Chapter 5
Review of Literature
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5.1 LITERATURE REVIEW: SEARCH STRATEGY

a. **Key Words:** Following key words were used for literature review searches in present study:

- Infant Motor Development; Child Development; Normal Motor Development;
- Motor Development; Gross Motor Development; Fine Motor Development; Motor Development Theories; Culture and Motor Development; Motor Development in Indian Children; Motor Development and Gender Differences; Gross & Fine Motor Skills; Longitudinal Motor Development; Longitudinal Researches in Motor Development; Cross-sectional Researches in Motor Development; Motor Development and Psychometrics; Developmental Norms; Peabody Developmental Motor Scales and Peabody Developmental Motor Scales-Second Edition (PDMS-2).

b. **Search of Resources for Literature Review:** Following research resources were used in this study for literature search:

1. ProQuest Databases for Dissertations and Theses;
3. http://Mymanipal/ library databases for ProQuest, CINHAL, OVID and MD consult;
4. Central Library of Department of Home Science (Child Development), University of Agricultural Sciences, Dharwad (Karnataka); for journals and books on Child Development.

In addition to above search sources, manual searches and reviews were done for books, recent journal articles, dissertations and back volumes journal at the Central Library, Manipal University, Manipal and Central Library, Kasturba Medical College, Mangalore. Foreign University thesis is acquired through subscription of ProQuest Databases for Dissertations and Theses. PDMS-2 actual normative age specific sample size from birth to 36 Months (not provided in PDMS-2 manual) were
obtained from Ms. Laura Rogers (Research Associate, Prof-Ed Inc. Austin, TX, 787587) on request by the researcher to the publisher (Prof-Ed Inc. Austin, TX) of PDMS-2.

c. Outcome of Literature Search:
   1. Total Number of Books Reviewed: 65 (Published in year 1931-2009).
   2. Total Number of Journals Reviewed: 44 (Published in year 1957-2009).
   3. Total Number of PhD Thesis Reviewed: 6 (Year 1996-2007). 3 from University of Alberta and one each from James Cook University; Walden University and Quinnipiac University.

d. Reference Citations: Vancouver style.

5.2 PRINCIPLES OF MOTOR DEVELOPMENT

Basic principles of motor development apply to children developing typically or atypically. It helps in understanding movement differences or motor delays among children with specific concerns. Principle-1: The principle of reflex integration and the development of reaction formation. Natural integration of primitive reflexes into higher forms of movement occurs as the brain matures. Righting and equilibrium reactions emerge as voluntary movement progresses to stabilize body, and provide secure base from where child performs motor skills.

Principle-2: The principle of general to specific motor development. Earliest movements of young children are large full body actions. E.g. when a child begins to reach for objects, he/she does so with total arm and trunk movements. With refinement in these movements, child is able to use hands and fingers more precisely in actions.

Principle-3: The principle of cephalo-caudal direction in motor development.
Young children gain control of head and trunk, before lower extremities. Many children with neurological impairments lag behind in development of head control. Therefore during intervention, stabilization of head and trunk is most important in order to facilitate lower limb activities.

Principle-4: The principle of proximo-distal coordination.  

Movements occur from the midline of body to the extremities. It means muscles of trunk and shoulders develop and mature prior to the co-ordination of extremities.

Principle-5: The principle of bilateral to cross lateral movement coordination.  

Movement coordination begins if child is able to integrate movements of limbs. Bilateral control is seen when infant i.e. engages both arms by bringing hands to midline; simultaneously kicks both legs; grasps both feet by hands, or catches a ball. It helps Infant to reach out with one arm, if necessary, without overflow movement to other limbs. Thereafter cross lateral movement occurs during creeping/crawling, walking, kicking a ball or during running.

5.3 THEORIES OF MOTOR DEVELOPMENT

Development is a series of ‘stages’ through which an infant progresses in a fixed order of sequences. The process of development is complicated and sensitive that may be influenced by intrinsic and environmental factors. Early researches on motor development were descriptive studies of motor milestones. Historically, development was thought to be linear occurring in an invariant sequences for behavioral changes. It was considered as direct reflection of anatomical and physiological system maturation, which can be examined quantitatively and qualitatively.

Developmental theories provides coherent framework to study the development. Many theoretical concepts currently used in physical therapy evaluations and therapeutic interventions are based on theoretical constructs
developed in 1930s & 1940s. 67 Pediatric physical therapy practices have adopted ‘neuro maturational theory’ of development 41,67 where structure precedes function; and CNS maturation (higher centers inhibiting lower centers to elicit voluntary movement) leads to motor developmental changes. 67

Many clinicians/developmentalists believe that motor milestones occur in an invariant neurodevelopmental sequences 68 due to which developmental theories (addressing child’s physical development) are easily applicable in pediatric therapy interventions. 12 Significant literature on developmental schedule for motor skills in infancy and early childhood can be found, but relatively little information is available regarding ‘how motor skills emerges’. Different viewpoints exist among movement theorists, scientists or clinicians. 69 Few common theories are being reviewed here:

A. Hierarchical Theory/ Reflex Theory: It was early motor theory proposed by Schaltenbrand (1928) and Sherrington (1947). According to this theory reflexes are the building blocks for complex behavior because nervous system is organized in hierarchical order. 67 This theory led to the formulation of neuromaturational theory (classical theory of motor development).

B. Neuromaturational Theory: It gives theoretical foundation for pediatric physical therapy practices and forms the basis for clinical decision making in designing therapeutic interventions. 67 It is a widely accepted theory in the field of child development till today 12 which was developed and advanced by Piaget, Gesell, Bayley, and McGraw in early 1900s. 70,71 It has evolved from the reflex/hierarchical theories. 12 According to this theory, motor skills emerge in a predictable manner driven by central nervous system (CNS) maturation; and environment plays secondary role in the emergence of motor skills. 12

Neuromaturational theory is characterised by following four assumptions: 72,73
1. Movement progresses from primitive reflex patterns to voluntary controlled movement (reflecting on CNS maturation);
2. Motor development progresses in a caphalo-caudal direction;
3. Motor control proceeds in a proximo-distal direction;

4. Motor development rates and sequences are consistent for each infant and appear in predictable order according to the neurological maturation rate.  

Darrah J et al. (2003) opined that significant variability can be found in motor scores and individual domains within individual infant and among infants; 36 because typical development is non-linear 36, consisting of spurts, plateaus and regresions; which produces qualitative and quantitative changes in motor performances.63 They also reported that fine motor and gross motor skills appear independently. 36 McGraw and Gesell identified motor skills and their normative times of appearance, which provided base for many standardised assessment tools on motor abilities. 74,75

Scherzer and Tscharnuter (1982) wrote that motor development should be seen as a succession of integrated milestones leading to complex and independent functions. 76 Each stage of motor development is interdependent. It is closely related with progressive control of higher centers (CNS) and reduced influence of fixed reflexive behavior (e.g. sitting precedes crawling, crawling precedes walking; indicating that sitting and crawling are prerequisites for walking). 76 Documented variations in motor development shows that many infants do not follow general sequence of motor development, 77 as some could stand up before sitting, while some do not crawl before walking. 78 Therefore presence of crawling in developmental sequence is common but not mandatory. 78,80

Darrah et al. (2003) verified neuromaturational theory limitations and opined that ‘developmental changes is the result of interaction of multiple subsystems within a child, the environment and task demands’ and not depends solely on CNS maturation. 36 They suggested that specific developmental domain may not demonstrate stability of scores over time, and different developmental domains may follow different developmental trajectories. 36
C. Dynamic Systems Theory: This approach has been used as a theoretical basis for recently developed motor tests. Major principles of this theory are as follows:

1. Motor behavior results from inputs of many different subsystems (single element is not responsible for a motor action), and recognises the role of non-neural components in movement organisation;

2. Dynamic systems are non-linear i.e. subsystem may mature in asynchronous manner (one system is maturing rapidly, while another is maturing slowly);

3. Dynamic systems exhibit self organising autonomous properties. Structures involved in a movement operate autonomously and in synergy. Centrally coordinated instructions are not enough to account for motor acts complexities. Control is distributed at many structures and command is revised at many different levels; and,

4. Systems are organised in task specific manner. Therefore instruction may get revised in response to the task requirements.

Bernstein observed that joints and muscles work together in coordinated manner, but not in isolation. Ulrich (1997) have reported that neuronal organisation, muscle strength, joint structures, range of motions, motivation/arousal levels, support surfaces, and the tasks contributes for changes in motor behavior. Because functional motor synergies are highly adaptable, reliable, and organised around a goal therefore stable movement patterns become unstable prior to transition to a new movement. It permits motor systems to explore new possibilities, till a more effective pattern is discovered as per the desired goal.

Dynamic system theory provides explanation “why some infants avoid specific planes of movement?” E.g. Infants with weak neck or trunk muscles may avoid prone position and sitting is avoided by infants having muscle shortening or joint hypomobility. It suggests that motor behavior emerges through dynamic cooperation
of many subsystems in a task specific context. E.g. Infants with atypical body proportion or hypermobile joints may select shuffling instead of crawling as locomotor strategies.

Factors influencing motor behavior do not develop at uniform rate, because one factor may limit or prevent the system from generating a new motor behavior. Therefore, new motor skills arise only when the slowest component matures. Dynamical systems do not give CNS the preeminent role for change in motor behavior. It also limits the perception that infants and young children are passive recipients of information from the environment for motor acts, instead view them as active participants where movement assembles from many subsystems within the environmental context. Thus recommended that coordinative structures are organised in hierarchial manner, where all elements participate in movement decision.

The dynamical systems perspective provides information about the process of generation of new movement, thus it has important clinical application in infant, child or adult with movement dysfunction. For physiotherapists, dynamical system theory is useful in two aspects:

1. As a theoretical base to understand the efficacy of physical therapy treatment; and,
2. In providing different evaluation tools that may effectively identify changes in the movement.

5.4 MOTOR DEVELOPMENT AND ACQUISITION OF SKILLS

‘Motor development is the process of change in motor behavior brought about by interaction between heredity and environment’. It is a lifelong process of age-related changes occurring in a sequential manner. Haywood defined motor development as ‘the sub-disciplinary area of study concerned with changes and stability in motor behavior from conception to death’.


Motor developmental theorists are of opinion that changes in motor behavior are the result of growth, maturation and experiences; and factors like i.e. CNS maturation, physical growth, genetic, gender and culture have an impact on motor skills development. Right from birth, a child constantly brings sensations and movements together to form more organised movements and sensations. E.g. infant lying prone lifts and turns head to breathe more easily, putting on clothes, playing with toys, or riding a bicycle. In first year of life, normally-developing infant’s motor functioning rapidly translates from reflexive to more intentional and complex movement pattern.

Importance of motor development among children in educational system is evident through school sports. In our society, exercise and coordinated movement in sports and recreational activities are valued and is included in early child education because they have indirect influence on child’s motor, social and cognitive development. For motor development two mechanisms are responsible:

a. Congenital neural synapses, and,


Early researchers used to document the developmental progress of infants and children in descriptive manner i.e. activity descriptions and age of onset of specific motor behaviors. All such studies were conducted on children of European origin; therefore normative data, which formed the basis of our understanding of motor development and developmental scales, are principally of this cultural group. Findings of many researchers on motor development have provided information about:

a. Methods of measuring motor performance,

b. Details of dynamics of action (i.e. walking, running, reaching)

c. Anticipatory and ongoing postural adjustments.
This information has helped in developing more scientifically based effective program. Following information provide qualitative insights regarding motor development understanding among infants/children:

I. Role of Movement in Child Development

Movement and touch are the first sources of play and learning. Infants investigate themselves by kicking, reaching, smiling, wriggling and tilting their heads. They move to learn about themselves and about their environment to develop awareness through space which provides foundation for the movement. Studies suggest that gross motor skills should be taught to infants, once they start creeping and walking. When children feel good about their movement abilities, they make physical activity an integral part of their lives; and develop body awareness, control, balance and coordination through developmentally appropriate movement. It helps to gain physical strength, stamina and agility.

II. Development of Gross Locomotor Patterns

Motor development begins with reflexive behavior and progresses towards skilled movements. Folio and Fewell (2000) viewed motor skills as combinations, extensions and refinements of basic movements. Locomotion is one of the greatest milestones for human beings and locomotor movement includes i.e. crawling, creeping, walking, running, jumping, hopping, skipping, galloping, rolling and climbing. By end of first year of life, a child can stand without support and become proficient in basic bipedal walking that would soon transform into running, galloping etc.

The key attributes in early stage of walking includes short stride length, wide base of support, toes pointed outward, and arms held in high guard position. With scaling up of control parameters for running (lower limb strength, postural control and balance), the early running takes on the properties of more advanced running (i.e. full range of motion, flight phase, longer stride length, and alternating arms and legs), and child continues to add new patterns to this repertoire with advancing...
Transition between first upright steps and subsequent running, jumping and skipping relies on a number of rapidly changing rate-limiting elements. These helps child to run with increased stride length, narrow base, straight toes, and full range of motion.  

Initially, young child’s low strength level (weak lower limb muscles), poor balance, and insufficient postural control compared to an older child limits transition from primitive locomotion to a true running locomotion. Even if balance and strength improves, a child will not be able to run maturely until the system that regulates body strength (the slowest-developing system) reaches to the level of other rapidly developing systems. E.g. As legs become stronger and postural control improves (through increase in muscle mass, balance and control), child makes transition from walking to running i.e. without these changes, child will have limited motor development rate by the system, which is slowest in formation.

III. Development of Gross Motor Manipulative Patterns

Normally developing children demonstrate predictable developmental sequence with attainment of complex gross motor manipulative skills i.e. throwing, catching, striking, and kicking. In early throwing patterns, children shows characteristics like: no trunk action but only arms are active in force production, no backswing of arm, raised and forward elbow; and throw being executed by elbow extension alone without any forward step. With maturity, older children and adults perform these tasks in a qualitatively different manner i.e. differentiated trunk rotation, circular downward backswing of arm, arm becomes independent and lags after ball release, delayed forearm lag and contralateral long step during throw. With improvement in upper limb strength, postural control, and balance; early throw pattern translates in to more advance throwing skills.
IV. Development of Fine Motor Grasping Patterns

In early childhood, grasping and object manipulation are critical skills which are observed during infant’s attempt to i.e. eat, play piano, and reach to grasp a ball. Halverson (1931) had explained grasping development in following stages:

a. No contact - at 16 weeks of age,
b. Primitive squeezing - at 20 weeks,
c. Hand and Palm Grasp - at 28 weeks
d. Inferior-Forefinger Grasp - at 36 weeks (using a Pincer grip),
e. Superior-Forefinger Grasp - at 52 weeks.

By 4- months of age, infants begin to mold and shape their hands according to the object configuration and location. By 10- months of age, they can perform continuous direct reaching and grasping with a single hand indicating that refinement of reaching and grasping skills are achieved within first year of life.

V. Development of Fine Motor Reaching Patterns

During 1st year of life, normally developing infants’ progress through three types of reaching:

a. Prereaching - birth to 4 months,
b. Visually-guided reaching - 4 to 8 months,
c. Visually-elicited reaching - ≥ 9 months.

Traditionally, newborn’s attempt to reach was thought to be reflexive i.e. thrashing of the limbs. White et al. (1964) and Bower et al. (1970) had opined that very young infants are capable of limited hand-eye coordination with rudimentary attempts at reaching and object grasping. Visual control of hand significantly improves the efficiency of skilled attempts to reach for an object. von Hofsten (1982) suggested that early reaching is primarily a directional pointing towards specified target. Extended reaching movements towards the object and frequent grasping of it are considered as important pre-reaching behaviors (regardless of the degree of hand-eye coordination present) in newborns.
By 4-months of age, success in reaching for and grasping an object improves as infants begin to use vision to guide their hands and become more capable in making corrections before making contact with the object. \(^{104}\) By 10-months of age, they become more accurate in reaching \(^{103,104}\) and visual focus increases on the object’s size, location and shape. Prehension improves rapidly by end of the first year \(^{105}\) and child learns to manipulate an object with both hands (bimanual reaching), holds two objects in each hand, bangs them together and may insert one object into another or pull them apart. \(^{105}\) By two years of age, children are capable of performing cooperative tasks i.e. holding lid open with one hand and withdrawing contents from the container with other hand. \(^{105}\)

5.5 APPLICATION OF LONGITUDINAL RESEARCH

Previous studies on motor development were of global and descriptive character. \(^1\) Scientific interest in longitudinal approach dates back to 18th century, \(^1\) but has never really become the consistent feature for child development. \(^{45}\) This truth is not so much surprising, because practical and methodological difficulties constitute a formidable barrier for longitudinal research on child development. \(^{45}\)

Cross-sectional study for analysis of motor development is indispensable in following aspects: \(^{106}\)

a. For in-depth study of motor behavior at particular age, which can be integrated in to later follow-up studies, and,

b. Because of attrition or specific cohort differences, normative data cannot be obtained easily in longitudinal studies.

But, longitudinal method to study motor development is indispensable in following aspects: \(^{106}\)

a. Motor behavior is a process of continuous organisation and reorganisation,

b. Individual differences, and,
c. Relationship of early biological and environmental factors.

The rationale for longitudinal studies in human development is: 1) identification of intra-individual change; 2) identification of intra-individual differences in individual change; 3) identification of inter-relationships among classes of behavior during development; 4) analysis of causes of intra-individual change; 5) analysis of causes of inter-individual differences in intra-individual change and, 6) prediction of individual differences in one domain from individual differences in another domain.

Two basic types of longitudinal studies can be used to reach the rationale mentioned above. These are:

1. Basic study called ‘Developmental function’ which is average value of a dependent variable plotted over time. E.g. Growth curves concerning the development of speed or physical strength and depicting the continuity versus discontinuity of these variables over time.

2. The other study concerns with the issues of individual differences. It attempts to answer ‘whether individual subjects maintain approximately same relative rank order within their group at one age as they do at another’? It helps us to know about stability/instability of individual differences between the individuals over time.

These changes can be addressed by 3 types of longitudinal research:

A. Correlative Research: Here outcome is related to the previously measured antecedents in order to track intra-individual change and inter-individual differences in such changes. Typically, it involves measurement of the same function at each age.

B. Perinatal follow-up Research: It focuses on specialised cohorts selected for some specific characteristics and consists of group oriented studies. Here different kinds of data for different variables are assembled at different ages.
C. Experimental-manipulative approach: Here relevant variables are manipulated by the researcher and subjects are randomly assigned to experimental and control groups. Any differences between the groups on a dependent variable are attributed to the experimental treatment. Alternatively subjects may serve as their own controls, as in single-subject experimental designs.

Longitudinal researchers have often overlooked the fact that developmental function and stability of individual differences over time represent two separate aspects of the same problem. While cross-sectional and longitudinal studies are directed towards different questions about the development, their combined uses are recommended in order to overcome the retest problem.

5.6 IMPORTANCE OF AGE NORMS

Gesell (1954) saw development of motor control as waxing and waning of components combining in multiple ways in a spiral course. At each stage, components emerge, merge and become replaced, creating a new maturational transformation. Literature suggests that Gesell's insight about motor development was excellent, but he is primarily remembered for the age norms that his studies have produced.

Age norms are important, because it help us to form expectations about age specific performances. However it has severe limitations, such as:

1) Age norms are highly dependent on the group on which they are standardised. The rate of development will differ between the groups and between the generations, because of differences in child's nutrition and child care procedures. Therefore, age norms of today will be different from the age norms of a decade ago. It will also be different for children living in large towns compared to those living in rural areas.
2) Age norms hide the great natural variation in motor development between the individuals. Even though developmental functions in some aspects will look similar for all the individuals, but the rate of development is definitely unique for each one. Some develop ‘quickly’ while, others develop ‘slowly’. The same child may develop quickly at certain age and slowly at other ages. Developmental sequences of various components of a system may be different in different individual, because physical growth of body is different in different individual. 

3) Pooling of data for groups of individuals of same age will smear the developmental functions, and make it look smooth and uneventful. Such methods tend to hide the true function, which can be characterised by spurts and plateaus, and that will make it difficult to relate with various determinants of development to the performance.

4) Use of age norms as clinical tools does not distinguish between slow development and pathological development, because age norms just tell us whether child is deviant or not.

Since age itself is not a relevant variable and there is need to know how one part of the system is related to the other parts? This requires analysis of independent measures of subsystems which may contribute for specific motor behavior.

Therefore, longitudinal study is the only method that can provide answers about the process of development as well as construction and assembly of individual systems. It also helps in determining gradual and dynamic transitions of development. But in longitudinal studies, choice of ‘time interval’ between the successive measurements is vital. The time interval must be ‘large’ enough to detect intra-individual changes in development; and time interval must be ‘short’ enough to be able to measure the same motor functions or processes at two successive time points using the same instruments.
5.7 GENERAL RESEARCHES ON MOTOR DEVELOPMENT

Childhood (beginning from neonatal period to the termination of puberty) carries the individual from a condition of complete biological helplessness to the threshold of self dependence and creative activity.\textsuperscript{112}

An editorial reported that 23% children going to the mainstream primary school performed below 15th centile on Movement Assessment Battery for Children and 17% children demonstrated significant dysfunctional co-ordination during neurological examination, which is substantially more than the general figure of mid 1980s. Editor asked “What might be the cause of this secular change in motor performance?” and suggested that it would be due to multifactorial reasons and advises academia and researchers to come together to explore this problem.\textsuperscript{113}

McLaughlin et al. (1984) have suggested for routine screening and periodical assessment of the entire infant population, as most efficient strategy, to identify the children with developmental concerns.\textsuperscript{114} Since last 20 years, children’s neuromotor performance is gradually changing, because studies have reported significantly lower performance by infants on Alberta Infant Motor scale compared to previously assessed children.\textsuperscript{115,116}

Nair (1991) said that clinical entity of neurodevelopmental syndrome is a human tragedy; therefore it is important that we should be able to detect these children early and recommended formal developmental assessment by the tools having good sensitivity, specificity, and positive and negative predictive value. He advised compulsory developmental assessment of preschoolers and associated intervention measures.\textsuperscript{117} Such opportunities can be found in PDMS-2 scale, where methods for implementing the results through motor activities programs are well described.

In year 1957, Geber & Dean had reported advancement in gross motor development among African children compared to western in early months of life (0-3
months), and reason for such precocity had association with tropical climate and child rearing practices. ¹¹⁸

Infants from certain African Cultures were reported to be ahead in acquiring independent sitting motor skills compared to American babies; because parents (African) facilitate sitting behavior by digging a hole in sand and making infant to sit in it. ¹¹⁹ Studies also suggests that infants will initiate attempts to catch a target moving across the field of vision in the first month, if they are supported in a semi-reclined position. ¹⁰³

Zemke (1981) reported that certain motor milestones are consistent across large numbers of people i.e. most children learn to walk at approximately 1 year of age, but males and females infant appear to mature at different rates depending on the age. This study examined the effects of gender and age on a measure of motor maturity (Integration of asymmetrical tonic neck reflex) in normal preschool children (3 and 5 years old) and found no significant differences, which facilitated author to hypothesize that presence of ATNR (asymmetrical tonic neck reflex) response is normal in preschool children, but clinical measures of ATNR abnormality requires consideration. ¹²⁰

Sellers (1988) found that girls had ranked slightly higher than boys on two of the five measures, but opined against significance of gender differences for overall motor development. Author had studied 107 preschool children (52 male, 55 female) in the age group of 50-66 months on a non-standardised measures for quality of static balance and antigravity control. ¹²¹

Eaton (1989) used meta-analysis method to evaluate gender differences in motor performance. Author found that gender differences are typically less than one standard deviation in size for body magnitude, body composition, and activities. But during reporting about differences in motor performance tasks in age range 3 - 20 years, author is not specific about ‘at what age’ gender differences may appear. 4 of the measured tasks showed no gender differences before puberty; for 8 tasks, age
was unrelated to the size of the gender difference; 6 tasks showed small gender differences with differences increasing with age and 2 tasks (throw for distance and throwing velocity) showed large gender differences. But Eaton (1989) did not conclusively supported for gender differences in children aged 3 to 5 years. 122

Many studies have explored relationships between the motor development and the family’s socioeconomic status.123-125 Gottfried (1984) is of opinion that if motor behaviors determine cognitive functions, which have been related to the environmental variables; then a relationship between the motor development and socioeconomic status may be implied. 126

Another study examined the effects of home environment, maternal attitudes, marital adjustment, and socioeconomic status on infants (aged 2 years old) mental and motor development. They found significant correlation between motor development and socioeconomic status (father’s education, mother’s education, family income, and father’s occupation). However, Poresky and Henderson (1982) pointed that influence of socioeconomic status on an infant was mediated by parental care provided to infant. 125

A study on “normal gross motor development in relation to gender, race and socioeconomic status”, suggested that males and females advance faster for different portions of the development. But, Capute et al. (1985) reported that effect of socioeconomic status became negligible, when implication of race is considered. 123

Variations in gross motor development among children of different ethnic origins have been well documented, 38 including differences in motor development among children of different ethnic backgrounds living within countries such as Israel 127 and United States. 40,128-132 Many factors i.e. gender, socioeconomic status, nutrition, early postural experiences, and parental expectations (in addition to ethnic background), affect children’s rate and sequence of gross motor development.
The most probable reason for differences in motor development of Asian background children are due to less exposure to prone-lying (often positioned upright) increased incidence of sleeping in hammock and use of swaddling technique; causes them easy or more difficult to move.

Factors that play role in influencing motor development also includes level of emphasis placed on independence in activities of daily living at an early age, degree of importance given to motor skills like ball manipulation, and bicycle riding. Literature suggests that Asian background children may have less opportunity to try new skills as parents are protective because of fear from injury. But another study suggests that children of Asian background have greater opportunity to learn new motor skills as they are given more opportunity to move about once beyond infancy.

In a WHO-ICMR Collaborative Study, Lansdown et al. (1996) observed that linear association exists between poor nutritional status and slower development; which was high for fine motor skills and least for gross motor skills.

Mannerkoski et al. (2009) examined “how growth measurements and attainment of developmental milestones in early childhood” can reflect the need for full-time special education in age group 7-16 years (n= 900) using general linear model (growth measurements), binary logistic regression analysis (odds ratios for growth), and multinomial logistic regression analysis (odds ratios for developmental milestones). They concluded that children whose growth is mildly impaired (failed to attain certain developmental milestones), though in the normal range, will have increased probability for special education and therefore need special attention as toddlers.

With sole objective to examine cross-cultural differences in motor development of Hong Kong children (6-10years), Chui et al. (2007) investigated differences in fine motor performance on Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) scale and compared them with American normative samples.
They did not find any significant difference between the scores of two groups in Upper Limb Coordination and Response Speed Subtests. But, they noted that Hong Kong children performed significantly better on subtests of Visual-Motor Control, Upper Limb Speed and Dexterity. They found significant gender differences for all the subtest scores except for Upper Limb Speed and Dexterity subtests.  

Herschkowitz (2000) has reported that by 24 months of life, infants show many significant changes in their psycho-somatic behaviors i.e. initiation for language skills and its comprehension, vocal interchange, growing awareness of self as a person, psychological competencies and inference capability. While elaborating on self-awareness, author stated that effective integration of right hemisphere (representing sensory feelings), and left hemisphere (containing semantic representation of child's name and personal qualities) provides basis for the child's experience on self-awareness.

5.8 LONGITUDINAL RESEARCHES ON MOTOR DEVELOPMENT

Most of the studies on motor development of children are conducted in developed countries and norms are established for specific population. In human development, majority of research have used cross-sectional study designs with main objective to investigate the developmental differences among various age groups. Such study designs do not elicit developmental changes within individuals across chronological ages. Hence these studies cannot be considered ‘truly developmental’ because changes occurring over time within the individuals can be analysed via longitudinal approaches only. Academia and researchers have accepted that longitudinal follow up studies can provide reliable scientific information regarding motor growth and development among children.

Bhandari and Ghosh found that in age group of 0-3 months (n= 123), Indian children gross motor development is ahead in relation to Gesell’s (1951). On further comparison of theirs mean value with that of Gesell's (1951), Nelson’s (1975),
Bowley’s (1954), Ellis’s (1966) and Illingworth’s (1966), they reported that Indian children were ahead of western children in some aspects of gross motor development. Authors attributed these findings to the mother-child relationships as well as differences in environmental and socio-cultural set-up of their groups.\textsuperscript{151} Similar findings of developmental precocity among Indian children (Agra) compared to European children were also reported by Phatak (1969).\textsuperscript{152} Also, on comparison with another Indian study (Lucknow children)\textsuperscript{153} authors observed that their children were ahead in acquiring motor skills and cited socio-economic factor as the reason.\textsuperscript{151}

Gender differences in gross motor development at one year of age was found to be non-significant, where many children (56.9%) had developmental quotient (DQ) of 90-109, while 13.01% had DQ of >110. Similar observations were reported in a study on Bombay children where 53.1% had DQ 90-110, while 12.6% had >110.\textsuperscript{154} Study concluded that motor development of Calcutta children is better than Bombay children, but motor developmental skills of Indian children at the age of one year were less compared to the western children.\textsuperscript{151}

Bhandari and Ghosh (1980) in their longitudinal study found that first born children demonstrated higher developmental quotients (DQs) compared to the children born later, in areas like; gross motor, fine motor, language and speech. Higher DQs was found among children of families with higher income. They cited similar kind of research report from Scotland (1959) and Sweden (1968), respectively. They also reported that children of skilled parents may have higher DQs compared to unskilled parent’s children; because, developmental skills of a child is influenced by the family income, the environment, the training and the practice at home; which in turn is influenced by the father’s occupation. Similarly good relation were found between the mother’s education and child’s DQs. Authors concluded that developmental performance of children may vary from community to community,
because development is influenced by genetics, antenatal care, nutrition, education and training.\textsuperscript{112}

In a longitudinal study on motor development among fat babies, Jaffe and Kosakov (1982) found definite correlation between excessive weight and motor delays in younger babies, and also reported that both (body weight and motor development) tend to revert to normal over the years in most of the children.\textsuperscript{155}

A comparative longitudinal follow-up study on gross motor development of congenitally blind children and sighted children in first 3 years of life suggested that, 5-full term blind children had only slight delays in postural development but greater delays in locomotor development; while 5-preterm blind children (birth weight: 650-1,115 grams) showed major delays in all areas of gross-motor development which had consistently increased with age. Both the groups deviated from the developmental sequence of sighted children in the acquisition of skills requiring self-initiated change in posture and position (sitting or standing) and in crawling.\textsuperscript{156}

Influence of the environment at home on psychomotor development of infants (birth to 18 months) through stimulatory intervention were analysed in this semi-longitudinal study on a sample of 145 infants (both gender) from two villages, using Bayley's Scale of Infant Development (BSID) and significant association was found between the home environment and psychomotor development of infants.\textsuperscript{157}

A study was conducted to find the prevalence of asynchronous gross motor development in early infancy and its impact on gross and fine motor performances using Alberta Infant Motor Scale (AIMS). Evans (1993) reported that 15% population showed asynchronous gross motor development and frequency of asynchrony was consistent across the ages. Author did not find any significant differences between asynchronous infants and their matched controls on gross and fine motor performance in second year of life, which was measured by using PDMS and Minnesota Child Development Inventory (MCDI). Author reported that asynchronous early gross motor development does not have negative impact on the motor
performance in second year of life. Such findings support the assumptions of
dynamic motor theory that development is non-linear and asynchronous. In this study
infants identified as asynchronous, were found to be late walker, but they could
catch-up in their motor performance before their second birthday.\textsuperscript{158}

In this study, effects of aquatic therapy on hypotonic children’s gross motor
development was examined using PDMS instrument by converting the pre and post–
treatment PDMS results into age equivalent scores and scaled scores and compared
it with t-test. Significant differences were found between pre-test and post-test PDMS
age equivalent scores and PDMS scaled scores; and suggested that aquatic therapy
is beneficial for children with hypotonia.\textsuperscript{159}

Another research compared the changes in gross and fine motor
performance at 9, 11, 13, 16 and 21 months of age on the PDMS instrument between
typically developing English-speaking children (n=33) with suspicious motor
performance (at least on 2 instances gross and fine motor scores were below the
mean by 1 SD on PDMS) and similar socio-economic status control group infants
(n=72). Researcher concluded that low performance in one domain does not predict
low performance in another domain for typically developing infants, and infants with
substantial decline in ranked performance in one domain do not show an opposite
increase in ranked performance in another domain.\textsuperscript{160}

In a longitudinal observational study, motor development (gross and fine
motor skills) was analysed in a group of "apparently normal" high-risk infants (n=50)
at 18 months, 3 years and 5 years using PDMS instrument. Researchers reported
that many children (54% at 18 months, 47% at 3 years and 64% at 5 years)
continued to have fine motor deficits from 18 months to 5 years. Proportion of infants
with gross motor deficits significantly increased over this period (14%, 33% and 81%,
p<0.001), particularly for the 'micro preemies' (born <750 g).\textsuperscript{161}
5.9 RESEARCHES ON MOTOR DEVELOPMENT & PDMS-2

Provost et al. (2004) explored concurrent validity of age equivalents and standard scores of Bayley Scales of Infant Development II (BSID II) Motor Scale and the PDMS-2, as well as correlations and clinical agreement between the scores of two tests on 110 children aged 3 - 41 months. The correlation coefficients ranged from high to very high for age equivalent scores, and Locomotion Subscale had closest agreement with the BSID II Motor Scale age equivalent. The correlation coefficients were moderate to high for standard scores, and there were only slight agreement between tests for standard scores. They concluded that concurrent validity of tests is applicable only for certain subscale age-equivalent scores, particularly BSID II Motor Scale with PDMS-2 Locomotion Subscale. The findings indicated that standard scores have poor agreement and low concurrent validity.58

Maring and Elbaum (2007) conducted a study on 30 children with variety of developmental delay to determine the concurrent validity of Early Intervention Developmental Profile (EIDP) and PDMS-2. Authors found that PDMS-2 and EIDP were strongly correlated ($r_{0.91}$, $p_{0.01}$) but mean age equivalent scores were significantly different. Age equivalent scores were on average 26% higher on EIDP. Therefore authors recommended for using norm-based tests to determine about percentage of delay relative to the norm.29

In a study, Wang (2004) used PDMS-2 instrument in 60 Taiwan children (age group 3-5 Years) to know the effects of creative movement program on gross motor skills. They reported that children involved in creative movement program demonstrated higher gross motor skills ($p < 0.05$) compared to the children in control group. Author found significant differences in locomotion subtest score ($p < 0.05$) in creative movement program group compared to the controls, but differences were not significant for object manipulation ($p > 0.05$) and stationary ($p > 0.05$) subtests of PDMS-2 Gross motor component.162
Kolobe et al. (2004) examined ability of infants (n=61) on Test of Infant Motor Performance (TIMP) scores at 7, 30, 60 and 90 days after term age to predict the motor development at preschool age and at mean age of 57±4.8 months PDMS-2 instrument was administered. The correlation coefficients between the TIMP and PDMS-2 scores were statistically significant for all ages except at 7 days. Highest correlation coefficient was found at 90 days ($r=.69$, $P=.001$).

Babies placed habitually in prone by their parents appear to acquire motor milestones more quickly compared to infants placed habitually in supine. A study was conducted to know the importance of prone position in new born using locomotion subtest of PDMS-2 (as objective measures) at 6 and 18 months of age. The results suggested that infants who were regularly placed in prone demonstrated higher subtest score compared to babies who were not positioned regularly. Jennings et al. (2005) opined that significant gross motor differences for the 18-month-old babies were dependent on the amount of time they spent in prone for play before six months of age. The PDMS-2 Locomotion scores had range of 79-90 for the 18-month-old babies. Further comparison was done between the average Locomotion scores from all babies who were placed routinely in prone before the age of six months (84.9) to the average Locomotion score from all babies not placed routinely in prone to play (82.1); and the same was found to be significant ($p = .015$).

This study examined test-retest reliability, inter-rater reliability, convergent validity and discriminant validity of Fine Motor Scale of Peabody Developmental Motor Scales-second edition (PDMS-FM-2) on a sample of two groups of 18 children in the age group of 4-5 years with and without mild fine motor problems. The PDMS-FM-2 results were compared with the scores of Movement Assessment Battery for Children (M-ABC). For test-retest reliability and inter-rater reliability, correlation coefficients varied from $r= 0.84$ to 0.99, which suggests that PDMS-FM-2 has excellent test-retest and inter-rater reliability.
In this study Connolly et al. (2006) investigated concurrent validity of PDMS-2 and BSID-II Motor Scales in typically developing 12 months old infants through age equivalent scores of PDMS-2 Gross and Fine Motor Subscales and PDI of BSID-II. They found low correlations between FMQ, GMQ, TMQ of PDMS-2 and the PDI of BSID-II; as well as between age equivalent scores of PDMS-2 subtests (grasping, stationary, and Visual Motor Integration) and the BSID-II Motor Scale. But low negative correlation was found between the age equivalent scores of PDMS-2 subtest for object manipulation and the BSID-II Motor Scale. High correlation \( (r = 0.71, P < 0.05) \) found between the age equivalent scores of PDMS-2 subtest for locomotion and BSID-II Motor Scale. Authors concluded that there is lack of concurrent validity between the PDMS-2 standard scores and standard scores of the BSID-II Motor Scale and lack of agreement between age equivalent scores of BSID-II Motor Scale and PDMS-2 subtests (except for Locomotion subtest).

Tripathi et al. (2008) in a cross-sectional study had compared the scores of Indian children \((n=300)\) with that of PDMS-2 normative scores by comparing the z score of subtests and quotients. Their findings suggests that statistical difference for TMQ was significant for 0-11 months age group, very highly significant for 23-44 and >55 months age groups and non significant for 12-22 months. Critical observation of result's table indicates that for 0-11 month age group, in spite of GMQ and FMQ being not significant, TMQ was significant. Similarly for 23-44 months group, either GMQ or FMQ would have influenced the TMQ to become very highly significant. This study found Indian children ‘on par’ for age groups 12-22 and 45-55; ‘better’ for 0-11 months and ‘scored better’ for >55 months. For two age groups (23-33 months and 34-44 months) Indian children ‘scored lower’ compared to normative sample. Based on this, authors concluded that culturally sensitive tools are difficult to make across different geographical regions and environments.
Wang (2004) had also reported that most commonly used instruments to evaluate the motor skills are: PDMS-2, Mullen Scales of Early Learning: AGS Edition (MSEL: A) and Test of Gross Motor Development. 

Summary (Literature Review):

Most of the studies obtained through literature searches were of cross sectional or semi- longitudinal nature. On PDMS-2 scale, not a single longitudinal study was found in literature. Only one study had used PDMS-2 on Indian children but it was of cross sectional design. This study had reported that Indian children motor development is ‘less’ in age range of 23-33 months and 33-44 months, ‘better’ in <11 months & >55 months and ‘on par’ for 12-22 months & 45-55 months age ranges compared to normative sample. This study does not detail scientific explanation for their findings. I presume, such deficiency would probably be related to limitations the cross sectional study design offers, because age norms are highly dependent on the groups on which they are standardised. Since rate of development may differ between the groups and between the generations, because of differences in the child’s nutrition and child rearing practices. Therefore age norms variations between the two groups. Since cross sectional study design is a ‘shortcut method to represent the natural change’, so authors would have found limitations in finding the scientific basis.

The science of child development is dynamic for which periodical monitoring of child's motor performances with time is important. This can be done through longitudinal study only, because longitudinal study design focuses on the process of change of motor behavior which involves continuous organisation and re-organisation of motor skills. Also, individual differences have relationships with biological and environmental factors that again can be answered via longitudinal study only.
Literature has recommended that PDMS-2 is a valuable tool to study the nature of motor development in various populations of children. Therefore, there is a need to probe deeper into the motor performances of our children through longitudinal study design to know about the rate of motor development and similarities between the cross-sectional and longitudinal motor norms (to suggest for the need of modification/standardisation of PDMS-2 scale, if any); because longitudinal study design, can provide much greater information regarding composition of the PDMS-2 scale.