration of a range of optimum performance, and description of kinematics and kinetics using qualitative descriptors.

In order to overcome the disadvantages of existing models, the present model aimed to attain the following: incorporate both phase analysis and mechanical analysis (see Glossary of operational terms on page 6), associate technique variables with mechanical variables using principles of movement, use the performance of highly-skilled players as models of effective movement while at the same time recognize that developing children may use their own technical adaptations to execute the movement, evaluate perceptual limitations based on the literature and provide guidance to estimate kinematic and kinetic quantities from video, design user-friendly scoring references to conduct the analysis without the need for extensive biomechanical knowledge, and, also, adapt the scoring system to incorporate different performance levels (based upon Abendroth-Smith *et al.*, 1996). Finally, considering the disadvantages of the available models it was concluded that actual measures from a large group of children should be collected to provide reference data and evaluate the practical use of the model. Despite the synthesis of existing comprehensive models, special attention was drawn towards Hay and Reid's (1982) deterministic model which permits, more directly, identifying relevant variables for the analysis. Such deterministic model was later modified by McPherson (1990) to include technique variables, and Abendroth-Smith *et al.* (1996) suggested that the deterministic models are adapted to the skill level of the performer. The features from existing comprehensive models above were considered when outlining a model for the qualitative analysis of movement effectiveness.

1.2 Synthesis of existing observational models

Pedagogical observational models aim to facilitate descriptions of the spatial and temporal components of the performance for comparative analysis and include those of Hoffman (1983), Gangstead and Beveridge (1984) and Dunham (1994). In contrast, biomechanical observational models have the added advantage of facilitating the observation of selected technique and performance variables that are both mechanically related to performance and observable (these include the models of Brown, 1982; Ganstead and Beveridge, 1984; Hudson, 1985, 1995; and Abendroth-Smith *et al.*, 1996). Most of the existing observational models highlight the importance of selecting an appropriate vantage point (e.g., Brown, 1982; Ganstead and Beveridge, 1984; and Abendroth-Smith *et al.*, 1996). The optimum position of the observer is at 90° to the plane of motion for predominantly planar movement. Repeated observation over several trials has been pinpointed as a necessity when using direct visual observation (e.g., Ganstead and Beveridge, 1984; Abendroth-Smith *et al.*, 1996); while the use of video renders the recording of multiple trials per child unnecessary. The use of the gestalt impression, or *"general feeling approach"* (Knudson and Morrison, 2002; p. 98) has been recommended by Hudson (1985) and Dunham (1994) before observing specific components of the movement. A central principle in the majority of existing observational methods is the use of either a mental image of what the movement should look like based on models of optimum technique and performance (e.g., Brown, 1982; Arend and Higgins, 1976; Hay and Reid, 1982; Hoffman, 1983; McPherson, 1990; Abendroth-Smith *et al.*, 1996; Lees, 1999b) or the use of checklists and templates that describe optimum movement patterns (e.g., Frederick, 1977; Ballard *et al.*, 1979; Adrian and Cooper, 1995). The use of checklists may enhance consistency within and between observers (Adrian and Cooper, 1995) and the checklists typically use scales based on a numerical/continuum ranking such as '0 - 4' (e.g., Ballard *et al.*, 1979; Adrian and Cooper, 1995). In any case, Hudson (1985) suggested that any variables selected for the analysis *"must distinguish between skill levels, be observable qualitatively by the naked eye, and be subject to change by the performer"* (cited in Knudson and Morrison, 2002; p. 22).

Integration of the different observational strategies above allowed the development of an observational method with the following features:

1. Selection of an appropriate vantage point, whereby the video camera is positioned at 90° to the plane of motion for predominantly planar movement.
2. Initial use of the gestalt impression, followed by scrutiny of the movement of individual body segments using repeated observation of single trials from video.
3. Sequential observation from gross movement to finest movement.
4. Search for restrictions in the number of active body segments and for linear movement versus rotational movement to help assess skill level.
5. Search for signs of smoothness, gracefulness and effortlessness as well as sequential movement as indicators of good coordination, and distinction between simultaneous and sequential movement in relation to the development of coordination.
6. Search for instances of compactness, large limb flexion, during the back swing and of extension at the end of the propulsive phase as indicators of large ROM.
7. Placement of special attention to movements that begin and end each phase, and identification of any unnecessary movements.
8. Identification of cues and/or variables that help estimate the magnitude of other variables that are more difficult to measure (e.g., greater ROM means greater force generation).

In addition, the following recommendations derived from existing observational models compliment the basic observational strategies listed above:

1. Selection of variables that are important to performance, observable, that distinguish between skill levels, and are subject to change by the performer.
2. Use of user-friendly rating scales that include template-like diagrams to show a number of critical angles and/or body positions, qualitative descriptors that describe optimum movement patterns and relative qualitative descriptors that reflect the performance level of the participant.
3. Use of rating scales adapted to compensate for the variety of techniques used by children to ensure inclusion in the analysis.

1.3. Construction of a model for the qualitative analysis of mechanical effectiveness

The model (see Figure 4.1) and the protocol for its use (Table 4.1) were outlined based on the synthesis of existing comprehensive and observational models carried out in sections 1.1 and 1.2 above. The model consists of 8 stages and requires the user to, initially, pay attention to the mechanical aspects of the movement and, later, to the visual perceptual aspects of the analysis. The rationale for the structure of this model is explained as follows. A number of previous models (e.g., Hay and Reid, 1982; Lees, 1999b) have emphasised the importance of specifying the performance criterion prior to attempting to carry out biomechanical analysis of the movement. Thus, the first stage (**Stage 1**) in the model indicates the identification of such a criterion. Other previous models (e.g., Arend and Higgins, 1976; Kreighbaum and Barthels, 1996) have used phase analysis, which involves the identification of critical features of the movement, while mechanical models (Hay and Reid, 1982) are particularly useful to establish what variables of the movement should be included in the analysis. The need for the synthesis of such sequential and mechanical methods has sporadically cropped up in the past (e.g., McPherson, 1990). Further, biomechanical analysis with reference to movement principles has been of prime importance in a number of previous models including those of Arend and Higgins (1976), McPherson (1990), Kreighbaum and Barthels (1996) and Lees (1999b). Based on such prior research, **Stages 2-4** of the present model involve the integration of phase analysis and mechanical analysis. In practice, this is done by an association of the observable features of the movement and the key mechanical variables, using movement principles (Stage 4) and provides the rationale for variable selection for the analysis. Because Stages 2 and 3 of the model require undertaking two independent and parallel modes of analysis (phase analysis and mechanical analysis), these stages appear in the model as Stage 2a, 2b, 3a and 3b. Filtering of the variables that have priority in the analysis is attained at **Stage 5**, which marks the end of the mechanical part of the model. **Stage 6** deals with the issues of visual perception and observation of the performance factors. **Stage 7** addresses the construction of rating scales for the analysis of mechanical effectiveness in children based on the accuracy and reliability of the rater. Data to construct the scales originates from review of literature and observational phase analysis for such purpose. This culminates with the construction of a scoring reference. The actual rating of the performance factors and processing of score data occur at **Stage 8.**

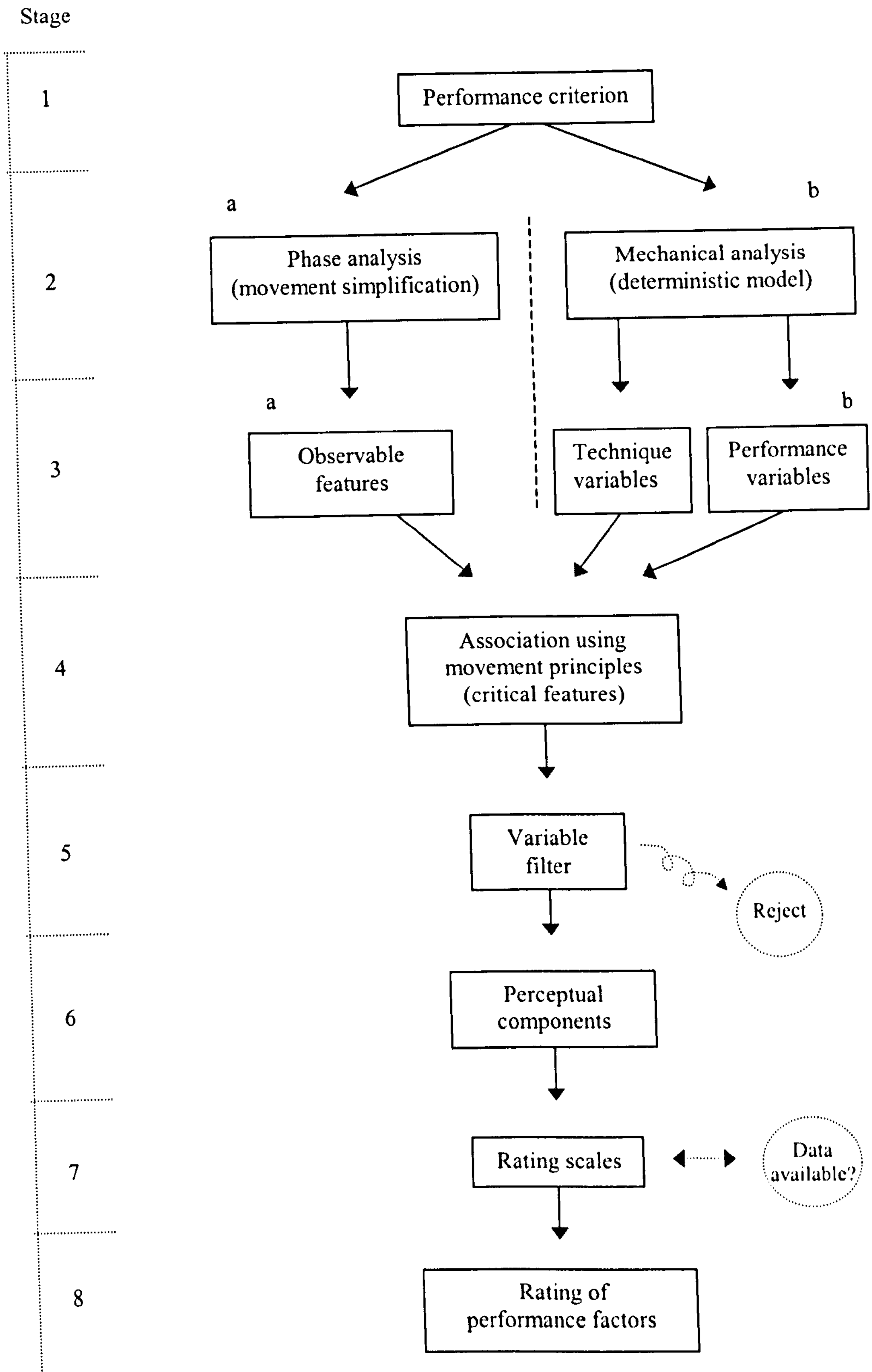


Figure 4.1: Qualitative model for the analysis of mechanical effectiveness.

Table 4.1: Protocol for the implementation of the model for the analysis of motor skills.

Stage 1. Identification of the performance criterion.

Stage 2. a) Simplification of the movement using phase analysis.
Stage 3. a) Identification of observable features of the movement of highly-skilled performers using phase analysis.

Stage 2. b) Parallel construction of a deterministic mechanical model specific for the movement.
Stage 3. b) Parallel identification of important technique and performance variables using the deterministic model.

Stage 4. Association between observable features of the movement (derived from phase analysis) and the mechanical, technique and performance, variables (derived from mechanical analysis) using movement principles, in order to identify the observable variables that are critical to optimum performance (critical features).

Stage 5. Assessment of the relative contribution of variables to mechanical effectiveness and filtering of variables according to whether their contribution may be 'significant' or 'negligible'.

Stage 6. Determination of optimum video playback speeds and conditions to estimate the magnitude of technique and performance variables based on the literature, identification of visual cues that help estimate kinematic and kinetic quantities, and selection of either standard SI units or categorical descriptors to estimate the magnitude of variables.

Stage 7. Development of a scoring reference for the qualitative analysis of the movement that contains a rating scale for each variable included in the analysis. Construction of the scales involves an initial outline of the scales using the literature. Observational phase analysis of the movement of both children and highly-skilled performers may be used when the literature provides insufficient data to develop a scale for a specific variable. The scales are subsequently adjusted using tests of accuracy and intra-rater reliability in the estimation of kinematic quantities from video. Tests of inter-rater reliability can also be performed to assess the adequacy of the scoring references.

Stage 8. Rating of the performance factors. The scoring reference allows obtaining scores per variable and by phase of the movement for a comprehensive analysis of the child's movement. Scores can be displayed graphically in the form of a profile for a visual inspection of the data. A total score is finally obtained that represents a measure of the overall mechanical effectiveness of the movement performed by the child.

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2. Implementation of the model to outline the analytical components (mechanical and perceptual) and to construct a scoring reference for the qualitative analysis of mechanical effectiveness in the soccer kick.

This section incorporates the application of the 8 stages of the model to the soccer kick.

Stage 1. Identification of the performance criterion

The goal of the soccer kick for maximum distance is to attain 'maximum distance' of the ball.

Stage 2a. Simplification of the kicking movement using phase analysis

The mature form of the soccer kick was divided into *approach, swing* and *follow through* phases to focus the analysis on the different parts of the movement (based on Lees, 1996; Bartlett, 1997; and Lees, 2002). The end of the approach phase is marked by the *instant of support foot contact* with the ground, and the end of the swing phase by the *instant of ball contact.* The key instants were, therefore, useful to mark the beginnings and ends of the range of movement of segments (Lees, 1999b). The *backswing* subphase of the approach phase was also thought to contain important mechanical information. It was concluded (observational phase analysis in Pilot Study 1) that the division of the kicking movement specified above was sufficient for the purposes of qualitative analysis of mechanical effectiveness. Subsequently, the mechanical purpose of each phase of the kick was identified to facilitate an understanding of the objectives of each phase (based on Kreighbaum and Barthels, 1996):

Approach phase: The objective is to develop momentum to be transferred to the ball later on at impact.
Backswing subphase: The long last step enables optimum positioning of the support foot, opening out of the hip, and general countermovement.
Swing phase: The objective is to attain end-point speed.
Follow through phase: The main aim is to dissipate forces gradually and, therefore, avoid injury (Robertson and Mosher, 1985), although a link between a proper follow through and performance has been identified (Tsaousidis and Zatsiorsky, 1995).

Stage 3a. Identification of observable features for each phase, sub-phase and key instant of the soccer kick

Identification of observable features of the soccer kick was carried out using phase analysis of the video recorded performance of highly-skilled soccer players appearing on television programmes. A number of observable features that may be included in a biomechanical analysis of the soccer kick as derived from phase analysis are listed below:

Technique-related observable features

Approach phase: Angle of approach.
Back swing subphase: Length of the last step, horizontal abduction of the opposite arm, horizontal adduction of the ipsilateral arm, maximum knee flexion, maximum hip hyperextension, and vertical displacement of the whole body.
Foot plant instant: Placement of the support foot, maximum backward trunk inclination, and maximum lateral body inclination.
Swing phase: Horizontal adduction of the opposite arm, horizontal abduction of the ipsilateral arm, maximum forward trunk flexion, hip internal rotation, knee extension, hip flexion, support leg knee angle and rigidity, and vertical displacement of the whole body.
Instant of ball contact: Neck flexion, and angle of kicking knee.
Follow through phase: Angle of ball release, maximum hip and knee flexion, and a number of steps normally accompanied with lowering of the body's centre of gravity (CG).

Performance-related observable features

Approach phase: Speed of approach.
Swing phase: Adduction velocity of the opposite arm, knee extension velocity, magnitude of the impact forces applied to the ball.
Instant of ball contact: Contact time.
Follow through phase: Velocity of ball release.
General: Coordination and rhythm.

Stage 2b. Parallel construction of a deterministic mechanical model specific for the maximum-distance soccer kick.

A deterministic mechanical model specific for the maximum distance soccer kick was constructed (Figure 4.2) based on a generalised deterministic mechanical model developed by Hay and Reid (1982). In the model, the performance criterion (distance) was divided into parts, and the mechanical factors that determine the different parts of the performance criterion were subsequently incorporated (each mechanical factor can be identified by a code and level in Figure 4.2). The mechanical variables in the deterministic model (e.g., 'shank angular velocity' at level 5; L 5) may be associated with the observable features of the soccer kick derived from phase analysis. Such association is carried out using movement principles.

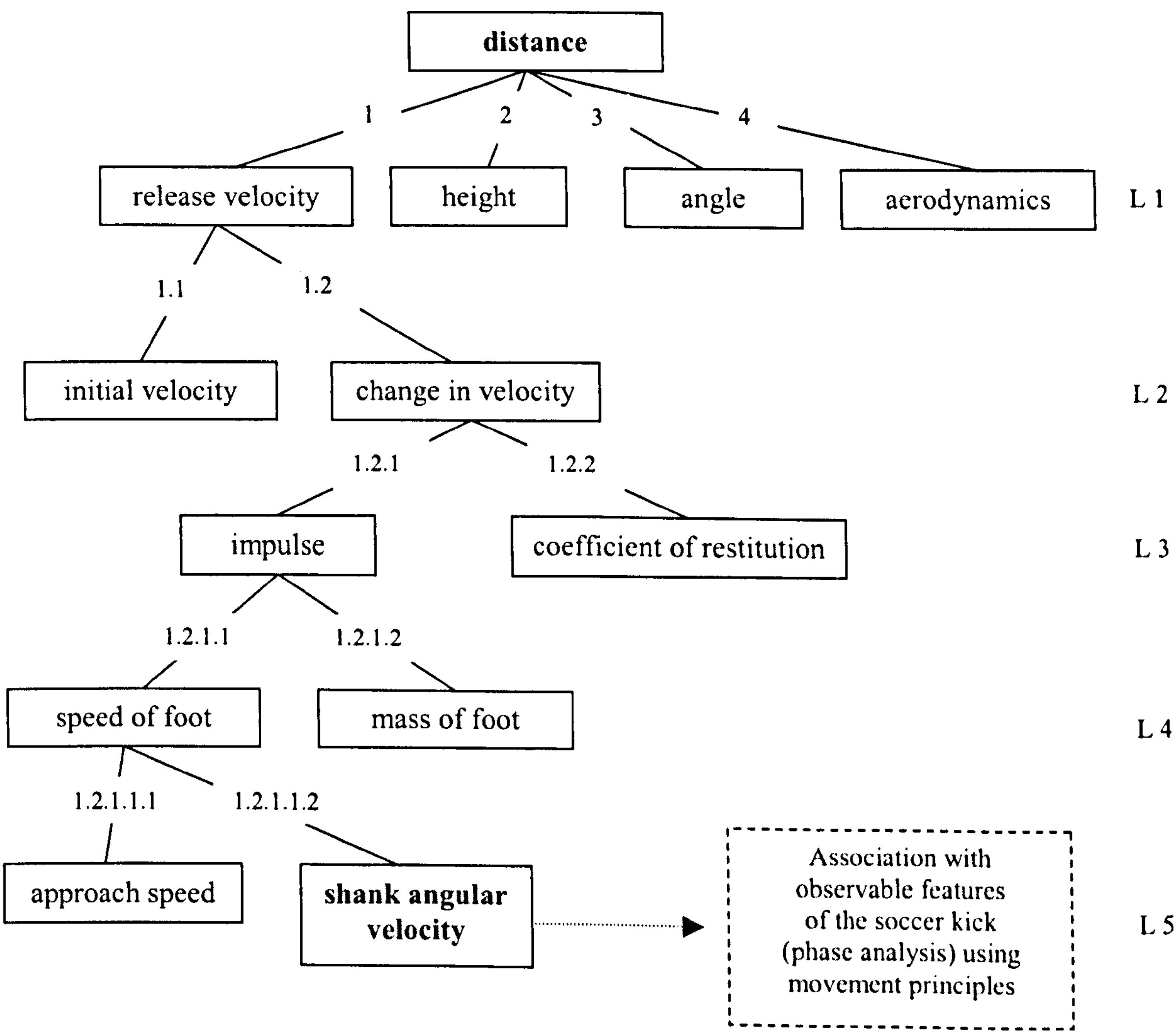


Figure 4.2: Deterministic mechanical model for the soccer kick for maximum distance (based upon Hay and Reid, 1982).

Stage 3b. Parallel identification of important technique and performance variables of the soccer kick using the deterministic model

The mechanical relationships identified in the deterministic model yielded the technique and performance variables relevant for the analysis; such as approach speed and velocity of release of the ball. Such variables appear throughout the deterministic mechanical model as subordinate factors (see Figure 4.2).

Stage 4. Association between observable features of the soccer kick (phase analysis) and mechanical variables (mechanical analysis) using movement principles in order to identify variables that are critical to optimum performance

It is important to consider that a 'critical feature' is a variable that is both observable and an essential contributor to performance (McPherson, 1990). The association provides the rationale for the variables chosen for the analysis, and the process involved in such association is explained below using two examples of critical features. The *speed of the approach* is observable during the approach phase of the soccer kick (phase analysis). This observable feature can be found as a variable in the mechanical model (mechanical analysis) at level 5 of Figure 4.2 and is identified with the code '1.2.1.1.1'. High but controllable speed of approach determines the speed of the foot at contact, since the player's speed generated during the approach is added to that of the kicking leg during the swing (application of movement principle). The movement and configuration of the opposite arm (*horizontal adduction of opposite arm, elbow angle* and *angle of shoulder abduction*; observable using phase analysis) affect the angular velocity of the kicking leg (shank angular velocity variable found at L 5 in the deterministic model with code '1.2.1.1.2'; mechanical analysis) since, according to Lees (1999a), the opposite arm balances the forward swing of the kicking leg in accordance with the principle of action-reaction (application of movement principle). This association between the observable features and the mechanical variables of the kick using movement principles allowed identifying all the observable variables that are critical for the optimum performance of the soccer kick.

Stage 5. Filtering of variables according to their contribution to the mechanical effectiveness of the kick

Stage 5 culminated with the selection of 14 technique variables and 5 performance variables that were thought to contribute most to the attainment of the performance criterion in the soccer kick. Mechanical contribution was simply classed as either 'negligible' or 'significant'. The selected variables are listed in Table 4.2. For example, the importance of the speed and angle of approach have been confirmed by Opavsky (1988) and Isokawa and Lees (1988), respectively. Some of the movements observed in Pilot Study 1 had been given little or no attention in previous research; however, this was not a strong argument for rejection from the analysis. For example, the *horizontal abduction-adduction movement of the opposite arm* (mentioned almost exclusively by Lees, 1999a) was considered to provide a substantial mechanical contribution to powerful kicking in the present research. However, it is important to report variables, and other movements observed in Pilot Study 1, that were not regarded worthy of inclusion in the analysis and state the reasons for rejection. A few examples follow. The *ipsilateral arm* performs a balancing function similar to that of the opposite arm; however, the range of movement is limited and the arms tend to remain by the body during the swing phase. During the forward leg swing there might be *upward displacement of the whole body*; however, the horizontal displacement and velocity of the body during the approach phase has got priority in the analysis due to a greater contribution to the velocity of the ball (Opavsky, 1988). *Knee joint rigidity* of the support leg takes place during the swing phase and is suspected to facilitate a pivoting action, where the fixation of the support leg allows elevation of the CG towards ball contact and a concomitant increase in foot velocity; however the actual rigidity of this joint does not appear to have been examined experimentally.

As a summary of the mechanical analysis of the soccer kick using stages 1 to 5 of the mechanical effectiveness model, Table 4.2 includes the analytical components (mechanical) of the soccer kick. Variables were classified as either technique variable or performance variable (see Glossary on p. 6); and the mechanical purpose for each specific variable was identified as well as the main underlying movement principle (as suggested by Kreighbaum and Barthels, 1996; movement principles taken from Lees 1999b). Kinematics and kinetics from proficient performers are also included. Where no data from the literature were available, the observations carried out in Pilot Study 1 and videotapes of proficient soccer players were used to delimit a range of optimal values.

Table 4.2: The 19 analytical components of the soccer kick (mechanical).

Phase, subphase or key instant	Critical variable	Classification of variable	Main mechanical purpose	Movement principle	Mechanical variable affected (deterministic model)	Optimum value (or qualitative description)	Range of optimum values
Approach phase	speed of approach	performance	build up of controlable speed	whole body running speed	approach speed 1.2.1.1.1	3.5 m/s [a]	3-4 m/s [a]
	angle of approach	technique	large acceleration path	end-point speed	swing angular velocity 1.2.1.1.2	45^0 [b]	$30\text{-}45^0$ [b]
Back swing subphase	length of last step	technique	opening out of hip	range of motion	swing angular velocity 1.2.1.1.2	*not defined*	80-120% [c]
	horizontal abduction of opposite arm	technique	pre-stretch	stretch-shortening cycle	swing angular velocity 1.2.1.1.2	180^0 [d]	$170\text{-}190^0$ [d]
	maximum knee flexion	technique	counter- movement	range of motion	swing angular velocity 1.2.1.1.2	$90\text{-}122^0$ [e]	$90\text{-}122^0$ [e]
	maximum hip hyperextension	technique	range of motion	range of motion	swing angular velocity 1.2.1.1.2	$18\text{-}36^0$ [f]	$18\text{-}54^0$ [f]

References - a) Opavsky (1988), Lees & Nolan (2002); **b)** Isokawa & Lees (1988); **c)** defined experimentally; **d)** defined experimentally; **e)** Plagenhoef (1971), Anderson & Sidaway (1994), Levanon & Dapena (1998); **f)** Browder *et al*. (1991), Lees (1999b, 2000); **g)** Bunn (1972), McLean & Tumilty (1993), Wang & Wiese-Bjornstal (1994), Hay (1993); **h)** Lees & Nolan (2002), defined experimentally; **i)** Lees & Nolan (2002); **j)** defined experimentally; **k)** defined experimentally; **l)** Wang & Wiese-Bjornstal (1994), Levanon & Dapena (1998), Lees & Nolan (2002); **m)** Asami & Nolte (1983); **n)** Luhtanen (1988), Opavsky (1988), Lees & Nolan (1998); **o)** Plagenhoef (1971), Bunn (1972), Levanon & Dapena (1998); **p)** defined experimentally; **q)** De Proft, Clarys, Bollens, Cabri & Dufour (1988).

Table 4.2 (cont.): The 19 analytical components of the soccer kick (mechanical).

Phase, subphase or key instant	Critical variable	Classification of variable	Mechanical purpose	Movement principle	Mechanical variable affected (deterministic model)	Optimum value (or qualitative description)	Range of optimum values
Foot plant instant	support foot placement	technique	optimum takeoff angle	flight & projectile	angle 3	8-15 cm [g]	5-15 cm [g]
	maximum backward trunk inclination	technique	optimum takeoff angle	flight & projectile	angle 3	26^0 [h]	$5\text{-}30^0$ [h]
	maximum lateral body inclination	technique	large acceleration path	end-point speed	swing angular velocity 1.2.1.1.2	16.4^0 [i]	*not defined*
Swing phase	horizontal adduction of opposite arm	technique	balance	action-reaction	swing angular velocity 1.2.1.1.2	180^0 [j]	$170\text{-}190^0$ [j]
	adduction velocity of opposite arm	performance	balance	action-reaction	swing angular velocity 1.2.1.1.2	*not defined*	*not defined*
	maximum forward trunk flexion	technique	balance	action-reaction	swing angular velocity 1.2.1.1.2	*not defined*	$15\text{-}45^0$ [k]
	applied impact forces	performance	end-point speed	limb rotational speed	swing angular velocity 1.2.1.1.2	*not defined*	*not defined*

Table 4.2 (cont.): The 19 analytical components of the soccer kick (mechanical).

Phase, subphase or key instant	Critical variable	Classification of variable	Mechanical purpose	Movement principle	Mechanical variable affected (deterministic model)	Optimum value (or qualitative description)	Range of optimum values
Ball contact instant	angle of kicking knee	technique	impulse	impulse-momentum	impulse 1.2.1	48^0 [l]	$35\text{-}61^0$ [l]
	contact time	technique	impulse	impact	impulse 1.2.1	12 ms [m]	*not defined*
Follow through phase	velocity of ball release	performance *'criterion-process'*	maximum range	flight & projectile	distance 0	20-30 m/s [n]	18-30 m/s [n]
	angle of ball release	technique *'criterion-process'*	maximum range	flight & projectile	distance 0	45^0 [o]	*not defined*
	maximum hip flexion	technique	force dissipation	injury prevention	swing angular velocity 1.2.1.1.2	*not defined*	$5\text{-}30^0$ [p]
General	coordination and rhythm	performance	timing	coordination	*'various'* coordination principle	*not defined*	*not defined*
movement goal	range	performance *'criterion-ultimate'*				52.5 m (male soccer players) [q]	33.1-52.5 m (males) [q]

Stage 6. Determination of the analytical perceptual components for the qualitative analysis of the soccer kick.

This involved: **1** - the determination of the optimum video playback speeds and conditions to estimate the magnitude of each the 19 technique and performance variables of the soccer kick included in the analysis, **2** - the identification of visual cues that help estimate certain kinematic and kinetic quantities (based on McPherson, 1990), and **3** - the selection of either standard SI units or categorical descriptors for each variable, or a combination of these. For example, some variables may be easily measured using standard SI units, such as degrees or metres. In contrast, other variables (e.g., velocities and force application) can best be measured using relative categorical descriptors, such as 'slow', 'fast' or 'very fast'. All three aspects of visual perception above were carried out using the literature and the analytical experience in qualitative analysis acquired in Pilot Study 1. Specifically, in Chapter 2 several studies have been reviewed that provide a number of visual evaluation techniques to facilitate the process of observation (e.g., Ragsdale, 1930; Frederick, 1977; Brown, 1982; Ganstead and Beveridge, 1984; Williams, 1986). Other research has provided an indication of how accurate the trained observer is when recording certain body postures and movements using direct visual observation and video analysis (e.g., Johansson, 1973; Cutting and Kozlowski, 1977; Ericson *et al.*, 1991; Carnegie, 1997).

The process of determination of the visual perceptual components for specific variables of the soccer kick can be illustrated using a few examples. The magnitude of *impact forces applied to the ball* can be perceived using normal speed video playback (Williams, 1986; Carnegie, 1997) and repeated observation (2-3 times, Pilot Study 1), and using the range of motion of the hip and knee and the velocity of leg swing as visual cues (Brown, 1982). Forces applied to the ball could be rated in a continuum using relative qualitative descriptors that range from 'low' to 'powerful kick' (Hudson, 1985; Adrian and Cooper, 1995; Knudson and Morrison, 2002). Although overall speed of the kicking movement may be best perceived when playing back a video sequence at normal speed (Carnegie, 1997), using frame-by-frame video display may help the analyst to rate *velocity of ball release* after contact. This consists in counting the number of frames or assessing the displacement of the ball on the screen over time/per frame (Pilot Study 1). Velocity can be conveniently measured using descriptors in a range from 'very low' to 'very high'. The *length of the last step* needs to be estimated as a percentage of the height of the child to account for differences in physique in children of different ages. Similarly, careful judgement is needed when rating *support foot placement* of children since, in reality, the rating should be height-of-the-child dependent (Wang and Wiese-Bjornstal, 1994). Finally, *coordination and rhythm* may be assessed by considering the whole movement sequence from approach to the ball to follow through; signs of 'hesitation' score low compared to signs of 'effortlessness' and 'smoothness' throughout the movement (Espenschade and Eckert, 1967; Brown, 1982; Hudson and Hills, 1991). Table 4.3 lists the perceptual components for the 19 variables included in the analysis of the soccer kick.

Table 4.3: The 19 analytical components of the soccer kick (perceptual).

Phase, subphase or key instant	Critical variable	Perceptual aspects (video)	Use of cues	Units / descriptors
Approach phase	speed of approach	normal speed, then frame by frame	frame count	qualitative descriptor
	angle of approach	slow motion	body orientation	deg.
Back swing subphase	length of last step	frame by frame	ROM of legs	percentage of child's height
	horizontal abduction of opposite arm	slow motion		deg. / qualitative descriptor
	maximum knee flexion	frame-freeze		deg.
	maximum hip hyperextension	frame-freeze		deg.
Foot plant instant	support foot placement	frame-freeze		cm
	maximum backward trunk inclination	frame-freeze		deg. / qualitative descriptor
	maximum lateral body inclination	normal speed & repeated observation	body orientation	qualitative descriptor
Swing phase	horizontal adduction of opposite arm	slow motion		deg. / qualitative descriptor
	adduction velocity of opposite arm	normal speed, then frame by frame	change in arm position	qualitative descriptor
	maximum forward trunk flexion	frame-freeze		deg. / qualitative descriptor
	applied impact forces	normal speed & repeated observation	ROM & angular velocity of hip & knee	qualitative descriptor
Ball contact instant	angle of kicking knee	frame-freeze		deg. / qualitative descriptor
	contact time	frame by frame	watch follow through	qualitative descriptor
Follow through phase	velocity of ball release	normal speed, then frame by frame	change in ball position	m/s / qualitative descriptor
	angle of ball release	frame-freeze	background references	deg. / qualitative descriptor
	maximum hip flexion	frame by frame		deg.
General	coordination & rhythm	normal speed, then slow motion	effortlessness	qualitative descriptor

Stage 7. Development of a scoring reference for the qualitative analysis of the soccer kick in children

This stage involved: **2.7.1** – an initial outline of rating scales, **2.7.2** – tests of accuracy and intra-rater reliability to adjust the scales, and **2.7.3** – development of a scoring reference for the maximum-distance soccer kick. A test of inter-rater reliability (**2.7.4**) was also carried out to assess the adequacy of the scoring references.

2.7.1 Initial development of the rating scales based on previous research and observational phase analysis

Initial five-level (0-4) rating scales for each of the variables of the soccer kick were constructed by an analyst experienced in qualitative analysis. The use of 5 levels was considered appropriate in the context of qualitative analysis, since the rater may not be able to discriminate between smaller scale intervals (based on Douwes and Dul, 1991 and Ericson *et al.*, 1991). Review of previous developmental studies (e.g., Bloomfield *et al.,* 1979; Gallahue and Ozmun, 1995) was used to establish the lower score in the rating scale for each variable. Pilot Study 1 allowed estimating range of motion for a number of movements for which the literature provided no data. For example, a straight approach to the ball corresponded to a score of 0. Similarly, kinematic and kinetic data from proficient performers (reported by Parassas *et al.*, 1990; Browder *et al.*, 1991; Wang and Wiese-Bjornstal, 1994; Barfield, 1998; Lees, 1999b; and others) were used to set the upper score in each rating scale. Often, the upper score consisted of a range of optimum values (based on Lees, 1999b and Knudson and Morrison, 2002). For example, an optimum *angle of approach* to the ball is about 30-45 degrees (Isokawa and Lees, 1988). Intermediate scores in the rating scale were simply equidistant between 0 and 4. The observation of the movement of highly skilled performers from video allowed estimating range of motion for variables for which the literature provided no data. Moreover, Pilot Study 1 identified a number of techniques used by the children and these techniques were incorporated into the scales. For example, a *running action* of the opposite arm contributes little to the kick and was used to set the score of 0 in the rating scale for opposite arm movement. Thus, preliminary rating scales for the qualitative analysis of the soccer kick were constructed. However, prior to using such scales it was important to assess whether such scales allowed acceptable accuracy and intra-rater reliability.

2.7.2 Tests of accuracy and intra-rater reliability of visually estimated variables for the adjustment of the rating scales

The use of the preliminary rating scales would have lacked scientific rigour had the accuracy and reliability of the observer not been tested to adjust the rating scales. Particularly, Knudson and Morrison (2002) have warned that criterion-referenced validity may exist for some variables but not for others.

Method

The video recordings of a sample group of 15 male children aged 5 - 9 (mean ± SD = 7.4 ± 2.24) years, chosen at random from the larger group of 45 children that took part in Pilot Study 1, were used to evaluate the accuracy and intra-rater reliability of visually estimated variables. In the **accuracy test,** one trial per child of the soccer kick was used for such purpose. A criterion validity test was conducted to compare on-screen kinematic measures to visually estimated measures. Therefore, sagittal plane video images of the children's performance were measured on the video monitor screen using rulers and protractors and frame count at 50 Hz to obtain sagittal plane kinematics, a practice that is gaining popularity in qualitative research (Knudson and Morrison, 2002). A vertical calibration tool consisting of a 1-metre ruler positioned by the stationary soccer ball had been previously filmed to allow conversion of monitor screen measures into actual distances. Changes in the position of the ball and time between video fields were used for the calculation of velocities.

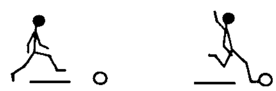
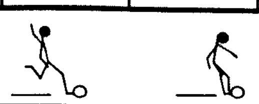
Only sagittal plane kinematic variables that could be measured using the on-screen method described above were included in the test. Thus, ten representative variables were selected which are listed in Table 4.4. Three dimensional kinematics and kinetic variables were not included in the analysis due to the impracticalities of obtaining these measures from school-aged children. The magnitude of the same ten variables was estimated by one analyst while watching a video sequence of the performance using various viewing conditions (i.e., normal-speed video playback, slow motion and frame-freeze, as required; see Table 4.3 above) at 50 Hz. The analyst viewed the same trials 1-3 times in order to estimate kinematic quantities as accurately as possible. Both onscreen and visually estimated measures were converted into a score according to the initial 5-level rating scales. Agreement between scores obtained from the conversion of on-screen measures into a score and scores obtained using visual estimation was assessed using percent agreement. Acceptable percent agreement for the purposes of qualitative analysis was set at 80% based upon Knudson and Morrison (2002). The number of measurement categories and the size of the intra-score interval allocated to each score in the rating scale for each variable was adjusted systematically until the acceptable level of percent agreement was reached. The accuracy of the final rating scales for the 10 variables was confirmed using Kappa statistic (Altman, 1999; Nicholls *et al.*, 1999; Howitt and Cramer, 2003). Once acceptable accuracy was achieved, the findings served to guide the adjustment of rating scales for other non-planar kinematic and kinetic variables not included in the analysis of accuracy.

Subsequently, assessment of **intra-rater reliability** was carried out by comparing scores collected using the rating scales in two separate occasions (test 1 and test 2) in order to further adjust the rating scales. Reliability was assessed using the same statistical tests as those used for accuracy, however all 19 variables selected for the analysis of the soccer kick were included (see Table 4.6). Acceptable percent agreement was set at 80 % (Knudson and Morrison, 2002). The time interval between test 1 and test 2 was four days in order to eliminate the effects of proximity between repeated testing. The sample group of children used for the reliability analysis was the same as for the assessment of accuracy.

Results

Table 4.4 shows the adjusted rating scale for each variable included in the tests of accuracy and Tables 4.5 and 4.6 summarise the results of the accuracy and reliability tests, respectively, when using the adjusted scales. In the **accuracy test**, agreement between on-screen scores and visually estimated scores was no lower than 80%. In the **reliability test**, a minimum of 80% agreement was also achieved. All Kappa results were significant ($p < 0.05$). These results indicated that the adjusted scales were suitable for the qualitative analysis of mechanical effectiveness in children.

Table 4.4: Rating scales for selected variables of the maximum-distance soccer kick.

Phase or instant	Variable	Score 0	1	2	3	4
Approach phase	approach speed (m/s; qualitative descriptor)	static	< 2; walking	> 2; running		
Backswing subphase						
	last step length (%)[1]	< 50	50 - 80	81 - 120		
	angle of maximum knee flexion (deg)[2]	> 135	135 - 111	110 - 70	< 70	
	angle of maximum hip hyperextension (deg)[3]	0 - 19	20 - 40	> 40		
Foot plant instant						
	support foot placement (cm)[4]	> 45	45 - 31	30 - 15	< 15	
	angle of maximum backward trunk inclination (deg)[3]	positive to - 5	-6 to -30			
Swing phase						
	angle of maximum forward trunk flexion (deg)[3]	negative to 0	1 - 15	16 - 45		
Follow through phase						
	velocity of ball release (m/s)		1 - 15	> 15		
	angle of ball release (deg)	0 - 4	5 - 9	10 - 19	20 - 29	30 - 40
	angle of maximum hip flexion (deg)[5]	-90 to -61	-60 to -31	-30 to -6	-5 to +5	+6 to +30

[1] Percentage of child's height; [2] Relative angle; [3] Measured to the vertical; [4] Distance from ankle joint centre to ball centre; [5] Measured to the right horizontal.

Table 4.5: Summary of the results of the accuracy tests (soccer kick; N = 15).

Variable	On-screen measures		Visually-estimated measures (median of scores)	Agreement (%) **	*k*	Sig.***
	Kinematic measure (mean ± SD)	Median score*				
speed of approach (m/s)	3.5 ± 0.7	2	2	90	0.634	0.008
length of last step (% of child's height)	91.8 ± 14.0	2	2	80	0.615	0.001
angle of maximum knee flexion (deg)	82.7 ± 22.6	2	2	80	0.789	0.001
angle of maximum hip hyperextension (deg)	40.7 ± 7.9	2	1	80	0.609	0.010
support foot placement (cm)	20.9 ± 16.3	3	3	80	0.651	0.001
angle of maximum backward trunk inclination (deg)	-12.3 ± 9.7	1	1	85	0.595	0.012
angle of maximum forward trunk flexion (deg)	27.7 ± 19.2	2	2	80	0.571	0.003
velocity of ball release (m/s)	13.6 ± 2.8	1	1	80	0.526	0.039
angle of ball release (deg)	15.5 ± 6.4	2	2	100	1.000	0.001
angle of maximum hip flexion (deg)	-7.2 ± 26.7	2	2	85	0.793	0.001

* Median of the scores obtained from the conversion of on-screen kinematic measures into a score using the rating scales in Table 4.4.

** Agreement between scores obtained from the conversion of on-screen measures into a score and scores obtained using visual-estimation.

*** All Kappa results are significant ($p < 0.05$)

Table 4.6: Results of the tests of intra-rater reliability in the determination of mechanical effectiveness (soccer kick; N = 15).

	Approach phase		Back swing subphase				Foot plant instant			Swing phase				Ball contact instant		Follow through phase			General
	Speed of approach	Angle of approach	Length of last step	Shoulder horizontal abduction	Maximum knee flexion	Maximum hip hyperextension	Support foot placement	Maximum backward trunk inclination	Maximum lateral body inclination	Shoulder horizontal adduction	Shoulder adduction velocity	Maximum forward trunk flexion	Applied impact forces	Angle of kicking knee	Contact time	Velocity of ball release	Angle of ball release	Maximum hip flexion	Coordination & rhythm
Median score (test 1)	2	1	2	3	2	2	3	1	0	3	2	2	1	1	2	2	3	2	2
Median score (test 2)	2	2	2	3	2	2	3	1	0	3	2	2	1	1	1	2	2	2	2
Agreement (%)	80	93	87	80	87	93	80	100	80	80	80	93	93	100	93	100	80	80	80
k	0.587	0.894	0.595	0.727	0.732	0.762	0.672	1.000	0.571	0.776	0.444	0.874	0.762	1.000	0.867	1.000	0.819	0.732	0.619
Sig. (*k*)*	0.013	0.001	0.012	0.001	0.001	0.002	0.001	0.001	0.025	0.001	0.038	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.002

* All Kappa statistical results are significant ($p < 0.05$)

2.7.3 Development of a scoring reference for the maximum-distance soccer kick

The tests of accuracy and intra-rater reliability were used to adjust the rating scale for each variable. This resulted in rating scales with an unequal number of measurement categories. Subsequently, a scoring reference and a scoring table for the maximum distance soccer kick were constructed (Tables 4.7 and 4.8). The scoring reference shows diagrammatically how to measure angle variables, according to whether the angle is absolute or relative. The scoring table allows: **1** - to record **scores for each variable, 2** - to obtain a measure of **mechanical effectiveness for each phase/instant** of the soccer kick (expressed as a percentage of maximum attainable mechanical effectiveness for each phase/instant), and **3** – to obtain a **total score** of overall mechanical effectiveness of the child (as a percentage of maximum attainable mechanical effectiveness). Instructions on how to obtain these measures are as follows:

1. **Scores for each variable:** Simply circle the score with a pen.

2. **Percentage for a particular phase/instant of the movement:** Add all the scores awarded for each variable in that phase/instant. Divide the resultant value by a value that represents the sum of the maximum scores attainable for that phase/instant (this latter value is provided in the scoring table; top right hand corner of the subtotal box for each phase/instant). Multiply by 100. Thus, (sum of scores/sum of maximum attainable scores) * 100. Examples of calculated percentages are provided in Table 4.8.

3. **Total score:** Add the scores for each of the 19 variables of the soccer kick, and divide by a value that represents the sum of all the maximum scores attainable for each variable (value provided in the total score box). Multiply by 100. Thus, (sum of scores/sum of maximum attainable scores) * 100.

Table 4.7: Scoring reference for the maximum-distance soccer kick.

Phase, subphase or instant	Technique / performance variable	Score 0	1	2	3	4
Approach phase	Speed of approach	static	walking/ jogging (50 Hz)	very fast run		
Approach phase	Angle of approach	0^0 (top view)	$1\text{-}29^0$	$30\text{-}45^0$		
Back swing subphase	Length of last step (relative to child's height)	< 50 %	50-80 %	81-120 %		
Back swing subphase	Horizontal abduction of opposite arm, elbow angle & angle of shoulder abduction	extension, flexed & very low	short arc, flexed & low	80^0 arc, semi-extended & medium	160^0 arc, extended & high	
Back swing subphase	Maximum knee flexion	$> 135^0$	$135\text{-}111^0$	$110\text{-}70^0$	$< 70^0$	
Back swing subphase	Maximum hip hyperextension	$0\text{-}19^0$	$20\text{-}40^0$	$> 40^0$		

Key:
blue - kicking leg
red - non-kicking arm or leg
--- beginning of ROM
— end of ROM
Note: Not all body segments shown.

Table 4.7 (cont.): Scoring reference for the maximum-distance soccer kick.

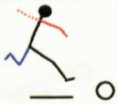
Phase, subphase or instant	Technique / performance variable	Score 0	1	2	3	4
Foot plant instant	Support foot placement (from ankle to ball center)	 > 45 cm behind	 45-31 cm	 30-15 cm	 < 15 cm	
	Maximum backward trunk inclination	 forward, vertical	 -5 to -30^0			
	Maximum lateral body inclination	rear view  remains vertical	 lateral inclination			
Swing phase	Horizontal adduction of opposite arm, elbow angle & angle of shoulder abduction	 flexion, flexed & very low	 short arc, flexed & low	 90^0 arc, semi-extended & medium	 ≥180^0 arc, extended & high	
	Adduction velocity of opposite arm	passive	low	powerful swing		
	Maximum forward trunk flexion	 inclined backward	 1 -15^0	 16 - 45^0		
	Magnitude of impact forces applied to ball	low	powerful kick			

Table 4.7 (cont.): Scoring reference for the maximum-distance soccer kick.

Phase, subphase or instant	Technique / performance variable	Score 0	Score 1	Score 2	Score 3	Score 4
Ball contact instant	Angle of kicking knee	straight to 170^0	< 170^0			
Ball contact instant	Contact time	sharp	short	long		
Follow through phase	Velocity of ball release		50 Hz low (1-15 m/s)	high (> 15 m/s)		
Follow through phase	Angle of ball release	rolling	5-9^0	10-19^0	20-29^0	30-40^0
Follow through phase	Maximum hip flexion	+ ve - ve -90 to -61^0	-60 to -31^0	-30 to -6^0	-5 to +5^0	+6 to +30^0
General	Coordination & rhythm	staccato	hesitant	smooth, effortless		

Table 4.8: Scoring table for the maximum-distance soccer kick.

Phase, subphase or instant	Technique / performance variable	Score					Subtotal
Approach phase	Speed of approach	0	1	**2**			2/4 50%
	Angle of approach	**0**	1	2			
Back swing subphase	Length of last step	0	1	**2**			5/10 50%
	Horizontal abduction of opposite arm, elbow angle & angle of shoulder abduction	**0**	1	2	3		
	Maximum knee flexion	0	1	**2**	3		
	Maximum hip hyperextension	0	**1**	2			
Foot plant instant	Support foot placement	0	1	2	**3**		4/5 80%
	Maximum backward trunk inclination	0	**1**				
	Maximum lateral body inclination	**0**	1				
Swing phase	Horizontal adduction of opposite arm, elbow angle & angle of shoulder abduction	0	1	**2**	3		4/8 50%
	Adduction velocity of opposite arm	0	**1**	2			
	Maximum forward trunk flexion	**0**	1	2			
	Magnitude of impact forces applied to ball	0	**1**				
Ball contact instant	Angle of kicking knee	0	**1**				2/3 67%
	Contact time	0	**1**	2			
Follow through phase	Velocity of ball release	0	**1**	2			5/10 50%
	Angle of ball release	0	1	2	**3**	4	
	Maximum hip flexion	0	**1**	2	3	4	
General	Coordination & rhythm	0	1	**2**			2/2 100%
	Total						24/42 57%

2.7.4 Test of inter-rater reliability in the use of the scoring reference for the maximum distance soccer kick

The results of the accuracy and intra-rater reliability tests allowed constructing a scoring reference for the maximum distance soccer kick. However, the **inter-rater reliability** needed also to be determined to assess the adequacy of this measuring tool.

Method

A group of 39 2nd year university Sport Sciences students were asked to rate the movement effectiveness of a 9-year-old male child in order to determine objectivity or inter-rater reliability in the use of the scoring reference for the maximum distance soccer kick. Students received a 10-minute instructional session on the use of the scoring reference, in which they familiarised themselves with the different variables and rating scales included in the scoring reference. Students were shown a video of mature kicking performance, first at normal video playback speed and then frame-by-frame, and the main movement pattern and technical points were described to them as they watched the video. Subsequently, a video of the kicking action of a 9-year-old was shown to the students. The experimenter played back the video using normal speed, slow motion, frame-by-frame, repeated viewing (2-3 times), and a combination of normal speed immediately followed by slow motion or frame-by-frame video playback, as required, for each of the variables included in the scoring reference (see Table 4.3). The students were asked to report the difficulties encountered when using the scoring reference for a subjective assessment of ease-of-use of the scoring reference. Inter-rater reliability was assessed by calculating the mode of scores (to establish a criterion measure on which to base the comparisons) and, then, using percent agreement (interobserver agreement; Thomas and Nelson, 1996) with the mode score. Acceptable percent agreement for the purposes of qualitative analysis of fast sports movement was set at 70 % based upon Knudson (1999) and Knudson and Morrison (2002). The test of reliability was consolidated using an item alpha reliability test (Howitt and Cramer, 2003; "*An alpha of .70 or above is considered satisfactory.*" p. 238). The coefficient alpha allows estimating reliability in items with various point scales (scores) with different items (mechanical variables); Thomas and Nelson (1996), Nicholls *et al.* (1999). The range of scores for each variable was also determined to inspect the dispersion of the scores.

Results

The results for the **inter-rater reliability** test appear in Table 4.9. The mean (± SD) percent agreement with the mode score was 74.8 % ± 11.9 %. The best agreement was found for the *maximum knee flexion* variable (97.4 % agreement) and the worst agreement for the *maximum lateral body inclination* (61.5 %) and *velocity of ball release* variables (61.5 %). The alpha reliability was 0.48, indicating that the scoring reference had moderate inter-rater reliability.

Table 4.9: Results of the inter-rater reliability tests (soccer kick).

Phase, subphase or instant	Technique / performance variable	Mode (score)	Range (scores)	Percent agreement with the mode score (%)
Approach phase	Speed of approach	2	1-2	66.7
	Angle of approach	1	0-2	82.1
Back swing subphase	Length of last step	2	1-2	66.7
	Horizontal abduction of opposite arm, elbow angle & angle of shoulder abduction	3	2-3	97.4
	Maximum knee flexion	3	2-3	97.4
	Maximum hip hyperextension	2	1-2	84.6
Foot plant instant	Support foot placement	3	2-3	87.2
	Maximum backward trunk inclination	1	0-1	64.1
	Maximum lateral body inclination	1	0-1	61.5
Swing phase	Horizontal adduction of opposite arm, elbow angle & angle of shoulder abduction	3	1-3	64.1
	Adduction velocity of opposite arm	2	1-2	84.6
	Maximum forward trunk flexion	1	1-2	66.7
	Magnitude of impact forces applied to ball	1	0-1	87.2
Ball contact instant	Angle of kicking knee	1	0-1	71.8
	Contact time	1	1-2	66.7
Follow through phase	Velocity of ball release	2	1-2	61.5
	Angle of ball release	4	3-4	74.4
	Maximum hip flexion	2	1-3	71.8
General	Coordination & rhythm	2	0-2	64.1

Mean	**74.8%**
SD	**11.9%**
Maximum	**97.4%**
Minimum	**61.5%**

Stage 8. Rating of the performance factors

The final stage of the model indicates the actual rating of the mechanical effectiveness of the soccer kick movement of the child. The use of the scoring reference can be enhanced by first establishing the technical level of the child using the hierarchical models from Study 1. Scores of mechanical effectiveness are obtained for each variable, and a percentage can also be obtained for each phase and instant of the movement to locate in what parts of the movement coaching attention needs to be focused. The scores obtained can be easily plotted to obtain a profile of movement effectiveness. There is also a total score that represents the overall mechanical effectiveness of the child.

3. Application of the model to outline the analytical components and to develop scoring references for the qualitative analysis of the overarm throw and the standing broad jump

The model for the analysis of mechanical effectiveness was used as for the maximum distance soccer kick above. The corresponding deterministic models appear in Figures 4.3 and 4.4. The analytical components for these two motor skills can be found in Tables A6.1-A6.4, in Appendix 6; which include the selected variables for each phase of the movement. The filtering of variables according to the relative mechanical contribution was carried out as for the soccer kick at Stage 5 of the implementation of the model. For example, in the **overarm throw** *length of the last step*, *maximum rotation of the body* and *throwing arm retraction* were considered significant contributors to throwing performance based on the studies of Tarbell (1971), Toyoshima *et al.* (1974) and Broer and Zernicke (1979). Although *throwing time* has been related to throwing performance (Raudsepp and Paasuke, 1995), other time-related variables such as the *rotational velocity of the throwing arm* and the *velocity of ball release* were given priority in the present research. In the **standing broad jump**, examples of variables considered to afford a significant contribution include: *arc of arm swing and elbow angle* (Dowell and Lee, 1991) and *angles of hips and knees (mid flight)* Horita *et al.* (1991). Other variables were not considered to have priority in the analysis, such as *hip extension velocity* during the propulsion phase (Robertson and Fleming, 1987) since assessment of *velocity of takeoff* is more meaningful.

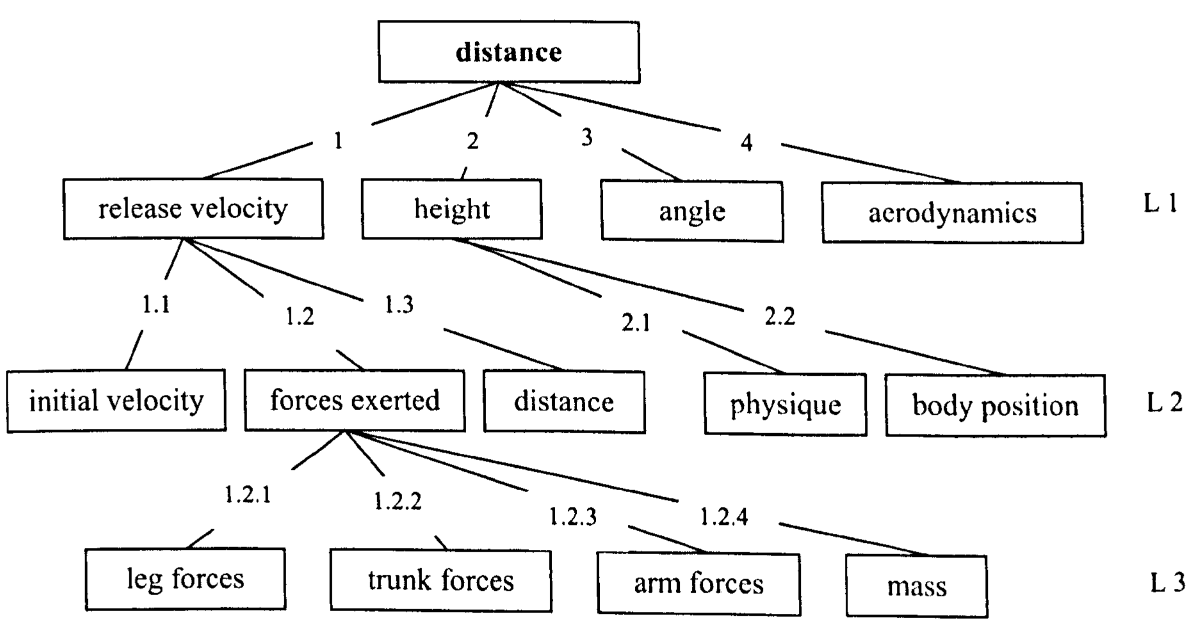


Figure 4.3: Deterministic mechanical model for the overarm throw for maximum distance (based upon Hay and Reid, 1982).

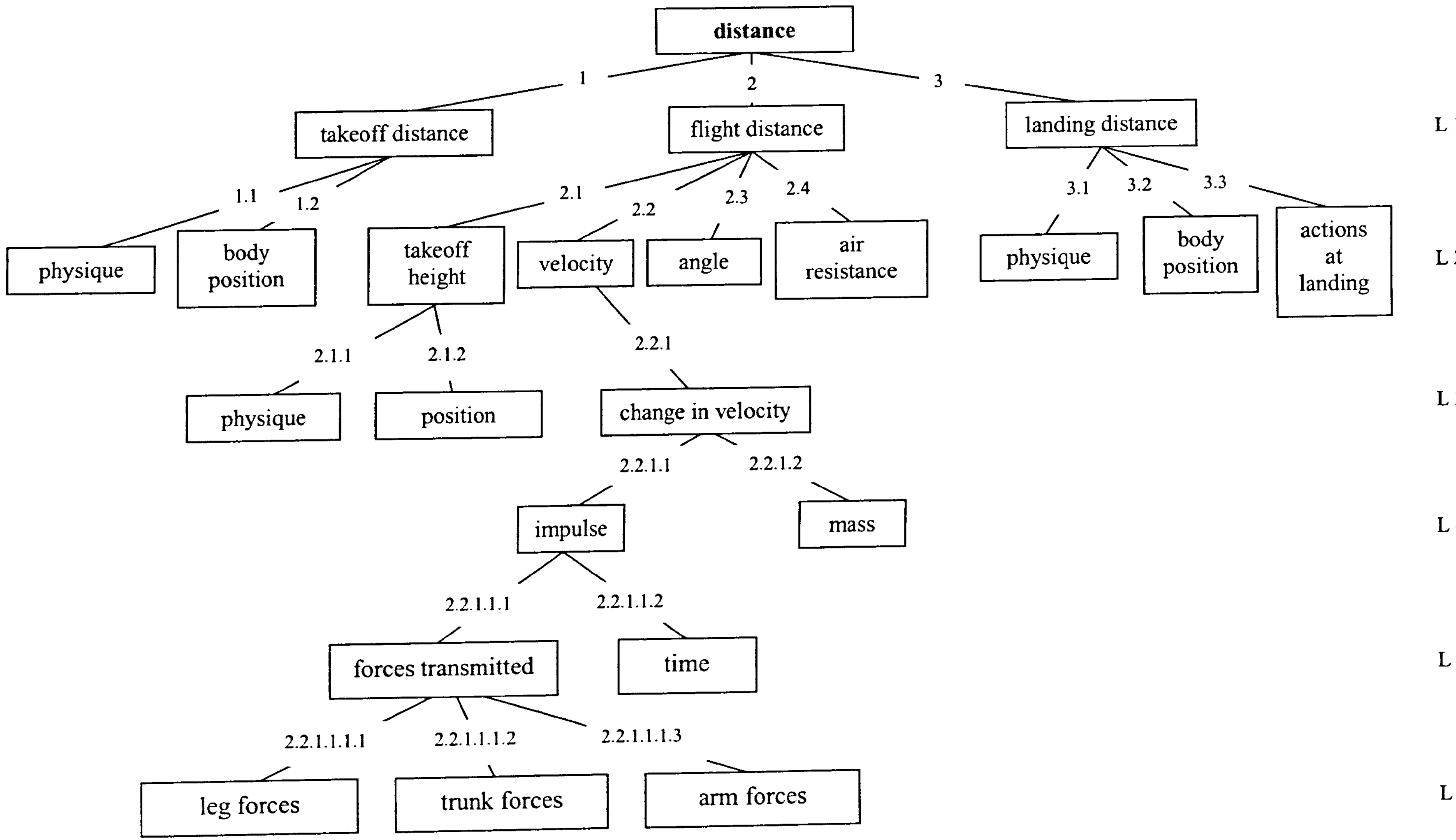


Figure 4.4: Deterministic mechanical model for the standing broad jump (based upon Hay and Reid, 1982).

3.1 Development of scoring references for the qualitative analysis of the overarm throw and the standing broad jump.

Method

Initial 0-4 rating scales for selected sagittal plane kinematic variables of the overarm throw and the standing broad jump were constructed using the literature and observation of the movement (Pilot Study 1). This was carried out following a procedure identical to that described for the soccer kick above. However, some of the children used a *homolateral step* pattern and others used *cricketer's* technique when throwing, as observed in Pilot Study 1. These technical variations affected the motion of the throwing arm and of the trunk. Therefore, supplementary scales for the analysis of throwing were developed to ensure inclusion of children in the analysis. Subsequently, the **accuracy** and **intra-rater reliability** of visually estimated variables of the two motor skills (the variables are listed in Tables A7.1 and A7.4, Appendix 7) were determined in order to adjust the rating scales. This was carried out using the same subjects and procedures as for the soccer kick above.

Results

Tables A7.1 to A7.6, Appendix 7, show the adjusted rating scales for the variables included in the **accuracy test** and summarise the results of the **accuracy** and **reliability tests.** Agreement of no less than 80% was reached using the adjusted rating scales and all Kappa results were significant. The adjusted rating scales for all variables included in the analyses of accuracy and reliability were used to construct scoring references and scoring tables for the overarm throw and the standing broad jump (Tables A8.1-A8.6, in Appendix 8). For the overarm throw, alternative rating scales (Table A8.2) and a supplementary scoring table (Table A8.4) were created for children who use either a *homolateral step* pattern or *cricketer's* technique when throwing. In this case, it is useful to determine the technical level of the child first, using the hierarchical models in Study 1, prior to attempting to rate mechanical effectiveness. The tests of accuracy and intra-rater reliability confirmed the adequacy of the scoring references for the qualitative analysis of mechanical effectiveness in the overarm throw and the standing broad jump.

3.2 Tests of inter-rater reliability in the use of the scoring references for the analysis of the overarm throw and the standing broad jump.

Method

Inter-rater reliability for overam throwing (using the scoring reference; Table A8.1, Appendix 8) and the standing broad jump (Table A8.5) was assessed using the same procedure as for the soccer kick (section 2.7.4). However, in these tests a different group consisting of 41 2nd year Sport Sciences University students (22 students in the tests for throwing; 19 for the jump) participated.

Results

The results for the **inter-rater reliability** test for the **overarm throw** appear in Table A9.1, Appendix 9. The mean (± SD) percent agreement (mean of all variables) with the mode of scores was 81.8 % ± 12.1 %. The best agreement was found for the *speed of approach* variable (100.0 % agreement) and the worst agreement for the *magnitude of ground reaction forces* (63.6 %) and *length of the 1st step & lowering of the CG* variables (63.6 %). The alpha reliability was 0.41, indicating that the scoring reference had moderate inter-rater reliability (Howitt and Cramer, 2003). In the **standing broad jump** (Table A9.2) the mean (± SD) percent agreement with the mode score was 76.5 % ± 12.9 %. The best agreement was found for the *dynamic balance* variable (100.0 % agreement) and the worst agreement for the *CG landing trajectory* (57.9 %) and *compression* variables (57.9 %). The alpha reliability was 0.64 indicating good inter-rater reliability. Inter-rater reliability in the use of the scoring references was considered acceptable.

Discussion

1. The construction of the model for the qualitative analysis of mechanical effectiveness

The main challenges of Study 2 consisted of outlining the mechanical effectiveness model and fusing the sequential and the mechanical approaches to movement analysis. Upon reflection, Arend and Higgins's (1976) model strikes as extremely complex to follow. In part, this complexity was overcome a few years later in the model of Hay and Reid (1982), but then new difficulties arose. Development of a deterministic mechanical model requires good knowledge of biomechanics and we do not know from the model what aspects of technique should be assessed. Later models solved some of the difficult issues by describing how to identify critical features (McPherson, 1990; Abendroth-Smith *et al.,* 1996; Kreighbaum and Barthels, 1996). However, it was not until recently that a practical guide to biomechanical analysis was available in which specific movement principles were clearly formulated and classified (Lees, 1999b). Fusing phase analysis and mechanical analysis represents a long sought solution to a methodological problem (Norman, 1975; Abendroth-Smith *et al.,* 1996) that impeded tracing the symptoms of faulty technique and poor performance to their source.

The existing comprehensive models (Arend and Higgins, 1976; Hay and Reid, 1982; McPherson, 1990; Abendroth-Smith *et al.,* 1996; Kreighbaum and Barthels, 1996; Lees, 1999b) had placed emphasis in the biomechanical analysis of the movement and in these models an evaluation of the visual perceptual limitations of the observer had not been carried out. Instead, the problem of observation has been addressed by a number of researchers (e.g., Brown, 1982; Ganstead and Beveridge, 1984; Hudson, 1985, 1995) and the accuracy and reliability of visually estimated kinematics has been of interest in ergonomics and the medical professions, and more recently in sports science (e.g., Krebs *et al.*, 1985; Painter, 1990; Eastlack *et al.*, 1991; Wilkinson, 1996). However, Stages 6 and 7 of the model represent a further integration of qualitative methods by considering the perceptual limitations of the rater after identifying the mechanical variables relevant to performance. The development of an optimum observational strategy to estimate technique and performance variables from video was possible by combining an understanding of the functions of the human eye (e.g., Watts and Bahill, 1990; Kluka, 1991; Knudson and Morrison, 2002), the integration of previous observational models that by trial and error have identified the perceptual difficulties in practical sports situations (i.e., Brown, 1982; Hoffman, 1983; Gangstead and Beveridge, 1984; Hudson, 1985; Dunham, 1994; and Knudson and Morrison, 2002), and consideration of research on the use of different video replay conditions (e.g., Ragsdale, 1930; Hupprich, 1941; Williams, 1986; and Carnegie, 1997).

2. Implementation of the model for the qualitative analysis of motor skills

Although the division of a motor skill into phases and subphases is arbitrary, in order to increase the level of detail of the analysis some authors have divided the swing phase of the **soccer kick** further into three subphases in which the hips open out maximally, the hips rotate forward, and the knee extends to contact (e.g., Lees, 1999b). However, in the present research the swing phase was treated as a single phase due to the limitations of human visual perception and the relatively low sampling rate used (50 Hz), which was considered insufficient to accurately locate the beginnings and ends of any sub-phases within the swing phase. The less detailed simplification of the kicking movement suggested here might be more practical when analysis of several variables, and not just the movement of the kicking leg, is required.

The process of constructing the rating scales showed that both the literature and observation of the movement (Pilot Study 1) are useful to initially outline rating scales. The factors that guided the construction of the initial 5-level scales were related to previous research and included: child and adult performance (e.g., Atwater, 1970; Roberton, 1978; Morris *et al.*, 1982; Gallahue and Ozmun, 1995; Carnegie, 1997), consideration of a range of optimum values (based upon Lees, 1999b and Knudson and Morrison, 2002), predicted accuracy of the observer (e.g., Douwes and Dul, 1991; Ericson *et al.*, 1991), predicted width of the intra-score intervals (e.g., Ballard *et al.*, 1979; Isokawa and Lees, 1988), use of visual cues that help estimate kinematic and kinetic quantities (based on McPherson, 1990), the use of scoring references with standard SI units and/or qualitative descriptors (e.g., Adrian and Cooper, 1995; Gallahue and Ozmun, 1995; Nicholls *et al.*, 1999) and template-like stick figures (McClenaghan, 1976; Ballard *et al.*, 1979). However, the tests of accuracy and intra-rater reliability showed the importance of adjusting the scales prior to their use for the analysis of mechanical effectiveness.

Such tests of accuracy and intra-rater reliability carried out in the present research differed from the conventional use of these tests, which are normally used to test the validity and reliability of tools or methodological procedures that are already in use (e.g., Merriman *et al.,* 1993; Looze *et al.,* 1994; Bernhardt *et al.,* 1998; Knudson, 2000; Yan *et al.*, 2000). When adjusting the rating scales there were differences in terms of the accuracy and the reliability achieved by the operator from variable to variable, indicating that some variables were more difficult to perceive than others. However, adjustment of the scales enabled a minimum of 80 % agreement; a level of agreement that, based upon then extensive documentation of previous research presented by Knudson and Morrison (2002), can be regarded as acceptable for the purposes of subjective analysis.

Further, it is important to point out that, in the rating scales, each score corresponds to a defined sector for angle measures or to a specific intra-score interval for measures of length. For example, an angle of *maximum knee flexion* in the **soccer kick** of >135° corresponds to a score of 0, an angle between 135-110° correspond to a score of 1, and so on (Table 4.7). The difficulty in using a scale of this type is that the observed angular position or length may be near the limits of the range of values allocated to each score, and therefore the rater may be indecisive as to whether award a score of, for example, 0 or 1 when the angle of *maximum knee flexion* is approximately 135°. While this may not be of consequence when rating the actual mechanical effectiveness of the child, it certainly affected the evaluations of accuracy and intra-rater reliability when constructing the scales. It was somewhat surprising that previous research had not identified the potential problem of end-of-range proximity when assessing validity and reliability of scales that contain interscore intervals.

Moreover, when using the model for the analysis of **throwing** and **jumping** interesting findings arouse. Specifically, the rating scale for projection velocity consisted of a three-level scale for all three motor skills (kicking, throwing and jumping). In comparison, projection angle allowed the use of a 5-level scale in the **soccer kick**, a 4-level scale in the **overarm throw**, and only a 2-level scale in the **standing broad jump**. This example shows that the degree of difficulty in measuring a particular parameter, in this case angle of release/takeoff, qualitatively may vary between motor skills. Incidentally, the use of rating scales with a varying number of measurement categories is not common, but has appeared occasionally in previous research (e.g., Ballard *et al.*, 1979). It is thought that the use of the ground in the **soccer kick** served as a horizontal reference from which the angle is measured. Then, estimating angle of takeoff of the centre of gravity of the child in the **standing broad jump** involves, first, estimating the ever changing position of the centre of gravity of the child in a dynamic situation, and then, the flight trajectory of the centre of gravity over a comparatively short initial path of projection. Although the video recording method used in the present research included no background references for consistency and to enable uncomplicated filming, observational strategies have highlighted the benefits of using background references to help estimate angle variables (i.e., Brown, 1982; Knudson and Morrison, 2002).

Overall, inter-rater reliability in the use of the scoring references was considered acceptable, given that the acceptable level was set relatively high (70 % agreement) in relation to the findings of Knudson (1999); where only 60 % of college students could rate consistently overall range of motion. Similarly, Knudson and Morrison (2002) reported that experimental studies showed 'poor-to-moderate' inter-rater reliability in qualitative analysis. However, in the **soccer kick** inter-rater agreement was below the set 70% for 9 variables (61.5 - 66.7 % agreement). *Maximum lateral body inclination* and *velocity of ball release* were the two variables that showed worst inter-rater agreement. The use of a camera view perpendicular to the main plane of performance may have dictated poor agreement with regard to *maximum lateral body inclination*. Also, *velocity of ball release* during the initial flight path is probably one of the most difficult parameters to estimate, perhaps due to deterioration of dynamic visual acuity (Watts and Bahill, 1990) and saccadic suppression (Kluka, 1991). In the **overarm throw**, agreement was below 70 % (63.6 - 68.2 % agreement) for 3 variables. Of these, students commented on the difficulty in estimating *magnitude of ground reaction forces*, and it seems that the students may have needed more time to locate and interpret the visual cues that can be used to estimate forces (Knudson and Morrison, 2002). In the **standing broad jump**, inter-rater agreement was below 70 % for 6 variables (57.9 - 68.4 % agreement). In this case disagreement may have been caused by the child's performance being in borderline between to adjacent scores. In fact, lack of inter-rater agreement may have been caused by end of range proximity in the rating scales, a factor that causes indecision in the rater when awarding a score. The use of a 10-minute introduction to the task may have not been sufficient for the students to familiarise themselves with the variables measured, the rating scales, and the movement pattern of the child. In fact, the students commented that should they use the scoring reference in the future, it would be much easier and quicker to carry out the analysis after having used it once. Finally, one student suggested using inter-score range of kinematic values graphically for all kinematic variables. However, this may add complexity to the stick figures used in the scales, although this comment may be considered in future developments of the scoring references.

To evaluate the model developed in Study 2, assessment of mechanical effectiveness shares certain features with the assessment of technical level described in Study 1. Both methods are based on the concept of movement effectiveness, thus the analysis is not just descriptive but allows quantification of how effective the movement is in attaining the performance criterion. A drawback common to both methods is that they require extensive observational phase analysis and biomechanical analysis to develop both the hierarchical models and the scoring reference. Nonetheless, the assessment of technical level is quick and straightforward using the hierarchical models, although the analysis of movement effectiveness it provides is only basic. In contrast, assessment of mechanical effectiveness is comprehensive including as many as, for example, 20 variables for the overarm throw, and the analysis includes all phases and key instants of the movement. The analysis of mechanical effectiveness is only qualitative, however, which limits some of the scales to two levels. Finally, the establishment of technical level using the hierarchical models enhances the subsequent analysis of mechanical effectiveness using the scoring references.

Limitations of the study and suggestions for future work

Although the model for the analysis of mechanical effectiveness can be used for the analysis of different motor skills, the exhaustive processes of review of previous research, observational phase analysis, and association between observable features and mechanical variables are time consuming and require thorough investigation. This indicates that it should be the researcher who carries out such tasks. This may justify the role of the sports biomechanist, who unfoundedly often claims to be able to assist the coach and PE teacher in the improvement of sports performance and the prevention of injury during sports activity (Lees, 1999a). Specifically, the literature showed a lack of kinematic data on a number of seemingly important variables of the three motor skills, such as the *speed of approach, length of the last step, maximum backward trunk inclination, maximum lateral body inclination,* and *maximum forward trunk flexion* in the **soccer kick**, and this required observational phase analysis to obtain such data. In addition, several movements associated with the **soccer kick** observed in Pilot Study 1 had received little attention in the literature, such as the movement of the opposite arm. Consequently, the contribution of such movements to kicking effectiveness was assessed subjectively. This calls for future quantitative experimental research in order to determine the contribution of such movements, particularly because the use of mechanical principles as universally accepted mechanical laws must be approached with caution (Lees, 1999a; Hong *et al.*, 2001). In fact, predictive analysis (Thomas and Nelson, 1996) can be used to evaluate the contribution of each variable included in the analysis to the attainment of the performance criterion.

Despite the integration of existing observational models, the two-dimensional nature of the analysis relied upon the use of body orientation and perspective to estimate range of motion in a number of non-planar movements. Although the use of two cameras would have added accuracy to the analysis, the use of a single camera is justified. This is because, first, the analytical method developed in the present research is meant to be time-efficient and uncomplicated, and second, the use of a rear view camera was assessed in Pilot Study 1 and proved to yield little extra information (Nicholls *et al.* (1999) had come to the same conclusion). The degree of difficulty to estimate kinematic and kinetic quantities using different video playback speeds and conditions was evaluated with reference to the findings of the scarce literature available on this topic (e.g., Hupprich, 1941; Carnegie, 1997). Further, given the qualitative nature of the analysis a manual method was used to obtain on-screen measures of the performance in order to carry out the accuracy tests. Although time consuming, further research may include digitised kinematic data for such purposes and, by so doing, strengthen the validity of the comparisons. Another limitation identified in the present study was the fact that kinematic variables corresponding to non-planar movements and kinetic quantities were not suitable for the tests of accuracy, since these could not be measured accurately using the on-screen method. This needs to be addressed in future research by including 3-dimesional analysis and kinetic assessment, which may include inverse dynamics for variables such as moment of inertia of the opposite arm in soccer (e.g., Barfield, 1995; Nunome *et al.,* 2002).

The issue of objectivity, or inter-rater agreement, needs also to be incorporated in future research. This is because the accuracy of the estimations by the students was not tested, where it is possible to have high reliability but low validity. Further, the scoring reference for the overarm throw had to be adapted for the inclusion of the different throwing techniques observed in the children (Pilot Study 1). It is thought that the findings of Langendorfer and Roberton (2002) who stated that *"within-person constraints eliminated certain movement relationships while encouraging others"* (p. 245), may have been responsible for the individual variations in technique observed in the children. The technical variations affected arm and trunk motion which, although this problem was overcome by supplementary scales, made the scoring reference a bit more difficult to use. However, the technical variations observed must be regarded a normal form of variability in the development of the overarm throw in children; in particular, a homolateral last step is typical of very young children (Marqués-Bruna and Grimshaw, 1997) and it tends to persist in female children (Thomas and Marzke, 1992).

Conclusions

Study 2 was concerned with the construction, and verification, of a model for the qualitative analysis of mechanical effectiveness in children. The model was the result of integration of existing comprehensive and observational models. One of the main features of the model was the fusion of phase analysis and mechanical analysis by association of observable features and mechanical variables using movement principles. Implementation of the model to delimit the analytical mechanical and perceptual aspects of motor skills was demonstrated using the **soccer kick** for maximum distance. The selection of variables for analysis was perceived as the task of the researcher due to its complexity, rather than that of the coach or PE teacher. A literature-based evaluation of issues of visual perception and of the measurement of kinematic and kinetic quantities from video was also carried out. This helped to filter out non-perceivable variables from the analysis and to establish optimum viewing conditions for each variable. Subsequently, rating scales for each variable of the soccer kick included in the analysis were developed using the literature and observation of the movement (Pilot Study 1). Nonetheless, the scales were adjusted using tests of accuracy and intra-rater reliability. The resulting rating scales were used to construct scoring references. Inter-rater reliability in the use of scoring references was considered acceptable. Stage 8 of the model indicated the actual analysis of the movement of the child, which allows obtaining partial and total scores of mechanical effectiveness. Finally, the model was used to develop scoring references for the analysis of the **overarm throw** and the **standing broad jump**. Analysis of mechanical effectiveness and its pattern of development in a group of school-aged children are the topics of Study 3.

Chapter V – Study 3

A qualitative analysis of the development of mechanical effectiveness in children

Introduction

The previous two studies examined the development of *technical level* in a group of children (Study 1) and presented a model for the qualitative analysis of *mechanical effectiveness* (Study 2). The determination of *technical level* in Study 1 focuses on the main form of the movement and resembles the traditional descriptive analysis of motor skills used for the study of motor development in past research (e.g., McClenaghan, 1976; Bloomfield *et al.,* 1979). Such analysis provides the uninitiated PE teacher or coach with some experience in biomechanical analysis before progressing to the analysis of *mechanical effectiveness,* which is a more comprehensive analysis of the movement of the child that includes all relevant technique and performance variables. The scoring references derived from the model developed in Study 2 were used here in Study 3 to measure **mechanical effectiveness** and to study the **development of mechanical effectiveness** in children. Concomitantly, various issues related to the study of motor development in children were addressed. The review of the literature indicated that little is known about the development of the soccer kick in girls (i.e., Bloomfield *et al.,* 1979 and Elliott *et al.,* 1980 used male children only), longitudinal data on child development is scarce (e.g., Langendorfer and Roberton, 2002), and the relative contribution of specific variables to the performance criterion remains a recurrent research problem (e.g., Hay *et al.*, 1986; Takei, 1992; Greig and Yeadon, 2000). Therefore, the **aims** of Study 3 were: **1-** to establish the mechanical effectiveness of the movements of a group of school-aged children in performing the three motor skills, and **2-** to study gender differences in the development of mechanical effectiveness in children.

Study 3 included: **1-** a **cross-sectional study** of the development of mechanical effectiveness in children, **2-** a **construction of profiles** of mechanical effectiveness, **3-** a **longitudinal study** of the development of mechanical effectiveness in children, and **4-** an **analysis of the relative contribution** of specific mechanical variables to the performance criterion.

Method

The subjects used in this study included the 187 children (cross-sectional study), the 55 children (longitudinal study), and the 31 adults or controls (cross-sectional measures) described in the main body of Study 1. The children were grouped according to gender and then allocated to absolute age (by year) groups as in Study 1. Rating of mechanical effectiveness for the three motor skills was carried out by a rater familiarised with the use of the scoring references. In the **cross-sectional study**, inspection of the data revealed low score-age correlation coefficients (e.g., *speed of approach* in the soccer kick, males; rho = 0.192, df = 104, p = 0.026 (significant)). Consequently, children were allocated to three age groups as in Study 1 (5 & 6, 7 & 8, and 9 to 11 years) and a two-tailed X^2 test (significance level set at $p < 0.05$) for each variable was used to determine the association between mechanical effectiveness and age of the children. The number of children obtaining specific scores on each variable, expressed as a percentage due to the unequal number of children in each age/gender group, was presented graphically using stacked graphs of frequency count, and the mean (± SD) total score of mechanical effectiveness (mean ± SD for all the children in each of the three age groups; see section 2.7.3 in Study 2) was also displayed graphically. The number of adult subjects, expressed as a percentage due to the unequal number of adults performing each motor skill, displaying a 'high level' of mechanical effectiveness, that is obtaining the 'highest score' in specific variables, was calculated and presented graphically. The number, as a percentage, of adult subjects attaining a *total score* of mechanical effectiveness of ≥ 75% mechanical effectiveness (a 'high' total score of mechanical effectiveness) was also included in the graphs.

Subsequently, **profiles** of mechanical effectiveness including all variables were prepared for a visual inspection of general developmental trends. For the profiles, mechanical effectiveness was expressed as a percentage to allow comparisons across variables with an unequal number of measurement categories.

In the **longitudinal study**, changes in the mechanical effectiveness of the children between test 1 and test 2 were assessed using a X^2 test ($p < 0.05$) for each variable, in order to infer developmental change. The time span between tests was as for the longitudinal study of the development of technical level in Study 1 (that is, mean ± SD of 6 ± 3 months).

A Spearman's Rho correlation test for each variable ($p < 0.05$) was used to determine the association between mechanical effectiveness and the range to assess the **relative contribution of specific variables** to the performance criterion. This included assessment of the association between the total score of mechanical effectiveness and the range. All tests and graphical displays above allowed inspecting gender differences in both mechanical effectiveness and its rate of development for the three motor skills.

Results

1. Cross-sectional study of the development of mechanical effectiveness with age in children

1.1 Soccer kick

Table 5.1 shows the results of the X^2 tests, and Figures 5.1 and 5.2 show the mechanical effectiveness of the children for the variables in which the X^2 tests yielded a significant association. The **rate of development** was generally faster in male children (i.e., higher X^2 values). Variables showing a **negligible association** with age of the children included *magnitude of impact forces applied to ball* and *angle of kicking knee*, in males, and *maximum forward trunk flexion* and *maximum hip flexion*, in females. **Early maturation**, that is high mechanical effectiveness at age 5 years, was observed in 14 variables for males and in 9 variables for females. The variables in which both male and female children (across the age group) showed **least effectiveness** included *maximum lateral body inclination* and *velocity of ball release.* Females showed also **low mechanical effectiveness** in the *angle of approach*. Considerable **gender differences** in mechanical effectiveness (males showed higher effectiveness) across the age range were observed for 7 technique variables including: *angle of approach, horizontal abduction of the opposite arm, maximum hip hyperextension, support foot placement, maximum lateral body inclination, horizontal adduction of the opposite arm,* and *maximum forward trunk flexion*; and 1 performance variable, *adduction velocity of the opposite arm.* The mean (± SD) **total score of mechanical effectiveness** for the children in each of the three age groups is shown in Figure 5.3. Figure 5.4 shows that not all **adult subjects**, particularly females, displayed 'high levels' of mechanical effectiveness (that is, the highest score in specific *variables* and a *total score* of ≥ 75% mechanical effectiveness); notice *maximum knee flexion* and *horizontal adduction of the opposite arm* variables and the *total score*.

Table 5.1: Results of the X^2 tests for the cross-sectional study of the development of mechanical effectiveness in the soccer kick with age.

Variable	Males			Females		
	X^2	*df*	Sig.	X^2	*df*	Sig.
Speed of approach	6.41	2	**0.041***	4.65	2	0.098
Angle of approach	15.75	4	**0.003***	10.85	4	**0.028***
Length of last step	2.41	2	0.299	12.61	4	**0.013***
Horizontal abduction of opposite arm, elbow angle & angle of shoulder abduction	10.25	6	0.115	4.08	6	0.666
Maximum knee flexion	9.64	6	0.141	10.50	6	0.105
Maximum hip hyperextension	10.53	4	**0.032***	10.56	4	**0.032***
Support foot placement	4.39	6	0.624	8.12	6	0.230
Maximum backward trunk inclination	0.49	2	0.783	0.99	2	0.608
Maximum lateral body inclination	8.33	2	**0.016***	3.19	2	0.203
Horizontal adduction of opposite arm, elbow angle & angle of shoulder abduction	17.52	6	**0.008***	6.01	6	0.422
Adduction velocity of opposite arm	4.97	4	0.290	3.00	4	0.557
Maximum forward trunk flexion	5.19	4	0.269	0.65	4	0.957
Magnitude of impact forces applied to ball	0.08	2	0.961	5.21	2	0.074
Angle of kicking knee	0.13	2	0.936	2.15	2	0.342
Contact time	5.01	4	0.286	6.20	4	0.184
Velocity of bal release	17.87	2	**0.001***	1.04	2	0.595
Angle of ball release	14.95	8	0.060	16.63	8	**0.034***
Maximum hip flexion	11.67	8	0.167	5.52	8	0.701
Coordination & rhythm	9.37	4	0.052	7.95	4	0.093

*** Significant ($p < 0.05$)**

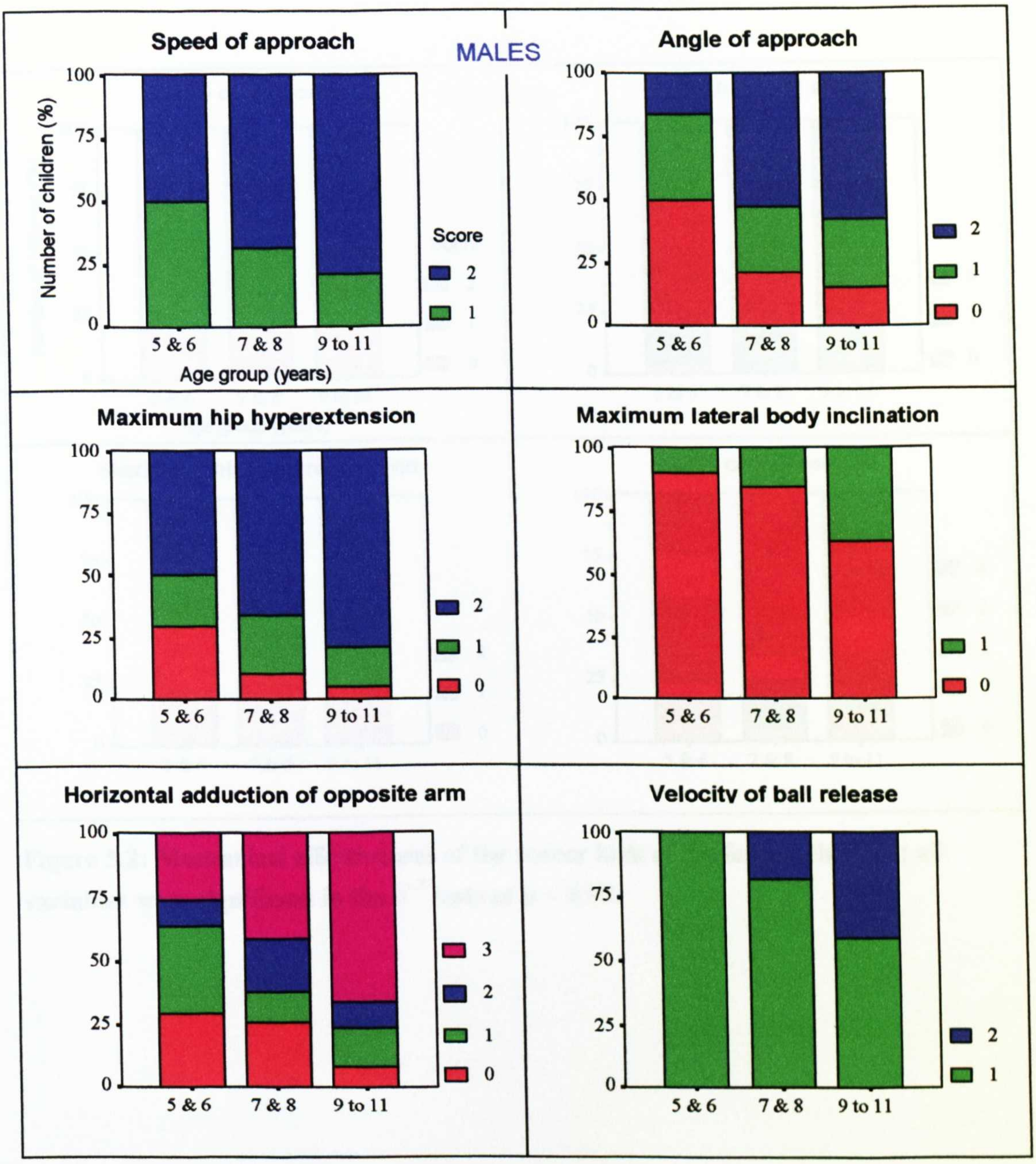


Figure 5.1: Mechanical effectiveness of the soccer kick of the male children; all variables were significant in the X^2 tests at $p < 0.05$.

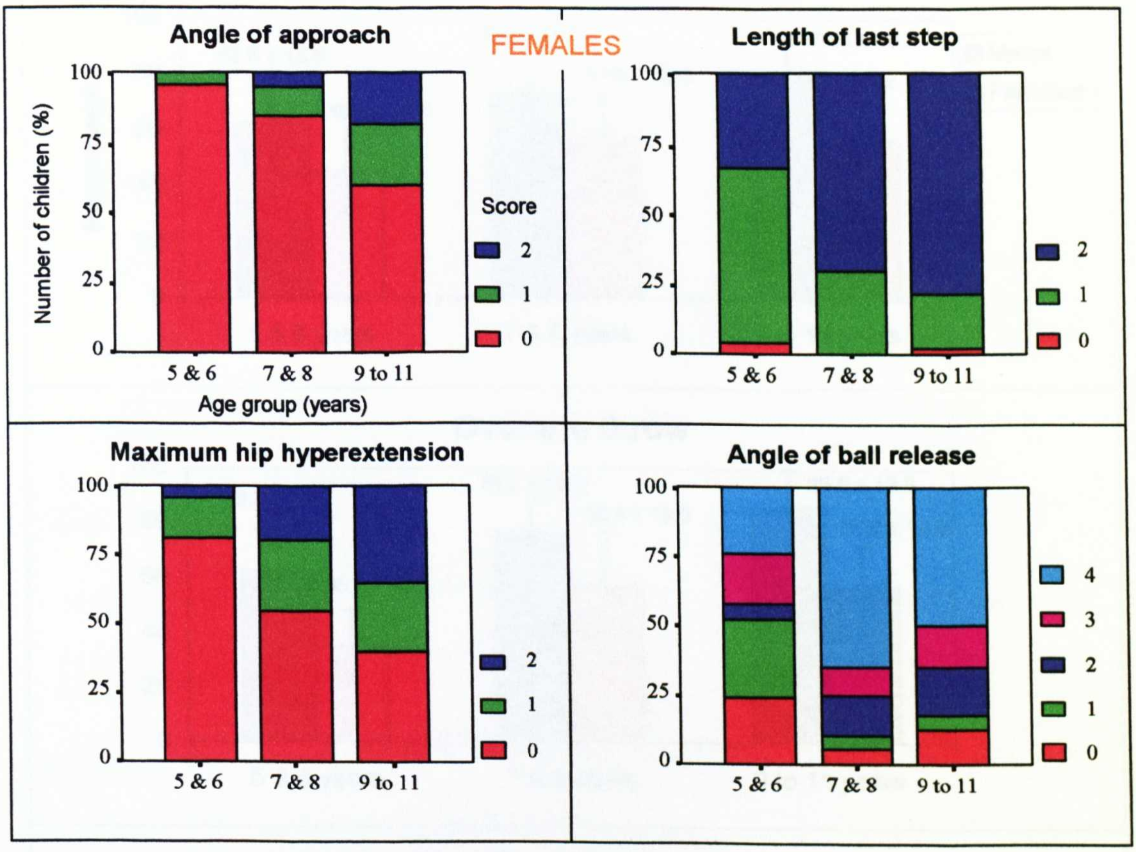


Figure 5.2: Mechanical effectiveness of the soccer kick of the female children; all variables were significant in the X^2 tests at $p < 0.05$.

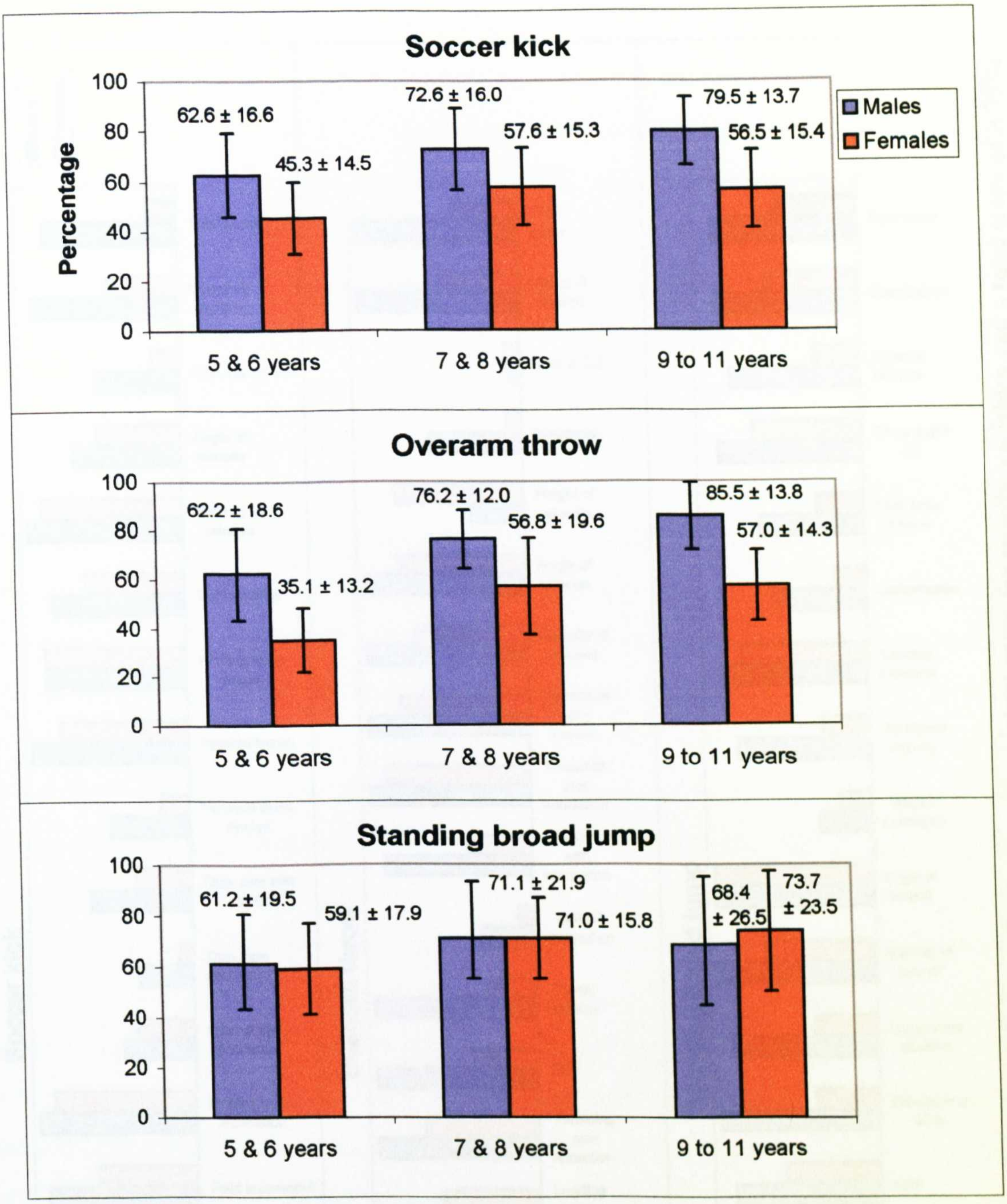


Figure 5.3: Total score of mechanical effectiveness (mean ± SD per age group).

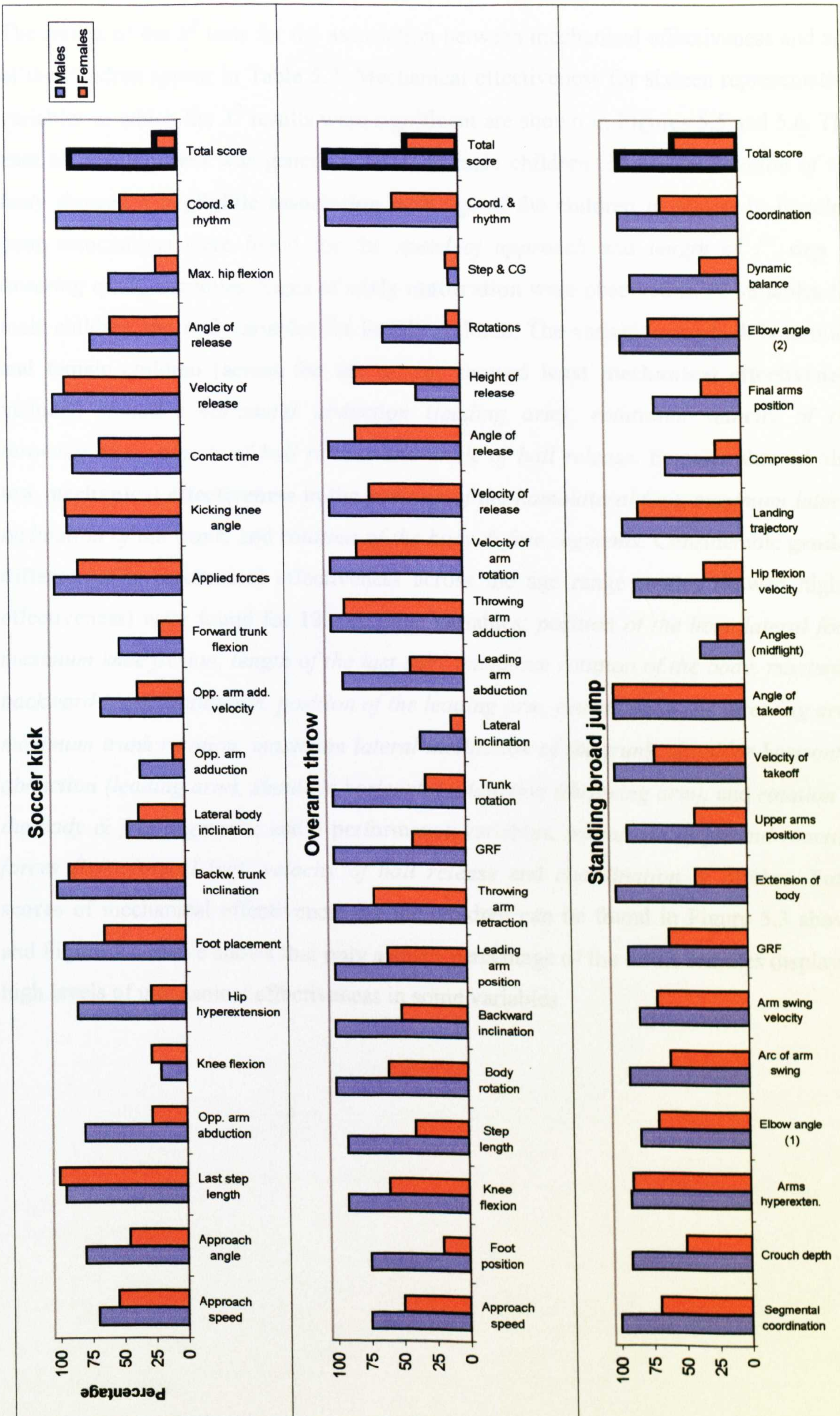


Figure 5.4: Percentage of adult subjects that displayed high mechanical effectiveness (the highest score for specific variables and a total score of ≥ 75% mechanical effectiveness).

1.2 Overarm throw

The results of the X^2 tests for the association between mechanical effectiveness and age of the children appear in Table 5.2. Mechanical effectiveness for sixteen representative variables in which the X^2 results were significant are shown in Figures 5.5 and 5.6. The **rate of development** was generally faster in male children. *Maximum rotation of the body* showed a **negligible association** with age of the children in males. In females, poor associations were found for the *speed of approach* and *length of 1st step & lowering of CG* variables. Signs of **early maturation** were observed in 12 variables for male children and in 2 variables for female children. The variables in which both male and female children (across the age group) showed **least mechanical effectiveness** included *shoulder horizontal abduction (leading arm)*, *rotational velocity of the throwing arm*, *velocity of ball release* and *angle of ball release.* Females showed also **low mechanical effectiveness** in the *position of the homolateral foot, maximum lateral inclination of the trunk,* and *rotation of the body & free segments.* Considerable **gender differences** in mechanical effectiveness across the age range (males showed higher effectiveness) were found for 12 technique variables: *position of the homolateral foot, maximum knee flexion, length of the last step, maximum rotation of the body, maximum backward trunk inclination, position of the leading arm, retraction of the throwing arm, maximum trunk rotation, maximum lateral inclination of the trunk, shoulder horizontal abduction (leading arm), shoulder horizontal adduction (throwing arm),* and *rotation of the body & free segments*; and 3 performance variables, *magnitude of ground reaction forces (homolateral leg), velocity of ball release* and *coordination & rhythm.* **Total scores** of mechanical effectiveness for the children can be found in Figure 5.3 above, and Figure 5.4 above shows that only a small percentage of the **adult females** displayed high levels of mechanical effectiveness in some variables.

Table 5.2: Results of the X^2 tests for the cross-sectional study of the development of mechanical effectiveness in the overarm throw with age.

Variable	Males			Females		
	X^2	*df*	Sig.	X^2	*df*	Sig.
Speed of approach	12.44	4	**0.014***	3.67	4	0.453
Position of homolateral foot	13.30	4	**0.010***	8.80	4	0.066
Maximum knee flexion	10.79	4	**0.029***	16.19	4	**0.003***
Length of the last step	26.02	6	**0.001***	15.58	6	**0.016***
Maximum rotation of the body	6.55	6	0.364	16.00	6	**0.014***
Maximum backward trunk inclination	29.32	4	**0.001***	8.72	4	0.069
Position of the leading arm	26.16	6	**0.001***	13.32	6	**0.038***
Throwing arm retraction, shoulder abduction & elbow angle	13.83	4	**0.008***	15.19	4	**0.004***
Ground reaction forces	7.09	2	**0.029***	2.57	2	0.277
Maximum trunk rotation	22.04	6	**0.001***	16.42	6	**0.012***
Maximum lateral inclination of the trunk	10.30	4	**0.036***	13.49	4	**0.009***
Shoulder horizontal abduction & elbow flexion (leading arm)	22.22	6	**0.001***	5.64	4	0.228
Shoulder horizontal adduction (throwing arm)	8.90	6	0.180	21.78	6	**0.001***
Rotational velocity of the throwing arm	3.41	2	0.182	11.91	4	**0.018***
Velocity of ball release	16.71	6	**0.010***	18.81	4	**0.001***
Angle of ball release	18.40	8	**0.018***	18.80	6	**0.005***
Height of ball release	10.99	6	0.089	8.46	4	0.076
Rotation of the body & free segments	19.33	6	**0.004***	16.23	6	**0.013***
Length of 1st step & lowering of the CG	8.17	6	0.226	5.31	6	0.505
Coordination & rhythm	26.13	4	**0.001***	25.90	4	**0.001***

*** Significant ($p < 0.05$)**

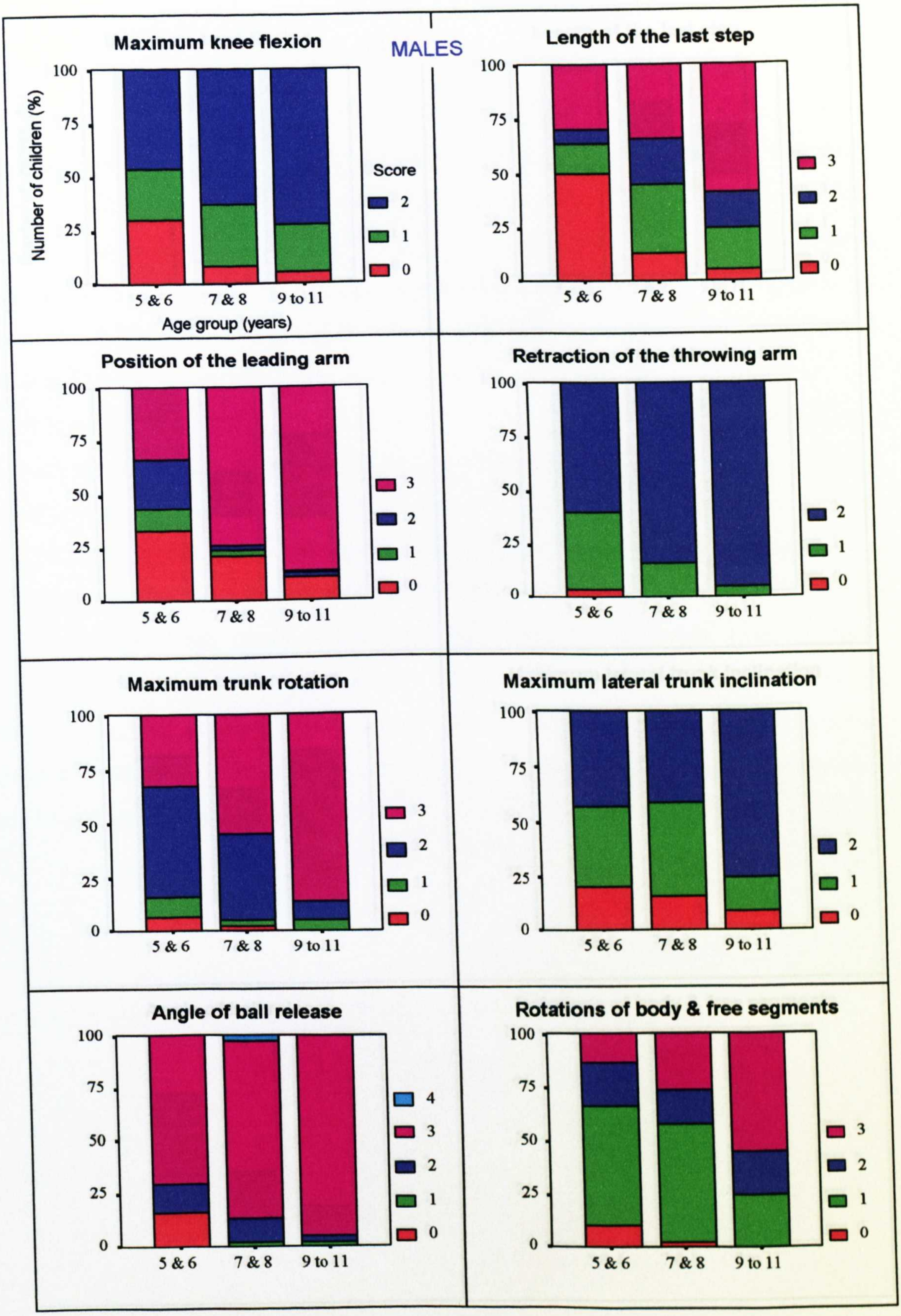


Figure 5.5: Mechanical effectiveness of the overarm throw of the male children; all variables were significant in the X^2 tests at $p < 0.05$.

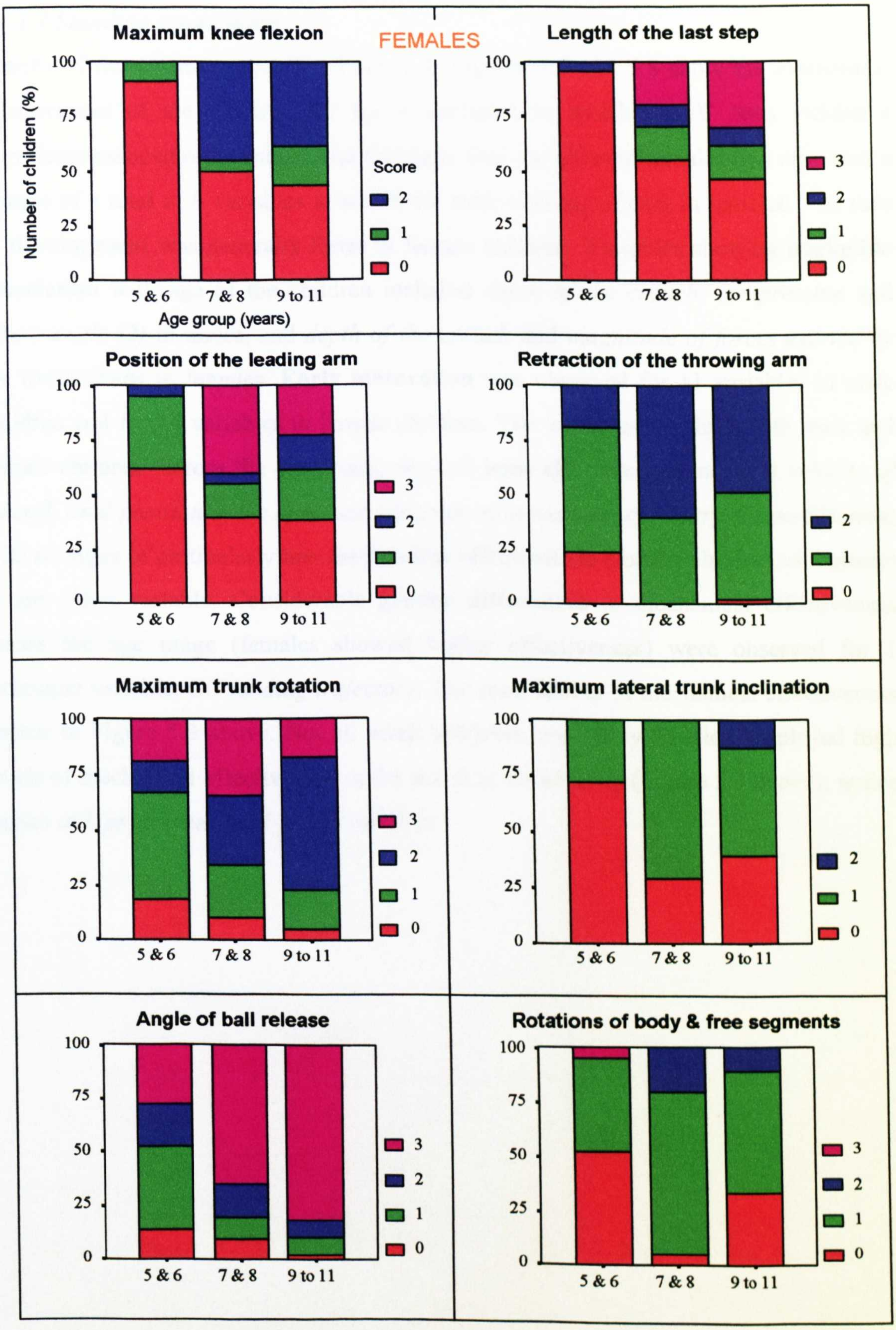


Figure 5.6: Mechanical effectiveness of the overarm throw of the female children; all variables were significant in the X^2 tests at $p < 0.05$.

1.3 Standing broad jump

Results of the X^2 tests appear in Table 5.3. Figures 5.7 and 5.8 show the mechanical effectiveness of the children for the 4 variables in which the X^2 tests yielded a significant association in males, and the same four variables in females that represent a sample of a total of 8 variables in which the tests were significant in females. The **rate of development** was generally faster in female children. Variables showing **negligible association** with age of the children included *depth of the crouch, compression* and *elbow angle (2)* in males, and *depth of the crouch* and *magnitude of forces exerted by the lower limbs* in females. **Early maturation** was observed for 11 variables in male children and for 14 variables in female children. The variables in which both male and female children (across the age group) showed **least effectiveness** included *velocity of takeoff, final position of the arms* and *direction of movement, symmetry & coordination*; with no signs of particularly **low mechanical effectiveness** (for the children as a group) in any other variable. Considerable **gender differences** in mechanical effectiveness across the age range (females showed higher effectiveness) were observed for 1 technique variable, *CG landing trajectory*. The **total scores** of mechanical effectiveness appear in Figure 5.3 above. Not all **adult subjects**, especially females, displayed high levels of mechanical effectiveness in the standing broad jump (Figure 5.4 above); notice *angles of hips & knees (mid-flight)* variable.

Table 5.3: Results of the X^2 tests for the cross-sectional study of the development of mechanical effectiveness in the standing broad jump with age.

Variable	Males			Females		
	X^2	*df*	Sig.	X^2	*df*	Sig.
Segmental movement coordination	12.41	4	**0.015***	16.26	4	**0.003***
Depth of the crouch	0.38	2	0.826	1.92	4	0.750
Maximum arms hyperextension	18.33	8	**0.019***	18.99	8	**0.015***
Elbow angle (1)	15.16	8	0.056	7.02	8	0.534
Arc of arm swing & elbow angle	19.39	8	**0.013***	20.52	8	**0.009***
Velocity of arm swing	3.80	4	0.434	7.94	4	0.094
Magnitude of forces exerted by the lower limbs	3.85	4	0.427	2.20	4	0.699
Extension of body segments	7.62	6	0.267	24.69	6	**0.001***
Position of the upper arms	12.57	8	0.127	9.11	8	0.333
Velocity of takeoff	9.23	6	0.161	5.97	4	0.202
Angle of takeoff (CG)	0.59	2	0.743	0.93	2	0.628
Angles of knees & hips (mid flight)	5.56	6	0.474	13.21	6	**0.040***
Velocity of hip flexion	1.14	2	0.565	2.32	4	0.678
CG landing trajectory	5.87	4	0.209	5.00	4	0.287
Compression	2.81	6	0.832	17.23	6	**0.008***
Final position of the arms	3.52	6	0.742	5.94	6	0.431
Elbow angle (2)	2.82	6	0.831	3.05	4	0.549
Dynamic balance	2.21	4	0.697	15.16	4	**0.004***
Direction of movement, symmetry & coordination	14.11	4	**0.007***	17.78	4	**0.001***

*** Significant ($p < 0.05$)**

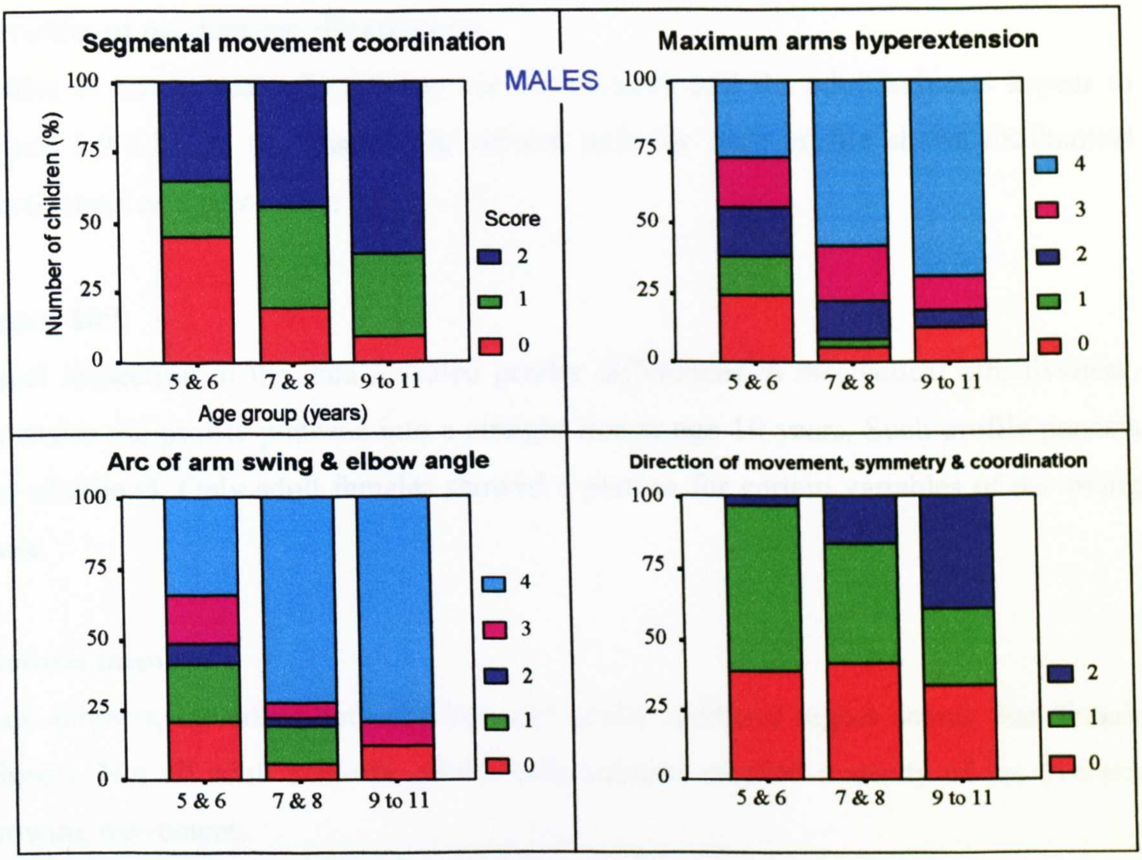


Figure 5.7: Mechanical effectiveness of the standing broad jump of the male children; all variables were significant in the X^2 tests at p < 0.05.

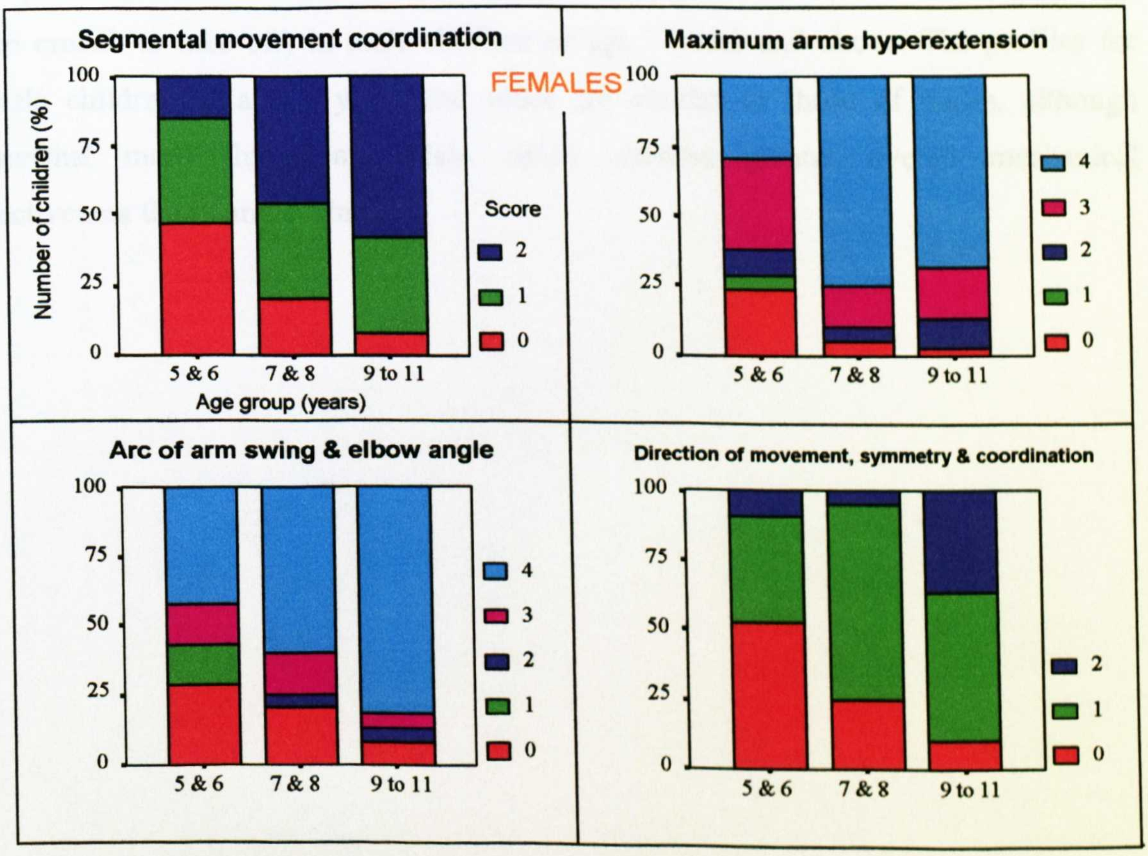


Figure 5.8: Mechanical effectiveness of the standing broad jump of the female children; all variables were significant in the X^2 tests at p < 0.05.

2. Profiles of mechanical effectiveness

Profiles of mechanical effectiveness for the children and the adult subjects appear in Figures 5.9-5.11. In the graphs, the vertical axis for each profile shows mechanical effectiveness as a percentage.

Soccer kick

Visual inspection of the data revealed gender differences in mechanical effectiveness. For males the profile plateaus into a straight line at age 10 years. Such profile persists into adulthood. Only adult females showed a plateau for certain variables of the swing phase.

Overarm throw

Male subjects, including both children and adults, obtained higher scores than female subjects. Not all adult subjects, particularly women, reached maturity of the overarm throwing movement.

Standing broad jump

The profile plateaus in the first half of the throwing movement (that is, all variables from crouch to take off) in male children of age 7 years and above. The profiles for female children of age 7 years and older are similar to those of males, although somewhat more fluctuating. Male adults showed greater overall mechanical effectiveness than female adults.

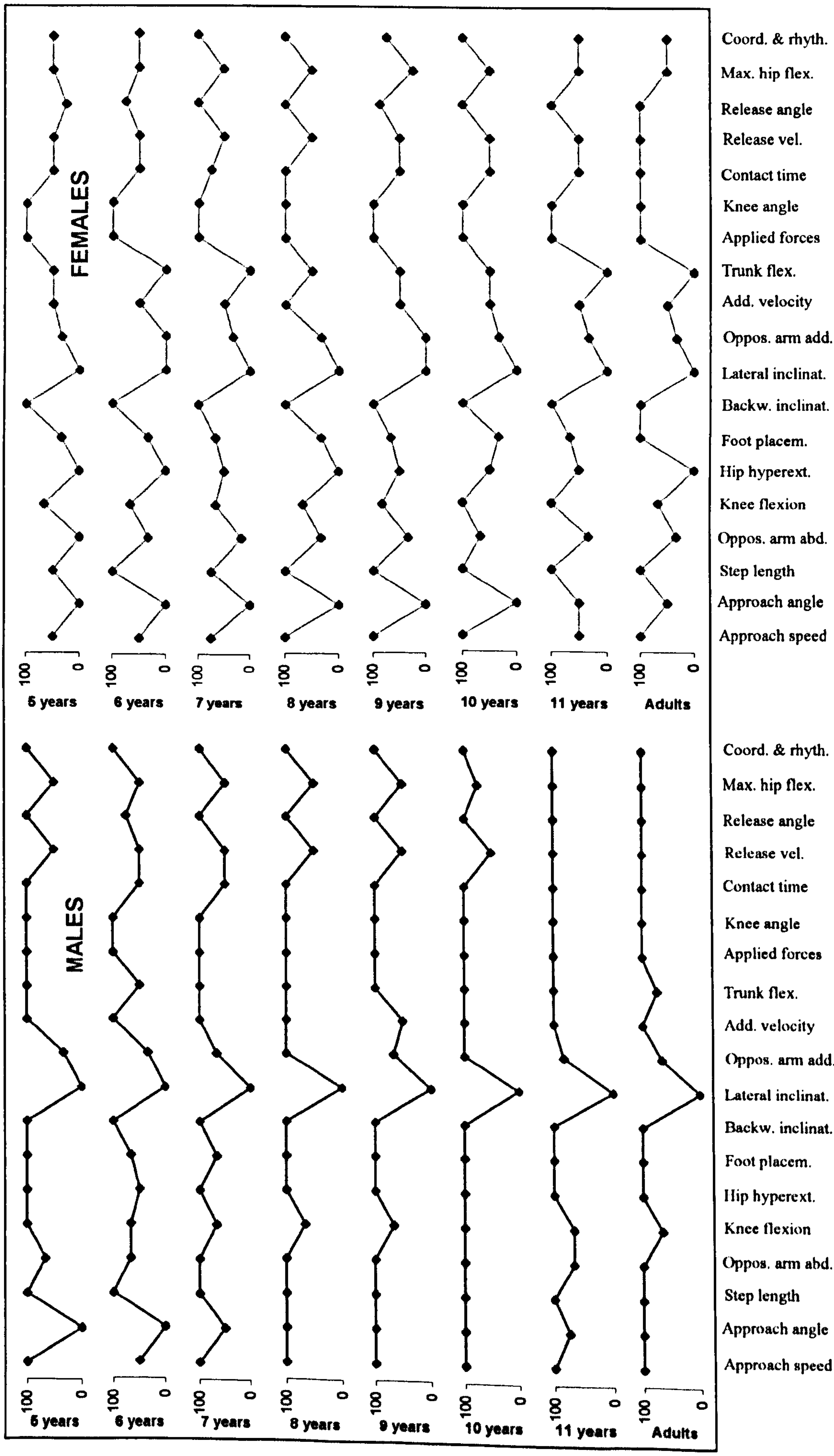


Figure 5.9: Profiles of mechanical effectiveness in the soccer kick.

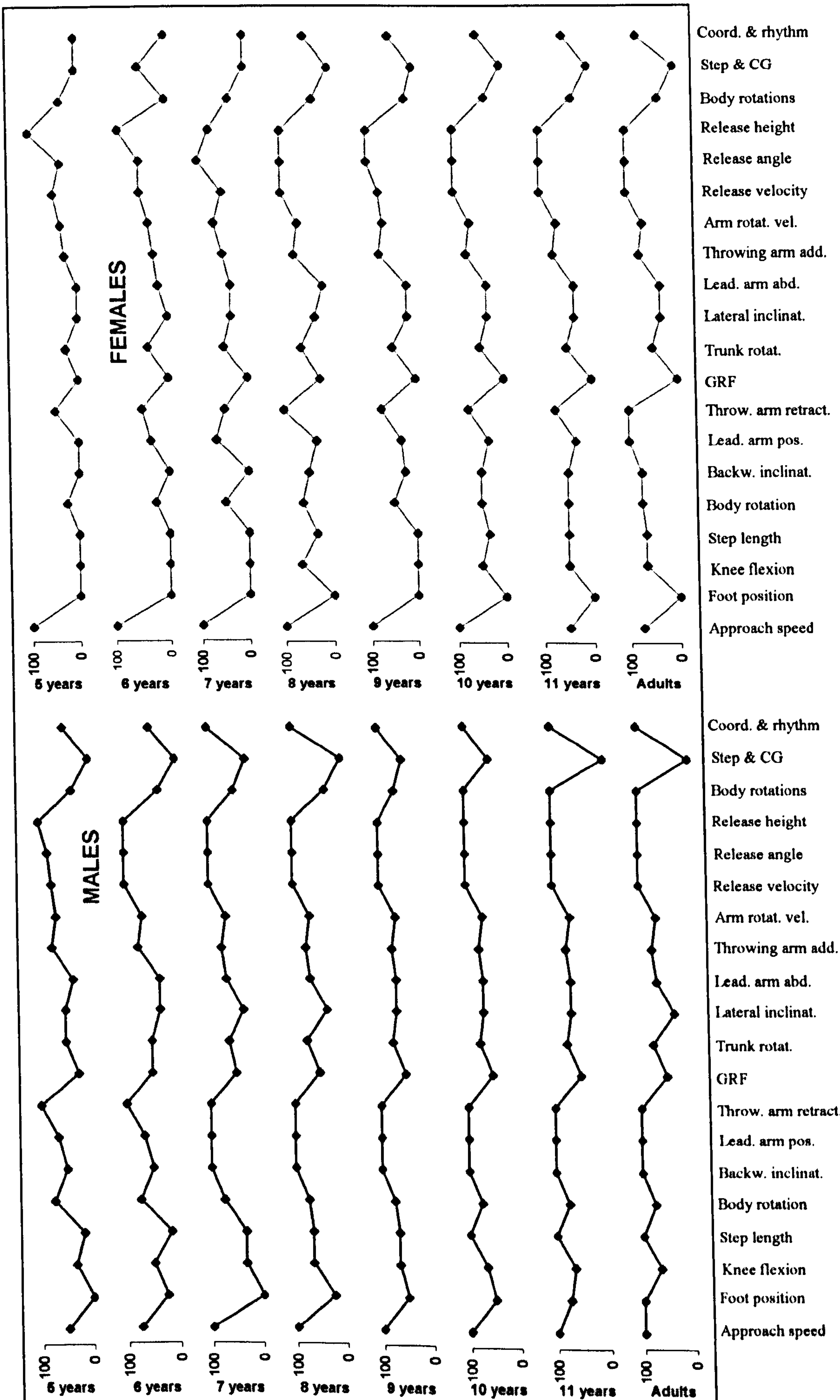


Figure 5.10: Profiles of mechanical effectiveness in the overarm throw.

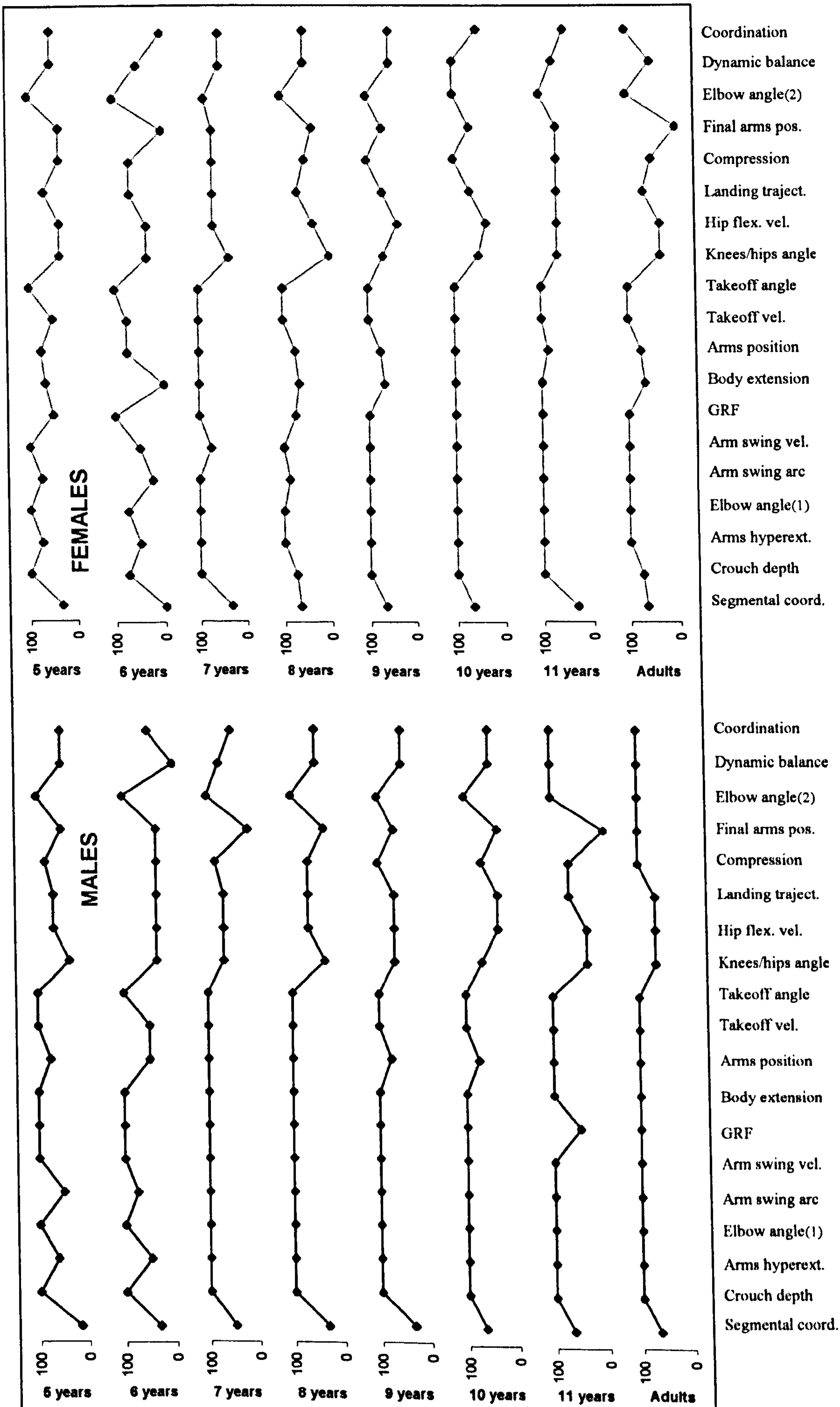


Figure 5.11: Profiles of mechanical effectiveness in the standing broad jump.

3. Longitudinal study of the development of mechanical effectiveness

The results of the X^2 tests were non-significant for most variables, however the results showed positive development in a greater number of variables for male children (Tables 5.4-5.6). In the **soccer kick**, male children showed increased mechanical effectiveness in 7 variables, and female children in 6 variables. In the **overarm throw**, males showed increased mechanical effectiveness in 17 variables, and females in 1 variable. In the **standing broad jump**, increase was found in 8 variables for males and in 7 variables for females. Decreased mechanical effectiveness was more prominent in female children in the **soccer kick** and the **overarm throw**, while developmental changes were better matched between males and females in the **jump**. The variable showing the largest increase for males and females, respectively, was: **soccer kick** – *maximum knee flexion* and *magnitude of impact forces applied to ball*; **throwing** – *rotation of the body & free segments* and *rotational velocity of the throwing arm*; **jump** – *velocity of arm swing* and *arc of arm swing & elbow angle*. Representative variables showing an increase, a decrease and negligible overall change in the mechanical effectiveness of the children, as a group, appear in Figures 5.12-5.14.

Table 5.4: Results of the X^2 tests for the longitudinal study of the development of mechanical effectiveness in the soccer kick with age.

Variable	Males			Females		
	X^2	*df*	Sig.	X^2	*df*	Sig.
Speed of approach	0.08 (~)	1	0.783 (1.000)**	0.68 (-)	1	0.409 (0.583)**
Angle of approach	2.39 (-)	2	0.302	1.36 (~)	2	0.508
Length of last step	0.00 (~)	1	1.000 (1.000)**	0.70 (+)	1	0.402 (0.577)**
Horizontal abduction of opposite arm, elbow angle & angle of shoulder abduction	7.04 (+)	3	0.071	2.18 (-)	3	0.536
Maximum knee flexion	0.00 (~)	2	1.000	1.86 (+)	2	0.394
Maximum hip hyperextension	0.46 (~)	2	0.797	3.23 (+)	2	0.199
Support foot placement	1.80 (-)	3	0.614	3.98 (-)	3	0.264
Maximum backward trunk inclination	1.47 (-)	1	2.225 (0.422)**	1.03 (-)	1	0.311 (0.501)**
Maximum lateral body inclination	0.49 (+)	1	0.485 (0.729)**	1.02 (+)	1	0.313 (1.000)**
Horizontal adduction of opposite arm, elbow angle & angle of shoulder abduction	1.64 (+)	3	0.651	1.93 (-)	3	0.588
Adduction velocity of opposite arm	3.52 (+)	2	0.172	0.56 (-)	2	0.757
Maximum forward trunk flexion	0.42 (+)	2	0.809	8.63 (-)	2	**0.013***
Magnitude of impact forces applied to ball	1.08 (-)	1	0.299 (0.611)**	1.33 (-)	1	0.248 (0.387)**
Angle of kicking knee	7.79 (-)	1	**0.005* (0.012)****	0.00 (~)	1	1.000 (1.000)**
Contact time	0.51 (-)	2	0.776	4.80 (-)	2	0.091
Velocity of bal release	1.02 (~)	1	0.313 (1.000)**	1.02 (-)	1	0.313 (1.000)**
Angle of ball release	1.74 (+)	4	0.784	1.62 (+)	4	0.806
Maximum hip flexion	3.55 (+)	4	0.470	5.11 (-)	4	0.276
Coordination & rhythm	0.56 (~)	2	0.754	1.23 (+)	2	0.547

* Significant ($p < 0.05$)

** Fisher's exact significance (two-tailed; significant at $p < 0.05$ in bold)

(+) = increase; (-) = decrease; (~) = negligible overall change in the children, as a group.

Table 5.5: Results of the X^2 tests for the longitudinal study of the development of mechanical effectiveness in the overarm throw with age.

Variable	Males			Females		
	X^2	*df*	Sig.	X^2	*df*	Sig.
Speed of approach	0.78 (+)	2	0.676	2.30 (-)	1	0.130 (0.166)**
Position of homolateral foot	0.54 (+)	2	0.762	4.84 (-)	2	0.089
Maximum knee flexion	1.60 (+)	2	0.449	5.95 (-)	2	0.051
Length of the last step	4.64 (+)	3	0.200	1.71 (+)	3	0.634
Maximum rotation of the body	1.59 (+)	3	0.663	8.45 (~)	3	**0.038***
Maximum backward trunk inclination	0.96 (+)	2	0.619	5.37 (-)	2	0.068
Position of the leading arm	2.43 (+)	3	0.488	6.11 (-)	3	0.106
Retraction of the throwing arm, shoulder abduction & elbow angle	1.28 (~)	2	0.528	9.26 (-)	2	**0.010***
Ground reaction forces	0.33 (+)	1	0.564 (0.773)**	11.82 (-)	2	**0.003***
Maximum trunk rotation	4.87 (+)	3	0.182	8.25 (-)	3	**0.041***
Maximum lateral inclination of the trunk	2.35 (+)	2	0.308	8.27 (-)	2	**0.016***
Shoulder horizontal abduction & elbow flexion (leading arm)	3.87 (+)	2	0.145	4.56 (-)	2	0.102
Shoulder horizontal adduction (throwing arm)	6.97 (-)	3	0.073	24.14 (-)	3	**0.001***
Rotational velocity of the throwing arm	1.61 (~)	2	0.447	2.24 (-)	2	0.326
Velocity of ball release	1.03 (+)	2	0.599	4.24 (-)	2	0.120
Angle of ball release	1.02 (+)	3	0.796	6.27 (-)	3	0.099
Height of ball release	2.21 (+)	3	0.529	0.98 (~)	2	0.612
Rotation of the body & free segments	5.20 (+)	3	0.158	4.49 (-)	3	0.213
Length of 1st step & lowering of the CG	7.87 (+)	3	**0.049***	1.22 (~)	3	0.749
Coordination & rhythm	1.22 (+)	2	0.543	4.79 (-)	2	0.091

*** Significant ($p < 0.05$)**

**** Fisher's exact significance (two-tailed)**

(+) = increase; (-) = decrease; (~) = negligible overall change in the children, as a group.

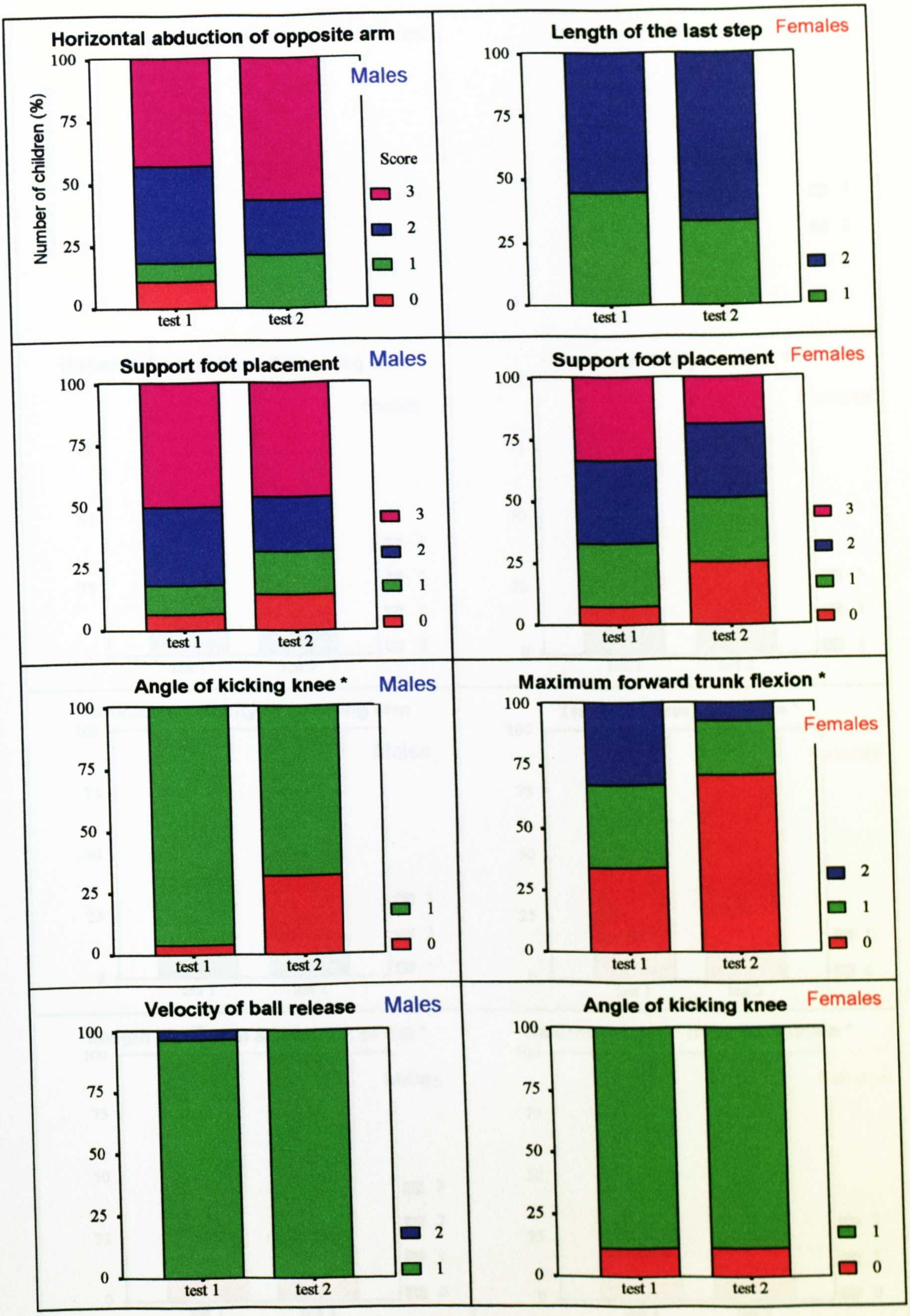
Table 5.6: Results of the X^2 tests for the longitudinal study of the development of mechanical effectiveness in the standing broad jump with age.

Variable	Males			Females		
	X^2	df	Sig.	X^2	df	Sig.
Segmental movement coordination	1.42 (+)	2	0.492	0.33 (+)	2	0.850
Depth of the crouch	2.44 (+)	1	0.118 (0.240)**	0.92 (~)	2	0.630
Maximum arms hyperextension	2.33 (+)	4	0.675	5.65 (+)	4	0.227
Elbow angle (1)	5.80 (+)	4	0.215	4.35 (+)	4	0.361
Arc of arm swing & elbow angle	2.67 (+)	4	0.615	1.48 (~)	4	0.830
Velocity of arm swing	29.94 (-)	2	**0.001***	35.73 (-)	2	**0.001***
Magnitude of forces exerted by the lower limbs	29.26 (-)	2	**0.001***	30.53 (-)	2	**0.001***
Extension of body segments	0.18 (~)	3	0.982	2.59 (+)	3	0.459
Position of the upper arms	3.07 (~)	4	0.546	2.22 (+)	4	0.696
Velocity of takeoff	4.92 (-)	3	0.178	5.62 (-)	2	0.060
Angle of takeoff (CG)	40.18 (+)	2	**0.001***	38.28 (+)	2	**0.001***
Angles of knees & hips (mid flight)	9.69 (+)	3	**0.021***	5.24 (+)	3	0.155
Velocity of hip flexion	23.13 (-)	2	**0.001***	22.99 (-)	2	**0.001***
CG landing trajectory	1.57 (-)	2	0.456	3.02 (-)	2	0.221
Compression	2.34 (+)	3	0.504	13.40 (-)	3	**0.004***
Final position of the arms	3.58 (-)	3	0.311	13.84 (-)	3	**0.003***
Elbow angle (2)	1.11 (-)	3	0.774	0.28 (~)	2	0.868
Dynamic balance	2.73 (-)	2	0.256	3.46 (-)	2	0.177
Direction of movement, symmetry & coordination	0.99 (-)	2	0.609	0.27 (~)	2	0.874

*** Significant ($p < 0.05$)**

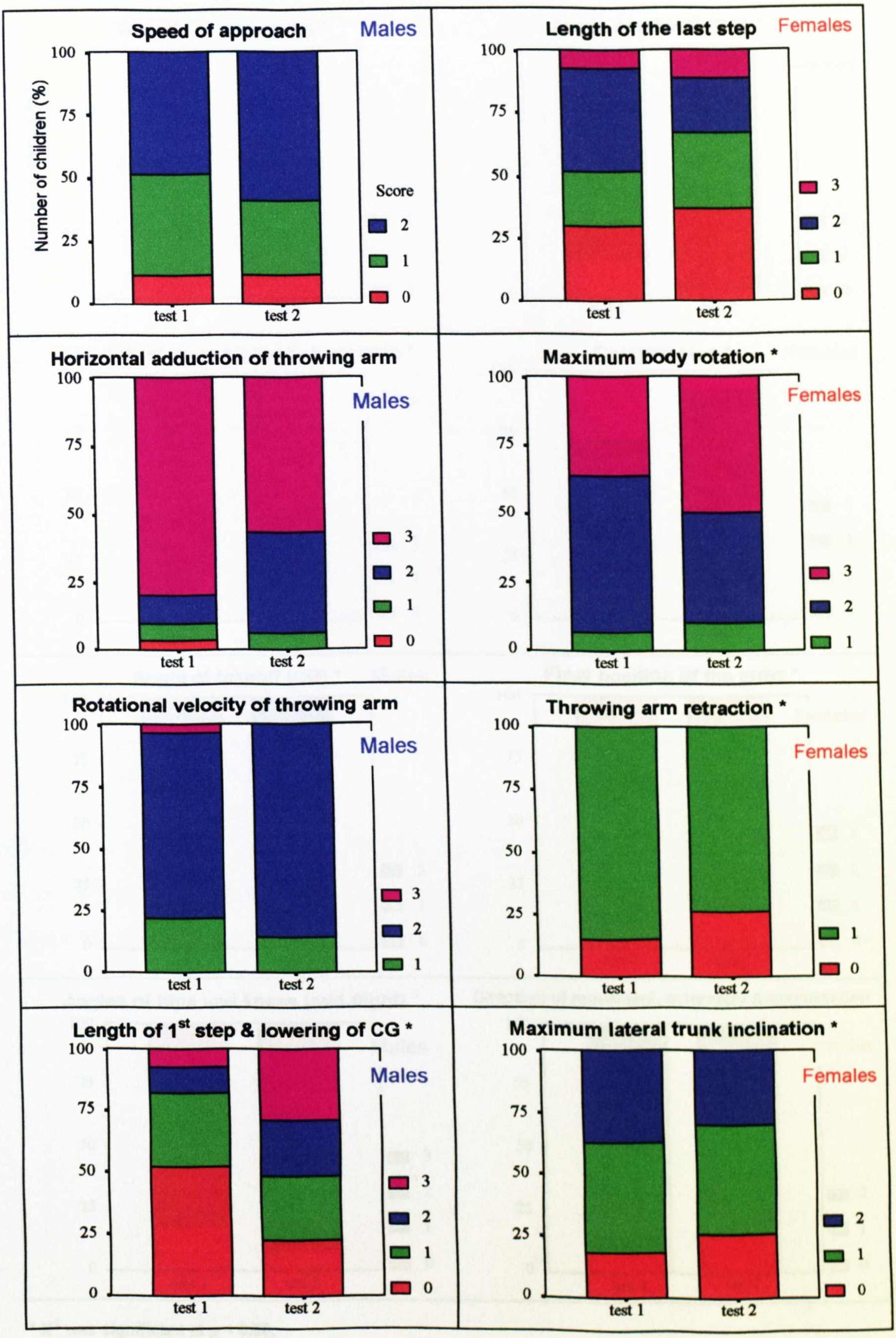
**** Fisher's exact significance in brackets (two-tailed)**

(+) = increase; (-) = decrease; (~) = negligible overall change in the children, as a group.



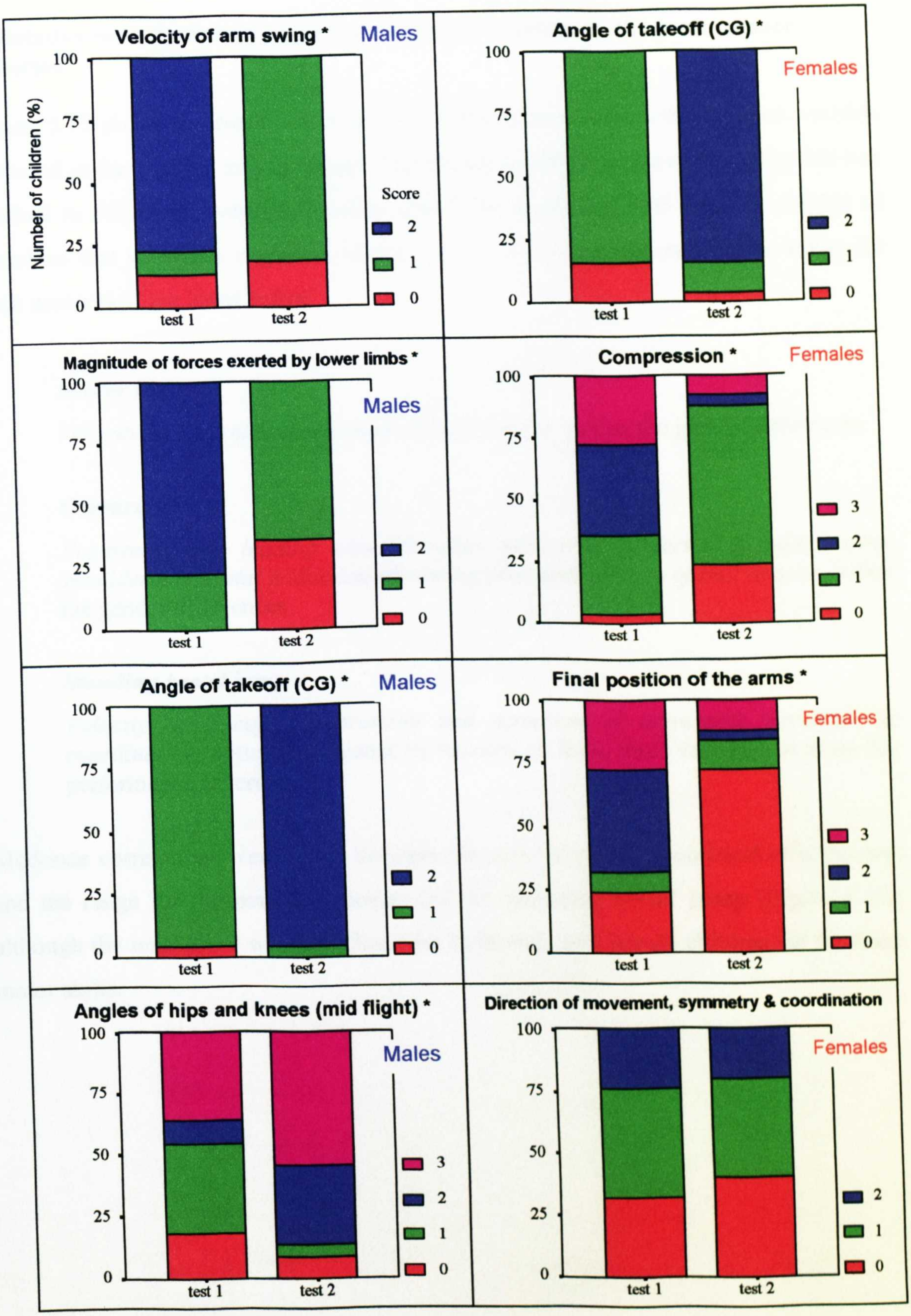
* X^2 was significant at $p < 0.05$.

Figure 5.12: Longitudinal change in the mechanical effectiveness of the soccer kick of the children.



* X^2 was significant at $p < 0.05$.

Figure 5.13: Longitudinal change in the mechanical effectiveness of the overarm throw of the children.



* X^2 was significant at $p < 0.05$.

Figure 5.14: Longitudinal change in the mechanical effectiveness of the standing broad jump of the children.

4. Relative contribution of specific mechanical variables to the performance criterion

Figure 5.15 shows the correlations between mechanical effectiveness for each variable included in the analysis and the range. Correlation coefficients above the horizontal line marked in the graphs were statistically significant at the $p < 0.05$ level. A number of variables that showed a moderate-to-high (*rho* > 0.50) association with the range for each motor skill are listed below.

Soccer kick

Velocity of ball release and *angle of ball release*, notice the gender differences.

Overarm throw

Position of the leading arm, *shoulder horizontal abduction* (*leading arm)*, *shoulder horizontal adduction* (*throwing arm)* and *velocity of ball release*, notice the gender differences.

Standing broad jump

Velocity of takeoff, compression and *direction of movement, symmetry & coordination,* notice the reliance of females on these three variables to attain the performance criterion.

Moderate correlations were found between the *total score* of mechanical effectiveness and the range for the **overarm throw** and the **standing broad jump** (Figure 5.15); although the *total score* was significant for both male and female children for the three motor skills.

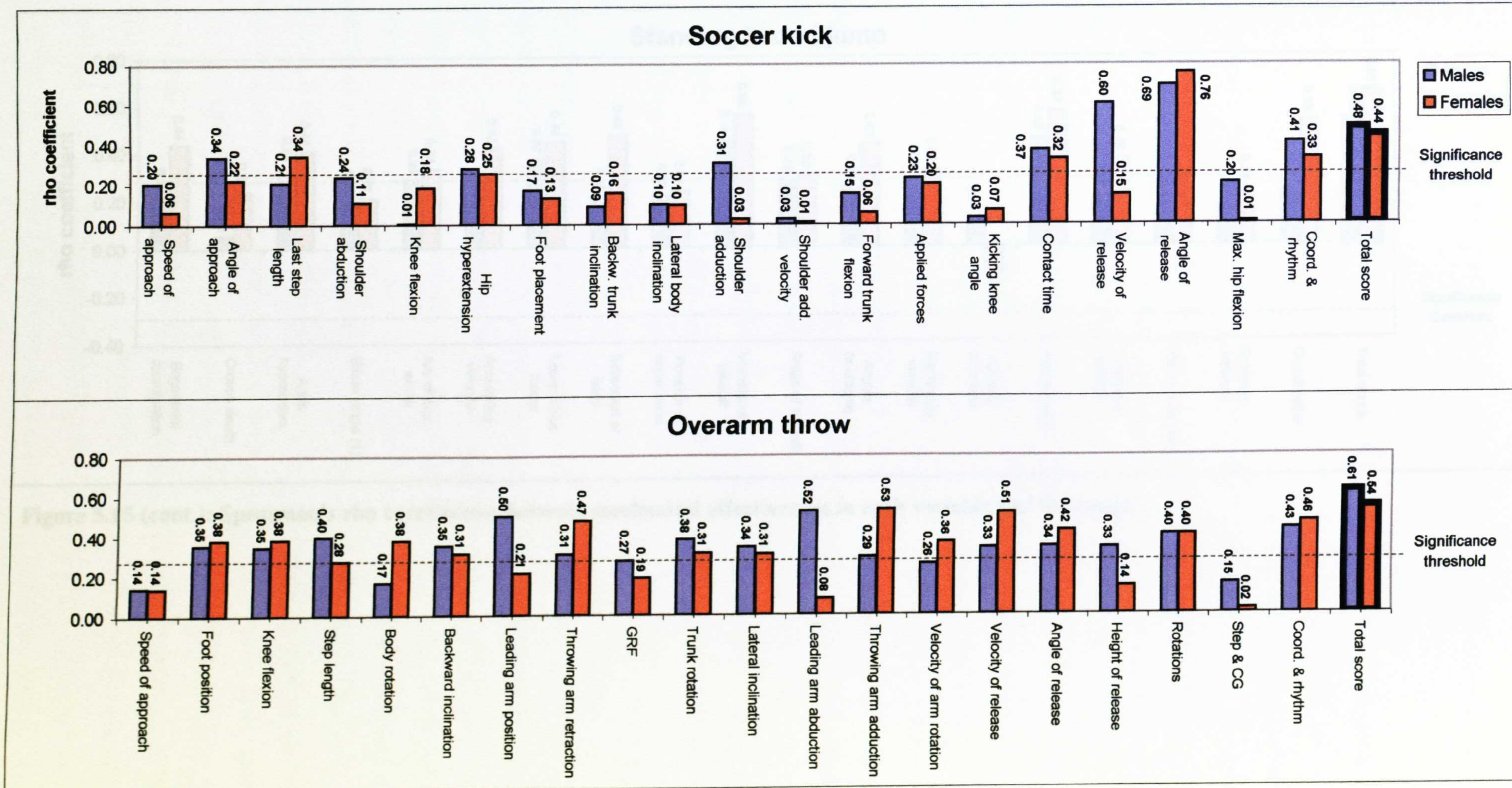


Figure 5.15: Spearman's rho correlations between mechanical effectiveness in each variable and the range.

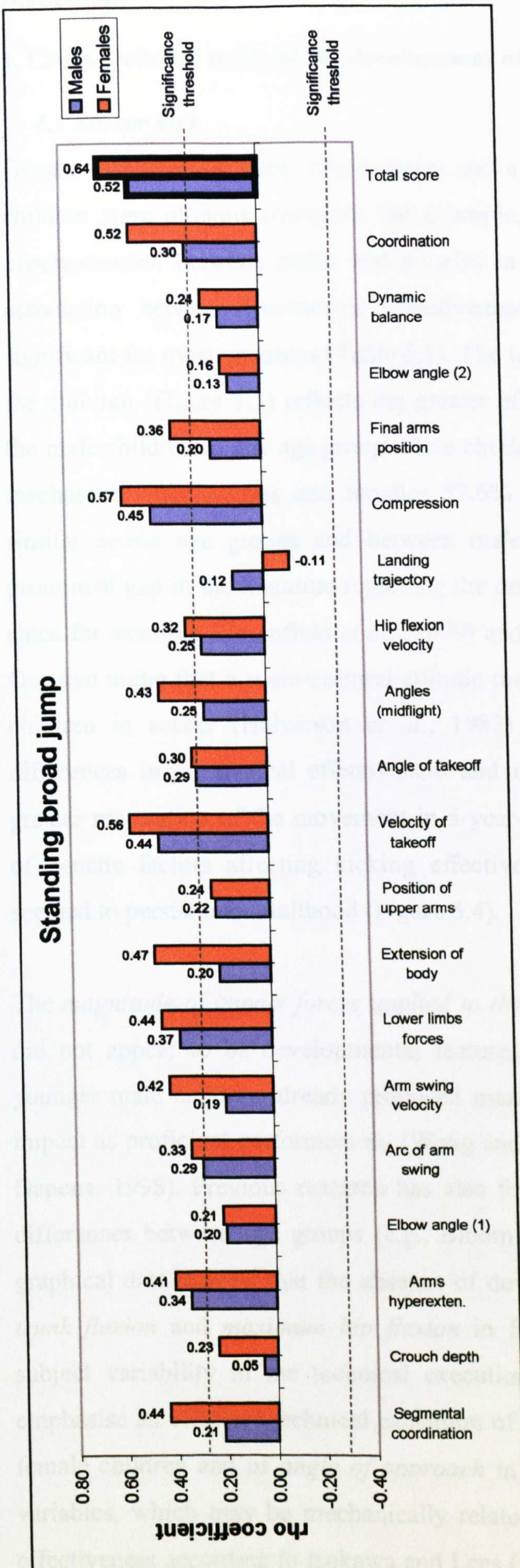


Figure 5.15 (cont.): Spearman's rho correlations between mechanical effectiveness in each variable and the range.

Discussion

1. Cross-sectional study of the development of mechanical effectiveness

1.1 Soccer kick

Greater overall mechanical effectiveness and a faster rate of development in the male children were obvious (compare, for example, *angle of approach* and *maximum hip hyperextension* between males and females in Figures 5.1 and 5.2), even though the association between mechanical effectiveness and age of the children was non-significant for most variables (Table 5.1). The total score of mechanical effectiveness of the children (Figure 5.3) reflects the greater effectiveness of the kicking movement of the male children in any age group. Male children reached 79.5% (9 to 11 years group) mechanical effectiveness and females 57.6% (7 & 8-years group). SD values were similar across age groups and between males and females. Such findings cover a prominent gap in the literature regarding the development of the soccer kick in females, since for example Bloomfield *et al.* (1979) and Elliott *et al.* (1980) studied only males. One can argue that a socio-cultural attitude that promotes greater participation of male children in soccer (Halverson *et al.*, 1982) may have impinged upon the gender differences in mechanical effectiveness and in development observed. However, the greater maturation of the movement in 5-year-old male children suggests the presence of genetic factors affecting kicking effectiveness. The gender differences observed seemed to persist into adulthood (Figure 5.4).

The *magnitude of impact forces applied to the ball* and *angle of kicking knee* variables did not appear to be developmental features of the soccer kick in males, since the younger male children already produced maximum relative force and knee flexion at impact as proficient performers do (Wang and Wiese-Bjornstal, 1994 and Levanon and Dapena, 1998). Previous research has also found variables that showed no significant differences between age groups (e.g., Bloomfield *et al.*, 1979; Yan *et al.*, 2000). The graphical data suggest that the absence of developmental change in *maximum forward trunk flexion* and *maximum hip flexion* in females may have been caused by inter-subject variability in the technical execution of the kick. The coach may need to emphasise an effective technical execution of *lateral body inclination* in both male and female children and of *angle of approach* in female children from an early age (both variables, which may be mechanically related, are significant contributors to kicking effectiveness according to Isokawa and Lees (1988), Wang and Wiese-Bjornstal (1994), Wang and Griffin (1997), Barfield (1998) and Lees (1999a)). Despite the increase in the mean total score of kicking effectiveness with age, **experimental hypothesis** H_6 – There is a significant association between mechanical effectiveness and age of the children (cross-sectional study) – was rejected with regard to the **soccer kick** on the basis that most variables (e.g., 13 out of 19 variables in males; Table 5.1) did not show a significant association.

1.2 Overarm throw

Gender differences in both mechanical effectiveness and its rate of development were found in the soccer kick; however such gender differences were more prominent in the overarm throw (Table 5.2 and Figures 5.5 and 5.6). Lack of movement maturation in females was also obvious in the adults (Figure 5.4). Such findings were predictable (Atwater, 1970; Leme and Shambes, 1978; Nelson *et al.*, 1991; to list a few authors). The negligible associations between mechanical effectiveness and age of the male children for the *maximum rotation of the body* were due to the younger children using large body rotation in the back swing phase. Similarly, *speed of approach* was relatively high in females of a young age, and the lack of development with age in the *length of the 1st step & lowering of the CG* variable in females occurred due to many of the older children showing a poor follow through action. Early maturation in *speed of approach* and *height of ball release* provided female children with proficiency in two important mechanical factors that determine effective throwing (Atwater, 1977, 1982) from an early age. However, the coach may need to pay special attention to the *shoulder horizontal abduction (leading arm)*, *rotational velocity of the throwing arm* and *angle of ball release* in both male and female children. Other aspects to emphasize in female children include *position of the homolateral foot*, *maximum lateral inclination of the trunk*, and *rotation of the body & free segments*. It is interesting to note that Halverson *et al.* (1982) proposed that girls in seventh grade lagged 5-6 years behind boys in throwing development. This delay was mainly attributed to the boy's greater participation and practice in throwing events. Whether lack of participation is as influential a factor at the turn of the 21st century needs confirming. The total score (Figure 5.3) shows the supremacy of males in this motor skill, as well as a consistent rate of development across age groups. Male children reached 85.5% mechanical effectiveness and females 57.0%. SD was largest in the group of 7 & 8-year-old females (19.6%), which reflects the amount of inter-subject variability at this age. **Experimental hypothesis** H_6 – There is a significant association between mechanical effectiveness and age of the children (cross-sectional study) – was accepted with regard to the **overarm throw** since more than half of the variables, particularly in males, showed a significant association (Table 5.2).

1.3 Standing broad jump

Unlike the soccer kick and the overarm throw, statistical analysis revealed a similar level of mechanical effectiveness between male and female children and a faster rate of development in female children in the standing broad jump (Table 5.3, Figures 5.7 and 5.8). The total score shows similar mechanical effectiveness between males and females for age groups 5 & 6 and 7 & 8-years (Figure 5.3), and greater jumping effectiveness in females (reaching 73.7%) than in males for age group 9 to 11-years. Male children showed greater variability at any age, reaching a SD of 26.5% by age group 9 to 11-years. The negligible associations between mechanical effectiveness and age found in several variables for both male and female children (Table 5.3) indicate that such variables were not developmental features of this motor skill, particularly due to many of the younger children performing the jump very effectively. An example of non-developmental variable was the *extension of body segments* at take off in male children, in agreement with Phillips *et al.* (1985) and Horita *et al.* (1991); however, the female children in the present research did show development in this variable. In contrast, and also in accordance with the findings of Phillips *et al.* (1985), the *position of the arms* at takeoff showed development with age. Early maturation, at age 5 years, was observed in a greater number of variables in female children, which may suggest that females have a head start in the learning of this motor skill. However, compared to male adults, female adults showed persistent lack of maturation of the movement (Figure 5.4). Both male and female children experienced similar technical weaknesses, whereby the coach or PE teacher needs to assist the children with respect to the *velocity of takeoff, final position of the arms,* and *direction of movement, symmetry & coordination*. It is interesting to notice that some of the technical difficulties identified in the present research matched those previously pinpointed by Hellebrandt *et al.* (1961) and McClenaghan (1976) including improper use of the arms, poor preliminary crouch, limited range of motion of arms and legs, and the 'winging' action which is a direct consequence of threatened balance. However, Hellebrandt *et al.* (1961), McClenaghan (1976) and Gallahue and Ozmun (1995) had also listed: inability to perform a two-footed take-off; too high an angle of take-off; incomplete extension of ankles, knees and hips at take-off; failure to extend the legs forward at landing; and backward movement of body weight on landing, which were not identified as particularly problematic in the present research (not even in the 5-year-olds). **Experimental hypothesis** H_6 – There is a significant association between mechanical effectiveness and age of the children (cross-sectional study) – was rejected with regard to the **standing broad jump** due to most variables not showing a significant correlation in males and less than half of the variables in females (Table 5.3). Finally, **experimental hypothesis** H_7 – There are distinct gender differences in mechanical effectiveness and its rate of development in children (cross-sectional study) – was accepted for the **three motor skills**. Although female children did show a faster rate of development in the standing broad jump, the gender differences in mechanical effectiveness were not as prominent as in the kick and throw.

The findings above regarding the development of mechanical effectiveness in children support the use of a component approach for the study of motor development (i.e., Roberton, 1978; Langendorfer, 1980, 1987; Roberton and Langendorfer, 1980; Clark and Phillips, 1985; Yan *et al.*, 2000), since children showed independent rate of development for different variables in all three motor skills. Accordingly, Horn and Williams (2003) have explained that *"motor performance is a product of several complex and interacting systems that do not develop at the same rate"* and that *"there is always one system lagging behind others"* (p. 61). Such lagging systems prevent the child from using an effective technique and have been named 'rate limiters'. In addition, the present research detected the presence of inter-subject variability within the same age group, showing that the children followed individual patterns of development (as reported by Roberton, 1978; Bloomfield *et al.*, 1979; Elliott *et al.*, 1980; and Barfield, 1998). Thus, the findings add support for the within-person constrain theory of Langendorfer and Roberton (2002), which accounts for technical change in developing children. However, statistical analysis and the graphical display of the data showed that, as a group, children followed a general trend of positive development towards maturity of the movement. Such findings call, however, for greater emphasis in longitudinal research to unveil both common and individual developmental pathways, perhaps by the study of 'profiles' as suggested by Langendorfer and Roberton (2002).

Moreover, a research question that was tackled by considering the findings of the cross-sectional studies in Studies 1 and 3 together was that of whether basic techniques used by the children develop into more effective techniques (increased technical level), or whether it is mechanical effectiveness that increases once the child has adopted a specific technique. The combined results of Studies 1 and 3 suggest that children change their less effective techniques for more effective techniques systematically as they grow up; that is, they increase their technical level. This has an effect on the scores of mechanical effectiveness when using the rating scales, since a higher technical level automatically translates into higher scores of mechanical effectiveness for certain variables (e.g., approach pattern in soccer). Comparatively, some children of an early age (5-6 years) showed a high technical level, while older children (10-11 year olds) who showed the same technical level as the younger ones usually displayed greater range of motion and speed, or simply better coordination; therefore obtaining higher scores in mechanical effectiveness. The results suggest, therefore, that both technical level and mechanical effectiveness develop harmoniously in school-aged children, excluding a minority of children who show a high technical level at a young age and in whom it is only mechanical effectiveness that increases. However, further longitudinal studies using a large sample are needed to confirm such developmental trends.

To summarise the findings of the cross-sectional study of the development of mechanical effectiveness, Study 3 covered a prominent gap in the literature by identifying gender differences in the development of the maximum-distance **soccer kick** in children. Boys showed greater mechanical effectiveness and a faster rate of development in the **soccer kick** and the **overarm throw** than girls in any age group. This is, therefore, in agreement with the findings of Langendorfer (1980), Halverson *et al.* (1982), Hardin and Garcia (1982), Nelson *et al.* (1991) and Thomas and Marzke (1992). However, hypothesis H_6, which indicates significant development, was only accepted for the overarm throw. Additionally, the throwing action of female adults was less effective than that of male adults. Immaturity of throwing patterns in adult women has already been documented (e.g., Atwater, 1970; Leme and Shambes, 1978). In comparison, gender differences in the effectiveness of the **jumping** movement were not so prominent as in kicking or throwing. Female children of 5 years of age showed early maturation, however adult females showed persistent technical weaknesses in the execution of the jump.

2. Profiles of mechanical effectiveness

The profiles of mechanical effectiveness in Figures 5.9-5.11 can be used as a reference in the assessment of individual, and small groups of, children. In the **soccer kick** a plateau at a high scoring level is obvious in males from age 10 years, but not in females. A plateau is not obvious in the **overarm throwing** movement, although male children obtained higher scores. Comparatively, in the **standing broad jump** only adult males showed a reasonable plateau at the high level of mechanical effectiveness. Finally, it should be born in mind that the concept of profiles in the present research differs from that in the work of Langendorfer and Roberton (2002), where the data is longitudinal and not cross-sectional as in the present study.

3. Longitudinal study of the development of mechanical effectiveness

Study 1 revealed the need for further longitudinal work for the understanding of the development of technical level in children. In the longitudinal assessment of Study 3, both male and female children showed development towards greater **kicking** and **jumping** effectiveness in less than half of the variables (Tables 5.4-5.6; Figures 5.12-5.14). Comparatively, in the **overarm throw** male children showed considerable improvement in their execution of the throw between test 1 and test 2. These results were somehow expected since, although the cross-sectional study showed general positive development of the children in all three motor skills, there was also considerable inter-subject variability in development. However, the between-day intra-subject variability in the mechanical effectiveness of the children was not determined in the present research due to the extent of the work, which may have helped to more accurately interpret the longitudinal changes observed. As with Study 1, future larger-scale longitudinal studies will throw light into the development of mechanical effectiveness in children; particularly because exceptions in predicted behaviour have occasionally occurred in other research, which were attributed to the specific characteristics of the sample used (Clark and Phillips, 1985). **Experimental hypothesis** H_8 – There are significant differences between the mechanical effectiveness of a group of children in test 1 and their mechanical effectiveness in test 2 (longitudinal study) – was rejected with regard to the three motor skills since most X^2 results were non-significant (Tables 5.4-5.6).

4. Relative contribution of specific mechanical variables to the performance criterion

Some of the predictors of successful performance, particularly those related to initial projection conditions, have already been identified in previous work (i.e., Bunn, 1972; Toyoshima and Miyashita, 1973; Isokawa and Lees, 1988; Hay, 1993), the contribution of different body parts to performance has been examined (Toyoshima *et al.*, 1974; Robertson and Fleming, 1987; Dowell and Lee, 1991), and the contribution of specific variables to performance studied using correlation analysis (Reilly *et al.*, 1991). However, the present research permitted the identification of the variables that best predict performance outcome in school-aged children (Figure 5.15). Variable selection is a typical research problem tackled, for example, by Hay *et al.* (1986), Takei (1992), Sanders (1999) and Greig and Yeadon (2000). Such identification of variables revealed further gender differences in mechanical effectiveness. For example, see *velocity of ball release* and *angle of ball release* in the **soccer kick** (Figure 5.15); gender differences occurred also in the two other motor skills. *Compression* in the landing phase was a particularly important predictor of performance for male children in the **standing broad jump**. Rather interestingly, this late phase of the movement is an important indicator of successful performance (Tsaousidis and Zatsiorsky, 1995). An ineffective follow through (see *maximum hip flexion* in **soccer** and *length of the last step & lowering of the CG* in **throwing**; Figure 5.15) may be the direct consequence of technical or performance-related weaknesses in the preceding phases of the movement. For example, a slow approach would lead to a weak follow through. Conversely, the use of a restricted follow through by the child may impede applying large forces to, for example, the ball at impact in soccer (Wang and Wiese-Bjornstal, 1994). Here a more intricate analysis is required to establish what is the cause and what is the effect of erratic technique and performance. In addition, *coordination & rhythm* maintained their importance and should also be emphasised by the soccer coach by including coordination exercises and, perhaps, relaxation sessions.

In the **standing broad jump**, female children attained a high scoring in *direction of movement, symmetry & coordination.* Such variable provided, therefore, a substantial contribution to the performance criterion. Better coordination of females when executing the standing broad jump has been previously reported (Roberton and Halverson, 1984; Phillips *et al.*, 1985). Particularly, coordination has been linked to high achievement in sport (Espenschade and Eckert, 1967) and has also been used as a predictor of motor development (Gallahue and Ozmun, 1995). The coach of young female athletes should, therefore, exploit this reliance on good coordination by girls when performing the standing broad jump. The results of the Spearman's rho tests for the association between the total score of mechanical effectiveness and the range of the ball in the soccer kick and the overarm throw showed a stronger association in males (Figure 5.15), indicating that male children relied on a good overall technical execution of the **kick**, while females may have relied on a number of key variables for effective **kicking** and **throwing** (e.g., *angle of release* (soccer kick) and *shoulder horizontal adduction (throwing arm)*). In the **standing broad jump** it was the girls who relied on a better overall technical execution of the movement (total score) in order to jump as far as possible. In fact, females showed higher overall technical ability, with 18 of the variables showing a stronger correlation between mechanical effectiveness and range (length of the jump) than in males (Figure 5.15).

Moreover, the poor and also the negative associations identified in the analysis question the importance of certain variables to attain the performance criterion, and the results suggest that school-aged children may not necessarily rely on those variables for the execution of the movement. A negative correlation was obtained for the *CG landing trajectory* in the **jump** (in female children) and negligible correlations were observed for several variables, particularly in the **soccer kick**, including *adduction velocity of the opposite arm* and *angle of the kicking knee*. This finding may be used to review the choice of variables included in the analysis, where variable selection was carried out subjectively based on their predicted contribution to the mechanical effectiveness of the movement (Stage 5 of the model; Figure 4.1 in Study 2). **Experimental hypothesis** H_9 – There is a significant association between mechanical effectiveness and the performance criterion – was accepted although it applied to only a few variables in the **soccer kick**, to about half of the variables in the **overarm throw** and in the **standing broad jump**, and to the total score for the **three motor skills.** In any case the significant correlations were only moderate (Figure 5.15).

5. General factors affecting motor development in children

When interpreting the findings of Study 3 regarding the development of mechanical effectiveness in children one must consider related developmental factors, including the effects of somatotype, alteration of movement patterns due to practice, the changes in body dimensions throughout childhood, chronological and biological age, and the biomechanical changes associated with growth and development. Abernethy *et al.* (1997) reported that children of the ectomorph and ecto-mesomorph type show greater participation in physical activity, which results in the acquisition of more effective movement patterns. However, the amount of practice by the children participating in the present research was not documented. Abernethy *et al.* (1997) also stated that the growth of some limbs at a different rate than others and changes in the relative amount of adipose and lean tissue can cause technical disturbances in the children. In addition, while bones and muscles are still growing they are mechanically inefficient (Clegg, 1998). This and gender differences in the onset of growth spurts (Davis *et al.*, 1994) can make it difficult for the child to perform motor skills and affect their strength, power and coordination. Nonetheless, the present research showed that the female children relied on coordination more than males did to perform the standing broad jump. Leon-Pérez (1984) has suggested that phases of fast physical growth of the child can provide a temporary advantage in sports due mainly to rapid increases in strength, although growth spurts may also lead to phases of retardation in motor performance in some children. Therefore, these general factors associated with normal child development may have accounted for the inter-subject variability in mechanical effectiveness observed, and the low associations between mechanical effectiveness and age of the children found in the early diagnosis of the data in the present research. Consequently, although chronological age is a convenient reference in the study of motor development, where possible individual characteristics regarding the physical growth of the child should also be taken into account.

Limitations of the study and suggestions for future work

The poor and the negative associations found between mechanical effectiveness and the range for certain variables suggest that the subjective process of variable filtering at Stage 5 of the model may have allowed the use of variables with little contribution to the mechanical effectiveness of the movement. Bearing in mind that identifying which variables need to be included in the analysis to help athletes improve their performance has been described as *"probably the most difficult task for the biomechanist"* (Lees, 1999a; p. 300), this issue of relative importance of variables needs to be addressed in any future developments of the mechanical effectiveness model presented in Study 2, or when using the model for the analysis of other motor skills. The longitudinal study was limited to two testing sessions per child. This was due to difficulties in keeping track of the children assessed, since children dropped from sports clubs, were soon reallocated to another coaching club according to their age, or changed school. Finally, although the analysis of mechanical effectiveness was characterised by its simplicity of measure (use of scoring references) so that the analysis can be reproduced time-effectively by the coach and PE teacher, the preparation of profiles of mechanical effectiveness increased the complexity of data processing. Creating profiles for the children measured involved converting scores into percentages. However, the provision of normative data should be carried out by the sports scientist in future uses of the model for other motor skills, in order to facilitate the work of the coach and PE teacher. Simplicity of the analytical tool has been encouraged by a number of authors in the past (i.e., Frederick, 1977; Brown, 1982; and Lees, 1999b).

Conclusions

To sum up, in the **cross-sectional study** gender differences were found in the mechanical effectiveness of the movements performed by the children, with males showing greater effectiveness in the *kick* and *throw* and females displaying greater overall effectiveness in the *standing broad jump*. In addition, the rate of development of mechanical effectiveness was also generally faster in male children for the *soccer kick* and the *overarm throw* and in female children for the *standing broad jump*. **Profiles of movement effectiveness** were developed that can be used as a quick reference for comparative analysis. In the **longitudinal study**, male children showed a considerable increase in the mechanical effectiveness of the *overarm throw* over time. However, further longitudinal studies are needed to enable us differentiate between-day intra-subject variability from true developmental change. **Predictive correlation analysis** allowed identifying the variables that had a greater impact on the performance criterion, in this group of children. Such performance predictors showed further gender differences in mechanical effectiveness, which must be taken into account in teaching and coaching settings. However, it was suspected that Stage 5 of the model may have permitted the use of variables with a limited contribution to the mechanical effectiveness of the movement. Finally, general factors that affect motor development in children were discussed to help interpret the findings of Study 3.

Chapter VI – Summary and future directions

Summary

This doctoral thesis embodies the development of a new approach to qualitative biomechanical analysis that consists of the determination of how effective a movement is in attaining the performance criterion. Movement effectiveness, including assessment of technical level and of mechanical effectiveness, and its pattern of development in a group of school-aged children were examined. Specifically, **Study 1** allowed determination of the technical level of the children when performing the soccer kick, the overarm throw and the standing broad jump. Although female children displayed a somewhat higher technical execution of the *standing broad jump* than male children the opposite was true in the *soccer kick* and the *overarm throw*, in which two skills the male children showed also a faster rate of development. The findings of Study 1 may assist coaches and teachers in their understanding of the use of technique by children of different ages and by so doing put emphasis on the technical problems identified. Nonetheless, the greatest limitation of Study 1 was related to the subjective approach used to construct the hierarchical models for the determination of technical level.

The review of literature highlighted the complexity of use and limitations of the existing models for the qualitative analysis of human movement. Therefore, a new model for the analysis of mechanical effectiveness was created in **Study 2** via synthesis of existing comprehensive and observational models. The main features of the model are the fusion of phase analysis and mechanical analysis, and the association between observable features and mechanical variables using movement principles. These permit selecting the variables for the analysis; although variable selection was, in fact, perceived as complex and thought to be the task of the researcher rather than that of the coach or PE teacher. After attending to the mechanical aspects, the model addresses issues of visual perception related to the estimation of the mechanical quantities from video. The use of the model to develop scoring references for the analysis of motor skills was demonstrated using the *soccer kick* as an example of a basic motor skill. Thus, rating scales for each variable of the *soccer kick* were outlined, and later adjusted using tests of accuracy and intra-rater reliability and put together to form scoring references. Inter-rater reliability in the use of the scoring references was acceptable. The model for the analysis of mechanical effectiveness was thereafter used to develop scoring references for the analysis of the *overarm throw* and the *standing broad jump*.

Analysis of mechanical effectiveness in a large group of school-aged children was carried out in **Study 3**, which found greater mechanical effectiveness and a faster rate of development in male children for the *soccer kick* and the *overarm throw*. Gender differences were not so prominent in the *standing broad jump*, a motor skill in which female children excelled. Profiles of mechanical effectiveness were developed to provide sample data to monitor child development. In a longitudinal study, children, as a group, showed little improvement in mechanical effectiveness over time. However, the need for further longitudinal research was highlighted due to relatively large inter-subject variability in development and the need for the assessment of between-day intra-subject variability in mechanical effectiveness. Finally, predictive analysis allowed identifying the variables of the movement that had a greater influence on the performance criterion in this group of school-aged children.

General discussion

Previous studies on the development of kicking, throwing and jumping have described the movements observed in children and have limited movement quantification to measures of the performance criterion or certain kinematics that may be associated with the performance criterion (e.g., Elliott *et al.,* 1980; Butterfield and Loovis, 1993). The present research, by determining movement effectiveness in children, represents a step forward in the methods used for the qualitative biomechanical analysis of child development, since it involves an appreciation of how effective movement patterns are. Determination of movement effectiveness is based on the rational application of movement principles, and is in line with the *kinematic continuum stages* model of motor development (Adrian *et al.*, 1984). The fact that analysis of movement effectiveness involves two modes of analysis, *technical level* and *mechanical effectiveness*, has got certain advantages. The determination of *technical level* resembles much more the traditional descriptive analysis used for the study of motor development in past research (e.g., Wild, 1937; McClenaghan, 1976; Bloomfield *et al.,* 1979) and focuses on the main form of the movement. Therefore, such analysis provides the uninitiated PE teacher or coach with some experience in biomechanical analysis before progressing to the use of a more complex mode of analysis of the movement of the child; that is, analysis of *mechanical effectiveness*, which includes all phases and important variables of the movement. Moreover, the analysis of *mechanical effectiveness* is enhanced by an understanding of the technical variations found in school-aged children; therefore it is useful to establish the *technical level* of the child prior to proceeding to the determination of the *mechanical effectiveness* of the movement of the child.

The most significant contribution to existing knowledge was attained by the synthesis of phase analysis and mechanical analysis (i.e., a research problem identified by Lees, 1996 and Bartlett, 1997) within the model of mechanical effectiveness. Then, at the experimental level, the model permits selecting important variables for the analysis, and the tests of accuracy and reliability help to develop a scoring reference. At the practical level, the scoring reference is used to assess state of motor development, providing an opportunity for the coach and PE teacher to locate technical and performance-related weaknesses in the movement of the child. The model is, therefore, directly applicable in coaching and teaching, where being aware of gender differences in the development of mechanical effectiveness can enhance the application of instructional strategies. The complete sequence from conceptualisation to implementation has rarely appeared in the biomechanics literature. However, the main operational difficulty when attempting to construct the model was the fact that literally only one author had previously classified and applied explicit movement principles to explain why human movement is performed the way we see it (Lees, 1999b). A dearth of literature was another concern in the present research, particularly regarding the development of the soccer kick in girls, data across the age spectrum that includes children from early to later childhood, longitudinal data on any of the three motor skills, and the assessment of intra-subject variability in performance. In addition, a dearth of kinematic data required the use of a pilot study to estimate the range of motion of a number of segments during the performance of the motor skills. In fact, a certain mismatch was noticeable in the literature between the critical features derived from theoretical models and the choice of kinematic and kinetic variables selected by other researchers for experimental analysis.

The **general hypotheses** of the research stating that the *performance, technical level* and *mechanical effectiveness* (GH_1) of children increase with age, and that there are gender differences in both *performance* and *movement effectiveness* and the pattern of development of these (GH_2) were accepted, in general terms, with regard to the **three motor skills**. Nonetheless, technical execution and performance were better matched between male and female children in the **standing broad jump**. Despite the general findings, non-significant associations were found for a high proportion of variables that lead to the rejection of some of the **experimental hypotheses**. Moreover, there were relatively small changes in the technique of the children with age compared with changes in performance. The low and moderate associations found between movement effectiveness and age of the children suggest that for the performance of motor skills technical execution is only one of a number of factors. Other aspects of human performance (e.g., strength -that may sometimes compensate for a poor technique, physique, ability to develop explosive power, agility –in the case of the standing broad jump; Gallahue and Ozmun, 1995; Thomas and Nelson, 1996) and motor development (e.g., heredity, socio-educational, practice, somatotype –and its effect on amount of practice, physical growth spurts; Halverson *et al.*, 1982; Leon-Pérez 1984; Thomas and Marzke, 1992; Davis *et al.*, 1994; Thomas and Nelson, 1996; Clegg, 1998) play an important role.

Another factor to consider regarding the execution of motor skills is the intra-subject variability in technical level over consecutive trials found, which may also result in inconsistent performance outcome over consecutive trials. These findings pose the question of to what extent the PE teacher and sports coach need to be concerned about the technique of the children. Perhaps, for children attending usual PE classes and extra-curricular sports events qualitative analysis of movement effectiveness should be used to identify major technique and performance related weaknesses in the child, and to generally increase awareness regarding the mechanical nature of the skill to enhance the design of coaching and PE programmes. In addition to intra-subject variability, there was considerable inter-subject variability in movement effectiveness and, also, in the rate of development of movement effectiveness. This was evident in the small differences in movement effectiveness even between extreme age groups. Variability, however, may be viewed as a normal component of human motor development, which allows exploration of movement and the subsequent acquisition of proficient movement patterns. Variability also allows adaptation to the biomechanical changes that occur as part of normal child growth and development (Abernethy *et al.*, 1997). The coach and PE teacher need to be aware of such variability and acknowledge that individual children develop independently. In some cases, teaching strategies may be tailored differently for boys and girls, and to cater for the needs of individual children.

Limitations of the research and suggestions for future work

Despite the methodological developments achieved in the present research, the three studies that comprise this thesis were not free from limitations. After all, the analytical process employed was qualitative, and although practical in use, there are issues of validity and reliability surrounding this type of analysis (documented by Knudson and Morrison, 2002). In fact, due to such issues the level of sensitivity of the rating scales was rather low compared to the use of quantitative biomechanical analysis. Some rating scales allowed no more than 2 or 3 measurement categories, and the children had to be allocated to three age groups to detect meaningful developmental change.

The accuracy and reliability attained when using the rating scales can be considered normal in day-to-day coaching and teaching work environments that rely on qualitative analysis. However, the scoring references can only be used in settings where a high degree of precision of measure is not required. For example, the scoring references are ideal for the gross assessment of state of motor development in large groups of children in PE classes, as long as a video player with jog shuttle facility is available, but it is unlikely to ever be used to try to refine the technique of elite athletes who may require 3-dimensional analysis and the use of a high-sampling rate (e.g., Lees and Nolan, 1998; Levanon and Dapena, 1998; Hong *et al.*, 2001; Nunome *et al.*, 2002). Also, the scoring references are suitable for children no younger than 5 years, since the phases of the movement and key instants may not correspond to the movement observed in very young children (based on Marqués-Bruna and Grimshaw, 1997, 1998). Nonetheless, the findings of the present research can be used as a base for future quantitative studies of mechanical effectiveness, since such findings can help to reduce down the quantitative variables that might be more sensitive predictors of motor development. Such quantitative method of analysis will not be readily accessible to the coach and PE teacher, however, in the way the qualitative method proposed in the present research is. Further, the lengthy and carefully performed task of variable selection was based on the theoretical application of movement principles; therefore the contribution of individual variables to the performance criterion could not be measured objectively in the present research. However, quantitative approaches may be used in future studies to assess the mechanical contribution of specific variables. Predictive research using computerised simulation may allow manipulating the magnitude of different variables, or removing one variable at a time, to test the effect on the performance criterion (Greig and Yeadon, 2000).

While the on-screen method used in the present research to obtain measures of range and kinematics is very practical within the context of qualitative analysis, such method involves manual measurement and introduces, therefore, systematic and random errors in the data. Although using the range as a measure of the performance criterion is invaluable, since this parameter incorporates factors of speed, angle and height of release, using speed of release on its own may also be used as an important indicator of the child's performance (Toyoshima and Miyashita, 1973; Raudsepp and Paasuke, 1995); and, thus, avoid obtaining values of 0 m range in children who are able to release the soccer ball at great speed (they tend to aim for speed), while in fact the ball is projected at a 0° angle of release. Furthermore, the soccer kick and overarm throw are certainly 3-dimensional movements, however the onscreen method used in the present research to obtain kinematics was based on 2-dimensional analysis. This introduced errors in the kinematic data that were used as a criterion reference in the assessment of accuracy and reliability of visually estimated kinematics. Clearly, future quantitative approaches should make use of 3-dimensional digitisation (e.g., Douwes and Dul, 1991; Nunome *et al.,* 2002). Moreover, the tests of accuracy and reliability of visually estimated kinematics used non-parametric statistical tests. While these tests are stringent, optimum statistical methods such as limits of agreement could not be used given the non-parametric nature of the score data in the present research (Ntoumanis, 2001; Howitt and Cramer, 2003).

Future longitudinal studies should aim to follow up a group of children over a number of years to further understand the development of movement effectiveness in children. Such studies need to include assessment of between-day intra-subject variability to differentiate between-day variability from true developmental change, particularly using longitudinal designs like the one recently proposed by Langendorfer and Roberton (2002). Finally, it would be interesting to find out how well the method for the qualitative analysis of movement effectiveness proposed in the present research can be applied in the field and implemented by PE teachers of coaches. Future research could assess the practical value of this approach and the difficulties encountered by its user; for example, whether practitioners can become skilled observers fairly quickly, and whether they are accurate and reliable in their estimations.

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Appendices

Appendix 1 – Consent forms

LIVERPOOL JOHN MOORES UNIVERSITY

The development of movement effectiveness in children – a qualitative analysis

Informed Consent Form

The experiment is designed to collect qualitative video data of the child performing two repetitions of basic motor skills. The child will be required to perform three activities: kick a soccer ball, throw a tennis ball from an overarm position, and perform a standing broad jump. The aim of the kicks, throws and jumps will be for maximum distance. The activity will be filmed with a video camera. The child will be required to wear normal sport/physical education type clothing.

The child will be required to perform the activities in as natural a manner as possible in a school area. The risks involved are minimal and a researcher and parent, guardian or teacher will be present at all times throughout the video recording.

The information that is produced will conform to the Data Protection Act and will be freely available to the subject, parent or guardian upon request. Furthermore, complete confidentiality will be maintained. The researchers reserve the right to publish the data and conduct statistical analysis on the data without consent, but within the regulations of the Data Protection Act defined above.

The information that is obtained during this test will be treated as privileged and confidential and will not be released to any unauthorised personnel without the expressed written consent of the parent or guardian. The information obtained may, however, be used for statistical purposes with the right of privacy maintained. Any questions that arise may be answered to the satisfaction of the parent or guardian. Permission for this test is voluntary and the parent or guardian may ask to withdraw their child from the test at any time, should they so desire. The parent or guardian also has the right to see a copy of the results, if they so wish.

The custodian of the video tape will be the researcher and access may be given to any research publishing authority, should they so wish, but without disclosure of the name of the subject. The video tapes will be retained under lock and key by the main researcher conducting the study.

There are no direct benefits of the work for the child, parent or guardian although these parties are welcome to receive a copy of the research findings if published.

I have read and fully understood the procedure and protocol relating to the experiment described here and I agree to allow participation of my child in the experiment described. Further, I fully understand that I am free to withdraw my consent and discontinue participation in this investigation at any time, without prejudice.

Name of child: .... (please print)

Name of parent or guardian: .... (please print)

Signature of parent or guardian: ....

Name (printed) and signature of researcher: ....

Date: ....

A copy of this form should be retained by the parent or guardian of the experimentee (child).

LIVERPOOL JOHN MOORES UNIVERSITY

The development of movement effectiveness in children – a qualitative analysis

Authorization for Inclusion of Photographs

We, ... (the father)

and .... (the mother),

parents of the child ...., authorize

Mr Pascual Marques to include photographs of our child on his Ph.D. thesis entitled: "The development of movement effectiveness in children – a qualitative analysis".

The photographs used will depict the action of the child when performing a soccer kick, an overarm throw and a standing broad jump, all for maximum distance. The photographs will be made available to the parents of the child should they request so. The use of such photographs will conform to the Data Protection Act and the photographs will not be used for any other purpose but to illustrate the work specified above.

Name of the child .... (please print)

Name (printed) and ....
signature of the father ....

Name (printed) and ....
signature of the mother ....

Name (printed) and ....
signature of the researcher ....

A copy of this authorization should be retained by the parents of the child.

Appendix 2 – Photosequences

Figure A2.1: Photosequence of the soccer kick for maximum distance performed by a 5-year-old boy.

Figure A2.2: Photosequence of the overarm throw for maximum distance performed by a 5-year-old boy.

Figure A2.3: Photosequence of the standing broad jump performed by a 5-year-old boy.

Appendix 3 – The worksheets and results of Pilot Study 1

Table A3.1: Model of the worksheet used to describe the movement of the child using descriptive narrative (example from the soccer kick).

Child's name: xxxxx	**Subject N: 1** **Soccer *Kick***
Description of the movement	
Approach phase	Angled, 2-and-a-half-step approach. **One-to-last step -** Leading / high opposite arm. Short step. **Last step -** Leading opposite arm. Most forward position of the arm at the point of toe off (kicking leg). Long leaping step.
Back swing Phase	Kicking leg flexes to a maximum of 90° angular position. Non-kicking leg remains slightly flexed.
Last foot plant Instant	Support foot placed by the ball. Opposite arm to the side and abducted, with a flexed elbow. Ipsilateral arm alongside the body.
Swing phase	Downward displacement of the CG followed by extension of the non-kicking leg. Diagonal (downward and forward) movement of the opposite arm.
Ball contact Instant	Trunk inclined backward. CG remains behind the ball. Ball contact with the side of the foot.
Follow through Phase	The kicking leg swings up and the knee flexes. The opposite arm adducts horizontally and swings across the chest. The support foot looses contact with the ground and the child produces a hopping action.
General observations	The child's kicking action seems fluid and stylish. The most prominent technical features are a jumping last step and a diagonal (downward and forward) movement of the opposite arm during the swing phase.

Table A3.2: Model of the worksheet used to describe the movement of the child using symbolic coding (example from the soccer kick).

Subject N = 1	Left leg	Right leg	Left arm	Right arm	Trunk	Head	CG	General descriptions
Approach phase							J	
Back swing phase		90°						
Last foot plant instant								
Swing phase								
Ball contact instant								
Follow through phase								

Technique type:	Diagonal	J
Main features:	Jumping action prior to ball contact	

Key to symbols used to describe and record movement patterns.

- Straight approach

- Curved approach

CG - Flat trajectory of the CG

- Path of the CG

- Sinking of CG

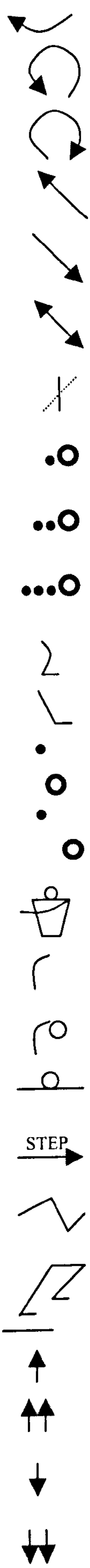
J - Jumping prior ball contact

90° - Angle of maximum kicking knee flexion during the back swing

Contral. - Contralateral

Homol. - Homolateral

- Leading arm



- Rotational direction of the leading arm
- Backward arm rotation
- Forward arm rotation
- Diagonal arm movement (upward and backward)
- Diagonal arm movement (downward and forward)
- Diagonal arm movement (both directions)
- Hip hyperextension
- Foot placement '*by ball*' (typically about 5-15 cm)
- Foot placement '*behind ball*' (about 15-30 cm)
- Foot placement '*well behind ball*' (about 30-50 cm)
- Flexed knee
- Straight knee
- CG above ball
- CG behind ball
- Arm across chest
- Trunk flexion
- Head depression
- Flat trajectory of the ball
- Forward step
- High knee
- Back foot looses contact with the ground
- Large
- Very large
- Limited
- Very limited

Table A3.3: Description of the different movement patterns of the opposite arm used by the children (soccer kick). *

Back sail	The arm rotates backwards around the shoulder joint. Sagittal plane predominantly.		
Rotational	The arm rotates forward around the shoulder joint. Sagittal plane predominantly.		
Horizontal	The arm abducts and then adducts in the horizontal plane.		
Diagonal	The arm travels diagonally from a 'down in-front' position to an 'up back' position, and then returns to the 'down in-front' position across the same diagonal path.		
Diagonal-Horizontal	The arm travels diagonally from 'down in-front' to 'up back', and then it adducts in the horizontal plane.		
Diagonal-rotational	The arm travels from 'down in-front' to 'up back', and then it rotates forwards in the sagittal plane		
Held up & in front	The arm remains held up in front of the body.		
Held low & behind	The arm is kept low behind the body.		
Running action	The movement of the arms (both arms) resembles a typical running action.		
Low running action	The movement of the arms (both arms) resembles a typical running action, but with the elbows fairly extended.		

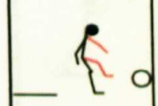
*** Opposite side of the body in red.**

Table A3.4: Description of the patterns of ball contact used by the children (soccer kick). *

Back lean	Just before contact the child's body is fully extended and upright, with a certain amount of backward inclination.		
Weighted	The child rises the body during the final step, then drops the centre of gravity prior to ball contact and seems to use body weight to transfer momentum to the ball.		
Jumping on	The child jumps in the air during the last approach step and seems to use the momentum generated during the descent to impart momentum to the ball.		
Sink & rise	The child lowers the centre of gravity following placement of the support foot and, then, raises the body using powerful support knee extension prior to ball contact.		
Running through	The child's approach, ball contact and follow through movements resemble a continuous running action.		

*** Opposite side of the body in red.**

Table A3.5: Description of the follow through actions used by the children (soccer kick). *

Static	The child remains on the spot, standing on the support foot.		
Step ahead	The child produces a forward step.		
Step over ball	The child produces a forward step characterised by high knee lift, as if they needed to clear the ball.		
Run over ball	The child continues the running action developed during the approach, but needs to adjust the direction of movement of the legs so as not to interfere with the moving ball.		
Running	The child continues the running action developed during the approach.		
Switch over	The child jumps high in the air after ball contact and crosses the legs so that the support leg becomes airborne and the kicking leg becomes the supporting leg.		
Right & back	The child makes a 90° left turn about the support foot after ball contact, and produces backward steps in a direction perpendicular to the direction of kicking.		
Drag & hop	The support foot is dragged forward by the body's momentum and lands a short distance ahead.		

*** Opposite side of the body in red.**

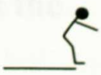
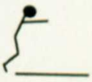
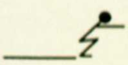
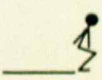
 **Rear view**

Table A3.6: Description of the different overall throwing actions used by the children (overarm throw).

Blocking	The child uses a blocking action of the front leg. The foot acts as a pivot about which the rest of the body rotates achieving forward and upward acceleration.		
Leading opposite arm	The child approaches the release point with the trunk facing sidewards. The opposite (leading) arm is extended forwards in the direction of the throw, while the throwing arm is retracted to a position behind the head. The child uses trunk rotation and horizontal adduction of the leading arm to transfer momentum to the throwing arm.		
Baseballer's	The child's throwing action resembles that used when pitching in baseball.		
Cricketer's	The child produces forward rotations with both arms, predominantly in the sagittal plane and with the arms fully extended, and the throwing action resembles that of a cricket bowler.		
Straight	The child uses minimal rotation of the body and movement occurs primarily in the sagittal plane.		
Wide arc	The child produces horizontal adduction of the throwing arm over a wide arc.		
Interrupted swing	There is a brief pause between the back swing phase and the swing phase; therefore the child fails to perform a continuous throwing action.		
Interrupted run up	The child stops briefly at the end of the approach run up, therefore the child fails to use the forward momentum developed during the approach effectively.		

 **Front view**  **Rear view**

Table A3.7: Description of the different movements of the arms used by the children (standing broad jump).

Back circle	The child produces backward rotation of the arms about the shoulder joint in the sagittal plane.		
Late back circle	The child produces backward rotation of the arms about the shoulder joint late towards the end of the flight phase.		
Pendulum	The child produces a pendulum-like forward action, whereby the arms swing about the shoulder joints in the sagittal plane.		
Pendulum - down	The forward pendulum-like movement culminates with a dropping down of the arms directly towards the ground.		
Pendulum – swing back	The child produces a pendulum-like forward, and then backward, action.		
Late pendulum-swing back	The child produces a pendulum-like forward and backward action late in the flight phase.		
Swing back	The child's arms remain close to the body during takeoff and flight and swing backward at landing.		
Throw-swing back	The child extends the elbows to position the arms forward and upward in an explosive manner during the propulsive phase, and then produces a pendulum-like backward swing.		
Throw-down	The child extends the arms in front of the body in an explosive manner, and then drops them down vertically at landing.		
Diagonal-down	The child swings the arms laterally (in the transverse plane) in a forward and upward direction and drops them down at landing.		
Mature	The arms swing forward during take off and remain in front of the body throughout the flight, landing and follow through.		
No swing	The child fails to take advantage of arm swing.		

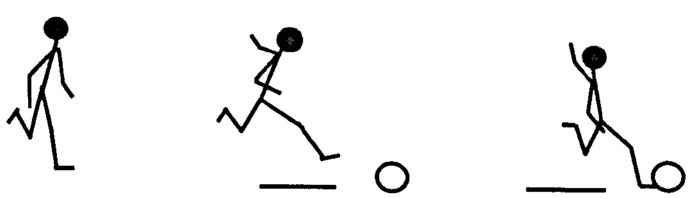
Appendix 4: Descriptions of the mature and less-skilled forms of the movement using movement principles.

Phase description of the mature and less-skilled kicking actions with reference to the underpinning mechanical and biomechanical principles (based upon Lees, 1999b).

Approach phase

Mature form

The player uses a multi-step run up to the ball to develop running speed. This is attained due to successive accumulation of impulse applied to the body on each stride as dictated by the principle of **'whole body running speed' (S1)** (see a description of each principle below). Speed of approach is kept submaximal to ensure the player attains controllable speed, plants the support foot close to the ball, and hits the ball with directional control under the principle of **'speed-accuracy trade off' (P1)**. The approach to the ball is angled. This enables combining linear and angular movement and a large acceleration path of the foot, thus facilitating **'end-point speed' (S2)**.



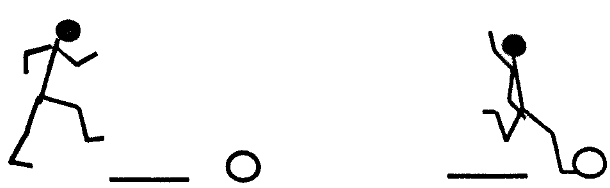
Less-skilled forms

Kicking techniques observed in the children and adults that differed from the mature form of the movement (*curved* approach to the ball) included *diagonal* and *straight* approaches, and these may be considered mechanically less effective since they represent infringements of movement principles. In the mature form, characterised by a *curved* approach, a longer last step and greater opening out of the hip lead to increased hip retraction and muscle stretch (Wang and Griffin, 1997). Such technique clearly complies with the **'stretch-shortening cycle' (C1)** principle. When using a *curved* approach the hip and knee are almost fully extended at the point of ball impact, while in the *straight* approach range of motion of the kicking leg is restricted since the hip and knee remain flexed during the swing in order for the foot to clear the ground. Such technique represents a violation of the **'range of motion' (F1)** and **'end-point speed' (S2)** principles. Also, in the *curved* approach the distance from the hip (support leg) to the foot (kicking leg) at ball impact is large as the body leans towards the non-kicking side. This increases the radius of rotation of the kicking leg (Wang and Griffin, 1997). In the *curved* approach, there is greater fixation of the ankle and knee and the resistance torque of the ground reaction force on the body is completely balanced by the leg active torque (Isokawa and Lees, 1988; Barfield, 1998). This leads to greater effective mass at the instant of ball impact than when using the *diagonal* or *straight* approaches. It is obvious, therefore, that the latter techniques fail to comply with the **'Impact to stationary ball' (F2)** principle, since the force component of the impulse applied to the ball is compromised. When using a *diagonal* approach the player benefits from a greater effective mass and attains greater foot velocity (Plagenhoef, 1971), perhaps due to greater overall range of motion of the swinging leg, than when using a *straight* approach.

Back swing subphase

Mature form

During the back swing, the player produces a long leaping last step. This enables opening out of the hip, and large hip hyperextension and knee flexion in order to maximize **'range of motion' (F1)**, which has the effect of increasing the time of application of muscle forces and therefore the impulse later during the swing phase. This countermovement facilitates **'stretch-shortening cycle' (C1; stretch part)** of muscle fibre activation in the hip flexors and knee extensors. The long last step also produces hip-to-shoulder separation in the transverse plane, while there is simultaneous horizontal abduction of the opposite arm. Such upper body movements are responsible for further **'stretch-shortening cycles' (C1; stretch part)** across the muscles of the trunk and upper girdle. The horizontal abduction of the opposite arm is also thought to enhance the backswing of the kicking leg in an **'action-reaction' (C2; action effect)** fashion.



Less-skilled forms

Compared to the *horizontal* movement of the opposite arm observed in skilled performers, the *rotational* and *running* arm techniques used by less-skilled performers can be regarded as less effective. The *horizontal* technique enhances maintenance of balance of the body (Lees, 1999a). The arm helps increase the moment of inertia of the arm-trunk unit and, therefore, it increases the resistance to rotation around the spine longitudinal axis. Transfer of momentum from the opposite arm to the kicking leg occurs in the horizontal plane. Thus, the transfer of momentum effect is increased as the opposite arm remains in an extended position and the arm segments are at a distance away from the body midline and kicking leg. There is also storage of elastic energy in the stretched muscles (i.e., pectorals, hip flexors). In contrast, in the *rotational* technique the movement of the opposite arm occurs mainly in the sagittal plane. The transfer of momentum from this arm may facilitate the back swing of the leg (opening out and hyperextension of the hip) when the arm is swinging in a backward direction. However, due to the direction of arm movement (sagittal plane), the **'action-reaction' (C2)** effect is smaller when using the *rotational* technique than when using the *horizontal* technique. The oscillatory running action of the arms in the *running* technique is not well coordinated with the kicking action. It is doubtful, therefore, that such arm motion contributes to the opening out of the hip during the back swing and the technique fails to comply with the principle of **'action-reaction' (C2)**.

Instant of foot plant

Mature form

Foot plant may be associated with a simultaneous blocking action of the support knee with the effect of creating a **'pivot' (P2)** that enhances the vertical movement of the CG and kicking leg during the swing phase. As the support foot is planted by the ball the trunk is in a position of backward inclination. Foot position and back trunk lean have been associated with an optimum projection angle (Bunn, 1972), which is necessary for a long distance kick under the principle of **'flight and projectile motion' (P3)**, and also enable attaining the largest angular velocity of the leg at the point of impact (Wang and Wiese-Bjornstal, 1994) which affects the speed of the foot according to the principle of **'end point speed' (S2)**.

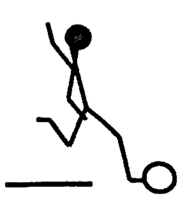
Less-skilled forms

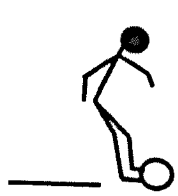
Compared to a *by ball* placement of the foot, the *behind ball* and *well behind ball* foot placements represent infringements of the **'flight and projectile motion' (P3)** and **'end point speed' (S2)** principles. By placing the support foot behind the ball the child is forced to 'reach' with the leg to make contact with the ball. Thus, ball contact occurs, not when the shank is travelling with near maximum angular velocity but, when the leg is already decelerating (Aitcheson and Lees, 1983; Wang and Wiese-Bjornstal, 1994). The child is forced to lean forward prior to ball contact, and this affects the amount of hip flexion and the duration of ball contact. As a result, the impulse applied to the ball is reduced, producing a less that optimum application of the **'impact to stationary ball' (F2)** principle.

Swing phase

Mature form

For the first half, or so, of the swing, the knee remains flexed. This facilitates **'limb rotational speed' (S3)** by decreasing the moment of inertia of the leg. However, extension of the kicking knee towards contact occurs in a **'proximal-to-distal sequence of movements' (C3)**. Although the reaction torque applied by the lower leg to the thigh causes the thigh to slow down, the lower leg actually speeds up. The lateral inclination of the body observed during the swing phase contributes, according to Wang and Griffin (1997), to balance and allows the leg to produce a smooth swinging movement, perhaps by allowing an uninterrupted **'proximal-to-distal sequence of movements' (C3)**. It can also be argued that lateral body inclination increases the length of the acceleration path of the foot (increased radius of rotation, orthogonal distance, from a vertical axis through the non-kicking hip to the kicking foot), thus increasing **'end-point speed' (S2)**. The powerful horizontal adduction of the opposite arm (**'action-reaction' (C2; action effect)**) produces a reaction effect on the kicking leg increasing the velocity of the swing. The elbow of the opposite arm is maintained in an almost fully extended position during the horizontal adduction of the arm, thus maximising moment of inertia and producing a greater reaction effect on the swinging leg. The perceptible raising-sinking-raising trajectory of body's CG during the swing occurs due to the **'pivot' (P2)** effect of the support leg that generates more vertical movement of the kicking leg, an by so doing increase **'end-point speed' (S2)**.





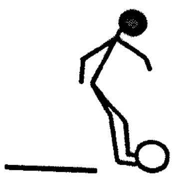
Less-skilled forms

In the mature form of the kicking action the opposite arm adducts horizontally in unison with the swing of the kicking leg. Thus, the *horizontal* technique enhances maintenance of balance; that is, the large moment of inertia of the arm helps increase the resistance to rotation around the trunk longitudinal axis (Lees, 1999a). Because the movement of the opposite arm occurs in the horizontal plane the transfer of momentum to the kicking leg is optimised. Particularly, because the arm remains in an extended position and the arm segments are kept at a distance away from the kicking leg. In contrast, in the *rotational* technique, the opposite arm rotates in the sagittal plane. It also produces a transfer of momentum that facilitates leg swing, but only during the part of the movement when the arm swings in a forward direction. The *rotational* technique fails, therefore, to optimise the application of the **'action-reaction' (C2)** principle. Clearly, in the *running* technique the oscillatory running action of the arms is not well coordinated with the kicking action. Therefore, it is hard to see how the swinging movement of the arms contributes to the effectiveness of the kick. The technique relies solely on the forward momentum of the body generated during the run up and on the transfer of this linear momentum to the ball at impact.

Instant of ball contact

Mature form

The forward flexion of the trunk and neck during the brief duration of ball contact enhance the forward swing of kicking leg about the pivot (non-kicking hip) in an **'action-reaction' (C2; action effect)** that allows applying greater forces to the ball. At first contact with the ball the kicking knee is slightly flexed. During contact the knee extends further. This enables applying forces to the ball for longer according to the principle of **'impact to stationary ball' (F2)** or impulse-momentum relationship. Proficient players show prolonged contact time in accordance with this mechanical principle, while young children occasionally produce a very short contact. At contact the aim is to attain high velocity of takeoff and a take off angle as close to 45° as possible as dictated by the principles of **'flight and projectile motion' (P3)**.



Less-skilled forms

The mode of contact with the ball has been used in the present research to classify contact techniques. The mature form involves leaning back prior to ball contact; *back lean* technique. This allows rising the hip of the kicking leg during the swing phase, which helps clear the toes, preventing them from hitting the ground (Barfield, 1998). Leaning back at the point of ball contact allows the kicking leg to be fully extended and unrestricted (Wang and Wiese-Bjornstal, 1994). This permits an increased range of motion of the leg and increased leverage with respect to the axis of rotation of the system (the non-kicking hip), according to the principle of **'end-point speed' (S2)**. The back lean of the body, together with the blocking action of the support leg, results in acceleration of the free segment (the kicking leg). Also Bunn (1972) and Parassas *et al.* (1990) have pointed out that leaning back allows a lower placement of the foot under the ball and, therefore, a greater takeoff angle. In the *weighted* technique, the child seems to make use of the force of gravity (the weight of the child) in an attempt to impart greater force to the ball. The overall range of motion of the kicking leg is restricted, in comparison with the *back lean* technique, and the movement lacks the coordination and smoothness of the *back lean* technique; probably infringing the principle of **'proximal-to-distal sequence of movements' (C3)**. The *running* technique of ball contact relies on the forward momentum generated during the approach run up, exclusively. In the *running* technique, mechanisms such as using the momentum from a leaping last step (*weighted* technique) or using a blocking action and large range of movement (*back lean* technique) are clearly absent.

Follow through phase

Mature form

Although a powerful kicking action is facilitated by an unrestricted follow through, perhaps the importance of the follow through lies in injury prevention. The principle is to gradually dissipate the forces generated during the propulsive part of the movement. Movement dissipation is performed under the principle of **'range of motion' (F1)**, which is based on the impulse-momentum relationship. In highly-skilled soccer players this is attained in two different ways: 1- by producing large hip flexion, sometimes in combination with a leaping action, and otherwise extension of body segments to increase moment of inertia and decrease rotational velocity (**'limb rotational speed' (S3)**), and 2- by producing a number of speed-quenching forward steps with simultaneous lowering of the centre of gravity, which works by accumulation of impulse applied to the body on each step (**'whole body running speed' (S1)** but in reverse).

Less-skilled forms

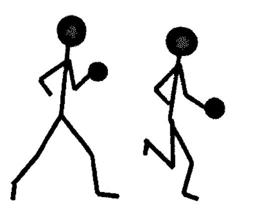
The *drag and hop* technique may be regarded as the mature form of follow through in the soccer kick for maximum distance (Lees and Nolan, 1998). Production of this movement pattern is evidence of large range of motion during the swing phase and of a powerful overall kicking action. It is also evidence that contact of the foot with the ball has been maintained for as long as possible. This increases the time factor in the impulse-momentum relationship and allows greater momentum to be imparted to the ball (**'impact to stationary ball' (F2)** principle). Towards the end of the follow through the knee is flexed to reduce the stretch on the hamstrings muscles, and the brief flight component in this technique, when the performer takes off from the ground, helps to reduce the possibility of injury by producing a gradual impact-free deceleration pattern. Compared to the use of the *drag and hop* technique, producing a forward *step* during the follow through is an indicator of a less powerful kicking action (**'range of motion' (F1)** principle), since this technique lacks the continuity and smoothness of the *back lean* technique. Moreover, the *step* technique may not be as effective in terms of injury prevention, since the hamstrings experience forced eccentric loading. *Rotational* movement in the follow through phase is the result of loss of balance after ball impact. Such action may be related to a poor use of the opposite arm that fails to balance the torque generated by the kicking leg during the swing phase, as evaluated through application of the **'action-reaction' (C2)** principle. A *rotational* technique compromises accuracy of the shot and it is a clear indication of restricted application of forces during the swing phase (Tsaousidis and Zatsiorsky, 1995). A *running* follow through is evidence of the performer's reliance on the forward momentum of the body generated during the run up, and a *static* follow through reflects low limb velocities and limited application of force throughout the kick. Both the *running* and the *static* techniques are reflections of a weak overall kicking action that fails to comply with the mechanical principles of **'range of motion' (F1)**, **'action-reaction' (C2)**, **'proximal-to-distal sequence of movements' (C3)**, and **'end-point speed' (S2)**.

Phase description of the mature and less-skilled throwing actions with reference to the underpinning mechanical and biomechanical principles (based upon Lees, 1999b).

Approach phase

Mature form

The speed developed during the final steps serves to generate forward momentum of the thrower, under the principle of **'whole-body running speed' (S1)**. Such momentum is transferred to the ball in a series of sequential movements following final foot plant. Speed of approach is kept submaximal to ensure the thrower attains controllable speed, and have enough control to hop with the homolateral leg, rotate the body towards the throwing side, and plant the front or contralateral foot ahead of the body. The thrower must also release the ball at an optimal angle and ensure directional control under the principle of **'speed-accuracy trade off' (P1)**. The approach is in a straight line in the direction of throwing, although the body rotates and faces sidewards during the last step to increase **'range of motion' (F1).**



Less-skilled forms

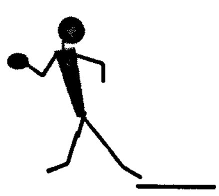
Besides the approach pattern characteristic of the mature throwing action outlined above, young children produce occasionally an *interrupted* run up (Marqués-Bruna and Grimshaw, 1998). An *interrupted* run up denotes lack of coordination and the need for attentional prioritisation. The momentum developed during the approach run is not used effectively, since such momentum is dissipated before the swing phase occurs. Such run up pattern ultimately fails to comply with the principles of **'force production' (F3)** and **'whole body running speed' (S1)**.

The mature throwing action is characterised by a well defined *contralateral* last step. Less skilled forms of throwing include either a *homolateral* last step or a continuous *running* action. Using a *homolateral* last step restricts the range of motion of the trunk and throwing arm (**'range of motion' (F1)**). In the *running* technique, the movement of the trunk and lower limbs are not coordinated with the movement of the throwing arm; this may restrict the range of motion of the trunk and throwing arm, depending on the relative timing of the lower and upper limb movements (**'range of motion' (F1)**). In both the *homolateral* and *running* techniques the storage of elastic energy associated with muscle pre-stretch is thought to be limited, affecting the effectiveness of the **'stretch-shortening cycle' (C1)**.

Instant of last homolateral foot contact

Mature form

Following a hoping action, the homolateral foot is planted ahead of the body. The leg is externally rotated with the toes pointing to the side. This foot position enables maintaining body weight over the back leg and flexion of the back knee and hip after contact. Such preparatory posture allows extension of the knee and hip and shifting of body weight forwards and upwards later during the swing phase (the underlying principle is **'range of motion' (F1)**), and therefore effective **'force production' (F3)** by pushing against the ground. However it is likely that the body **'pivots' (P2)** over the back foot following the point of maximum knee flexion when the knee becomes rigid facilitating the vertical displacement of the body during the swing phase. This is why the homolateral foot is planted in front of the body's CG.



Back swing phase

Mature form

During the back swing there is a forward step with the contralateral foot, although body weight remains over the back leg by means of leaning backwards. In unison, the trunk rotates backwards, and the throwing arm abducts horizontally and rotates externally. The forearm is held at 90° to the upper arm and therefore the hand describes a circular backward trajectory. Forward step, trunk rotation and arm movement occur simultaneously, rather than sequentially, since there is no need to develop large amounts of velocity during this phase of the throw and are all easily initiated at the point of second-to-last homolateral foot contact (first part of the hop) when the body starts rotating in the transverse plane and about the planted foot. The further the arm and trunk go back the longer will the arc of movement be later in the swing phase. Plagenhoef

(1971) has explained that maximal velocity of throwing involves a full **'range of motion' (F1)** of body segments. The elbow is maintained flexed, however, which allows minimum moment of inertia later at the beginning of the propulsive swing and therefore higher **'limb rotational speed' (S3)**. Elbow flexion at 90° allows an effective leverage during upper arm internal rotation later in the swing phase. Backward trunk inclination contributes to **'range of motion' (F1)**, although the amount of inclination is restricted given the muscular force that would be required if the large trunk segment presented excessive back lean. Knee and hip flexion during the back swing allow shifting of body weight forwards and upwards later during the swing phase. Therefore contributing to the overall **'range of motion' (F1)** of the throwing movement. The length of the last step is about 50% of the height of the thrower and therefore relatively short so as not to affect the height of release, which is important in order to comply with the principles of **'flight and projectile motion' (P3)**. During the back swing the non-throwing arm reaches the most forward and elevated position in front of the body. This position allows shoulder horizontal abduction and elbow flexion later during the swing phase and thus the application of a torque **(action effect in the 'action-reaction' principle, C2)** that facilitates forward trunk rotation and the rotational acceleration of the throwing arm as a reaction.

Swing phase

Mature form

At the point of last contact with the contralateral foot the back leg starts extending, the trunk flexes forwards and the hips commence forward rotation producing **'simultaneous joint movements for force/power production' (C4)**. At last foot plant the front knee becomes rigid creating a **'pivot' (P2)** action that enhances the vertical movement of the body. As the hips commence rotating forwards the shoulders are still rotating backwards. The differentiated hip/shoulder rotation triggers a **'stretch-shortening cycle' (C1; stretch part)**, which is followed by sequential trunk rotation **(C1; shortening part)**, shoulder horizontal adduction, arm internal rotation and elbow extension. This **'proximal-to-distal sequence of movements' (C3)** results in a gradual increase of velocity culminating with the wrist snap at release. In fact, Atwater (1979) reported that the sequence of segments reaching peak angular velocity in skilled throwers was pelvis, upper trunk, upper arm, forearm and hand. The trunk flexes laterally to the side opposite to the throwing arm. Such action increases the orthogonal distance from the longitudinal axis of rotation through the trunk segment to the ball facilitating **'end-point speed' (S2)**. Such distance is further increased during elbow extension. Also, lateral trunk flexion positions the non-throwing arm at a greater distance from the throwing arm therefore enhancing the reaction effect (forward rotation of the throwing arm) initiated by the action of the non-throwing arm (shoulder horizontal abduction and elbow flexion). The principle that applies here is **'action-reaction' (C2)**.

Less-skilled forms

The mechanisms present in the throw of less skilled individuals differ from those found in proficient throwers. Techniques classed as effective, based on the application of movement principles, include the *leading opposite arm* (as described above) and the *cricketer's* (characterised by the rotational movement of both arms in the sagittal plane with the arms fully extended). Less skilled throwing techniques include *blocking*, *arc*, *straight* and *interrupted swing* techniques.

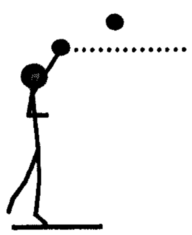
The *leading opposite arm* technique consists of a preparatory back swing that facilitates rotation of the body about the longitudinal axis. Such rotational movement allows the performer to maximize the impulse and work (Plagenhoef, 1971; Atwater, 1979), and also maximize the transfer of momentum from the non-throwing arm. The *cricketer's* technique comprises large rotational movement of the arms and shoulder girdle in the sagittal plane. Therefore, the radius of rotation of the throwing arm is long. The transfer of momentum from the non-throwing arm is very effective. There is a blocking action of the front leg that results in acceleration of distal segments (the throwing arm). However, the trajectory of the ball at release may be flatter compared to that when using the *leading opposite arm* technique. Both of these mature techniques are examples of good application of the principles of **'range of motion' (F1)**, **'end-point speed' (S2)**, **'action-reaction' (C2)** and **'stretch-shortening cycle' (C1)** during throwing; and of **'force production' (F3)**, **'limb rotational speed' (S3)** and **'pivot' (P2)** specifically in the *back lean* technique.

The blocking action of the front leg in the *blocking* technique, and subsequent deceleration of the trunk segment, causes acceleration of distal free segments (the throwing arm). This produces a whiplash effect on the throwing arm. While this is effective according to the principle of **'pivot' (P2)**, the *blocking* technique involves limited rotation of the trunk around the longitudinal axis and limited use of the opposite arm. This affects the speed of the ball at release according to the principles of **'range of motion' (F1)** and **'action-reaction' (C2)**. In the *arc* technique the performer produces rotation of the throwing arm in the transverse plane. Work done on the ball occurs due to horizontal arm adduction. It can be argued that the lateral component of the movement is not optimum for the forward propulsion of light objects; particularly when there is a run up preceding the back swing and swing phases. The moment of inertia presented by the partially extended throwing arm is relatively large. The *arc* technique shows, therefore, a poor application of the principle of **'limb rotational speed' (S3)**. There is an absence of rotation in the sagittal plane and, therefore, inefficient use of the power position typical of overarm throws. This technique relies on arm strength. The *straight* technique is mechanically ineffective. It relies on the forward momentum developed during the run up and the extension of the elbow, exclusively; in the absence of rotational movement of the trunk in the transverse plane. Thus, application of the principles of **'range of motion' (F1)**, **'stretch-shortening cycle' (C1)**, **'action-reaction' (C2)** and **'proximal-to-distal sequence of movements' (C3)** is not optimum. In young children the arm swing may be *interrupted* (Marqués-Bruna and Grimshaw, 1998). Such interruption denotes lack of coordination and attentional prioritisation in the child. Clearly, any elastic energy stored during the back swing (**'stretch-shortening cycle' (C1)**) is not used effectively due to the long delay between the end of the back swing and the swing.

Instant of release

Mature form

Release occurs when the hand reaches a position forward and above the head. At release the aims are to attain a high velocity of projection, to maximize the height of release, and to achieve a take off angle as close to 45° as possible as dictated by the principles of **'flight and projectile motion' (P3)**. Release height is enhanced by full extension of the body, as the body rotates about the ball of the planted foot.



Follow through phase

Mature form

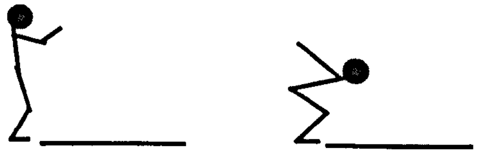
Although it is generally believed that the follow through adds nothing to the throw, an unrestricted follow through enables full force generation in the propulsive phase. Otherwise the follow through is used to dissipate the forward momentum and force-generating movements, and avoid strain and injury to the elbow joint and perhaps the lower back. The thrower may perform rotation of the body and free limbs over a large arc **('range of motion'; F1)** with the limbs fairly extended to maximise moment of inertia and perturb rotational speed **('limb rotational speed'; S3)**. Some throwers use a long forward step accompanied by lowering of the centre of gravity. This involves generating ground reaction forces over a relatively long time, which is effective as a follow through according to the principle of **('range of motion'; F1)**. However, such action involves eccentric loading of the quadriceps and glutei of the front leg and may not be as effective from an injury prevention viewpoint as dissipating the movement using aerial movements.

Phase description of the mature and less-skilled jumping actions with reference to the underpinning mechanical and biomechanical principles (based upon Lees, 1999b).

Countermovement phase

Mature form

According to Bunn (1972) the initial back swing serves to attain a rhythm of movement before the jump. Such rhythm enhances range of motion and facilitates the occurrence of **'stretch-shortening cycle' (C1)** across different muscle groups during the countermovement, particularly the glutei, quadriceps and calf muscles. As the arms pass the vertical position during the back swing the centre of gravity starts shifting forwards which enables an optimum direction of ground reaction force application and the associated take off angle later in the jump, needed to comply with the principles of **'flight and projectile motion' (P3).**

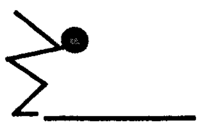


Instant of lowest crouching position

Mature form

The preliminary swing places the arms in a hyper-extended position that allows a forward swing of the arms through as large an arc as possible later in the propulsion phase. This enables longer application of ground reaction forces under the principle of **'range of motion' (F1).** The hyperextension of the arms pre-stretches the pectoral muscles allowing **'stretch-shortening cycle' (C1; stretch part).** Extension of the elbows permits greater length of the moment arm of the arms at the end of the swing and therefore a more effective lever system and a greater pre-stretch of the pectorals. Glutei, hamstrings and calf muscles are also pre-activated at the point of lowest crouching position. Extension of the elbows permits greater forward shift of the centre of gravity, therefore increasing the take off distance (or horizontal distance from the toes to the CG; based on Hay, 1993). The amount of crouch is proportional to muscle strength. Although a low crouch can be associated with increased range of hip and knee extension during the propulsive phase (**'range of motion'; F1**), the jumper reaches an optimum depth of the crouch to take advantage of the **'stretch-shortening cycle' (C1;**

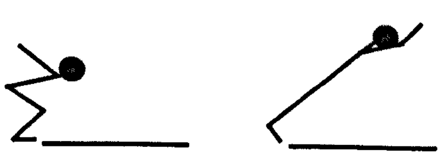
stretch part). However, if the jumper crouches too low the shortening part of the cycle may be compromised.



Propulsion phase

Mature form

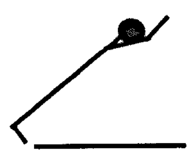
The large **'range of motion' (F1)** of the arms during the propulsion phase increases the impulse of the ground reaction force. Rotational acceleration of the arms during the swing allows greater takeoff velocity attained by greater peak ground reaction force and a higher rate of ground reaction force development. The elbows remain extended during the swing **(action effect)**, therefore increasing the length of the moment arm of the arms and by so doing increasing the ground reaction force **(reaction effect)**; under the principle of **'action-reaction' (C2)**. Arm movements need to be performed in the sagittal plane, since movements in any other direction are not effective in generating ground reaction forces in a forwards-upwards direction (**'force production'; F3)**. Hip and knee extension become **'simultaneous joint movements for force/power production' (C4)**. The ground reaction forces act on the centre of gravity of the jumper in a direction that enables a take off angle close to 45° as dictated by the principle of **'flight and projectile motion' (P3)**.



Instant of take off

Mature form

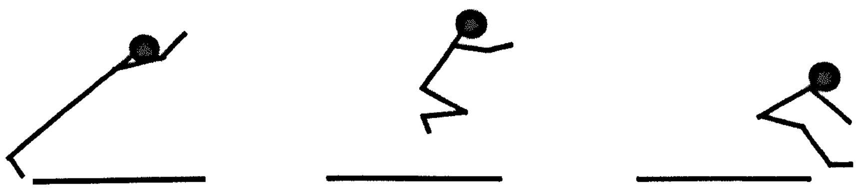
At take off the ankles are plantar flexed, the knees, hips and trunk are fully extended, and the take off angle nears 45°. These allow the highest position of the body's centre of gravity and an optimal angle of projection that determine the length of the jump under the principles of **'flight and projectile motion' (P3)**. Although full extension of the body and taking off from the toes permits application of force for the greatest possible distance (**'range of motion' (F1)** principle) and concomitantly increase the impulse, the highest projection velocity is attained just before the toes lose contact with the floor since plantar flexion provides little extra impulse. High velocity of take off is needed to conform to the principle of **'flight and projectile motion' (P3).** At the instant of take off the arms are held high above the head. That means that the maximum effective arc of arm swing has been attained.



Flight phase

Mature form

In mid flight the legs should be bent with the heels almost touching the buttocks, therefore creating minimum moment of inertia for greater **'limb rotational speed' (S3).** Forward swing of the legs occurs in a **'proximal-to-distal sequence of movements' (C3).** Although the reaction torque (**'action-reaction' (C2)** principle) applied by the lower legs to the thighs may cause the thighs to slow down, the lower legs actually speed up. Near touchdown the arms should be brought down, with the effect of elevating the feet a bit further as a reaction (**'action-reaction'; C2**) for a maximum forward reach.



Less-skilled forms

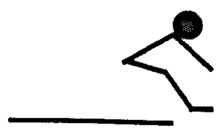
A mature jumping action (*mature* technique) involves movement of the arms in the sagittal plane in a well coordinated manner. The motion of the arms increases ground reaction forces during the propulsive phase and there is an effective transfer of momentum from the arms to the rest of the body (Bunn, 1972; Chen *et al.*, 1999), according to the principles of **'range of motion' (F1)** and **'force production' (F3).** The position of the arms after landing ensures balance and continued forward motion of the body's centre of gravity. Other less effective movements of the arms during the flight phase include the *pendulum*, *back circle*, *throw* and *no swing* techniques.

In the *pendulum* technique the contribution of arm movement to the jump is limited. The movement of the arms occurs in the sagittal plane but the lack of power is obvious. In the *back circle* technique, initially, the backward circular motion of the arms in the sagittal plane adds a propulsive component to the movement. However, the main function of the *back circle* motion is to correct for over rotation of the trunk, and this facilitates a delayed landing. The upward and forward throwing-like motion of the arms increases the ground reaction forces during take off in the *throw* technique. The child relies on the strength of the extensor muscles of the legs. Then, the downward or backward swing of the arms prior to landing is used in an attempt to prolong airborne time. If the child produces *no swing* of the arms at all, there is no contribution of the upper body segments to the jump. It is obvious that any of the less effective techniques used in the standing broad jump result in lower take off velocity, since these movements fail to comply with the mechanical principles of **'range of motion' (F1)** and **'force production' (F3)**.

Instant of touch down

Mature form

At landing, the arms should come forward to shift the centre of gravity forwards and keep the centre of gravity travelling along the arc of flight. This increases the landing distance (Hay, 1993).



Landing phase

Mature form

The landing pattern helps to dissipate the shock of landing by increasing the distance over which forces act. Landing involves large lower limb flexion (**'range of motion'; F1)**. Good dynamic balance increases the landing distance (Hay, 1993). High and forward position of the arms with the elbows extended helps to maintain the CG above or ahead of the feet to ensure **'stability' (F4).**

Description of the mechanical and biomechanical principles

Speed principles

S1 - Whole body running speed: Attained via successive accumulation of impulse applied to the body on each stride according to the impulse-momentum relationship ($F \cdot t = \Delta m \cdot v$), which is derived from Newton's Second Law.

S2 - End-point speed: This is equal to the product of speed of rotation and length of axis of rotation ($v = r \cdot \omega$).

S3 - Limb rotational speed: When a limb is flexed it has a low moment of inertia and an applied torque will cause a greater angular acceleration and angular velocity. This principle represents the angular form of Newton's Second Law ($T = I \cdot \alpha$).

Force principles

F1 - Range of motion: Increasing the range of motion extends the distance of force application ($W = F \cdot d$). This has direct effect on kinetic energy ($F \cdot d = \frac{1}{2} m \cdot v^2$), as stated in Newton's Second Law. Greater range of motion is likely to result in longer time of force application and therefore greater impulse. This will have an effect on the takeoff velocity of the ball or centre of gravity according to the impulse-momentum relationship ($F \cdot t = \Delta m \cdot v$), which derives from Newton's Second Law.

F2 - Impact to stationary ball: An impulse results in a change in the total momentum of the system according to the impulse-momentum relationship ($F \cdot t = \Delta m \cdot v$), derived from Newton's Second Law.

F3 – Force production: Based on Newton's 3rd Law, an action force is applied to the ground by using joint extension and the reaction force is responsible for the movement of the body.

F4 – Stability: From Newton's Second Law, this mechanical principle expresses the relationship between work and energy ($F \cdot d = \Delta m \cdot g \cdot h$). The height of the centre of gravity above the base of support determines the stability of the system.

Coordination principles

C1 – Stretch-shortening cycle: A biomechanical principle. A muscle can generate a greater angular impulse if it is activated maximally when at zero shortening velocity – this creates a preload.

C2 – Action-reaction: Here Newton's Third Law and the principle of conservation of angular momentum derived from this law are applied to angular movement.

C3 - Proximal-to-distal sequence of movements: Based on Newton's Third Law and the conservation of angular momentum, this mechanical principle implies build up of velocities from segment to segment in an open kinetic chain, even tough the proximal heavier segment is decelerated in the process.

C4 - Simultaneous joint movements for force/power production: Based on Newton's 3rd Law, an action force is applied to the ground by using joint extension and the reaction force is responsible for the movement of the body. To ensure that a linked body segment chain kinetic utilises the ground as a firm base for force production the muscles around the body must produce force simultaneously, so that there is no 'giving' at any joint.

Specific performance principles

P1 - Speed-accuracy trade off: This biomechanical principle is based on the fact that neuromuscular control becomes less precise as the speed of movement increases.

P2 – Pivot: The effect of a pivot is the same as that stated for the conditions of 'end-point speed' (S2) above. However, the pivot affects the vertical component of the velocity.

P3 - Flight and projectile motion: This principle dictates the motion of objects when the solely force acting upon them is gravity (disregarding air resistance).

Appendix 5: Relative range values vs. technical level.

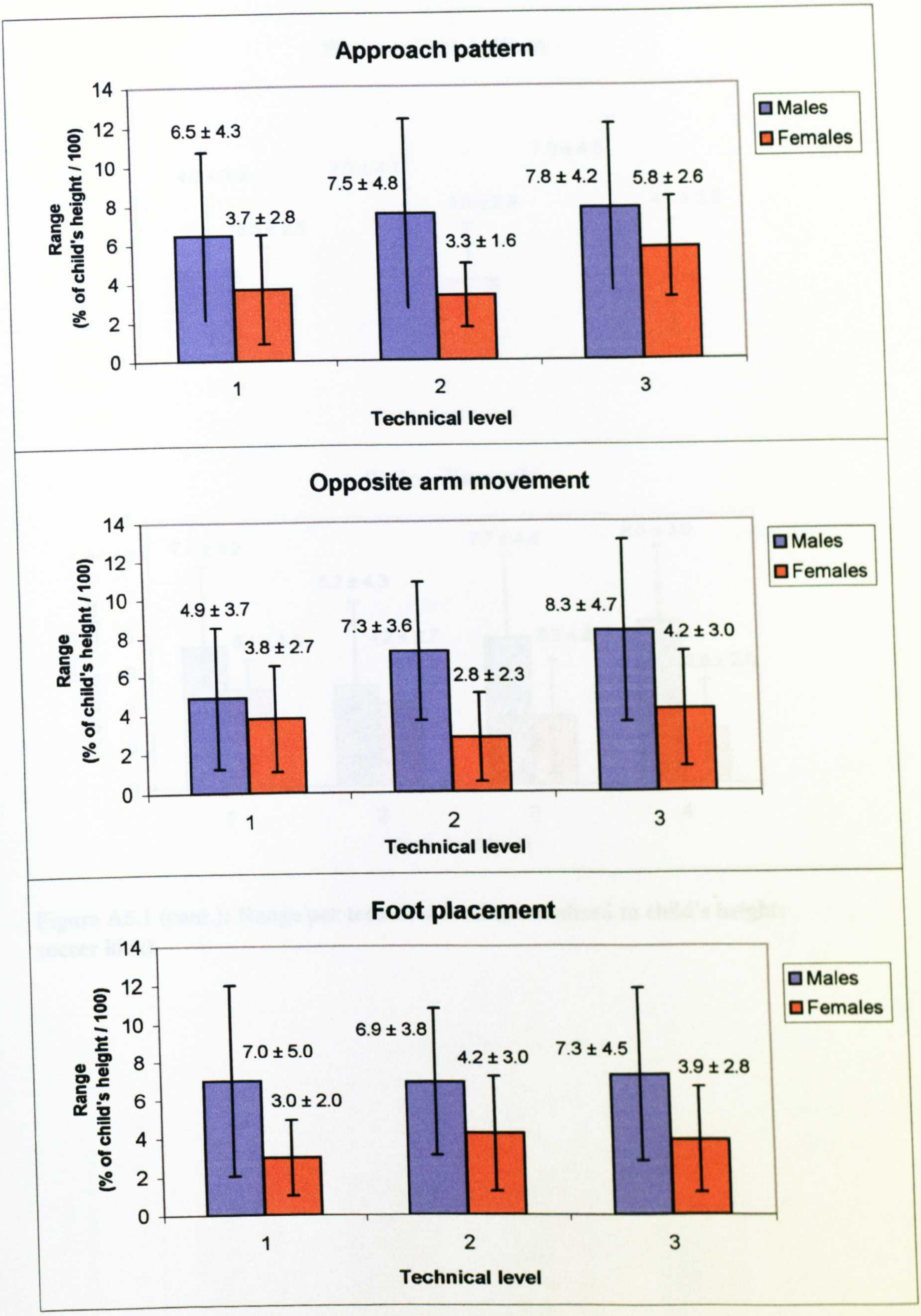


Figure A5.1: Range per technical level (normalised to child's height; soccer kick).

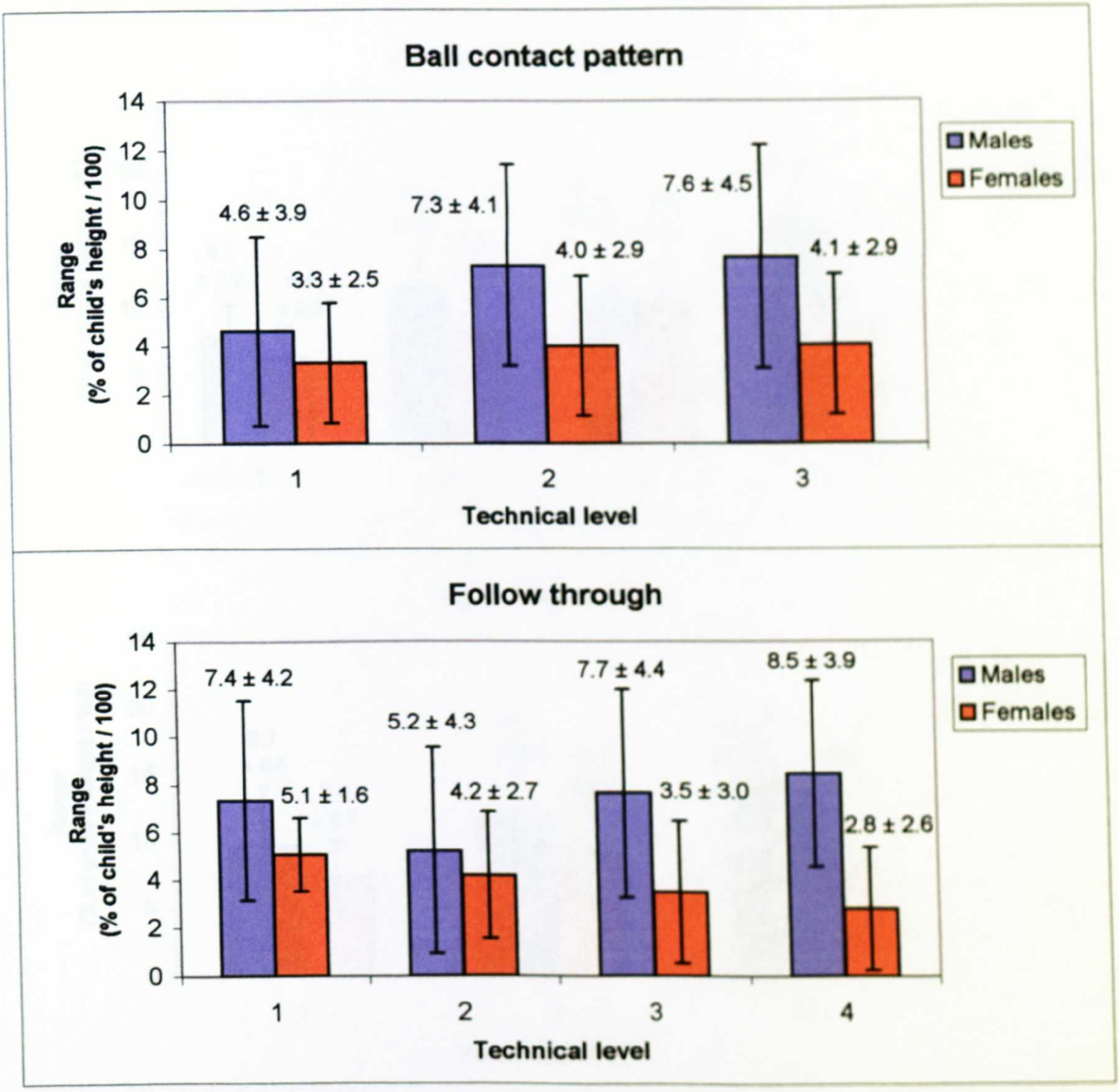


Figure A5.1 (cont.): Range per technical level (normalised to child's height; soccer kick).

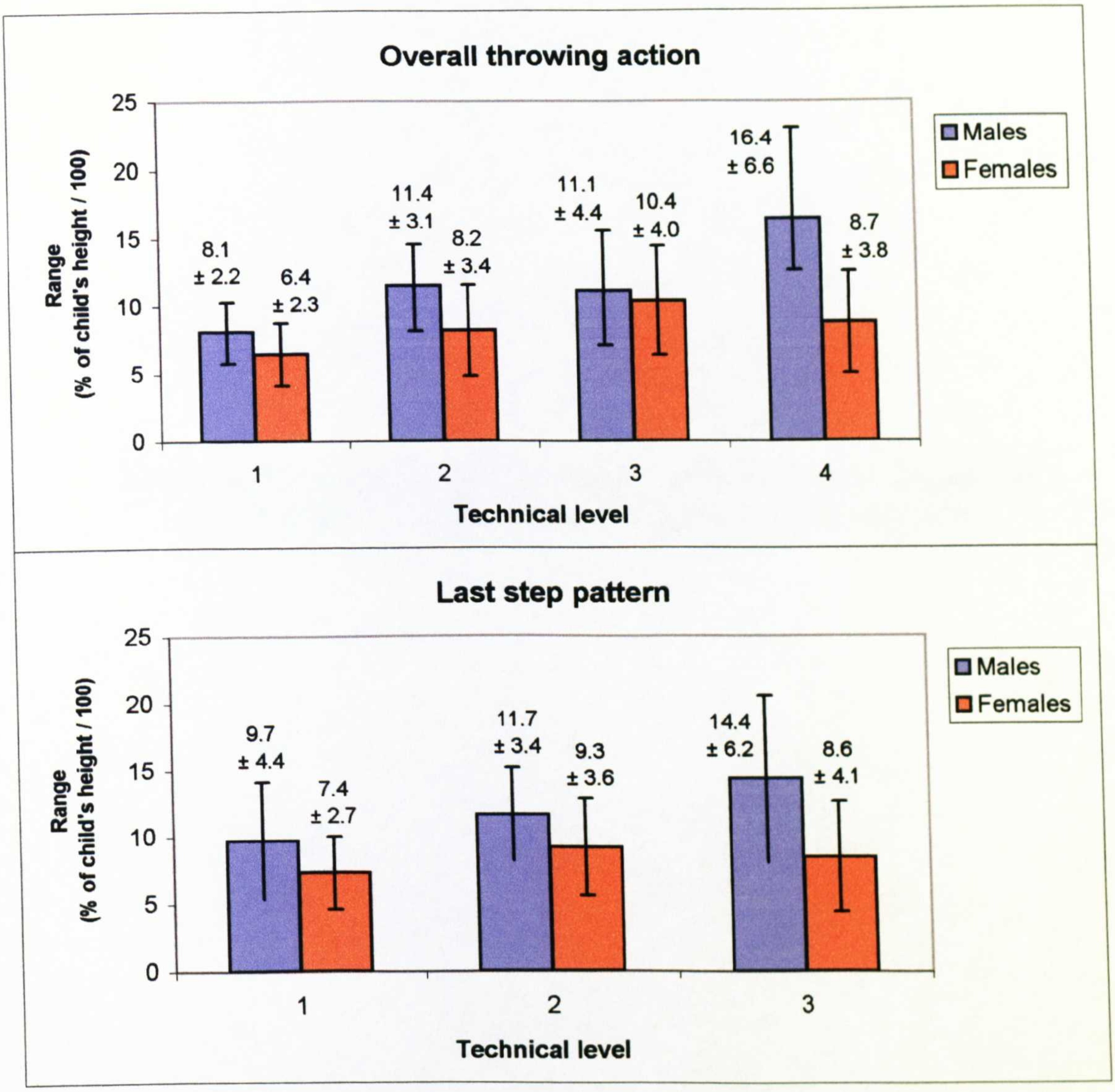


Figure A5.2: Range per technical level (normalised to child's height; overarm throw).

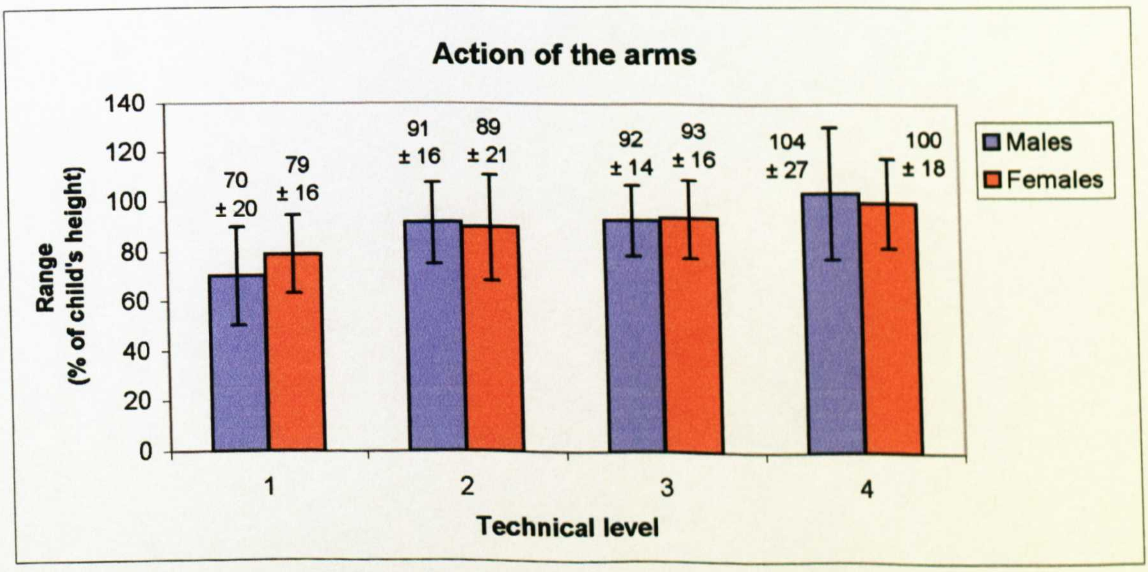


Figure A5.3: Range per technical level (normalised to child's height; standing broad jump).

Appendix 6: Analytical components of the overarm throw and the standing broad jump (mechanical and perceptual)

Table A6.1: The 20 analytical components of the overarm throw (mechanical).

Phase, subphase or key instant	Critical variable	Classification of variable	Mechanical purpose	Movement principle	Mechanical variable affected (deterministic model)	Optimum value (or qualitative description)	Range of optimum values
Approach phase	speed of approach	performance	build up of controlable speed	whole body running speed	initial velocity 1.1	fast run [a]	*not defined*
Last homolateral foot contact instant	homolateral foot position	technique	pivot	pivot	distance 1.3	> 20 cm [b]	*not defined*
Back swing phase	maximum knee flexion	technique	impulse	range of motion	leg forces 1.2.1	large [c]	*not defined*
	length of the last step	technique	impulse	range of motion	leg forces 1.2.1	1.18 m or 65 % height (males); 1.0 m or 60 % (females) [d]	1.28-1.65 m or 65-94 % (males); 0.5-1.0 m or 33-60 % (females)
	maximum rotation of the body	technique	pre-stretch	stretch-shortening cycle	trunk forces 1.2.2	90^0 [e]	*not defined*
	maximum backward trunk inclination	technique	range of motion	end-point speed	trunk forces 1.2.2	approx. 20^0 [f]	*not defined*
	position of the leading arm	technique	balance	action-reaction	arm forces 1.2.3	forwards and high [g]	*not defined*

Table A6.1 (cont.): The 20 analytical components of the overarm throw (mechanical).

Phase, subphase or key instant	Critical variable	Classification of variable	Mechanical purpose	Movement principle	Mechanical variable affected (deterministic model)	Optimum value (or qualitative description)	Range of optimum values
Back swing phase (cont.)	throwing arm retraction, shoulder abduction, & elbow angle	technique	pre-stretch	stretch-shortening cycle	arm forces 1.2.3	>90° horizontal abduction 90° abduction 90° angle [h]	90 ± 15° abduction [h]
Swing phase	ground reaction forces	performance	power	force production	leg forces 1.2.1	vigorous leg drive is essential [i]	*not defined*
	maximum trunk rotation	technique	range of motion	end-point speed	trunk forces 1.2.2	90° [j]	almost 90°
	maximum lateral trunk inclination	technique	balance	stability	arm forces 1.2.3	45° [k]	*not defined*
	shoulder horizontal abduction & elbow flexion (leading arm)	technique	balance	action-reaction	arm forces 1.2.3	arm moves forcefully towards body' [l]	*not defined*
	shoulder horizontal adduction (throwing arm)	technique	proximal to distal sequence	end-point speed	arm forces 1.2.3	90° adduction ~180° angle [m]	75-105° adduction 50-60° (women)- ~180° angle [m]
	rotational velocity of throwing arm	performance	power	end-point speed	release velocity 1	humeral internal rotation = 1000 deg/s (females); 2000 deg/s (males) [n]	swing time = 233-197 ms (females) [n]

Table A6.1 (cont.): The 20 analytical components of the overarm throw (mechanical).

Phase, subphase or key instant	Critical variable	Classification of variable	Mechanical purpose	Movement principle	Mechanical variable affected (deterministic model)	Optimum value (or qualitative description)	Range of optimum values
Release instant	velocity of ball release	performance *'criterion-process'*	maximum range	flight & projectile	distance 0	25.6 m/s (women); 40 m/s (men) [o]	33.5-40 m/s (men); 15-25.6 m/s (women) [o]
	angle of ball release	technique *'criterion-process'*	maximum range	flight & projectile	distance 0	45^0 [p]	*not defined*
	height of ball release	technique *'criterion-process'*	maximum range	flight & projectile	distance 0	2.15 m [q]	30-40 cm above head [q]
Follow through phase	rotation of body & free limbs	technique	force dissipation	injury prevention	*'post release'*	*very large* [r]	*not defined*
	length of 1st step & lowering of CG	technique	force dissipation	injury prevention	*'post release'*	> 75% & 'very low' [s]	*not defined*
General	coordination & rhythm	performance	timing	coordination	*'various'* coordination principle	*sequential pattern described* [t]	*not defined*

Table A6.1 (cont.): The 20 analytical components of the overarm throw (mechanical).

Phase, subphase or key instant	Critical variable	Classification of variable	Values for children (5-6 years)	(7-8 years)	(9-11 years)
movement goal	range	performance *'criterion-ultimate'*	7.7-13.4 m (boys); 4.2-7.6 m (girls) [u]	15.2-19.2 m (boys); 8.5-10.7 m (girls) [u]	18.7-23.3 m (boys); 8.8-17.5 m (girls) [u]

References - a) determined experimentally; **b)** determined experimentally; **c)** Atwater (1970), Hay (1993); **d)** Atwater (1979); **e)** Atwater (1979); **f)** Atwater (1979); **g)** Plagenhoef (1971), Atwater (1979); **h)** Atwater (1979), Knudson & Morrison (2002); **i)** Miller (1980); **j)** Atwater (1979); **k)** Atwater (1979); **l)** Payne & Isaacs (1991); **m)** Atwater (1970), Plagenhoef (1971) (*'strong throwing position'*, p. 97), Atwater (1979); **n)** Atwater (1970), Thomas & Marzke (1992); **o)** Logan, McKinney, Rowe & Lumpe (1966), Straub (1968), Atwater (1970), Tarbell (1971), Toyoshima & Miyashita (1973), Toyoshima *et al*. (1974), Anderson (1976), Cooper & Glassow (1976), Leme & Shambes (1978); **p)** Bunn (1972), Raudsepp & Paasuke (1995); **q)** Atwater (1977, 1982); **r)** determined experimentally; **s)** determined experimentally; **t)** Toyoshima *et al*. (1974), Atwater (1979), Haywood & Getchell (2001), Hay (1993); **u)** Hardin & Garcia (1982), Nelson *et al*. (1991), Raudsepp & Paasuke (1995).

Table A6.2: The 20 analytical components of the overarm throw (perceptual).

Phase, subphase or key instant	Critical variable	Perceptual aspects (video)	Use of cues	Units / descriptors
Approach phase	speed of approach	normal speed, then frame by frame	frame count	qualitative descriptor
Last homolateral foot contact inst.	homolateral foot position	frame-freeze	locate CG	cm / qualitative descriptor
Back swing phase	maximum knee flexion	frame-freeze		qualitative descriptor
	length of last step	frame-freeze	child's height	percentage of child's height
	maximum rotation of the body	frame by frame	body orientation	deg.
	maximum backward trunk inclination	frame-freeze		deg.
	position of the leading arm	frame by frame		deg. / qualitative descriptor
	throwing arm retraction, shoulder abduction, & elbow angle	frame by frame	watch prestretch	deg. / qualitative descriptor
Swing phase	ground reaction forces	normal speed & repeated observation	extension of leg	qualitative descriptor
	maximum trunk rotation	slow motion	trunk orientation	deg.
	maximum lateral trunk inclination	frame by frame	trunk orientation	qualitative descriptor
	shoulder horizontal abduction & elbow flexion (leading arm)	slow motion		qualitative descriptor
	shoulder horizontal adduction (throwing arm)	slow motion		deg. / qualitative descriptor
	rotational velocity of throwing arm	normal speed & repeated observation	consider ROM & time	qualitative descriptor

Table A6.2 (cont.): The 20 analytical components of the overarm throw (perceptual).

Phase, subphase or key instant	Critical variable	Perceptual aspects (video)	Use of cues	Units / descriptors
Release instant	velocity of ball release	normal speed, then slow motion	watch follow through	qualitative descriptor
	angle of ball release	slow motion	background references	deg. / qualitative descriptor
	height of ball release	frame-freeze	child's height	qualitative descriptor
Follow through phase	rotation of body & free limbs	slow motion	trunk orientation	qualitative descriptor
	length of 1st step & lowering of CG	frame-freeze & slow motion	child's height	% of child's height / qual. descriptor
General	coordination & rhythm	normal speed, then slow motion	effortlessness	qualitative descriptor

Table A6.3: The 19 analytical components of the standing broad jump (mechanical).

Phase, subphase or key instant	Critical variable	Classification of variable	Mechanical purpose	Movement principle	Mechanical variable affected (deterministic model)	Optimum value (or qualitative description)	Range of optimum values
Counter-movement phase	segmental movement coordination	technique	timing	coordination	*'various'* coordination principle	excellent timing [a]	*not defined*
Lowest crouching position instant	depth of crouch	technique	large acceleration path	whole-body speed	leg forces 2.2.1.1.1.1	compact [b]	*not defined*
	maximum arms hyperextension	technique	pre-stretch	stretch-shortening cycle	arm forces 2.2.1.1.1.3	*'arms move high and to rear'* [c]	*not defined*
	elbow angle (1)	technique	impulse	range of motion	arm forces 2.2.1.1.1.3	fully extended [d]	*not defined*
Propulsion phase	arc of arm swing & elbow angle	technique	impulse	range of motion	arm forces 2.2.1.1.1.3	$>225^0$, extended [e]	*not defined*
	velocity of arm swing	performance	power	power production	arm forces 2.2.1.1.1.3	powerful swing [f]	*not defined*
	forces exerted by lower limbs (GRF)	performance	power	force production	leg forces 2.2.1.1.1.1	leg production~ 81% of distance jumped [g]	*not defined*

Table A6.3 (cont.): The 19 analytical components of the standing broad jump (mechanical).

Phase, subphase or key instant	Critical variable	Classification of variable	Mechanical purpose	Movement principle	Mechanical variable affected (deterministic model)	Optimum value (or qualitative description)	Range of optimum values
Takeoff instant	extension of body segments	technique *'criterion-process'*	optimum takeoff height	flight & projectile	flight distance 2	full extension of arms overhead [h]	*not defined*
	position of upper arms	technique *'criterion-process'*	optimum takeoff height	flight & projectile	flight distance 2	> 160^0 of shoulder flexion [i]	*not defined*
	velocity of takeoff	performance *'criterion-process'*	maximum range	flight & projectile	flight distance 2	very high [j]	*not defined*
	angle of takeoff (CG)	technique *'criterion-process'*	maximum range	flight & projectile	flight distance 2	45^0 [k]	about 45^0 [k]
Flight phase	angles of knees and hips (mid flight)	technique	moment of inertia	limb rotational speed	body position 3.2	$< 60^0$/ $<20^0$ [l]	*not defined*
	velocity of hip flexion	performance	range	limb rotational speed	body position 3.2	powerful swing [m]	*not defined*
Touch down instant	CG landing trajectory	technique	range	flight & projectile	body position 3.2	heels 5.5 inches ahead of CG [n]	*not defined*

Table A6.3 (cont.): The 19 analytical components of the standing broad jump (mechanical).

Phase, subphase or key instant	Critical variable	Classification of variable	Mechanical purpose	Movement principle	Mechanical variable affected (deterministic model)	Optimum value (or qualitative description)	Range of optimum values
Landing phase	compression	technique	balance	stability	actions at landing 3.3	compact [o]	*not defined*
	final position of the arms	technique	range	stability	actions at landing 3.3	$< 30^0$ [p]	*not defined*
	elbow angle (2)	technique	moment of inertia	stability	actions at landing 3.3	*not defined*	$150\text{-}180^0$ [q]
	dynamic balance	technique	balance	coordination	actions at landing 3.3	*not defined*	*not defined*
General	movement direction, symmetry & coordination	technique/ performance	timing	coordination	*'various'* coordination principle	outlined [s]	*not defined*

Table A6.3 (cont.): The 19 analytical components of the standing broad jump (mechanical).

Phase, subphase or key instant	Critical variable	Classification of variable	Values for children (5-6 years)	(7-8 years)	(9-11 years)	Optimum value (or qualitative description)	Range of optimum values
movement goal	range	performance *'criterion-ultimate'*	109.2 - 86.4 cm (boys & girls)	119-148 cm (boys); 114-132 cm (girls)	140-155 cm (boys); 127-142 cm (girls) [t]	281.7 cm adult males	203 cm to 281.7 cm adult males [t]

References - **a)** determined experimentally; **b)** determined experimentally; **c)** Gallahue & Ozmun (1995; pp. 255); **d)** determined experimentally; **e)** determined experimentally; **f)** determined experimentally; **g)** Dowell & Lee (1991); **h)** Payne & Isaacs (1991); **i)** Clark & Phillips (1985); **j)** determined experimentally; **k)** Bunn (1972), McClenaghan (1976), Gallahue & Ozmun (1995); **l)** determined experimentally; **m)** determined experimentally; **n)** Felton (1960); **o)** determined experimentally; **p)** determined experimentally; **q)** determined experimentally; **r)** not defined; **s)** Hellebrandt *et al.* (1961), McClenaghan (1976), Keogh & Sugden (1985), Hudson (1986), Bobbert & Ingen Schenau (1988), Gallahue & Ozmun (1995); **t)** Morris *et al*. (1982), Clark & Phillips (1985), Keogh & Sugden (1985), Dowell & Lee (1991), Merriman *et al*. (1993), Raudsepp & Paasuke (1995).

Table A6.4: The 19 analytical components of the standing broad jump (perceptual).

Phase, subphase or key instant	Critical variable	Perceptual aspects (video)	Use of cues	Units / descriptors
Counter-movement phase	segmental movement coordination	normal speed	unusual, erratic movement	qualitative descriptor
Lowest crouching position instant	depth of crouch	frame-freeze	watch knee & hip flexion	qualitative descriptor
Lowest crouching position instant	maximum arms hyperextension	frame-freeze		deg.
Lowest crouching position instant	elbow angle (1)	frame-freeze		deg. / qualitative descriptor
Propulsion phase	arc of arm swing & elbow angle	frame by frame	background references	deg. / qualitative descriptor
Propulsion phase	velocity of arm swing	normal speed, then frame by frame		qualitative descriptor
Propulsion phase	forces exerted by lower limbs (GRF)	slow motion, normal speed	ROM	qualitative descriptor
Takeoff instant	extension of body segments	frame-freeze		qualitative descriptor
Takeoff instant	position of upper arms	frame-freeze	background references	deg. / qualitative descriptor
Takeoff instant	velocity of takeoff	normal speed, then frame by frame		qualitative descriptor
Takeoff instant	angle of takeoff (CG)	slow motion	watch flight trajectory	deg.
Flight phase	angles of knees and hips (mid flight)	frame-freeze	compactness	deg.
Flight phase	velocity of hip flexion	normal speed	ROM of legs	qualitative descriptor
Touch down instant	CG landing trajectory	slow motion	watch landing action	qualitative descriptor
Landing phase	compression	slow motion	watch hip & knee flexion	qualitative descriptor
Landing phase	final position of the arms	slow motion	background references	deg. / qualitative descriptor
Landing phase	elbow angle (2)	frame by frame		deg.
Landing phase	dynamic balance	normal speed	unusual movement	qualitative descriptor
General	movement direction, symmetry & coordination	normal speed, then slow motion	effortlessness	qualitative descriptor

Appendix 7: Results of the accuracy and intra-rater reliability tests for the overarm throw and the standing broad jump

Table A7.1: Rating scales for selected variables of the maximum-distance overarm throw.

Phase or instant	Variable	Score 0	1	2	3	4
Approach phase	speed of approach (m/s; qualitative descriptor)	static	< 2	> 2		
Last homol. foot contact instant	position of homolateral foot (cm; qualitative descriptor)[1]	behind or underneath	1-20	> 20		
Back swing phase	length of last step (%)[2]	< 30	30-40	41-50	> 50	
	maximum backward trunk inclination (deg)[3]	0-5	6-20	> 20		
	position of the leading arm (deg)[4]	-90 to -61	-60 to -31	-30 to 0	positive	
	retraction of throwing arm (deg; qualitative descriptor)[*,5]	arm-dominated	±11-45 /30-60	±10 /61-90		
	throwing elbow angle (deg)[6]	> -30	-30 to -1	positive		
Release instant	velocity of release (m/s)		1-10	> 10		
	angle of release (deg)	negative or 90	0-10 or 89-71	11-25 or 70-51	26-50	
	heigth of release (%)[2]	< 80	80-90	91-99	100	> 100
Follow through phase	length of 1st step (%)[2]	< 25	25-50	51-75	> 75	
	lowering of the CG (%)[7]	0	5-10	11-20	> 20	

*** overarm/cricketer's technique**

[1] Relative (forward) to CG position; [2] Percentage of child's height; [3] Measured with respect to the vertical; [4] Measured to the right horizontal; [5] Angle of humerus to left horizontal; [6] Relative angle; [7] Percentage of standing CG height.

Table A7.2: Summary of the results of the accuracy tests (overarm throw; N = 15).

Variable	On-screen measures		Visually-estimated measures (median of scores)	Agreement (%) **	*k*	Sig.***
	Kinematic measure (mean ± SD)	Median score*				
speed of approach (m/s)	1.6 ± 0.8	1	2	80	0.654	0.001
position of homolateral foot (cm)	10.3 ± 8.6	1	1	90	0.894	0.001
length of last step (%)	47.7 ± 12.5	3	2	80	0.694	0.001
max. backw. trunk inclination (deg)	16.9 ± 10.2	1	2	80	0.667	0.001
position of the leading arm (deg)	8.6 ± 46.8	3	3	85	0.760	0.001
retraction of throwing arm (deg)	30.7 ± 44.7	2	2	100	1.000	0.001
throwing elbow angle (deg)	1.7 ± 41.2	2	2	90	0.508	0.005
velocity of release (m/s)	12.7 ± 2.4	2	2	80	0.583	0.024
angle of release (deg)	35.5 ± 12.4	3	3	80	0.545	0.018
heigth of release (%)	108.8 ± 8.9	4	4	80	0.762	0.002
length of 1st step (%)	16.7 ± 15.8	0	0	90	0.865	0.001
lowering of the CG (%)	4.3 ± 3.8	0	0	85	0.732	0.005

* Median of the scores obtained from the conversion of on-screen kinematic measures into a score using the rating scales in Table A7.1.

** Agreement between scores obtained from the conversion of on-screen measures into a score and scores obtained using visual-estimation.

*** All Kappa results are significant ($p < 0.05$)

Table A7.3: Results of the tests of intra-rater reliability in the determination of mechanical effectiveness (overarm throw; N = 15).

	Approach phase	Last contact instant	Back swing phase						Swing phase						Release instant			Follow through phase		General
	Speed of approach	Homolateral foot position	Maximum knee flexion	Length of last step	Maximum body rotation	Max. backward trunk inclination	Leading arm position	Throwing arm retraction	Ground reaction force	Maximum trunk rotation	Max. lateral trunk inclination	Leading arm abduction	Throwing arm horizontal adduction	Rotational velocity (throwing arm)	Velocity of ball release	Angle of ball release	Height of ball release	Rotation of body & free limbs	Step length & CG lowering	Coordination & rhythm
Median score (test 1)	2	0	2	3	3	2	3	2	1	3	2	2	3	2	2	3	4	2	0	2
Median score (test 2)	1	1	2	3	3	2	2	2	1	3	2	2	3	2	2	3	4	2	0	2
Agreement (%)	80	80	80	93	93	87	87	93	93	87	87	87	93	87	100	93	100	80	87	87
k	0.679	0.685	0.681	0.892	0.773	0.694	0.796	0.898	0.634	0.773	0.688	0.783	0.762	0.634	1.000	0.773	0.634	0.696	0.877	0.737
Sig. (*k*)*	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.008	0.001	0.001	0.001	0.002	0.008	0.001	0.001	0.008	0.001	0.001	0.001

* All Kappa results are significant ($p < 0.05$)

Table A7.4: Rating scales for selected variables of the standing broad jump.

Phase or instant	Variable	Score				
		0	1	2	3	4
Lowest crouching position instant	depth of crouch (%)[1]	< 25 or > 50	25-35	36-45		
	maximum arms hyperextension (deg)[2]	> -90	-90 to -46	-45 to 1	0-45	> 45
	elbow angle (1) (deg)[3]	< 90	90-120	121-150	151-170	171-180
Propulsion phase	arc of arm swing (deg)	< 90	90-135	136-180	181-225	> 225
Takeoff instant	extension of body segments (deg)[4]	< 120	120-140	141-160	161-180	
	position of the upper arms (deg)[5]	> -90	-90 to -46	-45 to -6	-5 to 5	> 5
	velocity of takeoff (m/s)		0-2	> 2		
	angle of takeoff (CG) (deg)	0-19 or > 45	20-45			
Flight phase	angle of knees (mid flight) (deg)[3]	> 120	120-91	90-60	< 60	
	angle of hips (mid flight) (deg)[5]	> 80	80-61	60-46	45-20	< 20
	velocity of hip flexion (deg/s)		< 400	>400		
Landing phase	compression (deg)[6]	135	134-91	90-50	< 50	
	final position of the arms (deg)[5]	> 90	90-61	60-30	< 30	

[1] Percentage of standing CG height; [2] Measured with respect to the left horizontal; [3] Relative angle; [4] Mean of hip and knee angles; [5] Measured to the right horizontal; [6] Measured using relative knee angle.

Table A7.5: Summary of the results of the accuracy tests (standing broad jump; N = 15).

Variable	On-screen measures		Visually-estimated measures (median of scores)	Agreement (%)**	*k*	Sig.***
	Kinematic measure (mean ± SD)	Median score*				
depth of crouch (%)	37.8 ± 4.3	2	2	80	0.553	0.036
maximum arms hyperextension (deg)	16.9 ± 52.9	3	4	80	0.691	0.001
elbow angle (1) (deg)	166.8 ± 34.4	4	4	80	0.468	0.025
arc of arm swing (deg)	201.4 ± 74.1	3.5	3	80	0.710	0.001
extension of body segments (deg)	168.0 ± 15.7	3	3	80	0.462	0.040
positon of the upper arms (deg)	5.1 ± 61.5	4	3.5	80	0.759	0.001
velocity of takeoff (m/s)	2.1 ± .6	1.5	1	85	0.714	0.005
angle of takeoff (CG) (deg)	26.8 ± 9.2	1	1	80	0.759	0.003
angle of knees (mid flight) (deg)	69.7 ± 28.8	2	2.5	80	0.691	0.001
angle of hips (mid flight) (deg)	38.0 ± 12.9	3	3	80	0.745	0.001
velocity of hip flexion (deg/s)	417.9 ± 92.2	2	2	85	0.650	0.015
compression (deg)	86.3 ± 32.0	1.5	2	80	0.687	0.001
final position of the arms (deg)	69.3 ± 39.6	1.5	2	80	0.689	0.001

* Median of the scores obtained from the conversion of on-screen kinematic measures into a score using the rating scales in Table A7.4.
** Agreement between scores obtained from the conversion of on-screen measures into a score and scores obtained using visual-estimation.
*** All Kappa results are significant ($p < 0.05$)

Table A7.6: Results of the tests of intra-rater reliability in the determination of mechanical effectiveness (standing broad jump; N = 15).

Phase	Criterion	Median score (test 1)	Median score (test 2)	Agreement (%)	k	Sig. (k)*
Countermovement phase	Segmental movement coordination	1	1	80	0.661	0.001
Lowest crouching position instant	Depth of the crouch	2	2	80	0.720	0.001
	Maximum arms hyperextension	3	3	80	0.718	0.001
	Elbow angle (1)	4	4	80	0.696	0.001
Propulsion phase	Arc of armswing & elbow angle	3	3.5	87	0.897	0.001
	Velocity of arm swing	2	2	80	0.548	0.011
	Force exerted by lower limbs	2	2	80	0.553	0.036
Take off instant	Extension of body segments	3	3	87	0.440	0.047
	Positon of the upper arms	3	3	80	0.682	0.001
	Velocity of takeoff	1	1	93	0.851	0.001
	Angle of takeoff (CG)	1	1	100	0.632	0.011
Flight phase	Angles of knees & hips (mid flight)	2	2	87	0.691	0.001
	Velocity of hip flexion	2	2	93	1.000	0.001
Touch down instant	CG landing trajectory	1	2	80	0.661	0.001
Landing phase	Compression	2	2	80	0.659	0.001
	Final position of the arms	2	2	87	0.780	0.001
	Elbow angle (2)	3	3	80	0.720	0.001
	Dynamic balance	1	1	80	0.661	0.001
General	Direction of movement, symmetry & coordination	1	1	80	0.558	0.006

* All Kappa results are significant ($p < 0.05$)

Appendix 8: Scoring references and scoring tables for the overarm throw and the standing broad jump

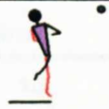
Table A8.1: Scoring reference for the maximum-distance overarm throw.

Phase, subphase or instant	Technique / performance variable	Scores 0	1	2	3	4
Approach phase	Speed of approach	static	jog	fast run		
Instant of last homolateral foot contact	Position of homolateral foot (relative to CG)	behind or below	1-20 cm forwards	> 20 cm well forwards		
Back swing phase	Maximum knee flexion (homolateral leg)	none	moderate	large		
	Length of the last step (relative to child's height)	< 30 %	30-40 %	41-50 %	> 50 %	
	Maximum rotation of the body (transverse plane)	none	$1\text{-}30^0$	$31\text{-}60^0$	$61\text{-}90^0$	
	Maximum backward trunk inclination	$0\text{-}5^0$	$6\text{-}20^0$	$> 20^0$		
	Position of the leading arm	-90 to -61^0	-60 to -31^0	-30 to 0^0	forward & high	
	Retraction of the throwing arm, angle of shoulder abduction, & elbow angle	arm-dominated	on the side, too low/high, & underflexed	behind head, $\sim 90^0$, & $\sim 90^0$		

Table A8.1 (cont.): Scoring reference for the maximum-distance overarm throw.

Phase, subphase or instant	Technique / performance variable	Scores: 0	1	2	3	4
Swing phase	**Magnitude of ground reaction forces (GRF) (homolateral leg)**	low	powerful push			
	Maximum trunk rotation (transverse plane)	none	$1\text{-}30^0$	$31\text{-}60^0$	$61\text{-}90^0$	
	Maximum lateral inclination of the trunk (to non-throwing side)	none	slight (back view)	large		
	Shoulder horizontal abduction & elbow flexion (leading arm)	none	partial	large		
	Shoulder horizontal adduction (throwing arm)	arm-dominated	$\sim 60^0$ arc	$\sim 120^0$ arc	$\geq 180^0$ arc	
	Rotational velocity of the throwing arm		low	powerful throw		
Instant of release	**Velocity of ball release**	very low	medium (50 Hz)	very high		
	Angle of ball release	downward or too vertical	$0\text{-}10^0$ or $80\text{-}71^0$	$11\text{-}25^0$ or $70\text{-}51^0$	$26\text{-}50^0$	
	Height of ball release (relative to child's height)	below shoulder	neck level	face level	top of head	very high

Table A8.1 (cont.): Scoring reference for the maximum-distance overarm throw.

Phase, subphase or instant	Technique / performance variable	Scores				
		0	1	2	3	4
Follow through phase	**Rotation of the body & free limbs (transverse plane)**	 none	 slight	 large	 very large	
	Length of 1st step (relative to child's height) & lowering of the CG	 < 25 % & high	 25-50 % & low	 51-75 % & low	 > 75 % & very low	
General	**Coordination & rhythm**	staccato	fair	smooth, effortless		

Key:
red - non-throwing side
solid - initial posture
dashed - final posture

 front  back

Table A8.2: Alternative scoring reference for the maximum-distance overarm throw.

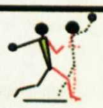
Phase, subphase or instant	Technique / performance variable	Scores 0	1	2	3	4
Homolateral step pattern						
Back swing phase	Differentiated rotation of the trunk (transverse plane)	 none	 1-30^0	 31-60^0	 61-90^0	
Swing phase	Magnitude of GRFs generated by the legs	low	powerful push			
	Rotation of the trunk (transverse plane)	 none	 1-30^0	 31-60^0	 61-90^0	
Cricketer's technique						
Back swing phase	Position of the throwing arm	 horizontal	 1-30^0	 31-60^0	 61-90^0	
Swing phase	Rotation of the leading arm	 none	 partial	 large		
	Rotation of the throwing arm	 < 120^0 arc	 120-140^0 arc	 141-180^0 arc	 > 180^0 arc	

Table A8.3: Scoring table for the maximum-distance overarm throw.

Phase, subphase or instant	Technique / performance variable	Score					Subtotal
Approach phase	Speed of approach	0	1	2			50% 2
Last homol. inst.	Position of the homolateral foot	0	1	2			0% 2
Back swing phase	Maximum knee flexion	0	1	2			15
	Length of the last step	0	1	2	3		
	Maximum rotation of the body *	0	1	2	3		
	Maximum backward trunk inclination	0	1	2			
	Position of the leading arm **	0	1	2	3		
	Throwing arm retraction **	0	1	2			
Swing phase	Ground reaction forces *	0	1				13
	Maximum trunk rotation *	0	1	2	3		
	Maximum lateral inclination of the trunk	0	1	2			
	Shoulder horiz. abduction & elbow flexion (leading arm)	0	1	2			
	Shoulder horizontal adduction (throwing arm) **	0	1	2	3		
	Rotational velocity of the throwing arm	0	1	2			
Release instant	Velocity of ball release	0	1	2			9
	Angle of ball release	0	1	2	3		
	Height of ball release	0	1	2	3	4	
Follow through phase	Rotation of the body & free limbs	0	1	2	3		6
	Length of 1st step & lowering of the CG	0	1	2	3		
General	Coordination & rhythm	0	1	2			2

* Use the alternative scales if the child uses a homolateral step pattern.

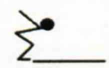
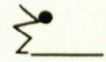
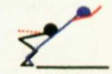
** Use the alternative scales if the child uses a cricketer's technique.

Total 49 50%

Table A8.4: Alternative scoring table for the maximum-distance overarm throw.

Phase, subphase or instant	Technique / performance variable	Score				Subtotal
	Homolateral step pattern					
Back swing phase	Differentiated rotation of the trunk	0	1	2	3	3 33%
Swing phase	Magnitude of GRFs generated by the legs	0	1			4 75%
	Rotation of the trunk	0	1	2	3	
	Cricketer's technique					
Back swing phase	Position of the throwing arm	0	1	2	3	3
Swing phase	Rotation of the leading arm	0	1	2		5
	Rotation of the throwing arm	0	1	2	3	

Table A8.5: Scoring reference for the standing broad jump.

		Scores				
Phase, subphase or instant	Technique / performance variable	0	1	2	3	4
Counter-movement phase	**Segmental movement coordination**	 erratic	 fair timing	 excellent timing		
Lowest crouching position instant	**Depth of the crouch**	 insufficient / excessive	 slight / too low	 compact		
	Maximum hyperextension of the arms	 > -90°	 -90 to -46°	 -45 to 0°	 0-45°	 > 45°
	Elbow angle (1)	 < 90°	 90-120°	 121-150°	 151-170°	 fully extended
Propulsion phase	**Arc of armswing & elbow angle**	 <90°, flexed	 90-135°, flexed	 136-180°, flexed	 181-225°, extended	 >225°, extended
	Velocity of arm swing	no swing	low	powerful swing		
	Magnitude of forces exerted by the lower limbs (GRF) (relative to child's age)	minimal	low	powerful push		

Key:
--- beginning of ROM
— end of ROM
solid - initial posture
dashed - intermediate posture
blue - final posture

Table A8.5 (cont.): Scoring reference for the standing broad jump.

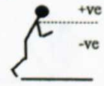
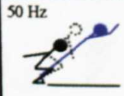
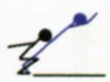
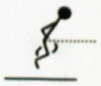
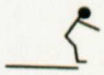
Phase, subphase or instant	Technique / performance variable	Scores: 0	1	2	3	4
Take off instant	**Extension of body segments**	 large flexion	 some flexion	 partial extension	 full extension	
Take off instant	**Position of the upper arms**	 by body	 -90 to -46^0	 -45 to -6^0	 -5 to 5^0	 forward & high
Take off instant	**Velocity of takeoff**		 low	 very high		
Take off instant	**Angle of takeoff (CG)**	 0-19 or > 45^0	 20-45^0			
Flight phase	**Angles of knees & hips (mid flight)**	 > 120^0 / 80^0-61^0	 120-91^0 / 60^0-46^0	 90-60^0 / 45^0-20^0	 < 60^0 / < 20^0	
Flight phase	**Velocity of hip flexion (1st half of flight phase)**	minimal	low	powerful swing		
Touch down instant	**CG landing trajectory (relative to feet position)**	 undershoot / overshoot	 fairly short / over	 towards midfoot		

Table A8.5 (cont.): Scoring reference for the standing broad jump.

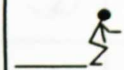
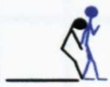
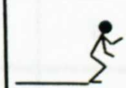
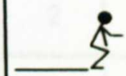
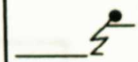
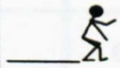
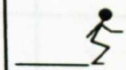
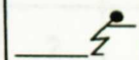
Phase, subphase or instant	Technique / performance variable	Scores 0	1	2	3	4
Landing phase	**Compression**	 standing / backward fall	 slight flexion	 partial flexion	 compact	
	Final position of the arms	 by body or back	 90-61^0	 60-30^0	 < 30^0	
	Elbow angle (2)	 < 90^0	 90-120^0	 121-150^0	 151-180^0	
	Dynamic balance	 loss of balance	 fairly balanced	 well balanced		
General	**Direction of movement, symmetry & coordination**	lateral, asymmetrical untimely	fair	sagittal, symmetrical, effortless		

Table A8.6: Scoring table for the standing broad jump.

Phase, subphase or instant	Technique / performance variable	Score					Subtotal
Counterm. phase	Segmental movement coordination	0	1	2			2 50%
Lowest crouching position instant	Depth of crouch	0	1	2			10 50%
	Maximum hyperextension of the arms	0	1	2	3	4	
	Elbow angle (1)	0	1	2	3	4	
Propulsion phase	Arc of armswing & elbow angle	0	1	2	3	4	8
	Velocity of arm swing	0	1	2			
	Magnitude of forces exerted by the lower limbs	0	1	2			
Takeoff instant	Extension of body segments	0	1	2	3		10
	Position of the upper arms	0	1	2	3	4	
	Velocity of takeoff	0	1	2			
	Angle of takeoff (CG)	0	1				
Flight phase	Angles of knees and hips (mid flight)	0	1	2	3		5
	Velocity of hip flexion	0	1	2			
Touch down inst.	CG landing trajectory	0	1	2			2
Landing phase	Compression	0	1	2	3		11
	Final position of the arms	0	1	2	3		
	Elbow angle (2)	0	1	2	3		
	Dynamic balance	0	1	2			
General	Direction of movement, symmetry & coordination	0	1	2			2
						Total	50 47%

Appendix 9: Results of the tests of inter-rater reliability in the use of the scoring references for the overarm throw and the standing broad jump

Table A9.1: Results of the inter-rater reliability tests (overarm throw).

Phase, subphase or instant	Technique / performance variable	Mode (score)	Range (scores)	Percent agreement with the mode score (%)
Approach phase	Speed of approach	1	1	100.0
Last homolat. contact ins.	Position of homolateral foot	0	0-1	95.5
Back swing phase	Maximum knee flexion	1	1-2	90.9
	Length of the last step	2	1-2	90.9
	Maximum rotation of the body	1	0-2	77.3
	Maximum backward trunk inclination	1	1-2	95.5
	Position of the leading arm	3	1-3	90.9
	Retraction of the throwing arm, shoulder abduction & elbow angle	1	0-1	72.7
Swing phase	Ground reaction forces	0	0-1	63.6
	Maximum trunk rotation	1	0-1	95.5
	Maximum lateral inclination of the trunk	0	0-1	72.7
	Shoulder horizontal abduction & elbow flexion (leading arm)	1	0-2	72.7
	Shoulder horizontal adduction (throwing arm)	1	0-2	72.7
	Rotational velocity of the throwing arm	1	1-2	77.3
Release instant	Velocity of ball release	1	1-2	86.4
	Angle of ball release	2	2-3	68.2
	Height of ball release	4	1-4	95.5
Follow through phase	Rotation of the body & free limbs	1	0-1	86.4
	Length of 1st step & lowering of the CG	2	0-2	63.6
General	Coordination & rhythm	1	0-1	68.2

Mean	81.8%
SD	12.1%
Maximum	100.0%
Minimum	63.6%

Table A9.2: Results of the inter-rater reliability tests (standing broad jump).

Phase, subphase or instant	Technique / performance variable	Mode (score)	Range (scores)	Percent agreement with the mode score (%)
Counterm. phase	Segmental movement coordination	1	0-2	63.2
Lowest crouching position instant	Depth of the crouch	1	0-1	63.2
	Maximum arms hyperextension	0	0-1	89.5
	Elbow angle (1)	2	1-3	63.2
Propulsion phase	Arc of arm swing & elbow angle	1	0-3	63.2
	Velocity of arm swing	1	1-2	94.7
	Magnitude of forces exerted by the lower limbs	1	0-2	68.4
Take off instant	Extension of body segments	3	2-3	89.5
	Position of the upper arms	3	2-3	73.7
	Velocity of takeoff	1	1-2	73.7
	Angle of takeoff (CG)	1	0-1	78.9
Flight phase	Angles of knees and hips (mid flight)	2	1-2	78.9
	Velocity of hip flexion	1	1-2	89.5
Touch down instant	CG landing trajectory	1	0-2	57.9
Landing phase	Compression	2	1-3	57.9
	Final position of the arms	0	0-1	84.2
	Elbow angle (2)	1	0-2	78.9
	Dynamic balance	1	1	100.0
General	Direction of movement, symmetry & coordination	1	0-1	84.2

Mean	76.5%
SD	12.9%
Maximum	100.0%
Minimum	57.9%

Appendix 10: Abstracts of studies derived from the research within this thesis (conference presentations)

Abstracts included:

1. Marqués-Bruna, P., Lees, A. and Scott, M. (2001). The application of mechanical principles to study sports technique development in children. *6th Annual Congress of the European College of Sport Science.* Cologne. Germany. July.

2. Marqués-Bruna, P., Lees, A. and Scott, M. (2002). Visual perception of mechanical variables for the analysis of technique in sport. *7th Annual Congress of the European College of Sport Science.* Athens. Greece. July.

3. Marqués-Bruna, P., Lees, A. and Scott, M. (2003). An integrated analytical model for the qualitative assessment of kicking effectiveness in football. *5th World Congress on Science and Football.* Lisbon. Portugal. April.

4. Marqués-Bruna, P., Lees, A. and Scott, M. (2003). Development of mechanical effectiveness of the soccer kick in children. *8th Annual Congress of the European College of Sport Science.* Salzburg. Austria. July.