

by Frank Wilson.

in hardbound copy, same in paper back!!—p98:

—on the functioning of eyes and hand:

One extremely important difference between the eyes and the upper limb as movable explorers has to do with the biomechanical (hence “computational”) complexity of moving the sensor (retina or fingertip) to the target of interest. The eye, assuming the hand to be in a favourable position, need only rotate toward the target to bring light from it to the retina. The hand, however, is located at the end of a complex biomechanical linkage and must actually *get to* the object to be touched. The body may first have to be moved toward the target. Once there, and taking into account its configuration as it approaches the target, the reaching arm has wide latitude in the combinations of joint angles and contraction-relaxation patterns of trunk and upper extremity muscles that can be assumed in order to bring the hand itself into contact with the physical target.

The infant...is not given this skill but must learn it. The long march toward physical and mental agility begins while the infant is still on its back. where it must remain until the muscles of the neck can hold hold the head still while the eyes search and study. Newborn babies will reach toward objects placed in front of them by the time they are two weeks old. When a baby’s neck muscles are strong enough to support the head, reaching rapidly becomes accurate in an upright posture. This may seem a small technical point, but it is not: the hand works under the guidance of the eye, but cannot do so until the head has become a dependable platform for the visual system.This system also leads to perceptual stabilisation of the visual world.

The coupling of hand and eye movement is an enormously complex learning task in which the child must be intensively engaged before it can ever hope to pry its bottom off the floor.

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Before the baby can (or should) stand and walk, its brain must develop and integrate a multi-sensory reference system to track

limb movements on an on-going basis—the nervous system must know at all times where each hand is with respect to the midline, with respect to its root at the shoulder, with respect to the other hand, to the foot, to the mouth, and to the eyes.

Inevitably this same process helps to establish a coordinate system for external objects located in three-dimensional space. Where is the hand with reference to mother's breast, a rattle, a handle, or the puppy's ears. Increasing the range of exploration permits the calibration of bodily movement against space and objects in the real world. and while all this is going on, the hand is learning to operate at the end of the arm, beginning to capture objects of interest and to bring them closer to the body.

Before the fingers begin to work independently, two critical and apparently separate events in neuromuscular development are necessary: the arm must have learned to move to a target under the guidance of the eyes, and the hand must have learned to orient and shape itself in preparation for grasping the target. The first of these stages is normally complete before the age of five months, and the second before the age of ten months; after that, the hand is ready for a lifetime of physical exploration.

The truth is, there is no point lifting the baby's little bottom off the ground until the brain is prepared to confront the explosion of visual-spatial information that will result. The newly mobile brain will then discover through direct experience the consequences of its own incessant relocation in space, of the destabilisation of horizontal and vertical landmarks, and of the independent movement of targets that have their *own* trajectories and that can and do change course whenever they please. Once the brain takes off in its own two feet, there are immediate and continuous changes in the physical state of the body, as well as in relations between the body and the world, and these will have to be recomputed many times every second.

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We know from observations of young children that a great deal happens during the first year of life to prepare a child for walking and maneuvering

among objects that move independently in the environment. The first essential milestone in this development is the creation of a stable platform for the visual system (the head supported by the neck) so that the eyes can reliably guide movements of the upper limb. No young child can become a successful hunter (or third baseman, or skater, or tennis player) until the brain becomes adept at manipulating an elementary physics equation (distance = speed x time) needed to solve “relative motion” problems. It is in the child’s earliest experiences in practical physics—watching, locating with both hand and eye, and then intercepting moving objects—that the nervous system builds its own unique library of solutions to the computational problems presented by coordinated movement.

The critical importance of such a library means that a baby’s instinctive attraction to movement, followed by the impulse to reach and then to grasp (catch), is one of the earliest maturational imperatives in the human nervous system. Without ever being told to do so, or having rehearsal strategies explained to it, the baby will play this game and rehearse these movements endlessly, as it gives itself things to do with its body that are more and more difficult. These games are created by the nervous system in order to teach itself a concrete, experiential sense of physics.

One of the most important physiologic consequences of these accumulated body lessons in physics is the establishment of an internal temporal reference system—a biologic clock—and juggling makes it clear just how important an accurate internal clock is. The juggler throws a weighted object that will rise and fall a certain distance, and he must time the preparations for a catch accordingly. Whatever is going up is going to come down, and nothing will change its reach or fall. This seemingly trivial fact leads, however, to a somewhat surprising finding in the MIT study: the accuracy of the toss depends on *when* you let go. As Austin puts it, “Timing seems to be so critical that even what looked like errors in space (the direction of the toss is wrong) usually have to do with an error in the timing of the release.” What does this mean? It means that you will never be able to throw accurately enough to hit a target unless

your own internal clock, which controls the timing of muscle activity, is perfectly calibrated. Based on what we have learned about the normal behaviour of babies less than a year old, that clock is not set or calibrated until the head is under control. And when that time comes, the setting and calibration is organised through active movement, including the catching games the child plays.