Developing Embodied Multisensory Dialogue Agents

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Abstract. A few decades of work in the AI field have focused efforts on developing a new generation of systems which can acquire knowledge via interaction with the world. Yet, until very recently, most such attempts were underpinned by research which predominantly regarded linguistic phenomena as separated from the brain and body. This could lead one into believing that to emulate linguistic behaviour, it suffices to develop ‘software’ operating on abstract representations that will work on any computational machine. This picture is inaccurate for several reasons, which are elucidated in this paper and extend beyond sensorimotor and semantic resonance. Beginning with a review of research, I list several heterogeneous arguments against disembodied language, in an attempt to draw conclusions for developing embodied multisensory agents which communicate verbally and non-verbally with their environment.

Without taking into account both the architecture of the human brain, and embodiment, it is unrealistic to replicate accurately the processes which take place during language acquisition, comprehension, production, or during non-linguistic actions. While robots are far from isomorphic with humans, they could benefit from strengthened associative connections in the optimization of their processes and their reactivity and sensitivity to environmental stimuli, and in situated human-machine interaction. The concept of multisensory integration should be extended to cover linguistic input and the complementary information combined from temporally coincident sensory impressions.

Keywords: embodiment, sensorimotor resonance, semantic resonance, language, multisensory integration, robotics

1 INTRODUCTION

... His eyes only see His ears only hear ...

—Wiesława Szymborska No End of Fun (1967)

In the ‘traditional’ view, going back to René Descartes, cognition has been seen as manipulation of symbolic, mental representations, with the brain conceived of as an input-output processor, a problem-solving device running abstract, generalised computational programs which enable us to process incoming data into a perception/interpretation of the outside world. This ‘software’, separate from the body, was equated with the mind, while the body was regarded as an output system attached to the cognitive processing system, with similar tasks achieved by applying the same underlying motor program to different effectors:

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The information-processing approach or computer metaphor has become further entrenched over the latter half of the previous century due to the adoption of the digital computer as the platform to run the symbolic computations (Hoffmann et al., n.d.).

However, this dualist perspective has been increasingly challenged, beginning with Edmund Husserl, Martin Heidegger, John Dewey, and Maurice Merleau-Ponty, and it is today widely acknowledged that perception and cognition are grounded in bodily experience. The brain is not the sole problem-solving resource we have at our disposal; the organiser/filtering machine is the body-en-total. Heuristics depend on our physiology; cognition is not only influenced and biased by states of the body, but crucial to it are also the rest of the body beyond the brain, as well as the environment.

Until very recently, most language research has, in a Cartesian manner, traditionally regarded linguistic phenomena as internal, mental, isolationist and amodal (that is, separate and independent from perception, action and emotion systems, and the body); a view endorsed in psychology (e.g. Geschwind 1970; Kintsch 1998), philosophy (e.g. Katz & Fodor 1963; Fodor 1983), and linguistics (e.g. early Chomsky – 1957, 1975; Nowak et al. 2002; Jackendoff 2002)1. For instance, Chomsky’s most seminal theories were based on mathematical formalism and saw language as governed by a context-free grammar extended with transformational rules operating on (non-semantic) symbol strings and complemented by morphophonemic rules, with autonomous syntax at the core of the theory of language. The reason why his views for a long time did not go beyond such a perspective should not come as a surprise. His Syntactic Structures, which became a revolutionary and foundational work2 in linguistics, grew out of a series of lecture notes for an audience of undergrad (mainly electrical engineering and maths) students at the MIT.3 Also, Chomsky’s ideas were born at the

2 “There is a great difference between mind and body, inasmuch as body is by nature always divisible, and the mind is entirely indivisible. […] the mind or soul of man is entirely different from the body.”

3 A votum separatum in this domain is the field of biolinguistics, which hypothesizes a strong genetic (or neurobiological) endowment for language (UG) and determination of its structure (e.g. postulating selection—i.e. evolutionary fitness—advantages), treating the language faculty on a par with other biological systems (see e.g. Meader & Mayskens 1950; Lenneberg 1967; Patelli-Palmirini 1989; Hauser et al. 2002; Chomsky 2005; Di Sciullo & Boeckx 2011).

4 Ranked #1 on the list of the one hundred most influential works in cognitive science from the 20th century, selected by the University of Minnesota Center for Cognitive Sciences; http://www.cogsci.umn.edu/cent/calendar/past_events/millennium/final.html

5 Before that, at the University of Pennsylvania, Chomsky studied logic and foundations of mathematics.

http://www.cogsci.umn.edu/cent/calendar/past_events/millennium/final.html

Descartes (1641) Meditations de prima philosophia VI:19

magnus esse differentiam inter mentem & corpus. in eo quidquid corpus ex natura suá sit semper divisibile, mens autem plane indivisibilis … mentem a corpore omnino esse diversam.

—Descartes (1641) Meditations de prima philosophia VI:19
same time as the establishment of computer science as a distinct academic discipline, the beginnings of computational linguistics, and the founding of AI research, which all shared the dominant idea that thought can be described with formal logic.

The generative school inspired several decades of linguistic thought, and even theories trying to modify or undermine its tenets were still relying on the underlying view of language as a system manipulating abstract symbols. This dualistic view could lead one into believing that in order to credibly emulate linguistic behaviour, it suffices to develop ‘software’ operating on (i.e. applying combinatorial rules such as Merge and Move to) abstract representations that will work on any computational machine, and that its operations will be implementation-independent, functioning identically regardless of the physical hardware.

2 EMBODIED LANGUAGE IN HUMANS

to turn print into exciting situations in their skulls
—Kurt Vonnegut Slaughterhouse-Five (1969:205)

The dualistic approach just outlined above works to some extent in statistical machine translation, automatic text indexing and retrieval (think e.g. search engines), natural-language interfaces or dialogue systems, but if the system to be developed is to truly mimic human behaviour, the disembodied picture is not very accurate for several reasons. One may be doubtful about modularity and the existence of a specifically dedicated innate language acquisition device, but must still take into account the following phenomena and theoretical developments:

1. lateralization and localization of the language faculty in the brain. Linguistic capabilities have been shown to be limited to certain areas of the cerebrum, as evidenced primarily by various language disorders:

   - receptive aphasia, commonly known as Wernicke’s aphasia (Wernicke 1874): damage to the medial temporal lobe destroying local language regions and cutting them off from most of the occipital, temporal and parietal regions (cf. e.g. Price 2000; Bookheimer 2002; Damasio et al. 2004);
   - expressive aphasia (aka Broca’s or agrammatic aphasia; Broca 1861);

2. abnormal language developed in individuals with the left hemisphere removed (Dennis & Whitaker 1976). Six
3. Specific Language Impairment (SLI), which is unrelated to other developmental disorders, mental retardation, brain injury, or deafness (e.g. Joanisse & Seidenberg 1998; Bishop & Snowling 2004; Archibald & Gathercole 2006);
4. other cases of people with normal nonverbal abilities but impaired language, and ‘normal’ language but cognitive deficits (cf. the classic case studies of individuals with incommensurable linguistic and cognitive capacities: Genie (Curtiss 1981), Laura (Yamada 1990), Clive (Smith 1989), or Christopher (Smith et al. 1993)).

While these deficits cannot straightforwardly be taken as proof of the modularity of language (cf. e.g. Calabrese et al. 2003; Fodor 2005), they do point to localization of language processes;

3. embodiment of language in neuronal circuitry. FMRI studies have shown ‘activation’ of certain brain areas involved in language processing (e.g. Osterhout 1997; Hagoort et al. 1999; Embick et al. 2000; Horwitz et al. 2003; Pulvermüller & Assadollahi 2007), with different levels of language processing identified in specific regions, e.g. loci of syntax mainly in left-perisylvian language regions, especially Broca’s and Wernicke’s areas, but also adjacent neocortical areas, the insula, and subcortical structures including basal ganglia (cf. e.g. Ullman 2001; Grodzinsky & Friederici 2006), or phonology in the superior temporal sulcus and anterior superior temporal cortex (cf. e.g. Diesch et al. 1996; Obleser et al. 2006; Uppenkamp et al. 2006);

4. genetic influence on language. While mutations of the Foxhead box protein 2 (FOXP2 gene), deemed to cause a severe speech and language disorder (e.g. Lai et al. 2001; Verne et al. 2008; Fisher & Scharff 2009), were initially taken as evidence for a ‘language gene’, it was later discovered that the protein impacts a wide range of phenotypic features all over the body (including facial motor control) and that the impairments of the family affected with the mutation went beyond language to other cognitive capacities. It is now more believed that it is networks of gene interactions rather than individual genes that have an influence on language (Knopka et al. 2009), but the neurobiological influence is there;

4. many Universal Grammar-based constraints now being reinterpreted as learning and processing constraints. That is, the difficulty in the acquisition of certain aspects of language are being accounted for by their complexity, the computational load under which the user/learner operates, his/her memory and attention limitations, or ease of access to
representations (cf. e.g. Wakabayashi 2002; Van Hell & De Groot 1998; Wagek 2008).

5. maturation and the critical/sensitive period (but consider e.g. Marinova-Todd et al. 2000 for a contradictory view).

6. the Chomskyan competence vs. performance distinction (Chomsky 1965), explaining mistakes in (originally native) language users’ output (i.e., their actual deployment of the linguistic capacity) attributable to such psychosomatic states and factors affecting them as fatigue, tedium, intoxication, drugs, sudden changes of mind, haste, inattention, or external distractions;

7. interaction between (context-bound) language comprehension and production, and sensorimotor activation, manifested in both directions by:12

- motor resonance observed in linguistic (Lakoff & Johnson 1980; Lakoff 1987), behavioural (primarily with priming)13 modulating motor performance; e.g. Tanenhaus et al. 1995; Gentilucci et al. 2000; Spivey et al. 2001; Glenberg & Kaschak 2002; Glover et al. 2004; Buccino et al. 2005; Boulenger et al. 2008; Nazir et al. 2008; Frak et al. 2010; for grammar cf. Madden & Zwaan 2003; Bergen & Wheeler 2010), neuroimaging and TMS studies14 (e.g. Zatorre et al.

10 The Critical Period Hypothesis (or its idea), proposed by Penfield and Roberts (1959), posits the existence of an ideal window of time during which genetically endowed language acquisition can—given adequate stimuli—take place spontaneously, relatively effortlessly, and characteristically meeting a high degree of success, after which acquiring a language naturally, automatically and with complete ultimate attainment becomes impossible. “The earlier the better” rule of thumb captures the negative correlation between the age of acquisition onset and subsequent asymptotic attainment. Most evidence to support the claim was supplied by Eric Lenneberg (1967) in his Biological Foundations of Language. While the existence of a critical period is widely accepted where first language acquisition is concerned, attempts to extend it to second language acquisition still arouse a good deal of contention (for instance, Lamendella (1977) suggested the term ‘sensitive period’ to emphasise the fact that acquisition may be more efficient during childhood, but not restricted to that period).

11 The distinction can be considered on the example of any organic system: “Studies of the digestive system, for example, distinguish between its structural properties and what it is doing after you ate a sandwich” (Noam Chomsky, p.c. 8 Nov 2011), and can actually be traced back to the classic Aristotelian dichotomy between στοιχεῖον (potentiality) and ἐφαρμοσμένον (actuality).

12 This seems to be a reflection of a more general phenomenon where “there is no animal in which there is known to be a complete segregation of sensory processing” (Stein et al. 1996:497).

13 E.g. in the form of mention of tool and action concepts.

14 Somewhat importantly, motor resonance was not observed when the stimuli were used in idiomatic contexts (Rueschemeyer et al. 2010a) or metaphorical ones. Regarding the latter, Raposo et al. (2009) found activity in the pre- and motor cortex for literal-only usages of arm- and leg-related Vs, while Bergen et al. (2007) likewise demonstrated that visual imagery is triggered in sentence comprehension tasks (where general words of motion were employed) only where the utterances have literal spatial meaning. However, the picture is not completely clear-cut. This year, Lacey et al. (2012) showed that textural metaphors do activate parietal operculum regions important to the sense of touch. To explain this discrepancy, one could posit a qualitative difference between ‘directly’ embodied sensory experiences (e.g. texture or temperature) and more ‘indirect’ ones such as those grounded in visual perception. The former are more ‘primary’;15 sensed earliest – already in the womb, tacitoning being the first sense that begins to develop before 8 weeks gestational age together with the emergence of the nervous system (Montagu 1978), before taste and smell (14 weeks g.a.), hearing (16 weeks g.a.; Shahidullah & Hepper 1992) or vision (week 18 onwards).

ii)available in more ‘primitive’ organisms without vision or hearing, iii)perceptible during half-sleep, and iv)impacting our bodily functioning more strongly (the somatic reaction is more likely to be stronger than e.g. to an unpleasant sight or sound). This might account for the lack of activation in visual cortical areas.

15 But see e.g. Bedny et al. (2008), Postle et al. (2008), or Kemmerer & Gonzalez-Castillo (2010) for opposing views.

16 This conviction can also be found in ‘folk wisdom’. For instance, in one episode of a Malaysian edutainment program for children which I was consulting on for a European broadcaster, a monkey was hanging upside down because that was the position in which she last saw her orange juice.

17 I.e. texts describing an event in which the main character was spatially dissociated from a target object, e.g.: John was preparing for a marathon in August. After doing a few warm-up exercises, he took off his sweatshirt and went jogging.
embodiment—the interaction of the language faculty with the sensory apparatus and motor system—it is unrealistic to replicate accurately the processes which take place during language acquisition, comprehension, or production, or during non-linguistic actions. Cognitive mechanisms are synergistically intertwined with affective and somatic components, and largely inseparable (Ziemke 2011).

3 THE COROLLARIES FOR ROBOTICS

... it is the movement which is primary, and the sensation which is secondary, the movement of the body, head, and eye muscles determine the quality of what is experienced. In other words, the real beginning is with the act of seeing; it is looking, and not a sensation of light. —John Dewey (1896:358f.)

Since the official launch of AI as a new research discipline at the seminal Dartmouth conference in 1956, much of work in the field has been driven by the ‘Physical Symbol Hypothesis’ (Newell & Simon 1976): trying to construct systems that would possess or build internal, symbolic representations of objects and relations in the outside world—in other words, a “world model”—which usually had little to do with their hardware, sensorimotor experience, or current context, but were instead characterised by precisely defined states and finite lists of acceptable commands (Wang 2009:2f.). Under such a functionalist approach, the body is merely a platform on which cognitive operations are running. In some areas, such closed systems were able to achieve spectacular feats, for instance in defeating world chess champions.

Chess, however, is a formal game, set in a virtual world with discrete states, positions, and licit moves, a game involving complete information, and a static one: no move means no change, and the inventory of legitimate operations remains constant (Pfeifer & Scheier 1999:58f.). This is quite unlike what usually happens in the real world. Hence, the last two and a half decades have witnessed recurrent appeals for situated, embodied autonomous systems actively and directly interacting with the world around (cf. op. cit.; Brooks 1991; Varela et al. 1991) and constructing knowledge via this dynamic enactment (the active learning being qualitatively different from statistical machine learning; cf. e.g. Froese 2009; Vernon 2010). Evidently robots, even anthropomorphic ones, are far from isomorphic with humans in terms of both the ‘brain’ and the rest of the body, including the input and output devices (sensors and actuators).

Also, as one reviewer rightly remarks, in the language technology field priority is not necessarily to make a machine as humanlike as possible, with the same architecture; rather, it is to make the machine so that it does things on a level comparable to humans (or, I would add, surpassing that) – in other words, to achieve similar—or better—functionality in terms of mode, scope, or scale. Or, going completely beyond the anthropocentric GOFAI perspective (Haugeland 1985; cf. Wang 2008), since passing the Turing Test is not a sine qua non of being intelligent, as acknowledged by the test’s designer himself (Turing 1950).

This, however, means that robust artificial cognitive agents can bypass the human limitations inherent in most of the above points (just as they could overcome some contingencies resulting from the material properties of the human brain and bodily features such as synaptic speed and efficiency, the physical characteristics of the vocal tract, the auditory perception system, or muscular flexibility). Nevertheless, they could still benefit from strengthened associative connections owing to the motor and semantic resonance in both the optimization of their processes, and reactivity and sensitivity to environmental stimuli, across a range of tasks:

(i) in grounded language understanding (cf. e.g. Glenberg & Kaschak 2002; Feldman & Narayanan 2004; Gallese & Lakoff 2005; Sato et al. 2008), where structuring the environment acts as scaffolding and all inputs contribute to evidential support,

(ii) in automated articulation-based speech recognition (utilising motor information, i.e. combining spoken input with visual data—e.g. the shape of the speakers lips—and maybe even data such as strength of the incoming airstream),

(iii) while learning about context-dependent phenomena in the surrounding world (e.g. action sequences and argument structure in construction grammar; cf. Dominey 2007: since embodiment plays a constitutive role in the process of cognition; Vernon 2010), or in the process of language acquisition in general (because language—at least in the initial stages—is acquired by situated embodied direct engagement with the world, and not just passive perception, e.g. watching television; cf. e.g. Steels 2009),

(iv) to help with storage and retrieval due to the benefits of episodic memory,

(v) to support action prediction, planning and anticipation (Koelwijn et al. 2008; Stapel et al. 2010; van Elk et al. 2010),

(vi) to support action execution (with linguistic input making the actor better aware of the affordances, i.e. physically feasible action possibilities),

(vii) to reinforce feedback in ‘soft robotics’ and morphological computation, where there is no clear separation between the controller (or orchestrator) and the hardware (morphology), and the tasks are distributed between the brain, body, and environment (cf. e.g. Paul Van Emmerik & Paul Grush 1999).

19 The limitations need not in themselves necessarily be a bad thing; to the contrary, they may serve a useful role in limiting the search space and focusing attention on the most vital stimuli. The restrictions imposed on the vocal apparatus in turn mean that speech is segmented and decelerated enough to facilitate comprehension. The relative absence of such constraints on computers may be the exact reason why the latter have problems tackling tasks where humans perform with ease (Tom Froese, p.c., 9 Mar 2012).

20 Just as robots can have an advantage when equipped with e.g. infrared, or ultrasonic sensors.

21 Sensorimotor dynamics plays a crucial part in toddlers’ learning to categorise objects: it is only when the infant brings the object in front of their eyes and focuses on it that s/he learns to associate it with its name (Smith 2010).

22 Though originally grounded in sensorimotor experience, mental imagery, or simulation of interaction with the world, may subsequently become environmentally decoupled, as in forward models (Clark & Grush 1999).
(viii) in cognitive developmental robotics, aiming at understanding human cognitive developmental processes by synthetic or constructive approaches (Asada et al. 2009, Asada 2011, Ishiguro et al. 2011); (ix) in common grounding and alignment, which are crucial for fruitful situated human-machine interaction, and which are another area where sensory experience must be coordinated with linguistic interaction.

Principally, if our goal were to create machines which do things on a comparable level to—or surpassing—humans, we could do away with attempts at embodying them in human-inspired ways (Taivo Lints, p.c., 31 May 2012) – they could function perfectly well with totally nonhuman kinds of embodiment (different ‘bodies’, different sensors and effectors, different internal architectures... or even with embodiment in a virtual world; Bringsjord et al. 2008; Goertzel et al. 2008). Given the role played by the morphology of the sensory apparatus and the architecture of the sensorimotor loop in shaping and structuring the information that reaches the controller, and thereby in concept formation, it would anyway be difficult for a machine to form the same concepts, categories and behaviours as us without having comparable morphology (as remarked e.g. by Barsalou 1999 or Lakoff & Johnson 1998).

However, if our goal is to have machines ‘thinking’ and behaving in a way compatible with ours—which is a highly practical and desirable goal—then it is of high importance for them to develop, learn and function in a similar “experience space” (Taivo Lints, p.c.; cf. also Wang 2009:5).

The requirement that the behaviour, perception and conceptual apparatus of artificial intelligent agents be grounded in their experience of their own interaction with the outside world at once means that their concepts and categories need not necessarily rely on the same minimal constituents and grammatical categories as have been externally identified and defined in linguistics. Instead, the gradually emergent categories are more likely to be intrinsically meaningful behaviours and affordances (see also Kuniyoshi et al. 2004), action-oriented rather than orbocentric (Hoffmann & Pfeifer 2011). For instance, to a robot who has never kicked or observed anyone kick anything but footballs, the minimal unit of meaning may be <kick a ball> rather than <kick> alone (although this does not rule out the possibility of extrapolation and abstraction should a relevant opportunity arise).24 Similarly, irrespective of whether the input is expressed using [b]kicking a ball or [v]kicking a ball, it should activate the same action schema.

4 TOWARDS A BROADER DEFINITION OF MULTISENSORY INTEGRATION

23 The idea of morphological computation in animals can be well illustrated on the example of cockroaches skilfully climbing over obstacles that exceed their body height, using relatively few neurons, off-loading most tasks to morphology (by reconfiguring the mesothoracic shoulder joint), exploiting mechanical change and feedback, and capitalising on the stability of the local feedback circuits; cf. Watson et al. 2002; Pfeifer et al. 2007; Pfeifer & Gomez 2009).

24 See for instance the POETICON++ project (Robots need Language: A computational mechanism for generalisation & generation of new behaviours in robots: http://www.poeticon.eu/).

In order to form a meaningful experience and construct coherent, reliable and robust representations of the surrounding world, the human brain combines prior knowledge with sensory input arriving from various modalities and integrates these at multiple levels of the neuraxis. This serves to maximize the efficiency of everyday performance and learning, enhancing the salience of the events, helping increase the detection and identification of the external stimuli, disambiguate them, compensate for incomplete information, and shorten reaction times. In view of the inseparability of language and the body, the concept of multisensory integration—whether in natural or artificial cognitive agents—should be extended and cover both the linguistic input and the complementary information that the brain combines from temporally coincident sensory impressions. This does not mean that we should ‘dumb down’ the statistical processes where they operate successfully; instead, where the input stream in one channel is too noisy, turning on auxiliary channels25 and interacting with the environment in an active manner may generate ancillary data and help e.g. disambiguate the signal and take the right decision (see also Pfeifer & Scheier 1997; Beer 2003).26 An added benefit would then be significantly reduced programming costs.

CONCLUSIONS

A living organism enacts the world it lives in; its effective embodied action in the world actually constitutes its perception and thereby grounds its cognition.

—Stewart, Gapenne & Di Paolo (2010:viib)

I have started out with a brief depiction of the dualistic Cartesian approach that has characterised much of twentieth-century thought, including that underlying most of traditional AI. While adherence to such an outlook has in many domains led to very spectacular achievements, there are limits which purely symbolic systems cannot overcome. While the subject of the mind-body relationship is by no means new, the link, still very often ignored by cognitive science communities (logic, linguistics, computer science) may be the key element for bypassing the present limitations of AI systems.

Language, too, has for a long time been treated across scientific domains as an abstract system operating largely independently from the body (articulatory-perceptual organs notwithstanding). I have presented an inventory of heterogeneous evidence against such a view, addressing instead the issue of the link between language and body. While many of the embodied language phenomena specific to humans have little

25 These channels need not all be active at all times, especially when it might burden the cognitive load in non-essential tasks, when conflicting inputs can bring the machine to a halt, or when the benefits—e.g. in terms of speed—would be negligible (Richard Littauer, p.c., 26 May 2012). The system’s available resources should be dynamically allocated to different tasks in such a way as to achieve the highest overall efficiency.

26 One consequence for humans may be that the role of kinaesthetic modality, traditionally largely believed to dominate in children, but be negligible in adults (cf. e.g. Barbe & Milone 1981; Felder & Spurlin 2005), should be reassessed, as the effectiveness may be demonstrated of ‘learning-by-doing’ and task-based approaches to language learning and teaching where the students have to use their bodies (e.g. when acquiring novel lexis via common cookery classes).
direct translation to machines, there are others that can profitably be exploited and inspire the development of robust artificial autonomous agents that rely on semantics grounded in their past experience (both linguistic and non-verbal) as well as possible related operations on the concepts concerned. Agents which are adaptive to feedback and can, despite insufficient knowledge, time pressure and storage space constraints safely and successfully navigate, learn, and communicate in the complex and dynamic ecological niche they share with human actors.

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REFERENCES

[1] Archibald, L.M.D., Gathercole, S.E.: Prevalence of SLI in Language Resource Units. J Res Spec Educ 6(1), 3–10 (2006).
[2] Asada, M., Hosoda, K., Kuniyoshi, Y., Ishiguro, H., Inui, T., Yoshikawa, Y., Ogin, M., Yoshida, C.: Cognitive developmental robotics: a survey. IEEE Transactions on Autonomous Mental Development 1(1), 12–34 (2009).
[3] Asada, M.: Can cognitive developmental robotics cause a paradigm shift? In: Krichmar, J.L., Wagtusuma, H. (Eds) Neuromorphic and Brain-Based Robots: Trends and Perspectives, Cambridge: Cambridge University Press, 251–73 (2011).
[4] Bak, T.H., O’Donovan, D.G., Xuereb, J.H., Boniface, S., Hodges, J.R.: Selective impairment of verb processing associated with pathological changes in Brodmann areas 44 and 45 in the motor neurone disease–dementia–aphasia syndrome. Brain 124, 103–20 (2001).
[5] Bak, T.H., Yancopoulou, D., Nestor, P.J., Xuereb, J.H., Spillantini, M.G., Pulvermuller, F., Hodges, J.R.: Clinical, imaging and pathological correlates of a hereditary deficit in verb and action processing. Brain 129(2), 321–332 (2006).
[6] Barbe, W.B., Milone, M.N.: What we know about modality strengths, Educational Leadership 38(5), 378–80 (1981).
[7] Barsalou, L.W.: Perceptual symbol systems. Behavioral and Brain Sciences 22, 577–609 (1999).
[8] Beer, R.: The dynamics of active categorical perception in an evolved model agent. Adaptive Behav 11, 209–43 (2003).
[9] Bedny, M., Caramazza, A., Grossman, E., Pascual-Leone, A., Saxe, R.: Concepts are more than percepts: the case of action verbs. J Neurosci 28, 11347–11353 (2008).
[10] Bellugi, U., Marks, S., Bihrlle, A., Sabo, H.: Dissociation between language and cognitive functions in Williams syndrome. In D. Bishop, K. Mogford (Eds) Language development in exceptional circumstances. London: Churchill Livingstone, 177–189 (1998).
[11] Bellugi, U., Wang, P.P., Jernigan, T.: Williams Syndrome: An unusual neuropsychological profile. In S.H. Broman, J. Grafman (Eds) Atypical cognitive deficit in developmental disorders: Implications for brain function. Hillsdale, NJ: Lawrence Erlbaum, 23–56 (1994).
[12] Bergen, B., Lindsay, S., Matlock, T., Narayanan, S.: Spatial and linguistic aspects of visual imagery in sentence comprehension. Cogn Sci 31, 733–764 (2007).
[13] Bergen, B., Wheeler, K.B.: Grammatical aspect and mental simulation. Brain Lang 112, 150–158 (2010).
[14] Bishop, D.V.M., Snowling, M.J.: Developmental dyslexia and specific language impairment: same or different? Psychol Bull 130, 858–88 (2004).
[15] Bonda, E., Petrides, M., Frey, S., Evans, A.: Frontal cortex involvement in organized sequences of hand movements: Evidence from a positron emission topography study. Soc Neurosci Abstr 20, 353 (1994).
[16] Bookheimer, S.: Functional MRI of language: New approaches to understanding the cortical organization of semantic processing. Ann Rev Neurosci 25, 151–188 (2002).
[17] Boulenger, V., Hauk, O., Pulvermüller, F.: Grasping ideas with the motor system: Semantic somatotopy in idiom comprehension. Cereb Cortex 19(8), 1905–1914 (2009).
[18] Boulenger, V., Mechtouff, L., Thiobois, S., Broussole, E., Jeannerod, M., Nazir, T.A.: Word processing in Parkinson’s disease is impaired for action verbs but not for concrete nouns. Neuropsychologia 46(2), 743–756 (2008).
[19] Bringsjord, S., Shilliday, A., Taylor, J., Werner, D., Clark, M., Charpentie, E., Bringsjord, A.: Toward logic-based cognitively robust synthetic characters in digital environments. Artificial General Intelligence 2008, Amsterdam : IOS Press, 87–98 (2008).
[20] Broca, P.: Remarques sur le siège de la faculté de la parole articulée, suivies d’une observation d’aéphémie (perte de parole). Bull Soc Anatom (Paris) 36, 330–337 (1861).
[21] Brooks, R.A.: Intelligence without representation. Artif Intell 47, 139–59 (1991).
[22] Buccino, G., Riggio, L., Melli, G., Binkofski, F., Gallese, V., Rizzolatti, G.: Listening to action-related sentences modulates the activity of the motor system: a combined TMS and behavioral study. Cogn Brain Res 24, 355–363 (2005).
[23] Calabretta, R., Di Ferrari, A., Wagner, G. P., Parisi, D.: What does it take to evolve behaviorally complex organisms? BioSystems 69, 245–262 (2003).
[24] Capirci, O., Sabbadini, L., Volterra, V.: Language development in Williams syndrome: A case study. Cogn Neuropsych 13, 1017–39 (1996).
[25] Chomsky, N. Syntactic structures. The Hague: Mouton (1957).
[26] Chomsky, N. Aspects of the Theory of Syntax. Cambridge, MA: MIT Press (1965).
[27] Chomsky, N. Reflections on language. New York: Pantheon (1975).
[28] Chomsky, N. Rules and Representations. New York: Columbia University Press (1980).
[29] Chomsky, N. Three factors in language design. Ling Inq 36(1), 1–22 (2005).
[30] Clark, A., Grush, R.: Towards cognitive robotics. Adaptive Behav 7(1), 5–16 (1999).
[31] Curtiss, S. Genie: The Case of a Modern Wild Child. New York: Academic Press (1981).
[32] Damasio, H., Grabowski, T. J., Tranell, D., Hichwa, R. D., Damasio, A. R. A neural basis for lexical retrieval. Nature, 380, 499–505 (1996).
[33] Damasio, H., Tranell, D., Grabowski, T., Adolphs, R., Damasio, A. Neural systems behind word and concept retrieval. Cognition 92, 179–229 (2004).
[34] Dennis, M., Whitaker, H. Language acquisition following hemidecortication: Linguistic superiority of the left over the right hemisphere. Brain Lang 3, 404-433 (1976).
[35] Dewey, J. The reflex arc concept in psychology. Psychological Rev 3, 357–70 (1896).
[36] Di Paolo, E. From sensorimotor coordination to enaction: Agency, sense-making and sociality as horizons for embodied cognition. 1st EUCogII Members’ Conference “Challenges for artificial cognitive systems”, University Medical Center Hamburg-Eppendorf (2009, Oct 10).
[37] Di Sciuillo, M., Boecks, C. The Biolinguistic Enterprise. New Perspectives on the Evolution and Nature of the Human Language Faculty. Oxford: Oxford University Press (2011).

[38] Diesch, E., Eulitz, C., Hampson, S., Ross, B. The neurotopography of vowels as mirrored by evoked magnetic field measurements. Brain Lang 53(2), 143–168 (1996).

[39] Dijkstra, K., Kaschak, M., Zwaan, R.: Body posture facilitates retrieval of autobiographical memories. Cognition 102, 139–49 (2007).

[40] Dominey, P.F.: Spoken language and vision for adaptive human–robot cooperation. In: Hackel, M. (ed.), Humanoid robotics. ARS International, Vienna (2007).

[41] Elsabbagh, M., Karmiloff-Smith, A.: Modularity of mind and language. In K. Brown (Ed.), The Encyclopaedia of Language and Linguistics [2nd ed.]. Oxford: Elsevier, 218–24 (2006).

[42] Embick, D., Marantz, A., Miyashita, Y., O’Neil, W., Sakai, K.L.: A syntactic specialization for Broca’s area. Proc Natl Acad Sci USA 97, 6150–6154 (2000).

[43] Fadiga, L., Craighero, L., Buccino, G., Rizzolatti, G.: Speech listening specifically modulates the excitability of tongue muscles: A TMS study. Eur J Neurosci 15(2), 399–402 (2002).

[44] Fauconnier, G., Turner, M.: The Way We Think: Conceptual Blending and the Mind’s Hidden Complexities. New York: Basic Books (2002).

[45] Felder, R.M., Spurlin, J.: Applications, reliability and validity of the Index of Learning Styles. Int J Engng Ed 21(1), 103–12 (2005).

[46] Feldman, J., Narayanan, S.: Embodied meaning in a neural theory of language. Brain Lang 89(2), 385–392 (2004).

[47] Fischer, M.H., Zwaan, R.A.: Embodied language: A review of the role of motor system in language comprehension. Q J Exp Psychol 61, 825–850 (2008).

[48] Fisher, S.E., Scharff, C.: FOXP2 as a molecular window into speech and language. Trends Genet 25(4), 166–177 (2009).

[49] Fodor, J.A.: The Modularity of Mind: An essay on faculty psychology. MIT Press, Cambridge, MA (1983).

[50] Fodor, J.A.: Reply to Steven Pinker “So How Does the Mind Work?” Mind & Language 20, 25–32 (2005).

[51] Frak, V., Nazir, T., Goyette, M., Cohen, H., Jeannerod, M.: Grip force is part of the semantic representation of manual action verbs. PLoS ONE 5(3), e9728. doi:10.1371/journal.pone.0009728 (2010).

[52] Froese, T.: Hume and the enactive approach to mind. Phenomenology and the Cognitive Sciences 8(1), 95–133 (2009).

[53] Gallesè, V., Lakoff, G.: The brain’s concepts: The role of the sensory–motor system in reason and language. Cogn Neuropsychol 22, 455–479 (2005).

[54] Gentilucci, M., Benussi, F., Bertonali, L., Daprazi, E., Gangitano, M.: Language and motor control. Exp Brain Res 133(4), 468–490 (2000).

[55] Geschwind, N.: The organization of language and the brain. Science 170(961), 140–4 (1970).

[56] Glenberg, A.M., Kaschak, M.P.: Grounding language in action. Psychon Bull Rev 9(3), 555–562 (2002).

[57] Glenberg, A., Meyer, M., Lindem, K.: Mental models contribute to foregrounding during text comprehension. J Mem Lang 26: 69–83 (1987).

[58] Glover, S., Rosenbaum, D.A., Graham, J., Dixon, P.: Grasping the meaning of words. Exp Brain Res 154 (1), 103–8 (2004).

[59] Goertzel, B., Pennachin, C., Geissweiller, N., Looms, M., Senna, A., Silva, W., Heljakka, A., Lopes, C.: An integrative methodology for teaching embodied non-linguistic agents, applied to virtual animals in Second Life. Artificial General Intelligence 2008, Amsterdam: IOS Press, 161–75 (2008).

[60] Goldin-Meadow, S., Nusbaum, H., Kelly, S., Wagner, S.: Explaining math: Gesturing lightens the load. Psychological Sci 12, 516–522 (2001).

[61] González, J., Barro-Loscertales, A., Pulvermüller, F., Magenber, V., Sanjuán, A., Bellach, V., Avila, C.: Reading cinnamon activates olfactory brain regions. Neuroimage 32(2), 906–12 (2006).

[62] Grodzinsky, Y., Friederici, A.D.: Neuroimaging of syntax and syntactic processing. Curr Opin Neurobiol 16(2), 240–6 (2006).

[63] Hagoort, P., Ramsey, N.F., Rutten, G.J.M., van Rijen, P.C.: The role of the left anterior temporal cortex in language processing. Brain Lang 69, 322–325 (1999).

[64] Harnad, S.: The symbol grounding problem. Physica D 42, 335–46 (1990).

[65] Haugeland, J.: Artificial Intelligence: The Very Idea. Cambridge, MA: MIT Press (1985).

[66] Hauser, M.D., Chomsky, N., Fitch, W.T.: The language faculty: What is it, who has it, and how did it evolve? Science 298(5598), 1569–1579 (2002).

[67] Hoffmann, M., Assaf, D., Pfeifer, R.: Cognitivism. Retrieved from http://www.eucognition.org/index.php?page=cognitivism

[68] Hoffmann, M., Pfeifer, R.: The implications of embodiment for behavior and cognition: Animal and robotic case studies. In: W. Tschacher, C. Bergomi (Eds) The Implications of Embodiment: Cognition and Communication. Exeter: Imprint Academic, 31–58 (2011).

[69] Horwitz, B., Amunts, K., Bhattacharyya, R., Patkin, D., Jeffries, J., Zilles, K., Braun, A.R.: Activation of Broca’s area during the production of spoken and signed language: A combined cytoarchitectonic mapping and PET analysis. Neuropsychologia 41, 1868–1876 (2003).

[70] Ishiguro, H., Minato, T., Yoshikawa, Y., Asada, M.: Humanoid Platforms for Cognitive Developmental Robotics. Intl J Humanoid Robotics 8(3), 391–418 (2011).

[71] Iverson, J., Thelen, E.: Hand, mouth, and brain: The dynamic emergence of speech and gesture. J Consc Stud 6(11-12), 19–40 (1999).

[72] Jackendoff, R.: Foundations of Language. Oxford University Press, Oxford (2002).

[73] Iaenisch, E.R.: Grundformen menschlichen Seins. Berlin: Otto Elsner (1929).

[74] Joannis, M.F., Seidenberg, M.S.: Specific language impairment: A deficit in grammar or processing? Trends Cogn Sci 2, 240–47 (1998).

[75] Johnson, M.H., Paterson, S.J., Brown, J.H., Gisödl, M.K., Karmiloff-Smith, A.: Cognitive Modularity and Genetic Disorders. Science 286(5448): 2355–8 (1999).

[76] Karmiloff-Smith, A.: Development itself is the key to understanding developmental disorders. Trends Cogn Sci 2(10), 389–91 (1998).

[77] Karmiloff-Smith, A., Brown, J.H., Grice, S., Paterson, S.: Dethroning the myth: Cognitive dissociations and innate modularity in Williams syndrome. Developmental Neuropsychology 23(1-2), 227–242 (2003).

[78] Katz, J.J., Fodor, J.: The structure of a semantic theory. Lang 39, 170–210 (1963).

[79] Kaufmann, E., Kaul, Th.: Language switch costs and dual-task costs in bimodal language production. Paper presented at the conf. ‘Formal and Experimental Advances in Sign Language Theory’ (FEAST 2012), Univ. Warsaw (2 Jun 2012).

[80] Kenmerder, D., Castillo, J.G., Talavage, T., Patterson, S., Wiley, C.: Neuroanatomical distribution of five semantic components of verbs: evidence from fMRI. Brain Lang 107, 16–43 (2008).

[81] Kenmerder, D., Gonzalez-Castillo, J.: The two-level theory of verb meaning: an approach to integrating the semantics of action with the mirror neuron system. Brain Lang 112, 54–76 (2010).

[82] Kintzoch, W.: Comprehension: A Paradigm for Cognition. Cambridge University Press, Cambridge, MA (1998).

[83] Knopka G., Bomar, J.M., Winden, K., Coppola, G., Jonsson, Z.O., Gao, F., Peng, S., Preuss, T.M., Wohlschlegel, J.A., Geschwind, D.H.: Human-specific transcriptional regulation of CNS development genes by FOXP2. Nature 462, 213–217 (2009).
[84] Koelwijn, T., van Schie, H.T., Bekkering, H., Oostenveld, R., Jensen, O.: Motor-cortical beta oscillations are modulated by correctness of observed action. Neuroimage 40, 767–775 (2008).

[85] Kunioyoshi, Y., Yorozu, Y., Ohmura, Y., Terada, K., Otani, T., Nagakubo, A., Yamamoto, T.: From humanoid embodiment to theory of mind. In: F. Iida, R. Pfeifer, L. Steels, Y. Kuniyoshi (Eds) Embodied Artificial Intelligence. Berlin: Springer, 202–218 (2004).

[86] Lacey, S., Stilla, R., Sathian, K.: Metaphorically feeling: Comprehending textual metaphors activates somatosensory cortex. Brain Lang 120(3), 416–421 (2012).

[87] Lai, C.S.L., Fishet, S.E., Hurst, J.A., Vargha-Khadem, F., Monaco, A.P.: A forehead-domain gene is mutated in a severe speech and language disorder. Nature 413(6855), 519–523 (2001).

[88] Lakoff, G.: Women, Fire, and Dangerous Things. What categories reveal about the mind. University of Chicago Press, Chicago (1987).

[89] Lakoff, G., Johnson, M.: Metaphors we Live By. University of Chicago Press, Chicago (1980).

[90] Lakoff, G., Johnson, M.: Philosophy in the Flesh: The Embodied Mind and Its Challenge to Western Thought. New York: Basic Books (1998).

[91] Lamendella, J.T.: General principles of neurofunctional organization and their manifestations in primary and non-primary language acquisition. Language Learning 27: 155–96 (1977).

[92] Lenneberg, E.H.: Biological Foundations of Language. Wiley, New York (1967).

[93] Lamendella, C.J., Zwaan, R.A.: How does verb aspect constrain event representations? Mem Cognit 31, 663–672 (2003).

[94] Marinova-Todd, S., Marshall, D., Snow, C.: Three misconceptions about age and L2 learning. TESOL Quar 34, 9–34 (2000).

[95] Martin, A., Wiggs, C.L., Ungerleider, L.G., Haxby, J.V.: Neural correlates of category-specific knowledge. Nature 379, 649–52 (1996).

[96] Meader, C.L., Muyskens, J.H.: Handbook of Biolinguistics. Wiley, New York (1950).

[97] Montague, A.: Touching: The Human Significance of the Skin. New York: Harper & Row (1978).

[98] Nazir, T.A., Boulenger, V., Roy, A.C., Silber, B.Y., Jeannerod, M., Paulignan, Y.: Language-induced motor perturbations during the execution of a reaching movement. Q J Exp Psychol 61(6), 933–43 (2008).

[99] Neininger, B., Pulvermüller, F.: Word-category specific deficits after lesions in the right hemisphere. Neuropsychologia 41(1), 53–70 (2003).

[100] Newell, A., Simon, H.A.: Computer science as empirical inquiry: symbols and search. Communications of the ACM 19(3), 113–26 (1976).

[101] Nowak, M.A., Komorova, N. L., Niyogi, P.: Computation and evolutionary aspects of language. Nature 417, 611–617 (2002).

[102] Obleser, J., Poecke, H., Drzezga, A., Haslinger, B., Hennenlotter, A., Roettinger, M., Eulitz, C., Rauschecker, J.P.: Vowel sound extraction in anterior superior temporal cortex. Hum Brain Mapp 27(7), 562–571 (2006).

[103] Osterhout, L.: On the brain response to syntactic anomalies: Manipulations of word position and word class reveal individual differences. Brain Lang 59, 494–522 (1997).

[104] Paul, C.: Morphology and computation. Procs Int Conf Simulation Adaptive Behavior: From animals to animals, Cambridge, MA: MIT Press, 33–8 (2004).

[105] Penfield, W., Roberts, L.: Speech and Brain Mechanisms. Atheneum Press, New York (1959).

[106] Pfeifer, R.: The emergence of cognition from the interaction of brain, body, and environment. 4th EUCogII Members’ Conference “Embodiment – Fad or Future?”, Anatolia College, Thessaloniki (11 Apr 2011).

[107] Pfeifer, R., Gomez, G.: Morphological computation – connecting brain, body, and environment. In: B. Sendhoff, O. Sporns, E. Körner, H. Ritter, K. Doya (Eds) Creating Brain-like Intelligence: From Basic Principles to Complex Intelligent Systems. Berlin: Springer, 66–83 (2009).

[108] Pfeifer, R., Langarella, M., Iida, F.: Self-organization, embodiment, and biologically inspired robotics. Science 318, 1088–93 (2007).

[109] Pfeifer, R., Scheier, C.: Sensory-motor coordination: The metaphor and beyond. Robotics and Autonomous Systems 20, 157–78.

[110] Pfeifer, R., Scheier, C.: Understanding Intelligence. Cambridge, MA: MIT Press (1999).

[111] Piaget, P., Palmarini, M.: Evolution, selection and cognition: from “learning” to parameter setting in biology and in the study of language. Cognition 31, 1–44 (1989).

[112] Postle, N., McMahon, K.L., Ashton, R., Meredith, M., de Zubicaray, G.I.: Action word meaning representations in cytoarchitectonically defined primary and premotor cortices. Neuroimage 43, 634–644 (2008).

[113] Price, C.J.: The anatomy of language: contributions from functional neuroimaging. J Anat 197, 335–339 (2000).

[114] Pulvermüller, F., Assodallali, R.: Grammar or serial order? Discrete combinatorial brain mechanisms reflected by the syntactic mismatch negativity. J Cogn Neurosci 19(6), 971–980 (2007).

[115] Pulvermüller, F., Hauk, O.: Category-specific processing of color and form words in left fronto-temporal cortex. Cereb Cortex 16(8), 1193–1201 (2006).

[116] Pulvermüller, F., Hauk, O., Nikulin, V.V., Ilmoniemi, R.J.: Functional links between motor and language systems. Eur J Neurosci 21(3), 793–797 (2005).

[117] Pulvermüller, F., Pye, E., Dine, C., Hauk, O., Nestor, P., Patterson, K.: The word processing deficit in semantic dementia: All categories are equal but some categories are more equal than others. J Cogn Neurosci 22(9), 2027–2041 (2010).

[118] Rapps, A., Moss, H.E., Stamatakis, E.A., Tyler, L.K.: Modulation of motor and premotor cortices by actions, action words and action sentences. Neuropsychologia 47, 388–396 (2009).

[119] Rieser, J., Garing, A., Young, M.: Imagery, action and young children’s spatial orientation: It’s not being there that counts, it’s what one has in mind. Child Dev 45, 1043–1056 (1994).

[120] Rubba, J., Klima, E.S.: Preposition use in a speaker with Williams syndrome: Some cognitive grammar proposals. Center for Research on Language Newsletter, University of California, La Jolla, CA, 5, 3–12 (1991).

[121] Rueschemeyer, S.-A., Lindemann, O., van Rooij, D., van Dam, W., Bekkering, H.: Effects of intentional motor actions on embodied language processing. Exp Psychol 57(4), 260–266 (2010).

[122] Shahidullah, S., Hepper, P.G. Hearing in the Fetus: Prenatal Detection of Deafness. Intl J Prenatal and Perinatal Studies 4(3/4), 235–40 (1992).

[123] Siakaluk, P., Pexman, P., Aguilera, L., Owen, W., Sears, C.: Evidence for the activation of sensorimotor information during visual word recognition: The body-object interaction effect. Cognition 106, 433–43 (2008).

[124] Sato, M., Mengarelli, M., Riggio, L., Gallese, V., Buccino, G.: Task related modulation of the motor system during language processing. Brain Lang 105(2), 83–90 (2008).

[125] Simmons, W.K., Ramjee, V., Beauchamp, M.S., McAree, K., Martin, A., Barsalou, L.W.: A common neural substrate for perceiving and knowing about color. Neuropsychologia 45(12), 2802–10 (2007).

[126] Smith, L.B.: Grounding toddler learning in sensory-motor dynamics. keynote lecture, EUCogII Members’ Conf “Development of Cognition in Artificial Agents”, ETH Zürich (29 Jan 2010).

[127] Smith, N.V.: The Twitter Machine: Reflections on Language. Oxford: Blackwell (1989).

[128] Smith, N.V., Tsimpili, I.-M., Ouhalla, J.: Learning the impossible: The acquisition of possible and impossible languages by a polyglot savant. Lingua 91, 279–347 (1993).
[129] Spivey, M.J., Tyler, M.J., Eberhard, K.M., Tanenhaus, M.K.: Linguistically mediated visual search. *Psychol Sci* 12, 282–286 (2001).

[130] Stapel, J.C., Hunnius, S., van Elk, M., Bekkering, H.: Motor activation during observation of unusual vs. ordinary actions in the mirror neuron system. *Neurosci 5*, 451–460 (2010).

[131] Steels, L.: The origins and evolution of languages: Darwin's unsolved mystery. International workshop “150 Years after Darwin: From Molecular Evolution to Language”, Inst for Cross-Disciplinary Physics and Complex Systems, Palma de Mallorca (2009, Nov 26).

[132] Stein, B.E., London, N., Wilkinson, L.K., Price, D.D.: Enhancement of Perceived Visual Intensity by Auditory Stimuli: A Psychophysical Analysis. *J Cogn Neurosci* 8(6), 497–506 (1996).

[133] Stewart, J., Gepenne, O., Di Paolo, E.A. (Eds) *Enaction: Toward a New Paradigm for Cognitive Science*. Cambridge, MA: MIT Press (2010).

[134] Stroop, J.R.: Studies of interference in serial verbal reactions. *J Exp Psychol* 18(6), 643–662 (1935).

[135] Tanenhaus, M.K., Spivey-Knowlton, M.J., Eberhard, K., Sedivy, J.C.: Integration of visual and linguistic information in spoken language comprehension. *Science* 268, 632–634 (1995).

[136] Tettamanti M., Munenti, R., Della Rosa, P.A., Falini, A., Perani, D., Cappa, S.F., Moro, A.: Negation in the brain: Modulating action representations. *Neuroimage* 43, 358–367 (2008).

[137] Turing, A.M.: Computing machinery and intelligence. *Mind* LIX, 433–60 (1950).

[138] Ullman, M.T.: *A neurocognitive perspective on language: The declarative/procedural model*. *Nature Rev Neurosci* 2(10), 717–26 (2001).

[139] Uppenkamp, S., Johnsrude, I.S., Norris, D., Marslen-Wilson, W., Patterson, R.D.: Locating the initial stages of speech-sound processing in human temporal cortex. *Neuroimage* 31(3), 1284–96 (2006).

[140] van Elk, M., van Schie, H.T., Zwaan, R.A., Bekkering, H.: The functional role of motor activation in language processing: motor cortical oscillations support lexical-semantic retrieval. *Neuroimage* 50, 665-677 (2010).

[141] Varela, F.J., Thompson, E., Rosch, E.: *The Embodied Mind: Cognitive Science and Human Experience*. Cambridge, MA: MIT Press (1991).

[142] Vernes, S.C., Nicod, J., Elahi, F.M., Coventry, J.A., Kenny, N., Coupe, A.M., Bird, L.E., Davies, K.E., Fisher, S.E.: Functional genetic analysis of mutations implicated in a human speech and language disorder. *Hum Mol Genet* 15(21), 3154–3167 (2006).

[143] Vernon, D.: Cognitive development and the iCub humanoid robot. 2nd *EUCogII Members’ Conference “Development of Cognition in Artificial Agents”*, Univ Zürich (29 Jan 2010).

[144] Volterra, V., Capirci, O., Pezzini, G., Sabbadini, L., Vicari S.: Linguistic abilities in Italian children with Williams syndrome. *Cortex* 32, 663–677 (1996).

[145] Wang, P.: What do you mean by “AI”? *Artificial General Intelligence* 2008, Amsterdam: IOS Press, 362–73 (2008).

[146] Wang, P.: Embodiment: Does a laptop have a body? In B. Goertzel, P. Hitzler, M. Hutter (Eds) *Proc 2nd Conf Artificial General Intelligence, AGI 2009*, Paris: Atlantis Press, 174–9 (2009).

[147] Watson, J., Ritzmann, R., Pollack, A.: Control of climbing behavior in the cockroach, blaberus discoidalis. ii. motor activities associated with joint movement. *J Comp Physiol A* 188, 55–69 (2002).

[148] Wernicke, C.: *Der aphäische Symptomencomplex. Eine psychologische Studie auf anatomischer Basis*. Kohn & Weigert, Breslau (1874).

[149] Willems, R.M., Hagoort, P., Casasanto, D.: Body-specific representations of action verbs: Neural evidence from right- and left-handers. *Psychol Sci* 21, 67–74 (2010).

[150] Woll, B.: What can research on atypical signing tell us about the linguistics of sign language. Inv. talk, conf. ‘Formal and Experimental Advances in Sign Language Theory’ (FEAST 2012), Univ. Warsaw (2 Jun 2012).

[151] Woll, B., Morgan, G.: Language impairments in the development of sign: Do they reside in a specific modality or are they modality-independent deficits? *Bilingualism: Language and Cognition* 15(1), 75–87.

[152] Yamada, J.: *Laura: A Case for the Modularity of Language*. Cambridge, MA: MIT Press (1990).

[153] Zatorre, R.J., Evans, A.C., Meyer, E., Gjedde, A.: Lateralization of phonetic and pitch discrimination in speech processing. *Science* 256, 846–849 (1992).

[154] Ziender, T.: Human embodied cognition. Scientific evidence and technological implications. 4th *EUCogII Members’ Conference “Embodiment – Fad or Future?”*, Thessaloniki: Anatolia College (2011, Apr. 12).

[155] Zwaan, R.A., Taylor, L.J., de Boer, M.: Motor resonance as a function of narrative time: further tests of the linguistic-focus hypothesis. *Brain Lang* 112, 143–149 (2010).