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BIOLOGICAL CONSTRAINTS ON LANGUAGE: NEW DATA FROM HUMAN AUDITORY CORTEX

1. Preliminary remarks: from foundations to biological constraints of language

One of the classical perspectives among the studies on language, beginning with the aristotelic naturalism, considers the anatomical components as correlates, structures that allow the function. This stance gave birth to opposite positions during the last century: if, on one hand, those who reflected on language in a philosophical-linguistic perspective focused only in its functional aspects (ruling out the biological structures in a more or less explicit way, e.g. the chomskyan thesis, Saussure and the structuralism followers), on the other hand some multidisciplinary researchers favoured the structural analysis, regarded as an evolutionary mark of the linguistic function, some sort of guarantee of the language's unique presence in *sapiens* (LENNEBERG 1967, LIEBERMAN 1975, etc).

The cognitive sciences' point of view within the debate on human language's nature and function was unambiguous and rather extreme: putting aside the formalizing and dephysicalizating hopes of the cognitivistic first generation, the cognitive sciences focused on neuroanatomical structures, thanks to a growing amount of data about the working of the central nervous system during the execution of selected behaviours. For the cognitive paradigm of second generation, biological structures were the actual object of study, and the explanation of the function took sometimes a second place compared to the location of cerebral loci which are active during the execution of cognitive tasks (SWAAB 2010), the linguistic ones above all, that already had a specific neuroanatomical location. The essence of the linguistic function thus came down to the use of language central structures. The model suggested by an emergent part of the second generation's cognitive sciences was based on the brain primacy in the explanation of functions, without considering the link with the remaining organism: brain was regarded as a special organ ("brain is special") and the functions it controls, language first of all, were assigned a special position (PENNISI-FALZONE, 2011).

Evolutionary (cfr. JOHANSSON 2005, BOTHA-KNIGHT 2009a, BOTHA-KNIGHT 2009b) and comparative (FITCH 2010, HAUSER 1997) studies changed this setting turning the attention from the description of the event-related brain activity to the meaning of this activity for its adaptive and ecological role (GOULD, 2002): according to this perspective, language would be not only a complex cognitive function which cannot came down to the brain activity either to the communicative ability alone, but also a central and a species-specific function for the *sapiens*. Language, in other words, would be a central function since it influences human cognitive activities to such an extent to form a constrain, a functional and representational coercion, rather than being one among the various functions of human cognition that can be studied irrespective of its adaptive role.

The human language anatomical structures set up the way this constraint materializes screening the information about the world and allowing our typical modality of building representations of the world. *Sapiens*' sensory canals (like, *mutatis mutandis*, those of the other species) are built in such a way that they can be hit only by specific stimuli and these stimuli are recognized, categorized and processed on the basis of the typical human cognitive structures. We are cognitively blind to infrared, just as we are cognitively oriented to classify the objects we recognize as similar in shape or use as belonging to the same category, or to learn culturally driven information on the basis of the daily experiences in a specific linguistic community (HAGOORT et al. 2004).

We don't choose, we are forced to know the world on the basis of the biological-cognitive constraints the evolutionary history gave us. These constraints set the *Ümwelt* of each animal species (von UEXKÜLL 2010), making them different not only in a biological way but also in a cognitive one.

In this study we want to claim that the language's biological constraints, in the sense described above of biological-cognitive influences, allow the *sapiens* typical modality of using language to build and decode the representations of the material and relational environment. This would mean that the linguistic function is species-specific for the *sapiens*, a capacity that the human being can't help showing and that influences other cognitive activities. This constraint already appears in the biological structures which specifically decode auditory stimuli, and that are specific for linguistic and cognitively complex tasks. Auditory cortex would show indeed a species-specific setting for the *sapiens* which would make it sensitive to linguistic information in a number of different levels of competence.

1.1. Linguistic and auditory species-specificity

Before carrying on the description of the reasons in favor of the human auditory cortex's species-specificity, it is necessary to clarify that the species-specificity's "technical" notion we refer to in this work belongs to the classical ethology's tradition, according to which is species-specific a behavior that an individual, insofar as belonging to a species, can't help showing. No estimation about a behavior's spectacularity or exclusivity can be inferred by its species-specificity: formulated in the area of biological sciences, this concept would indicate that some organisms would be active only toward a specific animal or vegetal species (just think of those parasites that live only in specific animal species or plant). Lorenz borrowed this biological concept and he assigned it to a sphere that was higher than the simple chemical compatibility, the behavioral one, which follows working rules that are very different from those of the animal or vegetal biology.

The core component of the specificity's notion Lorenz intended to apply to the animal behavior was the constrictive element: the parasites that can't choose which plant to infest, rather they can, indeed they must, for their survival and reproduction, attack one and only species, show *Speziesspezifität*.

The founding father of ethology used thus this notion of functional coercion through applying it to the animal behavior. In the contemporary ethology, in fact, one must assume that "the behavior is largely driven by phylogenetic adaptations in the form of hereditary coordinations and innate release mechanisms" (EIBL-EIBESFELDT 1987: 382): this meaning specify the technical use of the "species-specificity" term.

Thus, the behavioral natural component lies in the species-specificity gradient an animal species shows: the higher the gradient, the more the behaviors of every member are constrained, and the more their execution, given a specific environmental condition, looks unstoppable. It is of course a general definition that can be applied to every behavior, but we have to take into account the functional complexity of the behavior we consider. If a behavior is species-specific it means that it materializes through selective filters which influence its execution.

In the case of human language it becomes clear that these filters are nothing but the language's central and peripheral biological structures that, as showed by a large amount of scientific data, influence the way we represent the world, both in the achievement of the communicative function and in the relations that language has with the other functions it relates to (HAGOORT 2003).

Studies that show the involvement of Broca's area both in tasks about visual perception with description of actions (PAPAFRAGOU et al. 2006 e 2008), and in complex cognitive tasks are well known. According to the most recent interactionist perspectives, Broca's area would be the place of integration of information about semantics, syntax and world knowledge. It would thus form the center of confluence and integration among meanings that are acquired and stored in the long term memory and the new ones, arising from the continuous interaction between the subject and the world. Broca's area would be a sort of multimodal neuroprocessor, a "super-area" of association, which would be able to keep the info coming from the different sensorial elaborations on line, in order to allow their categorization and integration in one own's encyclopedic knowledge. This view would highlight the Broca's area's role of representations' and linguistic procedure's maker, a role which influences and codetermine the achievement of the other high functions (actions' planning, objects' categorization, life experiences' storaging, and so on), binding the whole human cognition to language.

The data we'll show in this work, on the contrary, concern a cortical structure with linguistic-perceptual roles: the auditory cortex. A specific role for this area seems to arise from these data: it would present a functional specialization in recognizing linguistic sounds, in other words it would show a greater activity in the presence of stimuli belonging to spoken language. More precisely, recent studies seem to show the specialization of a specific part of the auditory cortex for such a highly adaptive task as the identification of single individuals on the basis of the emission of vocal sounds. These data, together with the classic behavioral works about the hearing and voice synergy in the building of primary relationships (MEHLER-DUPOUX, 2006), would suggest the specialization of the auditory cortex for the building of primary social relationships.

2. Adaptivity and specialization of the auditory cortex

The human auditory cortex presents a specific functional organization, with a tonotopic sensitivity: the primary cortex is thus organized in columns of associations that respond in a specific way to the heard frequencies, with a specialization in the posterior regions for the higher frequencies, and in the anterior regions for the lower ones (HUDSPETH 2003). This tonotopical maps represent the whole spectrum of the audible frequencies.

But linguistic stimuli represent a sort of "privileged input" for the human auditory cortex. Some studies (cf. FECTEAU et al. 2004, ZATORRE et al. 1996, ZATORRE in press) highlighted that the human auditory cortex is particularly sensitive to linguistic sounds, rather than to non-linguistic ones (e.g. music) or to other animals' sounds. More precisely, there would be a large amount of experimental proofs about the species-specificity of a particular portion of the auditory cortex, the Superior Temporal Sulcus, which shows a medium-level activation for non linguistic or belonging to other species' stimuli, while would show a very high activation (almost twice the BOLD activity) when in presence of human vocalizations.

From an ethologic point of view this element is relevant: this area seems to be sensitive to language in a species-specific way, for its activation is high for linguistic sounds and mild even for stimuli that are ecologically relevant, like sounds related to dangers. The greater sensitivity of the Superior Temporal Sulcus for linguistic sounds than to sounds that reveal dangers (like sudden or very loud noises) would suggest the specialization of a part of the auditory cortex for the species-specific vocalizations, which are also crucial for the survival of the species (cf. ANDREW 1963, ALTMANNN 1967, , PETERSEN 1982, SEYFARTH et al. 1980, TIAN-RAUSCHECKER 1998, van LAWICK-GOODALL 1968). In other words, a portion of the cerebral structures which process the auditory data would be selectively sensitive to human vocalizations: a species-specific structure that screens the information from the outside world and direct our "preference" towards linguistic inputs. Moreover, studies conducted on seven-months old's infants show a preference in the structures of the temporal planum for linguistic sounds belonging to the mother tongue (GROSSMANN et al. 2010), with a typical activation for the consonant-vocal units and for words of the mother tongue. Infants have a greater interest in linguistic auditory stimuli, more than the other sensory stimuli (e.g. visual or tactile ones) if these are made by the mother or by people they have primary relationships with (ZATORRE-GANDOUR 2008).

There would be thus a specific portion of auditory areas dedicated to vocal production. When we change to linguistic stimuli belonging to a specific language the evidences about the auditory cortex's specialization become even more convincing. Human auditory system is not only highly specialized in the perception of the auditory frequencies that are typical of the human language (one can think of the cochlea's tonotopical organization and its accuracy in the translation of the analogical auditory information to the electrical signals through the auditory nerve) but is also characterized to the central level by its ability to perceive and decode linguistic sounds. More precisely, it is the auditory cortex itself to integrate the information that are lacking in the peripheral auditory level: the ability to perceive the words of a language despite of the production's inaccuracy (according to a "cybernetic" model the smallest segmental unit of speech would be the phoneme, a model that slumped because of the data coming from the articulatory phonetics, cf. MAN e GOLDSTEIN 2000) would be allowed by the auditory cortex and by the integration's processes that are biologically guaranteed.

In order to assess the human auditory cortex's species-specificity we can refer to different studies by BELIN and coll. (2004) according to which the human voice not only is the vehicle of speech but it is also a sort of "auditory face" that gives important emotional and identity's information and also data about the relation between the speaker and the listener. Those information would be processed in a specific way by specialized areas (the so called Temporal Voice Area, made up by the central and the anterior components of the Superior Temporal Sulcus) and would have the same adaptive role than those of the cortical structures assigned to faces recognition (Face Area, cf. BRUCE-YOUNG 1986). BELIN et al. (2011) suggest an interesting model of interaction between the Temporal Voice Area and the Face Area in order to recognize conspecific that, in the case of human being, are “talking conspecific”.

Well strengthened studies found the auditory cortex of the left hemisphere, more specifically the posterior part of the Superior Temporal Gyrus and the Superior Temporal Sulcus, particularly sensitive to sounds that are linguistic comprehensible (SAMSON et al. 2011), in other words to words belonging to a specific language. Articulated language, on the contrary, is linked to a greater sensitivity of the auditory areas that are not primary (BA 22, Wernicke’area), the associative areas (BA 29), the Superior Temporal Gyrus of the STS and the temporal planum of the left hemisphere.

These recent data on the specialization of the secondary auditory cortex for linguistic tasks are no news for neuropsychologists of language: the areas that are specialized for sounds which are linguistically intelligible, would consist in structures that are known for their involvement in the classic model of the neuroanatomical functioning of language. More specifically, Heschl’s gyrus and the posterior part of the BA22 (Wernicke’s area) would work for the linguistic decoding and their alteration involves a damage in the ability of understand language (the aphasia of Wernicke).

It is interesting that these areas are part of a network that links the auditory and the prefrontal areas. More precisely, it has been found a network of activation that links auditory and non auditory areas: a large hierarchic model of the language processing that comes from the primary auditory cortex and extends to non auditory regions, mainly in the frontal cortex, and to a series of motor, premotor and prefrontal regions (DAVIS-JOHNSRUDE 2007, HICKOK-POEPPEL 2007, RAUSCHECKER-SCOTT 2009). The most corroborate neuroscientific models tend to detect a functioning network with functional epicenters (MESULAM 1998), rather than finding a single area as responsible for a specific function, as postulated in the classic modularist hypothesis (cf. FODOR 1983). These epicenters would be "nodes" where the data take an amodal format and are cathegorized and recognized. In the case of auditory cortex, too, especially in the secondary auditory cortex where the Wernicke's area is located, it is possible to find myelinated circuits of activation. More specifically some studies (RAUSCHECKER-TIAN 2000; ROMANSKI et al. 1999) tried to detect, in the auditory cortex, two ways of processing: a ventral stream, the "what pathway" that processes what the sounds indicate (i.e. the decoding process and the word's reference to elements of the outside world), and a dorsal stream, the "where pathway" (i.e. spatial location of the inputs).

Moreover, these data about the secondary auditory cortex's specialization for linguistic "qualitative" information (referring to the content) would assign the Wernicke's area a crucial cognitive role: that of processing the information referring to the outside world in a multimodal way, processing essential properties of language of an abstract kind. This would explain in part the activation of the Wernicke's area for the decoding of linguistic information even in born-deaf subjects (PETITTO et al. 2000).

These findings would show the specialization of the human auditory cortex for the linguistic sounds with a great preference for word-made stimuli already in infants, and a generic preference for the voice in the primary relationships. Studies conducted with brain imaging techniques, moreover, would show a specific competence of the Superior Temporal Sulcus and the Superior Temporal Gyrus of the left hemisphere for words and the activation of a temporal-frontal circuit that links the secondary auditory cortex (Wernicke's area) with two circuits that are functionally different.

These data could make us assume that the decoding of sounds and the typical organization of the auditory cortex are "special" for the *sapiens.* Rather the ethological comparison, unmerciful with every form of anthropocentrism, showed that this preference for the production of vocalizations and the resulting activation of the auditory cortex is far from being a human specialty.

It is indeed sure that the human auditory system is characterized by elements which are homologue to those of the non human primates, but it is interesting to note that these features are present only in specific animal species, where the vocal production is used to communicative aims within social groups. The organization of the non human primates' cortex, more complex than those of the other mammals, seems in fact to be fit to the perception of the complex vocal sounds that are peculiar to verbal communication.

3. Conclusions: exaptation of language's cerebral circuits

These data would then support the idea that the auditory cortical structures, phylogenetically inherited from previous species, has been exapted in *sapiens* for linguistic purposes, an exaptation occurred on a anatomical structure that was first selected for adaptive-communicative purposes. In humans, on the contrary, it seems to be present already in the cortical level a specialization for the human language's prosodic components and for linguistic sounds both meaningless and meaningful. Thus, the idea that there is a formal model of language production which is unrelated to the speaker's (and hearer's) biology rules out an explanation that is crucial and well grounded about how the human being produces language.

The hearing and the auditory cortex would be regarded as a constraint that qualitatively influences the functional and evolutionary realization of language (both in the individual and in the community), rather than simple "biological foundation" of the linguistic function.

In humans this biological constraint doesn't concern only the ability to recognize the subject's identity from his vocal production or the possibility to detect an emotive level through voice, but it concerns also the sequential decoding of linguistic structures. There would be a specific sensitivity to types of phonemes, even if the studies' results are controversial, and it is well known that the posterior part of the BA22 in the primary auditory cortex decodes linguistic process in a specific way: it is the Wernicke's area, which is classically viewed as the area of linguistic decoding, and is nowadays an interesting object of study for its ability to decode the categorizations of world-knowledge and the relationships the subjects entertain with it. It is still not clear whether it is possible to assign the Wernicke's area the competences that concern complex tasks as the decoding of categorized information and not only linguistic-decoding tasks. But it is clear that auditory cortex (more specifically STG, STS, and temporal planum) and the posterior frontal cortex are biological constraints that influence the way the sapiens build representations, a modality that phylogenetically evolved for intraspecific communicative aspects, and has been exapted for linguistic-representational purposes.

REFERENCES

ANDREW, R.J., (1963) «The origins and evolution of the calls and facial expressions of the primates» in *Behaviour*, n. 20, pp. 1-109.

ALTMANN, S.A. (1967), «The structure of primate communication» in Altmann, S.A. (Ed.), *Social Communication Among Primates*, Chicago, Chicago University Press, pp. 325-362.

BELIN, Pascal; FECTEAU, Shirley; BÉDARD Catherine (2004) «Thinking the voice: neural correlates of voice perception» in *Trends in Cognitive Sciences*, vol.8, n. 3, 129-135.

BELIN, Pascal; BESTELMEYER, Patricia E.G.; LATINUS, Marianne; WATSON, Rebecca (2011) «Understanding Voice Perception» in *British Journal of Psychology*, n.1, pp. 1-15.

BOTHA, Rudolf; KNIGHT, Chris (2009a), (eds.) *The Prehistory of Language. Studies in the Evolution of Language*, New York, Oxford University Press.

BOTHA, Rudolf; KNIGHT, Chris (2009b), (eds.) *The Cradle of Language*, New York, Oxford University Press.

BROWMAN, C.P.; GOLDSTEIN, L., (2000) «Competing constraints on intergestural coordination and self-organization of phonological structures» in *Bulletin de la Communication Parlée*, n. 5, pp. 25-34.

BRUCE, V.; YOUNG, A. (1986) «Understanding face recognition» in *British Journal of Psychology*, n. 77, pp. 305-327

DAVIS, M.H.; JOHNSRUDE, I.S. (2003) «Hierarchical processing in spoken language comprehension» in Journal of Neuroscience, n. 23, pp. 3423-3431

EGGERMONT J.J., WANG X., (2011) «Temporal Coding in Auditory Cortex», in J.A Winer, C.E. Schreiner (eds.) *The Auditory Cortex*, New York, Springer, pp. 309-328.

EIBL-EIBESFELDT, Irenäus (1987), *Grundriss der vergleichenden Verhaltensforschung*, München, Piper, trad. it. *I fondamenti dell'etologia. Il comportamento degli animali e dell'uomo*, Milano, Adelphi, 1995.

ELLIOT T.M., THEUNISSEN F.E., (2011) «The Avian Auditory Pallium», in J.A Winer., C.E. Schreiner (eds.) *The Auditory Cortex*, New York, Springer, pp. 429-442.

FECTEAU, Shirley; ARMONY, Jorge L.; JOANETTE, Yves; BELIN, Pascal (2004) «Is voice processing species-specific in human auditory cortex? An fMRI study» in *NeuroImage*, n. 23, pp. 840 – 848.

FITCH, W. Tecumseh (2010), *The evolution of language*, New york, Cambridge University Press.

GOULD, Stephen J. (2002), *The structure of Evolutionary Theory*, President and Yellow of Harward College, tr. it. *La struttura della teoria dell'evoluzione*, Milano, Codice, 2003.

FODOR, J. (1983), *The modularity of mind*, Cambridge (Mass.), MIT Press; trad. it. *La mente modulare*, Bologna, Il Mulino, 1988

GROSSMANN, T., OBERECKER, R., KOCH, S.P., FRIEDERICI, A.D. (2010) «Developmental origins of voice processing in the human brain» in *Neuron*, n. 65, pp. 852-858

HAGOORT, Peter (2003) «How the Brain Solves the Binding Problem for Language: A Neurocomputational Model of Syntactic Processing» in *NeuroImage*, n. 20, pp. S18-S29.

HAGOORT, Peter; HALD, Lea; BASTIAANSEN, Marcel, PETERSSON Karl M. (2004), «Integration of word meaning and world knowledge in language comprehension» in *Science*, n. 304, pp. 438-441.

HARRINGTON I.A. (2002) «Effect of auditory cortex lesions on discriminations of frequency change, amplitude change and sound location by Japanese macaques (Macaca fuscata)», Unpublished Doctoral Dissertation, University of Toledo.

HAUSER, Marc D. (1997), *The evolution of communication*, Cambridge (Mass), MIT Press.

HEFFNER H.E., HEFFNER R.S., (1986) «Effect of unilateral and bilateral auditory cortex lesions on the discrimination of vocalizations by Japanese macaques» in *Journal of Neurophysiology*, 56, pp. 683-701.

HICKOK, Gregory; POEPPEL, David (2007) «The cortical organization of speech processing» in *Nature Neuroscience*, vol. 8, pp. 393-402.

HUDSPETH A.J. (2003), «Sensory Transduction in the ear», in E.R. Kandel, J.H Schwartz., T.M. Jessell, (a cura di), *Principles of Neural Science*, 5th ed. McGraw-Hill, pp. 614-624.

JOHANSSON, Sverker (2005), *Origins of Language. Constraints on hypoteses*, Amsterdam, John Benjamins Publishing Company.

KAAS J.H. (2011) «The Evolution of Auditory Cortex: The Core Areas», in J.A.Winer, C.E. Schreiner (eds.) *The Auditory Cortex*, New York, Springer, pp. 407-428.

KELLY J.B., PHILLIPS D.P., (1991) «Coding of interaural time differences of transients in auditory cor-tex of Rattus norvegicus: implications for evolution of mammalian sound localization» in *Hearing Research*, n. 55, pp. 39-44

LENNEBERG, Erich H. (1967), *Biological Foundation of Language*, New York, John Wiley, tr. it. *Fondamenti biologici del linguaggio*, Torino, Boringhieri, 1971.

LIEBERMAN, Philip (1975) *On the origins of language: an introduction to the evolution of human speech*, New York, MacMillan, tr. it. *L'origine delle parole*, Torino, Einaudi, 1980.

MEHLER, Jaques, DUPOUX, Emmanuel (2006), *Naitre Humain* (3rd Edition), Paris, Editions Odile Jacob.

MESULAM, M. (1998) «From Sensation to Cognition», in *Brain*, n. 121, pp. 1013-1052.

PAPAFRAGOU, Anna; HULBERT, Justin; TRUESWELL, John (2008), «Does Language, Guide Event Perception? Evidence from Eye Movement» in *Cognition*, n. 108, pp. 155-184.

PAPAFRAGOU, Anna, MASSEY, Christine, GLEITMAN, Lila (2006) «When English Proposes What Greek Presupposes: The Linguistic Encoding of Motion Events», in *Cognition*, 98, pp. B75-B87.

PENNISI, Antonino; FALZONE, Alessandra (2011) *Le scienze della natura e la natura del linguaggio umano*, Modena, Mucchi.

PETERSEN, M.R. (1982) «The perception of species-specific vocalizations by primates: a conceptual framework» in Snowdon, C.T., Brown, C.H., Petersen, M.R.

(Eds.), *Primate Communication*, Cambridge, UK, Cambridge University Press, pp. 171–211.

PETERSEN, M.R., BEECHER, M.D., ZOLOTH, S.R., MOODY, D.B., STEBBINS, W.C. (1978) «Neural lateralization of species-specific vocalizations by Japanese macaques (Macaca fuscata) », in *Science*, n. 202, pp. 324-327.

PETITTO, LA, ZATORRE RJ, GAUNA K, NIKELSKI EJ, DOSTIE D, EVANS AC. (2000) «Speech-like cerebral activity in profoundly deaf people processing signed languages: implications for the neural basis of human language» in *Proc Natl Acad Sci* n. 25, pp. 13961-6.

PETKOV, Christopher; KAYSER, Christoph; STEUDEL, Thomas; WHITTINGSTALL, Kevin; AUGATH, Mark; K. LOGOTHETIS, Nikos (2008) «A Voice Region in the Monkey Brain» in *Nature Neuroscience*, no. 3, pp. 367-374.

RAUSCHECKER, J.P., TIAN, B. (2000) «Mechanisms and streams for processing of "what" and "where" in auditory cortex» in *Proc. Natl. Acad. Sci.*, n. 97, pp. 11800-11806.

ROMANSKI, L. M., TIAN, B., FRITZ J., MISHKIN, M., GOLDMAN-RAKIC, P. S., RAUSCHECKER J.P., (1999) «Dual streams of auditory afferents target multiple domains in the primate prefrontal cortex» in *Nature Neuroscience*, n. 2, pp. 1131-1136.

SAMSON, Fabienne, ZEFFIRO, Thomas A.; TOUSSAINT Alain; BELIN, Alain (2011) «Stimulus complexity and categorical effects in human auditory cortex: an Activation Likelihood Estimation meta-analysis» in *Frontiers in Psychology*, n. 241, pp. 1-23.

SEYFARTH, R.M.; CHENEY, D.L.; MARLER, P. (1980) «Monkey responses to three different alarm calls: evidence of predator classification and semantic communication» in Science, n. 210, pp. 801-803.

SWAAB, Dick (2010), *Wij zijn ons brein*, Uitgeverij, Contact, tr. It. *Noi siamo il nostro cervello. Come pensiamo, soffriamo e amiamo,* Roma, Elliot, 2011.

TIAN, B., RAUSCHECKER, J.P., (1998) «Processing of frequency-modulated sounds in the cat's posterior auditory field» in *Journal of Neurophysiology*, n. 79, pp. 2629-2642.

van LAWICK-GOODALL, J.A. (1968) «A preliminary report on expressive movements and communication in the Gombe Stream chimpanzees» in Jay, P.C. (Ed.), *Primates: Studies in Adaptation and Variability*, New York, Rinehart and Winston, pp. 313-374.

von UEXKÜLL, Jacob (2010), *Ambienti animali e ambienti umani. Una passeggiata in mondi sconosciuti e invisibili*, a cura di Marco Mazzeo, Macerata, Quodlibet.

ZATORRE, Robert J. (in press) «Sound analysis in auditory cortex» in *Trends in Neurosciences*.

ZATORRE, Robert J.; MEYER, Ernst; GJEDDE, Albert; EVANS Alan C. (1996), «PET Studies of Phonetic Processingof Speech: Review, Replication, and Reanalysis» in *Cerebral Cortex*, n. 6, pp. 21-30.

ZATORRE, Robert J.; GANDOUR, Jackson T. (2008) «Neural specializations for speech and pitch: moving beyond the dichotomies», in *Philosophical Transaction of the Royal Society B*, n. 363, pp. 1087-1104.