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The Development of Mature Gait*

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ABSTRACT: To determine the normal gait patterns in childhood, gait studies were performed on 186 normal children between the ages of one and seven years. Rotations of the lower-extremity joints in the sagittal, frontal, and transverse planes; step length; cadence; walking velocity; and duration of single-limb stance (as percentage of the gait cycle) were analyzed throughout a walking cycle using high-speed movies, a Graf-Pen sonic digitizer, a computer, and a plotter as well as electromyograms.

The sagittal-plane angular rotations in children from two years on are very similar to those of normal adults. Subjects less than two years old have greater knee flexion and more ankle dorsiflexion during stance phase, and their knee-flexion wave (stance-phase knee flexion after foot-strike and subsequent knee extension prior to toe-off) is diminished. Also, external rotation of the hip in these younger subjects is pronounced.

Reciprocal arm-swing and heel-strike are present in most children by the age of eighteen months. Since these commonly accepted indicators of gait maturity are present very early, we measured other gait determinants and found that the five important determinants of a mature gait are duration of single-limb stance, walking velocity, cadence, step length, and the ratio of pelvic span to ankle spread. As maturity advances, cadence decreases while walking velocity and step length increase. Important factors in the development of a mature pattern of these determinants are increasing limb length and greater limb stability, manifested by the increasing duration of single-limb stance (an index of limb stability). A mature gait pattern as determined by these criteria is well established at the age of three years.

CLINICAL RELEVANCE: Given these normative data, it will be possible to compare the gait patterns of abnormal children with the patterns of normal children of the same age, and thus to acquire a better understanding of the pathomechanics of gait disorders in childhood.

The usual sequence of events in human neuromuscular maturation and the development of locomotor skill are familiar. The infant is thought to acquire the ability to sit at approximately six months, to crawl at nine months, to walk with support at one year, to walk without support at fifteen months, and to run at eighteen months[18]. At the inception of independent walking, the toddler steps with a wide base and hyperflexion of the hips and knees, holds the arms in abduction and the elbows in extension, and moves in a staccato manner[13]. Following this early exploratory phase of walking, gradually the width of the base diminishes, the movements become smoother, reciprocal arm-swing appears, step length and walking velocity increase, and an adult pattern of walking emerges. There is general agreement that the development of walking skill is completed by the age of five years[13,17,19], but some authors have found evidence of earlier gait maturation[2,3,10,21].

Both learning and maturation of the central nervous system contribute to the evolution of mature gait. Many authors have commented on the relationship between the development of mature gait and maturational changes in the nervous system[13,17]. The course of maturation of the central nervous system progresses in a cephalocaudal manner[4,5,8,11,12,15,18,19].

While many excellent studies of gait maturation in children have been reported[2,3,17,19], very few measurements of the angular rotations of the limb segments were included, and those reported were for a relatively small number of subjects. With the current development of gait analysis and its increasing application to the study of pathological gait, there is a critical need for normative data for children who are one to seven years old. The objectives of the present study were: (1) to outline the changes in gait from the age of first walking to seven years; (2) to define mature gait in terms of specific gait parameters; and (3) to provide a substantial data base to make it possible to compare children who have gait problems with normal children of the same age.

Methods

Subjects Studied

One hundred and eighty-six normal children were studied, of whom 169 (91 per cent) were white. The remainder were Spanish, Oriental, and black. Their ages ranged from one to seven years. The distribution by sex and age is shown in Table I. Each child was studied within thirty days of the date when his or her birthday corresponded to the age group indicated.

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tween limb length and free-speed step length may be evidence of delayed neuromuscular maturation.

As we have shown, the joint motions during gait of normal children, whether mature or immature, are not characteristic. They differ only slightly from those of adults. Marked changes in joint-angle measurements as compared with normal measurements indicate disease or injury of the motor-skeletal system, not immaturity. For example, a patient with spastic diplegia and severe hamstring-muscle contractures will show increased knee flexion throughout stance phase[22].

While normative data for children are of great importance, we do not wish to imply that the presence of a mature gait pattern in a normal child can only be established by using elaborate laboratory techniques. The presence of heel-strike and reciprocal movements of the upper and lower extremities can be observed quite easily. Also, it is not difficult to differentiate visually between the wide base of the toddler and the narrow base of support of the mature walker. It is more difficult to determine the normal relationship between step length, cadence, and walking velocity, but two observers with a stopwatch can measure walking velocity and cadence and calculate step length. With these simple observations and measurements, it is usually possible to separate immature and mature walkers. A high level of sophistication can be achieved by using the Rancho Foot-Switch Stride Analyzer[16]. This system measures walking velocity, stride length, cadence, and duration of single-limb stance.

The real value of normative data is that they provide normal performance standards for children that permit comparison with pathological gaits[21]. It is no longer necessary to compare the walking pattern of a child who has a pathological gait with the pattern of a normal adult. We can now compare the gait patterns of children, whether pathological or unknown, with the patterns of normal children of the same age.

Our understanding of gait disorders in children will be improved by a clear understanding of the development of mature gait. Accurate measurements of gait parameters throughout the development of mature gait provide a framework on which we can build an understanding of the physiological events in human locomotion and the pathomechanics of gait disorders.

NOTE: The photographic measurement system was developed at San Francisco Shriners Hospital for Crippled Children by one of us (D.H.S.) and John Hagy. Expansion of the measurements and refinements of the technique have come about through collaboration between the gait laboratories of San Diego Children's Hospital and Health Center and the San Francisco Shriners Hospital for Crippled Children. The piezoelectric force-plate was developed at Shriners Hospital.

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