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Gestures for the Senses: an Evolutionary Perspective on the Multimodality of Gestures

WORKING PAPER

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The point of departure for the elaboration of an evolutionary multimodal (that is, multi-sensorial) theory of gestures can only be a brief review of the research that has been conducted during the last century. This research is neither multimodal nor evolutionary. It is rooted in the Classical tradition of rhetoric which endeavored to codify hand movements in relation to speech in the formal context of political discourse, religious preaching, and dramatic performances. As linguistics emerged as a descriptive science, efforts were made towards more comprehensive examinations and classifications of the (assumedly communicative) meaningful hand movements that occur when people interact within a particular culture whether in conjunction with speech or as self-contained means of communication for instance in ASL or in the case of gestures that can be classified as "emblems" in the nomenclature of Ekman and Friesen (1969). The description of gestures has always been experienced as a challenge when the goal was to reach some degree of generality and systematic consistency. Some researchers have attempted to transpose linguistic categories in order to create a metalanguage of gestures (e.g., Birdwhistell 1970) , others have invented new terms with the purpose of conceptualizing the observable flow of hand movements as sets of functional units that combine according to some hypothetical syntactic rules (e.g., McNeill 1992; Calbris 1990). There is, however, a general consensus that the results of this century-old research remain tentative in spite of the sophistication of the means of investigation and the rich repertories of distinctive dynamic behavior that laboratories have produced. Even a keen observer of the field of gesture studies such as Adam Kendon recognizes the lack of a clear definition of the very object of this research, let alone a consistent scientific paradigm (e.g., Kendon 2008). The planned monumental handbook entitled *Body – Language – Communication*, to be published by Mouton de Gruyter in Berlin, is characterized by the wide array of methodological and heuristic approaches it features rather than by a coherent body of research grounded on a consistent theory of human dynamic behavior as it relates to communication and other functions (Mueller et al. forthcoming).

Most gesture studies to date have in common that they focus exclusively on the visual perception of hand movements. Adam Kendon's most recent contribution to the field is typically subtitled: *visible action as utterance* (Kendon 2004). The purpose of this paper is first to direct attention to the other sensorial aspects of gestures, their multimodal semiotics. It will then propose a blueprint for a theory of gestures that will take an evolutionary view of primates' upper limb movements and tentatively offer a quantitative approach to the understanding of their adaptive functions, including their biological and cultural dimensions.

1. Gestures are not for the eyes only: a multimodal approach.

To date, empirical research on gestures have consisted mostly of gathering data in the form of verbal descriptions and visual documents focusing on the expressive and communicative movements of the upper limbs of interacting humans. The main goal of such research is to elaborate categories of gestures, usually inspired by the terminology of semiotics (e.g., indexical, iconic, and symbolic gestures), in relation to natural language or as autonomous systems of communication. A part of this research has addressed the issue of cultural differences in the forms and management of gestures. This latter approach has unveiled distinct cultural patterns for such basic behaviors as giving directions or signs of approval.

The current discourse on gestures is doubly constrained by descriptive strategies which rely on elementary narrative patterns (what the limbs do) and by two-dimensional representations of the narratives' agents and their dynamic paths (how the paths can be mapped on a two-dimensional plane). These micro-narratives presuppose indeed a spatial mapping that remains implicit most of the time. In general, a limb or a moveable segment of a limb is said to do something that consists of producing a meaningful stable or dynamic visual pattern in relation to another part of the body, another body, or a material object. These patterns are represented on a two-dimensional support (printed page, drawing board, or computer screen) with respect to up and down, right and left, from the point of view of the gesturing subject. The back and front directions are usually indicated by conventional symbols, or the gesturer is shown in profile at the cost of losing the lateral directionality. The source of the agency is implicitly or explicitly assigned to a human subject whether the movement is considered deliberate, intentional, automatic, or accidental. In descriptions, the limbs are often construed as agents by proxy of the subject, e.g., [John touches his left ear with his right hand] or [the right hand reaches the left ear].

In such contemporary research, the strategy through which the data are gathered consists of repeatedly observing video recordings of interactions in a specific cultural context and extracting from the flow of movements some identifiable patterns which are eventually calibrated in order to form a visual norm, a stereotype, which reoccurs in other interactions broadly pertaining to the same cultural context. A representative example of such an approach is found in Nick Enfield's book tellingly entitled *Anatomy of Meaning* (2009).

Let us note that this kind of approach is grounded on a preconceived notion of what a gesture is and on a variety of categories of two-dimensional patterns. This conceptual apparatus is, so to speak, cast upon the sea of movements and "catches" dynamic patterns which are analyzed in relation to communicative contexts. Typically, this is a "top-down" strategy designed to "recognize" dynamic patterns that qualify as gestures according to some (dubious) criteria such as intentionality, meaningfulness, or normalcy. According to this approach, informative patterns do not emerge from the observed dynamic flow as would be the case in a bottom-up approach but they are "recognized" as gestures by reference to a predetermined repertory of typical movements, some of which are metaphors such as "growth point" and "catchment" (Mueller & Cienki 2008) that their proponents themselves find extremely difficult to define in operational terms. At the same time, countless aspects of this dynamic flow are ignored either deliberately as irrelevant (noise) or because they are simply not perceived because they are not expected. In any empirical study, a restricted set of expectations is indeed built into the observational matrix. This is, of course, a methodological necessity but one which must be taken into consideration and questioned.

One sensorial aspect of gestures which is not usually fore-grounded is their *haptic* (that is, tactile) functions: gestures are needed to establish physical contacts either in self-directed touching as when we hold our forehead to convey the idea of "thinking" or throw our hands to the sides of our head to express or signify horror (viz. *The Scream* by Edvard Munch), or, in other-directed touching, as when we shake hand or gently pat somebody's back to mean reassurance or dominance. Naturally, these "contact" gestures can also be perceived and interpreted visually unless we are their initiator or receiver. However, thanks perhaps to our s0-called "mirror neurons" ,we have ways of assessing by proxy the strength, duration, and haptic quality of these gestures. We always know if a gesture involves a contact [e.g., the touching of knees in India] or the formal hand-kiss of French etiquette.

But there is a more subtle way in which gestures are haptically perceived. It has been empirically demonstrated recently that our skin is sensitive to the change in air pressure caused by movements to the extent that even the minimal air flow caused by speech is a factor in accurate auditory perception in face-to-face interactions. It has been shown that perceivers integrate naturalistic tactile information during auditory speech perception (Gick & Derrick 2009) More generally it is a common experience that air drafts are sensed in combination with thermal information. Moreover, in some now well understood pathological conditions the skin becomes hypersensitive to minimal variations of its interface with the milieu in which it is immersed (Drew & MacDermott 2009). But it is the result of a lowering of the threshold of sensitivity, not a totally new sensitivity. Ultimately, all gestures are mechanical variations of the environment and necessarily trigger perceptible modifications. A case in point is the use of the hand as a fan when we want to cool down our immediate atmosphere or displace some unpleasant odor. Air turbulence is necessarily created when we deny the validity of an argument or refuse to take an objection into consideration by sweeping the space in front of us with a wide hand gesture. Such haptic information is not usually processed consciously but, as

Alex Pentland has shown, the outcome of a face-to-face interaction depends on subtle factors that remain below the threshold of awareness and can be accounted for only through the use of appropriate sensors (Pentland 2008).

The range of sound waves created by gestures includes acoustic phenomena. Hand clapping and snapping fingers are gestures that convey meaning whether they are visually perceived or not. The abundant repertory of gestural sounds includes self-oriented frictions and concussions (e.g., rubbing hands as a sign of satisfaction, or the slapping of one's own hand as symbolic repression or punishment whenever a forbidden move is anticipated); other-oriented gestures such as high fives (let us note in passing that such a greeting that would not produce the expected sound would be interpreted as lacking in genuineness or as being a failure to be repaired immediately); and object-directed gestures such as the German way of applauding a lecture by repeatedly knocking on the desk or the Chinese popular expression of thanks through gently tapping the table twice with the knuckles. Each of these three categories is open-ended because new multimodal gestures constantly emerge as a result of creative extrapolations and metaphors. But even if, for the sake of convenience, one deliberately limits the study of gestures to the visual domain, exclusively focusing on the upper limbs constitutes a serious methodological shortcoming. Hand gestures are only a part of complex dynamic behaviors that involve the whole body including movements of the head and, of course, facial expressions. It is typical that observers of gestures focus on the hand and only rarely take notice of the correlated head movements, gaze management and posture control. Conversely, researchers interested in the expression of facial emotions generally fail to take into account that all such expressions are produced in conjunction with shifting of postures and hand gestures. Moreover, the identification of gestures as two-dimensional patterns not only is questionably abstracted from three-dimensional space but also pays only lip-service to the fourth dimension. This is, however, a necessary component of any gesture, both as the very substance of any movement and as the significant temporal variations that can be introduced in the implementation of particular gestures. For instance, clapping hands without producing any sound through inhibiting the contact or clapping hands very slowly to express the opposite of what this gesture is supposed to express are meaningful time and acoustic manipulations of the signs. The recent book by Nick Enfield (2009) introduces the interesting notion of “ enchrony” in order to include time within the conceptualization of gesture. This neologism is, of course, to be understood with respect to the Saussurean opposition between “synchrony” and “diachrony” .

This brief review illustrates the challenge of developing a science of gestures that would be comprehensive and would address the complexity of the object rather than reducing it to a collection of two-dimensional visual patterns of hand movements correlated to instances of meaning-making in the process of communicative interactions. But even if the whole array of possible points of view were encompassed by an exhaustive analytical approach, the resulting description would not have any explanatory value. Let us now tentatively turn to the “why” question in order to clarify the status of human upper limb movements in the context of Darwinian evolution. As we will see, the elusiveness of a satisfactory definition of gestures (e.g., Kendon 2008) which has always haunted gesture researchers might result from the fact that gestures have not evolved as an adaptation qua gestures but as the exploitation of an affordance which was a byproduct of bipedalism.

2. The evolution of gestures

Whatever the origins of bipedalism might have been, an adaptation to locomotion on tree branches (Thorpe et al. 2007) or endurance running to catch prey while reducing solar exposure (Bramble & Lieberman 2004), one of the most obvious consequences of this change of locomotion was that the forelimbs were progressively freed from their supporting functions and natural selection could operate on primary adaptations that had evolved under a set of constraints that no longer existed or whose modalities had drastically changed. Given the present functionality and versatility of the human arms and hands, one may legitimately wonder which new constraints might have acted upon natural selection to conserve the upper limbs, albeit with a somewhat reduced length with respect to the proportions of the body and the disappearance or at least vestigial conservation of some functions. These plausible factors will now be enumerated keeping in mind that usually more than one constraint has to be taken into consideration as they variously combine over time in changing environments.

To make a very long story short, it is generally assumed that when the tetrapods adapted to tree-dwelling by natural selection, they evolved limbs and a neurological apparatus able to negotiate gravity on narrow support. Digits and the actions they made possible were adapted to feeding on tender leaves, fruit, nuts, and insects, as well as self- and social grooming, fighting, catching flying or falling preys, and throwing small things. However, the primary function of the front limbs remained the locomotion in a tree environment including the grasping of branches to climb up or down (Clark 2002).

Life in trees is by definition sheltered from the sun and food is in principle within reach. With bipedal endurance-running in a savannah environment, the control of heat was bound to become an important constraint. Like the ears for the elephants, the upper limbs offered the sort of surface and independent mobility which could significantly contribute to the vital cooling of the blood. We still bare our arms to run in a Marathon and we pull up our sleeves when we do some hard work that makes us perspire. Gesticulation accelerates the cooling effect of evaporation. We also use our hands as natural fans. For an organism which increased in volume as it moved to open spaces less protected from the sun than it was in the trees, such an affordance of the upper limbs was not a luxury. The fact that the same organ can double up as a prey catcher and as a tool maker while contributing to the cooling of the blood constitutes a marked advantage.

Another function, less obvious but no less vital, of the arms is the dispersion of pheromones which play a crucial part in reproduction in combination with visual cues but with enhanced reliability. Empirical research indicates that the sensitivity of contemporary humans to pheromones still plays a role in the sexual behavior of both males and females (e.g., Miller & Maner 2009; Keller 2008). The diffusion of artificial perfumes in the surrounding space through movements of the body is an efficient way of alerting others to one's presence and to attract visual attention. Given that the molecular composition of a perfume always combines in subtle ways with the body's own chemistry, gestures are good sexual advertisers for establishing one's idiosyncratic olfactory presence by "coloring", so to speak, the surrounding space and capturing attention. Courting males tend to gesture a lot.

But the arms are also crucially instrumental for keeping our balance and enforcing the respect of our personal space. Indeed, a function which would have been irrelevant for a tree-dwelling organism is maintaining optimal distances between individuals engaged side by side in group activities. Progressing on branches forces several individuals to proceed as a single file and the four limbs are put to the use for which they were selected, that is, mobility.   For bipedal organisms upright posture combined with mobility requires a demanding control of gravity for which the upper limbs play a crucial balancing role. It is very obvious if we observe an acrobatic wire walker but it constantly happens in everyday life whenever the ground offers challenging obstacles to a smooth progression. Moreover, a social species whose survival depends on coordinated actions such as fighting enemies or catching a prey needs ways of maintaining a minimal distance between the members of the fighting or hunting band engaged in a collective action in order to prevent entanglement and collapse. Lethal stampedes that occur when a crowd tries to run away in panic from a source of danger bear witness to this liability of group mobility. Arms are essential to keep minimal distance between individuals in a way that is functional and compatible with collective tasks. In modern warfare and team sports the first elementary training is aimed at ensuring both the compactness and the fluidity of the group as it moves on the field. It is easy to observe the role of the arms in such processes. It is particularly obvious in large crowds in which each autonomous agent uses the upper limbs to avoid frictions and collisions of the bodies through managing a constant "elbow room" and projecting the arms forward. Visual monitoring and haptic sensing provide the necessary feedback and feedforward. More generally, the upper limbs make it possible to delineate (and at times enforce) a vital personal space that does not coincide with the volume determined by the skin envelop of the bulky body. Many gestures seems to have no other functions than staking out personal space both physically and metaphorically in argumentative discussions or in simple conversations through which mutual statuses are negotiated.

These kinds of social behavior are deeply rooted in our sense of personal space, an adaptive competence that has been shown to depend on neural processes located in the amygdala, a pair of almond-shaped regions of the medial temporal lobes which is also the seat controlling strong emotions such as anger and fear (Kennedy et al. 2009). We know from common experience how uncomfortable we feel, and how we often aggressively react when strangers stand "too close" to us. Keeping others at arm-length prevents from being suddenly grabbed. The personal space reflex cannot be, of course, too absolute since it would interfere with reproduction and nurturing. It is inhibited in social bonding behavior, the two or more “bubbles” (see the collective hugging of a sport team after victory) are integrated into a single one and the tactile sensitivity switches from the monitoring of distance to the negation of individual differences by fusing the group into a temporary single body. Such variations show the extent to which gestures are multimodal and versatile. Personal space reactions are also inhibited whenever survival is at stakes, in case of extreme cold or when confronting a danger that cannot be mitigated through dispersion of the group. A telling instance of this use of the limbs in survival behavior is the mounting of human pyramids [e.g., Kikeri Narayan and the Jenu Korubas], an acrobatic feat originally aimed at semiotically manipulating predators by creating what appears to the predator an unknown organism much larger than it is and thus falls beyond the range of the optimal size and appearance of its prey. Other cases of visual manipulation are observed in many species (e.g., ostrich sleeping with head in the sand which thus looks like a bush from a distance).

Researchers on gestures have always encountered the issue of defining what a gesture is. The categories that have been proposed are not only fuzzy but also they are not exhaustive. The distinctions between communicational and noncommunicational, or between meaningful and meaningless gestures is impossible to ground on precise observation of actual interactions. The criteria of intentionality do not stand scientific scrutiny. Only highly ritualized patterns which are more artifactual than natural can meet some conditional definitions in relations to other artifacts in definite contexts: social etiquette, religious rituals, marks of group affiliations, and the like. But in any case, those well-defined “gestures” are drowning in a sea of hand movements which prove to be impossible to relate to symbolic and communicational functions. Anybody who has tried to study gestures has experienced the frustration of coping with such elusiveness. Some researchers have simply given up and restrict their study to the laboratory in tightly controlled conditions (e.g., McNeil 2000, 2005) or in the contrived use of gestures by actors in dramatic performances, in which case the gestures are clearly cultural artifacts. As a result, gesture studies usually ignore the multi-functionality of the upper limb movements and focus on a very small subset of a priori abstracted assumed functions.

The border line between gesticulation and gesture as well as the scale of observation are arbitrarily determined by the points of view chosen by individual researchers and their followers.

The fundamental question with respect to gestures pertains to the evolution of the forelimbs when they became the upper limbs. It can be reasonably assumed that communication through gestures first evolved in combination with, or concurrently with vocal signaling when the common ancestors, now tentatively identified as *Ardipithecus ramidi,* became adapted, four and a half million years ago, to both bipedal mobility on the ground and tree-dwelling that involved climbing, grasping and balancing (Gibbons 2009). All the factors which have been listed above show that the movements of the upper limbs are adaptive for a host of vital functions which are not communicative. This must be kept in mind when the etiology of communicative or expressive gestures is the focus of a scientific inquiry. This does not question, of course, the validity of the research done during the last century on gesture but simply points to the much broader context that should be taken into consideration for elaborating a theory of gestures.

3. Toward a scientific theory of gestures

We have so far accumulated observations of a phenomenological nature and developed some evolutionary implications that can be plausibly derived from such observations. But there is more in nature than whatever we can process consciously. In order to reach out to what cannot be accessed directly or indirectly, we need to speculate and formulate theoretical constructions which are a measure of our ignorance. We can safely assert that a theory of gestures does not exist yet although gestures have a kind of hypothetical status in theories which construe gestures as the origins of language (e.g., Corbalis 2002). But this hypothesis overlooks the fact that, if indeed the common ancestor of primates evolved as a social tree-dwelling organism, gestures would be a particularly maladaptive way of communicating within a environment made of branches and leaves through which, by comparison, vocal signals such as alarm cries, territorial claims, and “phatic” information (i.e., reassuring sound indicators of who is where) can travel unimpeded. Primates like gorillas who live in often dense forests have close range communicative gestures such as chest-stomping and grinning but also use wood to wood percussion in some situations. In all these cases their signaling behavior is markedly multimodal and the acoustic components remain in the low frequency range that ensures efficient broadcast in their environment.

The challenge of sketching out a blueprint for a theory of gestures is twofold. On the one hand, the multimodal diversity of gestures must be accounted for in terms of the brain anatomy and neuro-chemistry which evolved by natural selection under environmental and social constraints, develop during maturation in each individual, and sustain the rich repertory of functional and symbolic behaviors which ensures our basic survival adaptations as members of a terrestrial social species. Cultural gestures are grounded in this affordance. On the other hand, we must strive to find a way to transcend the limitations of phenomenological descriptions which are fragmentary and relative to several points of view that are difficult to reconcile, and for which measurement has proved so far to be a frustrating task. In addition, these two approaches must be integrated into a single theoretical perspective that could provide both compelling explanations and practical applications.

The first approach – the understanding of the ways in which the brain deals with multimodal gestures in an integrated manner – is more advanced than it may seem. Neuro-pathologies which disrupt the normal functionalities of gestures, Parkinson's disease for instance, have received much scientific attention. Engaging in a meta-analysis of this literature would be a daunting task but one which is now within reach in the context of what is called "the fourth paradigm" (Hey et al. 2009). More has been achieved in gesture research than meet the eyes of humanists like Adam Kendon (e.g., 2004) or traditional psychologists like David McNeill (e.g., 1992) who are among the most visible specialists in this domain but ones whose approaches are still conditioned by the epistemological premises of the last two centuries and lack a clear theoretical horizon. By mistakenly considering video recording as the equivalent of the microscope as the best tool to advance gesture research, they remain focused on the visual modality and within an observational scale that excludes both the neuro-chemical substrates of gestures and their deep-time evolutionary significance.

Two domains of contemporary research will now be evoked as examples of relevant scientific inquiries that should bear upon our understanding of gestures.

First, let us note that the notion of multimodality is the result of an abstraction that construes the human senses of perception as separate channels. The reason for this is probably that each of the senses can selectively be impaired. Synesthesia, however, is more frequent and distributed than extreme cases may suggest. These " ontological" distinctions are artifacts of folk psychology and philosophy. In the actual processes of social interactions the human brain integrates without problem the range of information coming from the sense organs and produces adaptive behavioral responses and anticipations. A report that appeared last year in the *Annual Review of Neuroscience* (Angelaki & Cullen 2008) casts some light on the complex system that allows humans to process gestures both as multimodal events and solution to the challenge to gravity that all gestures create. Extending the arms forward or laterally must be compensated by an appropriate displacement of the upper body in the opposite direction lest we tip ahead or sideways. More generally, all gestures whatever functions they may serve act against gravity and eventually the limbs must come to rest once they have used up the available muscular energy provided by the organism. In some individuals, the early merging or interfacing of sensory neuronal tracks create hybrid perceptions such as sounds that have colors, tastes, or smells, or any other kind of synaesthesic combinations, but in "normal" humans the adaptive integration of multimodal information occurs in the vestibular system, a system which is crucial to control balance, that is the muscular negotiation of gravity with respect to spatial frames of reference. Gestures as we observe them in humans could not have evolved in the absence of such a system. Angelaki and Cullen (2008) review the abundant literature of the last two decades in the light of which they make the following points: The sensory structures in the inner ear compute head motion and constitute a kind of sixth sense. The information it provides in the central nervous system becomes immediately multimodal and contributes to a range of brain functions "from the most automatic reflexes to spatial perception and motor coordination" (p. 125). Although the issue of gestures is not addressed explicitly by the authors in their discussion of the vestibular system, it seems obvious that this system sustains the very possibility of gesturing in a way that is adaptive. Thus, it is important to note that "the need for multisensory integration necessitates vestibular representations in multiple reference frames" (ibid.). Attempts to understand gestures at a deeper level than the phenomenological observation of necessarily separated sensorial modalities (visual, acoustic, tactile, and proprioceptive points of view), must take into account the fact that "signals from muscles, joints, skin, and eyes are continuously integrated with vestibular inflow" (p. 126), an integration that is "vital" (i.e., adaptive) for the control of gaze and posture and, therefore, for gesturing. These processes remain below the threshold of consciousness except, to an extent, when gestures are deliberately produced to deceive or to perform for an audience, in which case they are not entirely spontaneous and usually create a variable impression of artificiality due to a delay of a few milliseconds with respect to speech and the natural flow of actions. Functional gestures require complex neuronal computations which integrate several frames of reference and multimodal information. The rich literature on the various neuro-pathologies of motility, particularly gestures, in aphasia, apraxia, autism, Alzheimer, and Parkinson should be tapped to investigate what it takes for a limb movement to be functional and meaningful in social contexts.

The second example opens a window on the role of chemical neurotransmitters in the evolution, development, and functionality of gestures. Intensive research on Parkinson's disease, as it has been recently summarized by Fred Previc (2009), has identified the role of dopamine, a neurotransmitter which is correlated to gesture production. There seems to be ample evidence that some of the dopaminergic systems in the brain regulate the gestural output of humans and that various levels of dopamine correlate with a range of gesture production, from scarcity to abundance. There are, of course, other neurotransmitters which play a role in gesture production, including those which act as inhibitors. Indeed, excessive, uncontrollable gesticulation which is the hallmark of some pathological conditions would be definitely maladaptive. But if Previc's theory is correct, the evolution of gestures in early bipedal hominins would have coincided with a change of diet during early migrations (iodine-rich shellfish). This argument is relevant to the object of this paper because it provides a plausible explanation for the relative lack of gestures in apes compared to the rich gesture resources of humans not only as technological and social tools but also as communicative and cultural displays. It is as if humans became endowed in the course of evolution with a new raw affordance which they exploited and managed for a host of unrelated purposes. This perspective suggests that the evolution of the upper limbs and the evolution of gestures are the results of two distinct natural selections: first for mobility in arboreal environments, secondly as multiple biological and socio-cultural adaptations.

But, to be complete, a theory of gestures must encompass both the underlying biological apparatus which has evolved by natural selection and its phenomenological perception in the context in which gestures have emerged. The challenge is to reconcile the knowledge of the neuro-chemical processes which drive the interactive motility of the upper body with the knowledge we can acquire from the observation of its dynamic manifestations. At rest, the upper limbs hang and dangle along the body following the laws of gravity but they are summoned to activity as soon as the dynamic interface between the body and its physical or social environment requires some action or reaction. In order to elaborate a comprehensive theory, the understanding of the physiology of gestures and their phenomenological description should have reached comparable levels of complexity and abstraction. This is why we must find a way of expressing mathematically the data provided by the systematic observation of gestures independently from the various meanings that we assign to them in particular cultural contexts.

The first step toward this goal is to acknowledge that the upper limbs rotate from joints which attach them to the trunk of the body and that they are themselves articulated into several segments whose rotations combine variously with the whole arms rotations. Since the limbs are three-dimensional objects, any of their movements form virtual volumes in 3-D space. Therefore we can conceive any gesture irrespective of its functions (either goal-oriented or purely mechanical) in terms of dynamic topology. Naturally, the arcs are constrained by the anatomy of the joints and the presence of the body (and other objects) which limits the range of possible rotations. It is nevertheless possible to construct within these constraints the multivariate architecture of gestures in relation to their proximal environment.

The second step is to take into account the fact that gestures are necessarily temporal objects and that a purely topological expression of the upper limb movements would miss their essential fourth dimension. Consequently, a mathematical description of gestures should necessarily include time variables which originate in the complex rhythms generated by the brain (Buzsaki 2006) but remain within the range of possibility determined by the laws of physics. Functional and symbolic variations of the temporal structure of gestures have been generally overlooked by gesture researchers. Achieving synchrony in group activities is indeed highly adaptive. Choreography and acrobatics display this function with particular acuity.

Obviously, if we step outside the naïve phenomenology which allows us to describe gestures in the form of mini-narratives or to represent them as two-dimensional graphs, we realize that gestures are extremely complex 4-D objects that only mathematics can adequately express. Then, the problem remains of relating these virtual objects to the neuronal computations which ground their pragmatic and semiotic functionality, keeping in mind that the understanding of gestures always involves the anticipation of their trajectory and that social interactions as well as team works required a felicitous merging of rhythms and path projections. Dance and acrobatics magnify visually and acoustically what we take for granted in handshakes or high five, or simply proceeding in a crowd. It is very unlikely that the gesture information processed by the brain is in the form of mini-narratives and 2-D graphs. Given the vital necessity for any organism of monitoring the motion of objects in its proximal and distal environment, the precise assessment of volumes, paths, and speed is an adaptive priority. It is in this evolutionary context that gestures have emerged and have proliferated once bipedalism freed the forelimbs from most of their supporting and mobility functions.

Conclusion

The blueprint for a comprehensive theory of gestures which has been outlined in this paper is still tentative and incomplete. But it is clear that such a theory should integrate a number of perspectives which for the time being have been neglected or treated as separate domains of inquiry by the “specialists” of gestures. There are, of course, exceptions such as Brian Rotman’s efforts towards an integrated approach to gestures both through his books and articles (e.g., 2008, 2009) and by organizing multidisciplinary meetings as this conference bears witness.

Let me summarize in conclusion the challenging agenda in front of us. First, gestures must be apprehended as multimodal phenomena. Secondly, they must be construed as 4-dimensional objects. Thirdly, they must be understood in the conceptual framework of evolution not only through narratives grounded on the fossil record but with reference to the evolved neural anatomy and physiology which make them possible and prominent in humans. Each one of these approaches constitutes a daunting scientific task and their theoretical conciliation will require a multi-disciplinary cooperation. Gestures at large remain a *terra incognita* to be explored or a "horizon of ignorance" that challenges the self-understanding drives of human ingenuity. It is not my intention to make an excessive claim for the merits of the tentative blueprint that has been sketched out in this paper but, given the general lack of a comprehensive theory of gestures, any proposal can serve as a useful starting point as long as it offers falsifiable hypotheses.

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