

AN OVERVIEW ON THE NEUROLOGICAL READINESS FOR RUNNING

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INTRODUCTION

In developing from a neonate totally dependent on others for his existence to a highly skilled and reasoning adult, the human organism undergoes rapid physical changes. Almost none of those changes are more important to him than those which allow him to make finely coordinated movements – to manipulate his body parts, to undertake locomotion, to respond to objects, to project other objects. It is well known that neurological processes make motor activity possible. Unfortunately, little is known about the relationship between a specific neurological development and the initial occurrence of some motor activity at a later time.

For many years those concerned with motor development have been able to identify normative ages for the onset of specific motor behaviours. In addition, the sequence of arrival of these behaviours has been established with individual variability duly noted. Little is known, however, about what may specifically spawn a specific motor behaviour – accumulated experience, desire for an object, increased muscular strength, further development of the nervous system, etc. Given what is presently known about the human organism, it would be naive to claim that one of the body's systems determines exactly when a given behaviour can be undertaken. Evidence of the high degree of integration and coordination of these systems is abundant. On the other hand, the fact that a given behaviour cannot be undertaken successfully without the functioning of all systems involved is evident.

It is the intention here to examine what knowledge is available about neurological development in relation to the onset of one motor activity. Running has been chosen as that activity. While the neuromuscular pattern for running may be essentially the same as that for walking (Espenshade and Eckert, 1967), information must be processed and acted upon in a shorter period of time during running than walking. The extensive changes which the central nervous system undergoes in early postnatal life and the dependence of a behaviour such as running on neurological processes suggest that an examination of this relationship would be justified. The changes in neurological processes that could affect motor behaviours necessary for running will be reviewed, as will the feasibility of training a child to run at an age considerably before the average age at the onset of running.

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NEUROLOGICAL DEVELOPMENT

a. Brain Development. Most of the changes that occur in the brain between birth and adulthood come in the first year after birth, although there is a great deal of individual variability in the timing of specific changes. According to Lowrey (1973), half of brain growth after birth comes in the first year, three-fourths of growth in three years, and nine-tenths in seven years; brain weight increases two-and-one-half times in the first year.

The cerebral hemispheres increase in size and in function during the early years of life. All of the neurones of the cerebral hemispheres are present at birth (Crelin, 1973; Robinson and Tizard, 1966) so that continued growth of the hemispheres is due mostly to an increase in white matter. Neurones of the cerebral hemispheres myelinate from birth to puberty: neurones of the olfactory, optic, and acoustic cortical fields myelinate first, followed by neurones of the motor cortex, the projectional, commissural, and finally association neurones. Myelination of the latter is thought to continue through adulthood (Crelin, 1973). During the first year the processes of each cortical neurone establish from one thousand to one hundred thousand connections with other neurones (Crelin, 1973). Neuroglia proliferate until five years of age while the neurones continue to increase in size.

The movements of the newborn infant are not regulated by the cerebral hemispheres and pyramidal tracts. Recent evidence (Robinson, 1969) suggests that the cerebral hemispheres are not entirely nonfunctional at birth, as was once thought, but may play some role in reactions, especially in turning the head to diffuse light and in smiling. Their role might be to modify stereotyped reflexes. Goldie and Hopkin (1964) suggest that the response of the newborn in watching the mother may be mediated by the cerebral hemispheres. Mass movements typical of the first months and regulated by the extrapyramidal system are inhibited by the corpus striatum (Peiper, 1963). At four to five months, goal-directed behaviour, which is mediated by the cortex and pyramidal tracts, is evident.

The cerebellum, hypothalamus, pons and brain stem are relatively small at birth (Crelin, 1973). Fissuring between the cerebellar hemispheres has taken place

(Robinson and Tizard, 1966) and the flocculonodular lobes and vermis are myelinated, as are cerebellar connecting neurones at birth (Larroche, 1966). The cerebellar cortex, however, is as yet undifferentiated. The cerebellum increases in size seven times between birth and the first ten years, as compared to a threefold increase in cranial capacity (Crelin, 1973).

Despite the fact that they are not fully functional (Peiper, 1963), the lower brain centres mediate many of the reactions and reflexes (Robinson and Tizard, 1966). Neurones of the brain stem and basal ganglia are myelinated at birth, as are the cranial nerves of the midbrain, pons, and medulla (Crelin, 1973) and the chief motor pathways of the pons and medulla (Timiras, 1972). Those centres with vital tasks are most mature (Peiper, 1963), with those overseeing respiration and food intake being completely developed at birth.

Although the exact significance of specific electrical activities as indicated by the electroencephalograph (EEG) of the brain is unclear, definite changes in the electrical activity of the brain occur in early life. In fact, the EEG does not reach its normal adult pattern until about thirteen years of age (Robinson and Tizard, 1966). At three to four months changes are indicated in waking EEG by the appearance of alpha rhythms in the occipital-parietal region (Ellingson, 1964). From this point to twelve months of age, alpha frequency increases, perhaps doubling its frequency.

In summary, the ontogenetic and phylogenetic older parts of the brain are more mature at birth. Maturation proceeds from the medulla to the basal ganglia, to the mesencephalon, to the cerebral cortex. According to Davidson and Dobbing (1966), the end-point of myelination of the brain has not been determined; however, brain weight increases until adolescence, which may imply that myelination continues until adolescence.

b. Spinal Cord and Nerve Pathway Development. The spinal cord is relatively small at birth and relatively much shorter (Crelin, 1973). Differential cord growth continues until maturity. At birth the central gray matter has long been in essentially adult form and myelin has formed around many fibres of the marginal layers, but thickening will continue into adolescence (Timiras, 1972). The order of myelination is generally cervical then lower, ventral motor roots then dorsal sensory roots. The corticospinal and tectospinal descending motor tracts myelinate during the first two years (Timiras, 1972; Crelin, 1973). The anterior pyramidal tracts are myelinated at birth, but the lateral pyramidal tracts do so after birth, although myelination of the pyramidal tracts proceeds at different rates in infants (Peiper, 1963).

Myelination is toward the brain in the sensory tracts and away from it in the motor tracts; sensory tracts will usually myelinate first, except that the ventral roots of the spinal cord and the efferent pathways of the cerebral hemispheres precede dorsal roots and afferent tracts, respectively.

Sensory myelination proceeds in the order: central pathways of the tactile and olfactory system, visual pathways, and finally auditory pathways. The optic nerve just begins to myelinate at birth (Peiper, 1963), but the optic chiasma and olfactory nerves are relatively large in size (Crelin, 1973). It is not until the second or third year that peripheral nerve myelination is completed (Peiper, 1963), although all of the sensory nerves can transmit to the brain at birth. There apparently is a marked increase in myelination of the peripheral spinal nerves around the second or third week after birth (Peiper, 1963).

c. The Reflexes. Reflex activity is high in the newborn. Peiper (1963) indicates that the reflex arc passes through the thalamus opticus and pallidum. For this reason, the level of reflex activity is thought to be an indication of cerebral cortex immaturity at birth (Timiras, 1972). As the cortex matures and assumes control of the lower brain centres, many of the reflexes either disappear or become localized in a fairly predictable time sequence. All of the responses at birth are unconditioned reflexes, since conditioned reflexes come about with the maturing of the cerebral hemispheres. The first weeks of life are characterized by persistence of most of the posture reflexes present at birth. These reflexes typically disappear during the first year of life.

In contrast, the gravity reflexes, which adjust positions and movements of the head, trunk, and extremities to gravity (Peiper, 1963), emerge during the first year. The labyrinthine righting reflex of the head is faint in the newborn but later serves as a prerequisite for learning to lift the head. Chain reflexes dependent on this reflex also develop. For example, the symmetrical chain reflex in the abdominal position gradually develops in the first months, but disappears during the second year.

Peiper (1963) classifies another group of reactions and reflexes as reflexes of station and gait dependent in part on gravity. These reflex movements approach the movements of locomotion, but disappear sometime before the onset of "real" movements. The stepping reflex movement can be elicited by holding the infant over a base and within leg reach of it. Both legs will then extend via simultaneous contractions of the flexors and extensors; one leg then flexes at the knee and hip and is put down just beyond the other foot. The supporting leg will then do the same. This reflex differs from "real" walking in that only the legs and none of the rest of the

body is used, but the slightly flexed knee and hip and the toe-out walk of the reflex is typical of a child learning to walk. At four to five months this reflex usually disappears while "real" walking begins at nine to ten months. The reflex can also be observed in ascending (but not descending) steps, both rightside up and with the infant upside down. Peiper (1963) claims this as evidence for the reflex being independent of gravity. If the neonate is put in the abdominal position and support is put against his soles, he can push his body forward against the unmovable resistance. This reflex movement disappears at three to four months; real creeping is seen at seven-and-one-half months. The reflex has been observed to persist longer with cerebral pathological conditions, while attempts to prevent its disappearance in normal infants has failed (Peiper, 1963).

Rhythmic swimming movements have also been observed in neonates, but they also become increasingly irregular around five months while "real" swimming is learned much later. Mounting or climbing reflex movements appear to follow the same pattern but exact identification of this reflex movement has been inhibited by lack of a good definition of "mounting" or "climbing."

According to Peiper (1963) disappearance of these reflex movements is evidence of the increasing maturity of the cerebral cortex, first to inhibit the reflex and then later to oversee development of the "real" movement. The cervicocaudal (descending) direction of the development of movements is in contrast to the cervicorostral (ascending) development within the brain.

Four gait patterns of independent locomotion have been identified (Peiper, 1963): creeping, crawling, sliding (on buttocks), and free erect gait, which must be learned, but not necessarily preceded by the other three patterns. It is Peiper's (1963) belief that the purpose reflex movements serve is to lead to fairly coordinated movements of the extremities in performing these gait patterns; there is, however, no temporal connection between the reflexes and gait patterns. It would therefore appear that some stage of cortical development beyond that which exists in the first months of life are necessary before independent locomotion, including running, may be undertaken. A time line of cortical development has not been established, but it may be recalled that conditioned reflexes associated with the cerebral cortex are observed at nine months. Since walking begins around nine to ten months, this period may be significant in that behaviour necessitating a fairly high degree of cortical involvement begins.

The neuromuscular pattern required for running is not very different from that of walking, but an increase in tempo, strength, and balance is required (Espenschade and Eckert, 1967). The stiff-legged run that may be

observed in many infants at eighteen months is not a true run since there is no period of flight. Also, the entire sole of the foot is planted as opposed to the heel-toe action that is achieved later. Between the ages of two and three years a smoother, true running stride is achieved; stopping and turning quickly is not very accomplished yet. Control over stopping, starting, and turning comes at four to five years, with improved power and form. By six years the adult manner of running is usually established.

NEUROLOGICAL READINESS FOR RUNNING

It has been established that myelination is an ongoing process of development in the nervous system during the first months of postnatal life. Contrary to early thought, a nerve may be functional before it is myelinated (Nash, 1970; Timiras, 1972), although Espenschade and Eckert (1967) state that a correlation between the order in which nerves become functional and the appearance of myelin can be found. Myelin does improve the speed and strength of conduction; in addition, it acts as an insulator to prevent signals from being lost to adjoining tissue or being diffused (Bijou and Baer, 1965). Little is known about how much myelin is needed to achieve a given level of motor coordination.

One of the necessities of locomotion and especially of running as compared to walking, would seem to be speed of nerve conduction in both the afferent and efferent pathways. Since the corticospinal tracts, which are concerned with finely coordinated voluntary movement, myelinate during the first two years of life, one may speculate that efferent nerve conduction must reach a certain velocity before finely coordinated locomotor movements may be undertaken. No research has apparently examined this issue, however. Espenschade and Eckert (1967) cite evidence that myelination is stimulated and accelerated by function, although myelination will not be retarded by the absence of function.

Studies by McGraw (1940, 1943), although involving small numbers of observations, have led her to conclude that training for a motor activity before neural mechanisms have matured to a certain level is useless. McGraw (1940) has taken the approach that the cerebral cortex plays no role in the micturition reflex of the newborn. As the cortex matures it has an inhibitory influence on the reflex; continued involvement of the cortex comes later, at ten to twelve months and associations of the act and the situation are made. McGraw concludes that training should be given only when the infant's behaviour indicates that there is cortical participation. Other cited studies (McGraw, 1943) involving a variety of activities — tricycling, climbing, jumping, and roller skating — support this line of thought.

Recent work by Zelazo et al (1972 a, b) challenges this viewpoint since their investigation found an early onset of walking after walking and placing reflexes were elicited daily in a small number of newborn babies. It was their belief that the walking response could be transformed from a reflex to an instrumental action. Pontius (1973) has in turn challenged this stand, pointing out that myelination of the pyramidal tracts at about eleven months is necessary for *voluntary* movement of the legs. This would preclude the "walking" observed by Zelazo et al (1972a) at two months of age being a learned response. Simpkins and Raikes (1972), Gotts (1972), and Pontius (1973) have questioned the advisability and ethics of continuing to elicit reflex responses in the newborn and of promoting early walking.

In light of these factors, the relation between a motor activity and neurological development can be speculated upon, although formation of a theory would be premature and well in advance of empirical support. It would seem, however, that it may be assumed that performance of independent locomotor acts in the first few months of life, i.e., some time before they are actually undertaken, would be neurologically impossible in addition to muscularly or structurally impossible. This assumption is made on the grounds that reflex activities during the early months indicate the cerebral cortex is at least limited in its degree of functioning; later disappearance of these reflexes and the onset of independent locomotor acts, which must necessarily be mediated by the cortex, further indicates a maturing of the cerebral cortex. Since the rule of thumb in development appears to be that of gradual changes rather than abrupt change, it is not surprising that the onset of locomotor activities, be it running, walking, etc., is gradual. Whether or not this gradual onset of a locomotor activity is due to gradual neurological changes or the development of other body systems, for example increase in muscle strength, is open to question.

Some available evidence (Peiper, 1963; McGraw, 1943) points to the fact that training or practice of a locomotor act well in advance of the time it naturally occurs is useless to the development of that act. It would seem therefore that little can be done to speed up the onset of locomotor acts, and if certain neurological changes occur before the locomotor act can be undertaken, they also would not be speeded up by practice.

Neurological changes have slowed considerably at the ages between the onset of walking and that of running. Since information must be processed and acted upon very rapidly while undertaking a run, however, the degree of myelination of the descending corticospinal tracts may be important. In addition, more coordination between the agonist and antagonist muscles is needed, so that cortical centres may need to be fairly developed to coordinate the complex movement of running. The exact difference between the stiff-legged, fast walking of the eighteen-month-old and the true run of the two-year-old may be due to many factors, including neurological development, strength development, etc., but in unequal amounts. That is, muscle strength may be a major contributing factor to the development of a true run while neurological changes are a minor factor.

It is clear that much more study in this area of development is needed, and further, would be warranted, since rapid changes in neurological systems definitely occur during the first years of life and particularly in the cerebral cortex. While it will probably never be stated that neurological readiness is the sole determiner of the onset of locomotor activities, certainly such changes do play a role. Advancement of knowledge in this area would give additional knowledge of the specific relationship between neurological function and motor performance, both in regard to normal and to abnormal motor behaviour.

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