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DEVELOPMENTAL PHYSIOLOGY

Developmental kinesiology: Three levels of motor control in the assessment and treatment of the motor system

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Summary Three levels of sensorimotor control within the central nervous system (CNS) can be distinguished. During the neonatal stage, general movements and primitive reflexes are controlled at the spinal and brain stem levels. Analysis of the newborn's spontaneous general movements and the assessment of primitive reflexes is crucial in the screening and early recognition of a risk for abnormal development. Following the newborn period, the subcortical level of the CNS motor control emerges and matures mainly during the first year of life. This allows for basic trunk stabilization, a prerequisite for any phasic movement and for the locomotor function of the extremities. At the subcortical level, orofacial muscles and afferent information are automatically integrated within postural–locomotor patterns. Finally, the cortical (the highest) level of motor control increasingly becomes activated. Cortical control is important for the individual qualities and characteristics of movement. It also allows for isolated segmental movement and relaxation. A child with impaired cortical motor control may be diagnosed with developmental dyspraxia or developmental coordination disorder. Human ontogenetic models, i.e., developmental motor patterns, can be used in both the diagnosis and treatment of locomotor system dysfunction.

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The neonate

The neonate is functionally and anatomically immature (Fig. 1). Organized at the spinal and brainstem levels of the CNS control, primitive general movements (GMs) display characteristic quality and intensity, involving the entire body (Einspieler and Prechtl, 2005). The GMs (Prechtl, 1997; Hadders-Algra, 2004) are not triggered by any obvious external stimuli (Adde et al., 2007) and do not serve any specific purpose, such as grasping, reaching or support. For example, a newborn cannot grasp purposefully; grasping reflex is an automatic, involuntary response to proprioceptive and tactile palm stimulation and does not serve a purposeful grasp. The absence of antagonistic co-activation, which is typical for early postural behavior, does not allow for segmental stability. Therefore, postural adjustment is quite different from the later development when motor functions such as reaching or walking occur (Hadders-Algra, 2005). Purposeful reaching also requires coordinated activity of the head, eyes and hand which, in turn, depends on trunk support. Such coordination is not available in the neonatal stage and appears only at 4 months of age (Bertenthal and Von Hofsten, 1998). A newborn's ability to hold a segment in a static position against gravity is very limited (Bertenthal and Von Hofsten, 1998; Orth, 2005). The body follows head rotation and an asymmetrical posture occurs (Orth, 2005). According to Prechtl, newborns are able to balance their head for a few seconds in a sitting position (Prechtl, 1997). Although ocular-motor coordination starts from the first month of life (Bloch and Carchon, 1992), constant visual fixation and tracking are quite limited in a newborn. This ability appears at 1 month of age and rapidly increases over the next few months of life. The contribution of head movements to visual tracking also appears at 1 month of age (Bertenthal and Von Hofsten, 1998). Orofacial muscle activity, including the tongue, becomes organized within general movements. Healthy newborn can coordinate sucking, swallowing and breathing which allows for a normal sucking pattern (Palmer et al., 1993).

Assessment of neonatal motor behavior can serve as a very early pediatric screening tool (Adde et al., 2007; Burger and Louw, 2009). The normal physiology of newborn GMs consists of a series of gross movements of variable speed and amplitude that involve all parts of the body (Hadders-Algra, 2004). For example, a newborn typically keeps its fists closed with the thumb inside the palm (Fig. 1). However, as a general movement of the arm occurs, it also involves the hand, leading to hand opening and the thumb moving outside the fist (Fig. 2). Under normal physiological conditions, the fist is not a fixed postural pattern (Hadders-Algra, 2004; Orth, 2005; Vojta, 2008). In the neonatal period, the GMs are writhing, "elegant", rather slow with specific amplitude and involve not only the extremities, but also the trunk and orofacial muscle systems. For example, under pathological conditions in infants who later develop cerebral palsy (CP), not only that their posture is different (Fig. 1C), but also their global movement patterns demonstrate different quality, which is best described as "cramped-synchronized" rather than "elegant". They involve mainly the proximal segments and muscles, with different intensity, speed and amplitude (Prechtl et al., 1997; Adde et al., 2007). Abnormal GMs are insufficiently variable and lack complexity and fluency (Hadders-Algra, 2004). Posturally, the physiologically normal neonate may prefer head rotation towards one side, which is known as "predilection" (Fig. 1A) (Orth, 2005; Vojta, 2008). However, the head rotation is not fixed and, even during the newborn stage, every healthy newborn should be able to rotate the head across midline.

Primitive & postural reflexes

During the neonatal stage, primitive reflexes organized at the spinal and brain stem levels can be elicited. Utilizing adequate proprioceptive and exteroceptive (non nociceptive) stimulation, certain reflexes, such as the crossed extensor reflex, suprapubic reflex, step reflex, supporting reflex and other reflexes (Fig. 3), can be observed. The assessment of spontaneous complex motor behavior, primitive reflexes and seven postural tests as outlined by Vojta can be used to examine the infant's developmental age. They can be used to determine whether the development is physiologically normal or whether there is a risk for an abnormal development (Zafeiriou, 2004; Orth, 2005; Vojta, 2008). An experienced clinician may even predict the

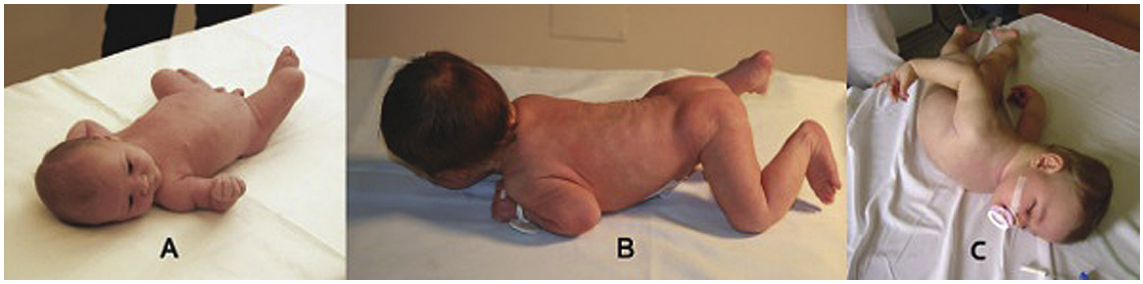

Figure 1 Neonate. A: A typical supine posture with the head rotated toward one side (called predilection), the hand closed in fist with thumb inside the palm, cranial chest position, no postural activity in abdominal muscles. B: A typical prone posture: the chest is the weight bearing area, the arm is in adduction, fist with thumb inside the palm, scapular elevation, anterior pelvic tilt, the baby cannot hold the head steadily above the mat as a result of a lack of equilibrium and a lack of supporting arm function. C: Baby with cerebral palsy — a pathological posture with opisthotonus; both the posture and quality of movements are different in comparison with those found in an optimally developing baby.