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The bodily basis of thought

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Abstract

Classical cognitivist and connectionist models posit a Cartesian disembodiment of mind assuming that brain events can adequately explain thought and related notions such as intellect. Instead, we argue for the bodily basis of thought and its continuity beyond the sensorimotor stage. Indeed, there are no eternally fixed representations of the external world in the "motor system", rather, it is under the guidance of both internal and external factors with important linkages to frontal, parietal, cerebellar, basal ganglionic, and cingulate gyrus areas that subserve cognitive and motivational activities. Indeed, the motor system, including related structures, is a self-organizing dynamical system contextualized among musculoskeletal, environmental (e.g., gravity), and social forces. We do not simply inhabit our bodies; we literally use them to think with.

> "The words of language, as they are written or spoken, do not seem to play any role in my mechanism of thought. The psychical entities which seem to serve as elements in thought are certain signs and more or less clear images which can be "voluntarily" reproduced and combined. . . . The above mentioned elements are, in my case, of visual and some of muscular type" (Einstein quoted in Hadamard, 1996, *The mathematician's mind*: *The psychology of invention in the mathematical field*. Princeton, NJ: Princeton University Press (original work published 1945).)

Keywords: Cognition; Brain; Action; Movement; Body; Embodied mind

1. Introduction

It has not been until recently that social and neuroscientists have seriously considered the nature and mechanisms of thought and cognition outside of the traditional domains of language and logic. Indeed, the latter two have often been thought of as two

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sides of the same proverbial coin with different systems of logic at various developmental periods undergirding the foundation of languages and numbers (Piaget, 1952). Suggest to one fortified by this belief that logic is not the sole province of these areas of cognition and immediately one is met with the usual recognizable incredulity: "Ah, but you are simply using the word inappropriately outside of its normal extension", goes the complaint. Yet, one is reminded of Alice's response in Lewis Carroll's childhood novel. "When *I* use a word", Humpty Dumpty said, "it means just what I choose it to mean — neither more nor less". "The question is", said Alice, "whether you *can* make words mean so many different things." "The question is," said Humpty Dumpty, "which is to be the master — that's all" (Carroll, 1872/1998).

Early theorists of sensorimotor learning and development, to their credit, recognized the central importance of movement in cognitive development (e.g., Piaget, 1952). Unfortunately, the main thrust of these theories absorbs sensorimotor learning into higher systems of thought draining it of its cognitive uniqueness and centrality in early as well as later learning. This is surprising given that the endpoint of any intellective activity is always some movement, action or activity (Montessori, 1949/1967). Indeed, movement occupies a central position in human cognitive activity (Laban, 1966). To be sure, it has been recently proposed that there is an elaborate information-processing system involved in movement with extensive bi-directional pathways to parallel systems in the brain that are involved in planning, reasoning, and emotion (Leiner, Leiner & Dow, 1986, 1989, 1993a,b). The cerebellum, traditionally viewed as directing and controlling voluntary movement may play a much larger role in thought itself (Ito, 1984, 1986, 1993). The resulting "information-processing" system could conceivably go beyond the traditional control of motor functions subserved by the cerebral motor cortex to enable the manipulation of kinesthetic ideas (Leiner, Leiner & Dow, 1986). In effect, it appears that we "think" kinesically too (Gardner, 1993; Iverson & Goldin-Meadow, 1998; Kennedy, 1997; Nicoladis, Mayberry & Genesee, 1999; Seitz, 1992, 1993, 1994a, b, 1996). For example, it has been postulated that thinking is an advanced form of skilled behavior that has evolved from earlier modes of flexible adaptation to the environment (Bartlett, 1958), that the body is central to mathematical understanding (Lakoff & Nunez, 1997), that speech and gesture form parallel computational systems (McNeill, 1985, 1989, 1992), and that mental practice alone improves physical skills (Hinshaw, 1992; Ogles, Lynn, Masters, Hoefel & Marsden, 1994).

In terms of development, nonverbal behavior is central to expression and communication. Infants and young children learn to communicate with gestures before they learn to speak (Bruner, 1983) and this mode of communication continues into adulthood where a large body of kinesic behaviors augments or replaces language (e.g., illustrators, regulators, affect displays, diectics, metaphoric gestures, emblems, and a huge class of procedural knowledge and skills) (Ekman & Friesen, 1969; McNeill, 1992). To be sure, there have been recent arguments made for the gestural origins of language and the fact that both speech and hand control originate from the same neural systems (Corballis, 1999). Choreography and dance, sports, and craftsmanship are but a few examples of nonverbal abilities. Evidences from the study of the deaf and sign languages (Klima & Bellugi, 1980), the blind and the reading of Braille text (Seitz, 1993), and use of body therapies (Feldenkrais, 1991), are a few other examples. Historically, the suppression of sign language use among the deaf has resulted in a significant deterioration in the intellectual achievement of deaf children (Sacks, 1990) and developmentally, in delays in cognitive and social development (Bebko, Burke, Craven & Sarlo, 1992). With regard to the blind, Braille is essentially the "reading" of a tactile code in which the number and spatial forms of the raised dots are critical (Hardman, Drew, Egan & Wolf, 1993). In human cultures, facial expression, gesture and posture, gaze, spatial behavior among conspecifics, touch, bodily movements, vocalization, smell, and appearance are essential and basic to communication (Argyle, 1989). Even Charles Darwin went so far as to suggest that, for example, head shaking in infants originates in the mother–child relationship (Darwin, 1872/1965).

The experience of music is an elegant specific example of the body in thought: Loudness, tonal colors, musical beat and tempo, dynamic changes, melodic phrasing and contours, chromatic harmonies, musical accents, accelerando, syncopation, rhythmic ostinato, among other aspects, form the bodily basis of meaning in the musical domain. Indeed, pedagogical practices such as the Dalcroze, Kodaly, Orff, and Suzuki methods capitalize on the fact that basic elements of music (rhythm and musical dynamics, intervallic relationships such as pitch and melody, and sonority) can be most effectively taught through physical motion using such devices as rhythm, rhythmic solfege, and improvisation (Jaques-Dalcroze, 1930/1976).

One reason for the importance of studying motor abilities is the recognition that evidence from the study of children's and adult's motor capacities can address long-standing questions in other psychological domains such as the nature of human learning and memory, planning, and categorization, to name a few. Another reason is that it throws into relief some of the major problems with the contemporary "representational" view of the mind. Classical cognitivist and connectionist models posit a Cartesian disembodiment of mind assuming that brain events can adequately explain thought and related notions such as intellect. While much has been written about the subject, little is known about how the mind actually represents anything. That is to say, how does the brain give rise to mental states that "represent" the external world (McGuinn, 1999)? One problem with the representational view is that it presumes an hierarchical system in which the brain is a distributor of commands and the body is an ambassador of purpose or, to put it another way, the brain regulates our bodies as does a CEO a corporation: the knowledge flow is one way and top-down. Linked to this view is the computer metaphor of the mind in which thinking is solely a brain-based (or CPU-based) activity. This standard view has been popularized in such early movies as "Invaders from Mars" (1963) in which a head in a glassfilled dome commands a motley assortment of unintelligent drones as they attempt to invade and take over the human world.

What has been left out of these accounts of cognition is the central importance of the body in thought. And when one puts the body back in thought, or what are now called "embodied mind" approaches to human thought and intelligence, one is left with a very different perspective on human thinking. For instance, the human propensity for categorization is structured by metaphoric, imagistic, and schematizing abilities that are themselves undergirded by perceptual and motor capacities (Jackson, 1983; Johnson, 1987). Moreover, these capacities rest on a biological infrastructure.

2. The biological basis of intelligent movement

Recent findings in the neurosciences indicate reciprocal and parallel neural pathways between the cerebellum, traditionally viewed as controlling gross and fine motor functions but now hypothesized to play a role in thought itself (Ito, 1984, 1986, 1993), and the frontal cortex, where working memory and executive functions such as planning, monitoring, task management, and focusing attention occur (Smith & Jonides, 1999). It has been suggested that the evolutionary significance of these pathways is that they enable the kinesic manipulation of concept and ideas (Bracke-Tolkmitt et al., 1989; Leiner et al., 1986, 1989, 1993a,b). For instance, inadequate network connections among the dorsolateral prefrontal cortex, thalamic pathways, and cerebellar sites lead to "cognitive dysmetria" or problems in the processing, coordination, and prioritizing of information that may play a role in the genesis of schizophrenia and other mental illnesses (Andreasen, Paradiso & O'Leary, 1998). Similarly, the "cerebellar cognitive affective syndrome" is linked to disturbances in language (e.g., agrammatism), personality (e.g., blunted affect), spatial cognition (e.g., deficits in visuospatial memory), and executive functions (e.g., difficulties in planning) as a result of disruption of network connections. Whereas cerebellar lesions are associated with disturbed affect, posterior lobe lesions are associated with problems in cognitive processing. Nonetheless, the cerebellum is posited to integrate diverse internal representations with self-generated activity and the external world through corticopontine, pontocerebellar, cerebellothalamic, and thalamocortical network pathways and loops (Schmahmann & Sherman, 1998). In fact, there is evidence of cerebello-thalamocortical loops from the dentate part of the cerebellum to the dorsolateral prefrontal cortex involved in spatial working memory that would suggest nonmotor functions (Middleton & Strick, 1994). Moreover, the parallel evolution of both the dentate nucleus and regions of the frontal lobe in hominids as well as the integration of stereoscopic vision and use of the hands in primate evolution (Sanides, 1970) suggests motor activity as the basis of intelligence. Indeed, it has been postulated that the core of human intellect is the capacity of more recent abilities to draw on computational domains that evolved for other tasks (Rozin, 1976).

The motor basis of concepts and ideas is also reported in case studies of cerebellar damage where there are deficits in practice-related learning (e.g., the wearing of magnifying or reducing prisms) and in detection of errors (e.g., selecting between synonyms and nonsynonyms). These studies suggest that if the cerebellum is the interface between sensory representations and motor output, it may serve as an anatomically distinct long-term memory and learning system (Fiez, Peterson, Cheney & Raichle, 1992) or modifiable pattern recognition system (Marr, 1969). Moreover, basal ganglia defects and deterioration of the substantia nigra, locus ceruleus, and raphe nuclei in the brainstem that upset dopamine pathways, result in cognitive (e.g., dementia and depression) as well as motor deficits. These deficits are characteristic of both Pakinson's disease, in which an increase in inhibitory signals leads to a reduction in cortical excitation and movement (DeLong, 1990; Youdim & Riederer, 1997), and Huntington's disease in which a reduction in inhibitory signals leads to an increase in cortical potentiation and movement (Cote & Crutcher, 1991); Middleton & Strick, 1994). Such dual circuits suggest that the ability to shift behavioral set, that is, initiate action, underlies the production of novel behavior or the amalgamation of patterned behavior into novel sequences. Indeed, repetitive stereotyped movement patterns (e.g., obsessive–compulsive behavior and Gilles de Tourette syndrome) indicate the malfunctioning of this system (Gazzaniga, Ivry & Mangun, 1998).

Since the beginning of the 1990s, research on the cerebellum and related "motor" structures has undergone a renaissance. The cerebellum is now known to play an important role in timing functions that are utilized by perceptual and cognitive systems (Gazzaniga et al., 1998; Ghez, 1991b; Wickelgren, 1998, 1999), but there is also recent evidence that it, along with the basal ganglia (Cote & Crutcher, 1991; DeLong, 1990; White, 1997), plays a role in planning, regulation, and attention (Akshoomoff & Courchesne, 1994; Courchesne et al., 1994). Indeed, there appears to be two separate pathways for planning movement: the extrapyramidal tracts originating in the brainstem and the corticospinal tracts originating in the motor cortex. Whereas the former specifies the goal or target location and is less flexible, the latter specifies the trajectory of action (i.e., distance) and has evolved as a more flexible system (Gazzaniga et al., 1998). Both pathways indicate that cognition follows action (e.g., specification of location and distance). Moreover, it has been posited that the cerebellum contributes to basic associative learning processes (e.g., associating words with colors; Bracke-Tolkmitt et al., 1989) and the ability to rapidly shift attention both within and between sensory modalities (Akshoomoff & Courchesne, 1994). The latter may lie at the core of autism, in which maldevelopment of the cerebellum leads to poor social and cognitive development even in the absence of damage to the hippocampus and amygdala (Courchesne et al., 1994). On the other hand, the basal ganglia, via the dorsolateral prefrontal circuit, appears to store representations of spatiotemporal contexts concerned with orientation in space, and the lateral orbitofrontal circuit with the ability to shift from one mental set to another (Cote & Crutcher, 1991). The storage of these representations in the basal ganglia may abet the frontal cortex in implementing appropriate behaviors (White, 1997).

Moreover, some parts of the motor systems are specialized for acquisition of new motor behaviors under external guidance (lateral premotor, parietal, and neocerebellar regions; Ghez, 1991a; Willingham, 1998), whereas other parts are specialized for already acquired skilled motor plans (supplementary motor, dorsolateral prefrontal, and basal ganglionic areas; Curran, 1995; Goldberg, 1985). Another "motor" structure, the posterior parietal cortex, is responsible for creating a frame of reference (i.e., spatial, visual, vestibular, and haptic) for movement (Ghez, 1991a; Willingham, 1998) and for coordinating multimodal sensory feedback with motor imagery (Crammond, 1997). Moreover, new evidence on the function of the motor cortex indicates that it stores (i.e., "kinesthetic" or procedural memory) and implements the serial order of a motor plan (Carpenter, Georgopoulos & Pellizzer, 1999), what I will call the syntax of movement or "motor logic", and the motor system as a whole organizes movement so that the parts work together (i.e., "motor organization"). Thus, it has been posited that there is a general-purpose module for sequencing that participates in both movement and language, among other cognitive tasks (Corballis, 1999; Greenfield, 1991; Lashley, 1951). Or to put it another way, there is evidence for a "mirror system" for both action recognition and intentional communication in the primate cortex (Rizzolatti & Arbib, 1998).

Therefore, motor logic, motor organization, kinesthetic memory, and on-line kinesthetic awareness form the core of the intelligent operation of the motor system. Nevertheless, movement and thinking do not exist in a cognitive and biological vacuum. Sensory systems guide movement and thought (Reed, 1982). The nervous system does not so much as direct behavior as shape the dynamics of the coupled system of brain, body, and environment (Chiel & Beer, 1997). So, for example, visual information is essential to the location of a sound source encoded in eye-based coordinates necessary for reaching in a spatial frame of reference — even in the dark (Batista, Buneo, Snyder & Andersen, 1999). Moreover, movement is contextualized) among musculoskeletal, environmental (e.g., gravity; Turvey, 1990), and social forces. Muscle neurons fire simultaneously in aggregate in concert with the olivocerebellar system to produce periodicity and patterned motor activity in an open loop system (Welsh & Llinas, 1997). Brain and environment form a synergistic relationship in which brain events are embedded in a social matrix (Saito, 1996). That is to say, there are no eternally fixed representations of the external world in the "motor system", rather, it is under the guidance of both internal and external factors with important linkages to frontal, parietal, cerebellar, basal ganglionic, and cingulate gyri areas that subserve cognitive as well as motivational activities. With regard to motor initiation, voluntary movement selection and initiation form an embedded system consisting of the rostral portion of the cingulate motor area, which is innervated by the amygdala and ventral striatum, and the caudal portion which innervates the primary and secondary motor areas, brainstem, and spinal cord with input from working memory in the prefrontal cortex (Shima & Tanji, 1998). Furthermore, there is evidence for a correlative distributed neural network, including the somatosensory cortex, limbic system, and cortical regions central to object- and self-recognition, that forms the neural basis for corporeal awareness, that is, one's representation of one's body or "body schema" (Berlucchi & Aglioti, 1997).

In fact, the "motor system" including related structures, is a self-organizing, distributed, nonlinear dynamical system in which a motor plan is but one component of internal and external forces that operate on and create intelligent movement. Action is self-organized from properties of the components that are structured at more abstract levels in a heterarchical, not hierachical, system (Thelen, 1995). Neurogenesis establishes maps among the brain, spinal cord, and motor neurons that possess overlapping and degenerate connections with multisensory input that calibrate perceptual–perceptual, perceptual–motor, and motor–motor configurations (Lockman & Thelan, 1993; Sporns & Edelman, 1993). Therefore, the context in which each part functions is essential to understanding the overall operation of the system. That is, the central nervous system is a massively parallel, adaptive system in which the biophysical makeup of the brain and its functioning are inextricably interwoven, continuously updating, modifying, replacing, and generating new neural connections (Koch & Laurent, 1999). Even human growth and development is not contingent on a central processor but emerges piecemeal from specific experiences the infant encounters through movement and activity "softly assembled" within the current task domain (Bertenthal, 1996). For example, early reaching is first guided by proprioceptive input followed by visual and auditory guidance by the end of the first year of life. Thus, transitions in reaching behavior and locomotor development in infants are structured by proprioceptive (position, orientation, and movement of body parts relative to each other), expproprioceptive (movement of body parts in relation to the environment), and exteroceptive (layout of surfaces and objects) indicating a close correspondence between action and perception (Bertenthal & Clifton, 1998).

Nonetheless, so-called "instrumental" abilities have been given short shrift in theories of intellect and abilities. Recent evidence, however, has been marshaled in support of a separate bodily intelligence (Gardner, 1993; Johnson, 1987). The latter involves two central components: Masterful coordination of whole body movements (so-called gross motor skills) and the ability to manipulate objects in a skilled manner (so-called fine motor skills) (Gardner, 1993). Moreover, such an autonomous bodily intelligence has important attributes that distinguish it from other forms of intellect. Of central importance is the role of the core mental operations in bodily-gestural expression.

3. Core cognitive abilities in movement

Three central cognitive abilities have been proposed for the bodily basis of thought: motor logic and organization, kinesthetic memory, and kinesthetic awareness (Seitz, 1992, 1994a, 1996). Motor logic comprises the subject's neuromuscular skill with regard to the articulation and ordering of movement what one could call the "syntax" of movement. Scientific support for this component comes from studies of ideational apraxia in which damage to the brain results in the dissolution of the "plan" or "idea" of movement (Roy, 1982). That is, there is a failure to represent the goal of movement and hence there is no activiation of muscle effectors. Each movement element is treated separately rather than part of an overall movement plan (Gazzaniga et al., 1998). The second component, kinesthetic memory, enables the subject to think in terms of movement by mentally reconstructing muscular effort, movement, and position in space. The designation shares some very important characteristics with what researchers of human cognitive capacities call procedural knowledge: knowledge of how to do something (e.g., ride a bicycle). Scientific corroboration for this component arises from the investigation of ideomotor apraxia in which injury to the brain results in loss of memory for movement sequences. In the first instance, if the supramarginal or angular gyrus is lesioned there is damage to the parietal visuokinestic areas and a consequent inability to differentiate well performed from poorly performed movements. In the second instance, if the lesions are anterior to the supramarginal gyrus disconnecting the premotor and motor areas from the visuokinesthetic areas, then subjects perform poorly to imitation and command (Heilman, Rothi & Valenstein, 1982). In both cases, the goal of movement is adequately represented, but there is a failure to specify muscle effectors to faithfully achieve the movement goal (Gazzaniga et al., 1998). The last component, kinesthetic awareness, operates through proprioceptors in the muscles and tendons that provide on-line information on posture, movement, and changes in body equilibrium as well as knowledge of resistance, position, and weight of objects.

4. Cognition and movement

4.1. Communication

The use of sign language as a medium of communication illuminates the role of movement and language use. American Sign Language (ASL) depicts complex linguistic structure by encoding it in spatial contrasts by way of the hands and the body (Sternberg, 1999). That is, the body is a vehicle for thought. ASL uses the spatial relationships of the hands and body to depict syntactic information such as verb objects and nouns by manipulating loci of the hands and body and relations among these loci in the immediate plane of signing space. Indeed, only deaf signers with damage to the left hemisphere show language aphasias. Right hemisphere damage results in distortions of space and spatial perspective and neglect of the left side of space (e.g., spatial descriptions of office layouts) but not competence in ASL, suggesting similar brain organization for both sign and spoken languages (Bellugi & Klima, 1997).

Sign language is capable of expressing nonliteral meaning by the overlapping, blending, and substitution of signs as in deaf theatre or sign poetry. Using form and design in space (i.e., external kinetic superstructure) that is superimposed on signs and signing, poetic structure, such as alliteration and assonance, is possible. Indeed, among the deaf, the use of ironic and metaphoric modes of communication occurs frequently in deaf communities (Klima & Bellugi, 1980). Children also produce figurative sign language through pantomine, sign modification, ritualized movement, and by adding iconic, visuospatial detail (Marschark, Everhart, Martin & West, 1987).

4.2. Categorization

Four-year-olds make significant use of motion cues to categorize objects regardless of whether the objects are geometric or animal figures. Seven-year-olds and adults tend to make use of motion cues more often to categorize animal figures (Mak & Vera, 1999). Similarly, infant vervets — small grey, African monkeys — use a motion-oriented categorization scheme to classify objects initially according to their actions or behavior (Allen, 1996). These studies indicates that motion plays a pivotal role in concept acquisition and guides human and infrahuman primates in both the categorization of objects and the learning of concepts across the lifespan.

4.3. Imagery

Mental practice, or the cognitive rehearsal of a physical skill in the absence of movement, includes both external, mental imagery (i.e., viewing oneself from the perspective of an observer) and internal, kinesthetic imagery (Magill, 1989). Meta-analytic studies indicate that the effect of mental practice over no practice is highly significant (effect size = 0.68, SD = 0.11). However, kinesthetic imagery is more effective than external imagery. This is hypothesized to be due to increases in muscle memory as well as spatial, temporal or sequential aspects of the symbolic components of the image (Hinshaw, 1992). On the other hand, external imagery is more effective for long distance runners who tend to dissociate the physical pain of the body as one might expect (Ogles, Lynn, Masters, Hoefel & Marsden, 1994).

Moreover, recent studies of physical imagery suggest that it is an analog of physical action rather than a correlate of visual perception (Schwartz, 1999). Traditional models of physical imagery have explained motion without regard to the physical forces that control them (e.g., Kosslyn, 1980; Shepard, 1978). Dynamic models, however, describe the forces acting on a system in motion (e.g., Kepler's theory of planetary motion). These include elements of force and resistance as well as their rate of change. Such enactive or "timing-responsive" representations allow individuals to anticipate, plan, and respond directly to the dynamic world through their physical actions. Moreover, both haptic and imagistic information are incorporated into the timing-responsive representation so that physical imagery is predictably tied to perception.

4.4. Gesture and touch

Studies of the acquisition of gesture in young children indicate that "iconics" (i.e., represent details of visual images) and "beats" (i.e., illustrate temporal structure of an utterance) exhibit a close relationship with spoken language development in bilingual children (Nicoladis et al., 1999). Iconics function by tying predicate structure (e.g., verbs, adverbs, and adjectives) to increasing mean length of utterance (MLU) and express aspects of complex concepts (e.g., predication) through cross-modal associations with language. Beats, on the other hand, function as part of the child's ability to use varying stress patterns with multimorphemic utterances. Nonetheless, "deictics" (pointing gestures), "emblems" (gestures which have a direct verbal translation as in "bye-bye"), and "gives" (i.e., hands outstretched) arise prior to spoken language and do not display these coordinated links to speech development. Indeed, gestural imitation of adults is unaffected by accompanying language at the earliest stages of lexical development in infants 13–16 months. Infants will ignore a linguistic cue if it conflicts with a modeled gesture in later stages, and in children designated as "high comprehenders" (131–233 vocabulary words), such speech–gesture conflict will negatively affect motor performance (Bates, Thal, Whitesell, Fenson & Oakes, 1989).

Deictic gestures comprise 80% of gestures in French–English bilingual children under four-years-of-age (Nicoladis et al., 1999). In adults, it has been reported that iconics and beats make up over 60% of gestures (McNeill, 1992). Iconic gestures highlight linguistic meaning through pairing movement isomorphic in form and manner of execution (e.g., hand rises upward) with language (e.g., "He crawls up the pipe"). Metaphoric gestures, however, convey nonliteral meaning by representing abstract concepts (e.g., knowledge) through the use of gesture that depicts the underlying meaning or vehicle of the metaphor (e.g., cupping the hands as to form a container). On this view, graphic drawings are essentially metaphoric gestures on paper.

> The perceptual qualities of shape and motion [in drawings] are present in the very acts of thinking depicted by the gestures (Arnheim, 1969, p. 118).

Developmentally, protogestures that link vocal and manual activities evolve in the postnatal period, iconic and deictic gestures develop over the next two years of life, followed by beats in the third year, and true metaphor gestures by five to six years of age. Other schemes suggest that the earliest gestures are depictive (e.g., a one-year-old child slowly opening and closing her mouth to represent analogous movement of a matchbox), deictic (i.e., pointing, showing, and giving), and enactive or recognitory gestures (e.g., pretending to comb the hair), followed closely in age by expressive (e.g., knitted brow) and instrumental (e.g., extending arms to be picked up) gestures (Bartin, 1979; Bates et al., 1989). Nonetheless, both schemes suggest that two kinds of thought processes are working in parallel: an imagistic, global-synthetic representation and a syntactic, linear-segmented one. Indeed, a visual-kinesthetic image is forged in parallel with an inner speech symbol such that gesture and speech share a computational stage in which the separate elements combine to form a more complex cognitive structure. Such a dialectical synthesis suggests that thought occurs within a field of oppositions and how it carves up the imagistic and syntactic parts is the very embodiment of thought (McNeill, 1985, 1989, 1992).

The foregoing studies, therefore, reveal the central importance of the role of the body in forming complex concept and ideas. Indeed, it has been suggested that there is no inherent distinction between thought and movement at the level of the brain; both can be controlled by identical neural systems (Ito, 1993). Therefore, concepts and ideas can be manipulated just as are body parts in motion. The "motor system" is thus a complex computational network that controls and directs the brain's circuitry or internal symbols: counting, timing, sequencing, predicting, planning, correcting, attending, patterning, learning, and adapting (Leiner et al., 1993a, b).

Indeed, gestures that accompany language may facilitate thought itself. For example, people speaking on the telephone routinely gesture even though it plays no obvious role in communication. Similarly, blind speakers when speaking to a blind listener will gesture even though such behavior does not depend on either an observer or on an adult model (Iverson & Goldin-Meadow, 1998). In studies of gesture–speech mismatch, the expression of concepts motorically before their linguistic realization may help facilitate the working out or "packaging" of ideas. Gesture–speech mismatch may also have communicative value because gesture highlights aspects of the mind of the speaker that are inconsistent with his or her spoken language (Goldin-Meadow, 1997). Indeed, in modern choreographic practice, much of the communicative and conceptual power of dance is facilitated by gesture (Kilian, 1999).

Moreover, studies of the drawings of individuals with congenital and acquired blindness indicate that blind individuals are able to describe motion by making use of metaphorical ways of indicating movement (e.g., curved spokes to denote motion of a wheel). Indeed, like sighted individuals who treat brightness borders as indicators of the edges of surfaces, blind individuals treat pressure borders as indicators of surface edges. Thus, it has been suggested that both visual and haptic information are coordinated by an amodal system (Kennedy, 1997). This system would make use of haptic information in the blind to use touch to "think with" just as the sighted use visual information to plan and organize visual reality.

4.5. Aesthetic (dance) movement

Recent research on aesthetic (dance) movement is beginning to classify the numerous ways that children express thoughts and ideas through movement, action, and activity. At a general level, the research indicates that 3- and 4-years-olds lack the ability to express tension or weight in their movement. Nonetheless, in terms of motor organization, they (a) have developed front–back but poor lateral movement, (b) have acquired quasi-skipping, -marching, and -jumping abilities, (c) demonstrate both asymmetric use of the body and body parts but, (d) lack more advanced balancing abilities. In terms of representational capacities, they can treat (a) one movement as another, (b) represent a movement for an absent concept, and (c) distort a property of a movement so as to treat it as another movement property. However, by 5- or 6-years of age, children (a) have acquired lateral movement, (b) have acquired complex movements such as skipping, (c) can coordinate movement with and around objects, (d) have acquired the first and second positions in modern ballet technique, and (e) can use their upper body to propel themselves forward in a horizontal plane. In addition, they (a) can create geometric shapes with body parts, (b) demonstrate metrical properties of rhythm in their movement, (c) show symmetric use of the body and body parts, and (d) have acquired more advanced balancing abilities. In all age groups, studies have found the use of metaphoric gestures (e.g., the use of a body part to stand in place of a concept or idea), simple diectic and spatial gestures, kinetographs (i.e., movements which depict a bodily action), and simple regulators (i.e., gestures that regulate action between group participants) (Carlson & Seitz, 1998; Lopez, 1999; Lopez & Seitz, 1998; Mirani & Seitz, 1998).

4.6. Mathematics

It has been suggested that our mathematical conceptual system is grounded in basic sensorimotor experiences and is heavily dependent on metaphorical mappings (Lakoff & Nunez, 1997). For instance, arithmetic is object collection (i.e., numbers as collection of physical objects), object construction (e.g., quantity), and physical motion (i.e., number locations as situated on a path or continuum). Moreover, the parietal lobes and the intraparietal sulci shape the neural circuit that underlies handshapes and finger movements which appears to contribute to finger counting and finger calculation (Butterwork, 1999). The latter is a universal cross-cultural stage in the learning of numbers by children. Indeed, it appears that the cortical representation of finger movements and numbers occupies an interrelated neural circuit (i.e., spatial layout of the fingers on the hand, the cerebral representation of the fingers, and the location of number on a number line) and obeys similar principles of cerebral organization. That is, there is a close relationship among our body maps, spatial maps, and the representation of number on a number lime (Dehaene, 1997). Indeed, in a rare disorder of "arithmetic epilepsy," there is periodic rhythmic discharges of the body.

Recent evidence indicates the mathematical intuition emerges from two distinct neural systems that underlie exact and approximate arithmetic (Dehaene, Spelke, Pinel, Stanescu & Tsivkin, 1999). Whereas the former is acquired in a language-like format and uses neural networks involved in word association, the latter is language independent and uses bilateral areas in the vicinity of the intraparietal sulci (Brodmann's area 39) that are active during visual guidance of eye and hand movements, mental rotation, and orientation to the environment. These areas are posited to be related to preverbal numerical abilities in both human infants and diverse animal species. Moreover, the Gerstmann syndrome, which involves deficits in the left inferior parietal region, is characterized by difficulties in writing, representing the fingers of the hand, distinguishing left from right, and acalculia. This suggests that the inferior parietal area may be the central brain region for numerical abilities including the representation of continuous quantities, abstract maps of spatial layouts of objects in the environment, and may be further subdivided into microregions specialized for finger movements and graphic abilities such as writing (Dehaene, 1997). Indeed, studies purporting to enhance spatial–temporal reasoning skills by exposure to music (e.g., Mozart Sonata, k. 448) or keyboard training and math video games, may be tapping into this composite neural circuit (Graziano, Peterson & Shaw, 1999; Rauscher, Shaw, Levine, Wright, Dennis & Newcomb, 1997). Such findings fit in well from what is known about the modular structure of the brain. The brain's circuits are highly compartmentalized receiving synaptic connections from less than 3% of neurons of the surrounding square millimeter of cortex. This indicates that neural circuits operate more efficiently by sharing information over a smaller number of units. The extent of connectedness is uniform across tree shews, prosimians, marmosets,and primates that differ in brain size by four orders of magnitude (Stevens, 1989). Outward folds separate strongly interconnected areas while inward folds separate weakly interconnected areas. Such compact wiring ensures that connections occur with high probability between juxtaposed regions and with less probability among more distance regions. Moreover, these neural arrangements develop early as local forces and mechanical properties of surrounding tissue shape neural growth and migration (van Essen, 1997).

5. The "embodied mind": a new paradigm for thinking about the relation of movement to thought

As electronic media (e.g., TV and computers), video games, and telecommunication devices (e.g., cellular phones) become increasingly popular, there is concern that such "mechanization of culture" will severely limit the use of the body. Childhood play is essential to development and traditional venues such as constructive, sociodramatic, and symbolic play facilitate bodily coordination and the physical basis of concept acquisition (Chirico, 1998). Practice in sports, chess, and music contribute to world-class performance (Goleman, 1994). Depression is closely associated with negatively distorted body images (Noles, Cash & Winstead, 1985). On the other hand, is it that our brains are largely formed independent of type of input? What will become of human minds in a "digitized" culture?

While it is largely true that physically handicapped children eventually develop normally in spite of motoric impairments, their success is largely due to their ability to compensate for their motor limitations and not because of them (Bebko et al., 1992). The physically impaired seek out intellectual, social, and environmental stimulation and make optimal use of what motor abilities are still intact (e.g., visual saccades or auditory scanning) as the nervous system reroutes degenerated sensory modalities and reorganizes defective brain regions (Gazzaniga et al., 1998). Technological innovation has enabled the blind to "read" printed text (e.g. Optacon scanner). The evolution of brain areas that subserve mechanical skills underlies technological development that abetted modern civilization (Seitz, 1992, 1993). The rise of modern technology has freed the hand to "think" and the voice to proffer instruction (Corballis, 1999). Indeed, sign language systems satisfy every criterion of a language in terms of generativity, syntax, semantics, and pragmatics (Sacks, 1988). To be sure, there is a syntax of movement as there is a syntax of speech and a logic of numbers as there is a "physiology of logic"; as all skillful behavior involves the same aspects of sequence and seriation or a "generalized schemata of action" (Lashley, 1951). Kinesthetic thinking lies in orchestrating a sequence of activities; integrating intellective, emotional, and multisensory experience; and selecting and executing appropriate movement, action or activity.

Throwing, hitting, typing, writing, signing, singing, dancing, driving a car, playing a musical instrument, and so on, suggest that motor capacities are deeply involved with, and constitutive of, other intellective competencies. All the aforementioned activities partake of timing, force, selection, and sequencing, orchestration, and integration that lie at the core of human intellectual activity. Therefore, the boundaries between perception, action, and cognition are porous. If human communication evolved from the capacity to recognize actions in early hominid populations to a mirror system for intentional gestured and spoken discourse, then thought, action, and perception are indissolubly tied. The organization of the brain and body is not top-down but organized at the level of the system that is dependent on local, distributed, and contextual factors and constraints.

Indeed, the study of dance movement suggests how little is known about how children and adults use their gestural and postural abilities to express concepts and ideas. By sketching out both the "objective" features (i.e., motor logic, motor organization, kinesthetic awareness, and kinesthetic memory) that are hypothesized to be at the core of cognitive abilities central to human action, and the "subjective" features — including repleteness (i.e., volume, line, and movement texture), exemplification (i.e., the ability to convey rhythm or shape through movement), expression or representation (i.e., the ability to use one movement to stand in place of another), and composition (i.e., the ability to create a spatial design(s) with the body — current empirical studies will gain further insight into the relationship of thought and movement. By tracing its ontogeny and the role of expressive and cognitive factors in aesthetic movement, such studies will begin to explicate the role of kinesthetic sense and memory, motor logic, and motor organization in human learning that occurs through the senses, hands, and body,

Thinking is an embodied activity. Although humans may be best characterized as symbol-using organisms, symbol use is structured by action and perceptual systems that occur in both natural environments and artifactual contexts. Indeed, human consciousness may arise not just from some novel feature of human brains, but way of the body's "awareness" of itself through its exteroceptive and prioprioceptive senses. Indeed,the body structures thought as much as cognition shapes bodily experiences.

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