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Language, embodiment, and the cognitive niche

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Embodied agents use bodily actions and environmental interventions to make the world a better place to think in. Where does language fit into this emerging picture of the embodied, ecologically efficient agent? One useful way to approach this question is to consider language itself as a cognition-enhancing animal-built structure. To take this perspective is to view language as a kind of self-constructed cognitive niche: a persisting but never stationary material scaffolding whose crucial role in promoting thought and reason remains surprisingly poorly understood. It is the very materiality of this linguistic scaffolding, I suggest, that gives it some key benefits. By materializing thought in words, we create structures that are themselves proper objects of perception, manipulation, and (further) thought.

Introduction

What is the cognitive role of language? Are words and sentences merely vehicles for the communication of preformed ideas, or are they part of the process of thinking itself? In what follows I suggest that words and sentences form part of the process of thinking, and that they do so not merely in virtue of their contents but also in virtue of their very materiality: their physical existence as encountered and perceptible items, as sounds in the air or as words on the printed page. For by materializing thought in words, we structure our environments, creating 'cognitive niches' that enhance and empower us in a variety of non-obvious ways. By treating language as (in part) real external structure created and maintained by situated niche-constructing agents we begin to bring together the study of language and thought, and the emerging body of work increasingly becoming known as 'embodied cognitive science' [1–4]. This work highlights the transformative effects of bodily form, bodily activity and material environmental scaffolding on mind and cognition.

At first, much of this work targeted quite simple forms of adaptive behavior. But in recent years suggestive links have begun to emerge between basic themes in embodied and situated cognition and new ways of understanding the learning, evolution and cognitive role of language [3–6]. In this article I focus on one such emerging theme, the role of language (and material symbols more generally) in providing a new kind of thought-enabling cognitive niche [7–9]. By a cognitive niche I mean an animal-built physical structure [10] that transforms one or more problem spaces in ways that (when successful) aid thinking and reasoning about some target domain or domains [11–13]. These physical structures combine with appropriate culturally transmitted practices to enhance problem-solving, and (in the most dramatic cases) to make possible whole new forms of thought and reason.

I present three ways in which to begin to flesh out this idea, and sketch a computational (connectionist and dynamical) framework in which to embed it. I end the argument by suggesting an additional (non-essential but potentially important) refinement: that linguistic activity might turn out to be a mode of cognition-enhancing self-stimulation in a system with no 'Central Meaner' orchestrating the whole [14,15].

Pure translation models of language understanding

There is a popular view stemming from the work of Jerry Fodor [16,17] that says that knowing a natural language is knowing how to pair its expressions with encodings in some other, more fundamental, and at least expressively equipotent, inner code ('Mentalese' or the Language of Thought). Language influences thought, on such accounts, in virtue of a process of translation: one that fully transforms the public sentence into the content-capturing inner code. This is a prime example of what might be dubbed a 'Pure Translation' view of language. If this view is correct, encountered language (be it speech or the written word) merely serves to activate complexes of internal states or representations that are the real cognitive workhorses. The actual public language items, on this view, are mere vessels to be kicked away once content has, however imperfectly, been transmitted from person to person.

An alternative to the translation picture makes the role of public language less like that of a mere vessel and more like that of a fundamental representational (or cognitive) resource in its own right [9,18–20]. Language, on this view, affects cognition even on the short timescale of individual acts of thought and reason. On this approach, language (and material symbols more generally [21]) play a double role. On the one hand, exposure to, or rehearsal of, such items always activates or otherwise exploits many other kinds of internal representational or cognitive resource. But on the other hand, the public language encodings *also* play an irreducible role as the more grossly structured items they are. There are various ways to unpack this broad claim. One way [9,22,23] is to suggest that the role (and the power) of such items (spoken or written words and sentences) is to provide a new kind of cognitive niche whose

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features and properties *complement* but do not need to replicate the basic modes of operation and representation of the biological brain.

Words as targets in the material world

Central to this vision of language as a complementary resource is an appreciation of the power of added worldly structure (in this case, perceptible material symbols) to transform the tasks that confront an intelligent agent. Insofar as these effects involve, as they often do, an agent's appreciating the meaning assigned to the material symbols, it can be easy to overlook or underplay the continuing role of the perceptible material structure itself. Yet it is the visible, audible or (occasionally) tactile materiality of language that is both its key distinguishing feature and the source of much of its cognitive potency. To see this, we can consider a few simple examples in which these material aspects seem to be playing a major role.

New targets for old strategies

Consider first the well-known case [24] of Sheba and the treats. Sheba, an adult female chimpanzee, has had symbol and numeral training. In the experimental set-up, Sheba sits with Sarah (another chimp), and two plates of treats are shown. What Sheba points to, Sarah gets. Sheba finds herself repeatedly pointing to the greater pile, therefore getting less herself. However, when the treats arrive in containers with a cover bearing numerals on top, the spell is broken and Sheba points to the lesser number, thereby gaining *more* treats. The experimenters speculate that the material symbols (the numerals on the lids), by being perceptually simple and stripped of most treat-signifying physical cues, allow the chimps to sidestep the capture of their own behavior by ecologically-specific fast-and-frugal subroutines. The symbol thus helps to de-couple the intelligent agent from the immediate pull of the encountered scene. It seems to do so by providing a new perceptible target for selective attention and thus a new focal point for the control of action.

In much the same way, the simple act of labeling creates for the learner a new realm of perceptible objects (the associated tags or labels) upon which to target her more basic capacities of statistical and associative learning (Box 1). The actual presence of the tags or labels, or even (importantly) of their shallow imagistic counterparts, thus alters the computational burdens involved in certain kinds of learning and problem-solving [25] (see Box 1 for discussion). In addition, there is now an increasing body of developmental and simulation-based work suggesting that the presence of words and labels alerts the learner to the existence of deeper and more abstract commonalities between presented items [26–28] and that the contextual learning of object names trains processes of attention that speed category learning and, in turn, support faster word learning [29]. In all these ways, the addition of layers of symbolic structure to the environment in which we learn and reason pays rich cognitive dividends.

Words as constituents of hybrid thoughts

Dehaene and co-authors [30–32] present a compelling model of precise mathematical thought that reserves a special role for internal representations of language-specific number words. Precise mathematical thought, they suggest, depends on the productive intersection of three distinct cognitive contributions. The first involves a basic biological capacity to individuate small quantities: '1-ness', '2-ness', '3-ness' and 'more-than-that-ness', to take the standard set. The second involves another biologically basic capacity, this time for approximating magnitudes (discriminating, say, arrays of 8 dots from arrays of 16, but not more closely matched arrays). The third, although not biologically basic, but arguably transformative, is the learnt capacity to use the specific number words of a language, and the eventual appreciation that each such perceptually distinct number word names a distinct quantity. Notice that this is not the same as appreciating, in at least one familiar sense, just what that quantity is. Most of us cannot form any clear image of, for example, '98-ness', unlike, say, '2-ness'. But we appreciate nonetheless that the number word '98' names a unique quantity in between 97 and 99.

When we add the use of number words to the more basic biological capacities, Dehaene argues, we acquire an evolutionarily novel capacity to think about an unlimited set of exact quantities. We gain this capacity not because we now have a mental encoding of 98-ness just like our encoding of 2-ness. Rather, the new thoughts depend directly (but not exhaustively) upon our 'tokening' numerical expressions themselves in some way, as symbol strings of our own public language (Box 2). The precise numerical thought, on this model, is obtained courtesy of the *combination* of this tokening (of the symbol string of a given language) and the appropriate activation of a set of more biologically basic resources. In this way the presence of actual number words in a certain public code (and then of shallow internal representations *of those very public items*)

Box 1. Relational learning in *Pan troglodytes*

Thompson, Oden and Boyson [25] studied learning and problem solving in chimps (*Pan troglodytes*). They trained language-naïve chimps trained to associate an arbitrary plastic marker (a yellow triangle, say) with pairs of identical objects (such as 2 identical cups), and a different marker (a red circle, say) with pairs of different objects (such as a shoe and a cup). With the plastic tokens then removed, the token-trained chimps proved able to learn to solve a new class of abstract problems. This is the class of problems – seemingly intractable to chimps not provided with the initial training with material tags – involving recognition of certain higher-order relations. Thus, confronted with two (different) pairs of identical items (a pair of identical shoes and a pair of identical cups, say) the higher-order task is the judge the two pairs as exhibiting the '*same*' relation;that is, to judge that you confront two instances of *sameness.* The authors conjecture that the token-training regime enables the chimp, on confronting, for example, the pair of identical cups, to retrieve a shallow imagistic representation of the physical *sameness* token itself (the yellow plastic triangle). Exposure to the two identical shoes will likewise cause retrieval of some kind of shallow image of that token. At that point, the otherwise very demanding higher-order task is effectively reduced to the simple, lower-order task of identifying the (images of the) two yellow plastic tokens as 'the same'. Experience with external tags and labels might thus enable the brain, simply by *re-presenting, at appropriate moments,* those tags and labels, to solve problems whose level of complexity and abstraction would otherwise leave us baffled.

Box 2. Precise numerical understanding using hybrid representational forms

Mature human arithmetical competence has recently been argued [30–32] to be dependent on the combined (and interlocking) contributions of distinct cognitive resources. One such resource is an innate, parietal-lobe based tool for approximate numerical reasoning. Another is an acquired, left frontal lobe based tool for the use of language-specific numerical representations in exact arithmetic. This claim is based on (i) evidence from studies of arithmetical reasoning in bilinguals, suggesting that exact arithmetical reasoning (unlike approximate reasoning) recruits resources specific to one language, (ii) studies of patients with differential damage to each of the two target neural subsystems, displaying different forms of impairment in mathematical reasoning, and (iii) from neuroimaging studies of normal subjects engaged in exact and approximate numerical tasks [30,31]. These results are together presented as a demonstration 'that exact calculation is language dependent, whereas approximation relies on non-verbal visuo-spatial cerebral networks' and that 'even within the small domain of elementary arithmetic, multiple mental representations are used for different tasks' ([31], pp. 970, 973).

forms part of the coordinated representational medley that constitutes many kinds of arithmetical knowing. Embodied agents embedded in a world of concrete perceptible numerals are thus enabled to engage in forms of reasoning that would otherwise elude them.

Words as anchors for thinking about thinking

The augmentation of biological brains with 'linguaform' resources might also shed some light on our ability to engage in second-order discourse, to create our own training routines, and to think about (and evaluate) our own thoughts and those of others [33–36]. It has recently been suggested, for example, that our capacities for flexible reasoning about others' beliefs depends directly upon the linguistic externalization of beliefs using the grammatical structures of embedded complements [36]. Consider also the cluster of powerful capacities that include self-evaluation (looking at our own problem-solving performance) self-criticism (picking out weak spots in our own performance), self-improvement (systematic attempts to train our skills and repair our faults) and finely honed critical self-reflection (assessing the soundness and value of our own arguments); or, moving to a kind of meta-meta level, thinking about the conditions under which we think best and trying to bring them about. In all these cases, we are effectively thinking either about our own cognitive profiles or about specific thoughts, reasons and feelings.

Such explicit 'thinking about thinking', appears to be a good candidate for a distinctively human capacity and one that might be directly dependent upon language for its very existence. To formulate a thought in words (or on paper) is to create an object available to ourselves and to others [9,34,35], and, as an object, it is the kind of thing we can have thoughts about. In creating the object, we need have no prior thoughts about thoughts – but once it is there, the opportunity immediately exists to attend to it as an object in its own right. The process of linguistic formulation thus creates the stable attendable structure to which subsequent thinkings can attach. Hence, Jackendoff [34] suggests that the mental rehearsal of sentences might be the primary means by which our own thoughts are able to become objects of further attention and reflection.

If this view is correct, linguaform reason is not just a tool for the novice (as suggested by, for example, Dreyfus and Dreyfus [37]) Instead it emerges as a key cognitive tool enabling us to objectify, reflect upon, and hence knowingly engage with, our own thoughts, trains of reasoning, and personal cognitive characters. This puts language in a position to act as a kind of *cognitive super-niche*: a cognitive niche one of whose greatest virtues is to allow us to construct ('with malice aforethought', as Fodor rather elegantly puts it [38]) an open-ended sequence of new cognitive niches. These might include designer environments in which to think, reason and perform and special training regimes to install the complex skills such environments demand.

Beyond translation

What more general model of language and its relation to thought do these various illustrations suggest? A good place to begin is with the conception of language as complementary to more basic forms of neural processing [7,9,14,22,23]. According to this conception language works its magic not (or not solely) by means of translation into appropriate expressions of 'Mentalese' or the 'Language of Thought' [16] but by something more like a coordination dynamics [6,39,40] in which words and structured linguistic encodings act to stabilize and discipline (or 'anchor') intrinsically fluid and context-sensitive modes of thought and reason.

This notion of anchoring is best appreciated in the light of connectionist or artificial neural-network models of memory, storage and processing [40–44]. For present purposes, what matters is that such models posit a fundamentally fluid system in which the fine details of recent context affect recall and representation in quite fundamental ways. For systems such as these, the problem of stabilization [22] becomes pressing. On the one hand, it is a virtue of these systems that new information automatically influences similar items that are already 'stored', and that information retrieval is highly context-sensitive. On the other hand, advanced thought and reason plausibly require the ability to follow trajectories in representational space, and to lead others reliably through certain trajectories. All this requires some means to discipline our own, and others', mental spaces in ways that tame (but never eradicate) those biologically more 'natural' processes of merging and change. Words and linguistic strings are among the most powerful and basic tools that we use to discipline and stabilize dynamic processes of reason and recall.

Elman [41,43] suggests that words, rather than being cues for the retrieval of meanings from some kind of passive storage, might be thought of as sensorily encountered items that 'act directly on mental states' ([43], p. 301). Linguistic inputs, on this model, are quite literally modes of systematic neural manipulation, and operate in similar ways both between and within human individuals [40,44]. Words and sentences act as artificial input signals, often (as in self-directed inner speech) entirely self-generated, that nudge fluid natural systems of encoding and representation along reliable and useful trajectories. This remarkable display of virtuoso artificial self-manipulation allows language-laden minds to sculpt and guide their own processes of learning, recall, representation [45] and selective attention. In this way the symbolic environment (very broadly construed) can influence thought and learning *both* by selectively activating other internal representational resources *and* by allowing the material symbols themselves, or image-like internal representations of them, to act as additional fulcrums of attention, memory and control.

Anarchic self-stimulation?

One obstacle to appreciating the full cognitive potency of self-produced language (whether overt or covert) is the temptation to posit a powerful Central Executive – the 'Central Meaner' to use [14] – which 'uses' linguistic self-stimulation as a means to its own (pre-formed, fully thought-out) cognitive ends. In place of such an all-knowing inner executive, we should consider the possibility (Box 3) of a vast parallel coalition of more-or-less influential forces whose largely self-organizing unfolding makes each of us the thinking beings we are. Remove the Central Meaner, and instead of treating linguaform self-stimulation as fundamentally providing only as a kind of inner scratch-pad (the 'articulatory rehearsal loop' [46–48]) useful for keeping pre-chosen verbal forms alive in working memory, we can begin to see it as one of the many simultaneously unfolding processes that contribute to the construction and origination of our thoughts, and not merely to their short-term maintenance and expression [49]. The use of words in inner rehearsal can thus be likened to the role of writing while struggling to formulate a thought. Phenomenologically, this is quite unlike the case of writing something down as a simple hedge against forgetting. Instead, the very thought itself takes shape thanks, in part, to the properties of looping into the world via that special channel. Similarly, although it is no doubt true that we can (and often do) use inner rehearsal simply as a cheap verbal-information preserving loop, it might also function as a stream of self-created inputs that productively drive many other forms of processing. In place of the Central Meaner whose pre-formed ideas the self-produced input stream merely reflects, we should instead consider various forms, grades and flavors of a more distributed, heterarchical organization in which, for the most part 'the manipulanda have to manipulate themselves' [15].

Thus consider, to mention one final concrete case, the role of gesture in what Gallagher [3], following Merleau-Ponty, dubs the 'accomplishment of thought'. It does not seem to be the case that our ongoing gestures during problem-solving merely express ideas that are fully present to our verbal reasoning [50,51]. Rather, the gestures are themselves elements in a loose-knit, distributed representational economy, whose contents might conflict with those of other elements in that same economy. Such conflicts are said to create points of instability [52] that can be productive in moving our reasoning along. The wrong image here (if such accounts are correct) is that of a single central reasoning engine that uses gesture to clothe preformed ideas for expressive purposes. Instead, gesture and (overt or covert) speech emerge as interacting parts of the overall reasoning machinery itself [6,50–52]. As embodied agents we are able to create and maintain a wide variety of cognitively empowering, self-stimulating loops whose activity is as much an *aspect* of our thinking as its *result*.

Box 3. Pandemonium

In various writings [14,15] Daniel Dennett depicts the human mind in terms that more closely resemble a semi-anarchic parallel organization of competing elements, whose average level of intelligence remains well below that traditionally ascribed to a Central Executive (a horde of competing mini-executives, or perhaps maxi-assistants with no-one to assist). Within this flatter competing/co-operating nexus, different elements gain control at different times. But crucially, no element in the dodging and bumping horde is the privileged source of thinking such that the job of the rest is simply to articulate or store its fully-formed (but not yet verbally unarticulated) thoughts. Instead, Dennett is tempted by an almost maximally anarchic 'pandemonium' model of the origins of verbalized thought, according to which some more-or-less spontaneous or random activations of words help seed some of the processes that compete for dominance in the construction of a verbal output. Between pandemonium and full-scale central control lie a wealth of options involving intermediate grades of intelligent and semi-intelligent orchestration, and of hierarchical and semi-hierarchical control [54].

Conclusions

Embodied agents encounter language first and foremost as new layers of material structure in an already complex world. They also come to produce such structures for themselves, not just for communicative effect but as parts of self-stimulating cycles that scaffold their own behaviour. These layers of structure play a variety of cognition-enhancing roles. They act as new, perceptually simple targets that augment the learning environment, they mediate recall and help distribute attention, they provide a key resource for freezing and inspecting complex thoughts and ideas, and they seem fit to participate in truly hybrid representational ensembles. All these benefits are available both 'online' (in the presence of written words on a page, or sounds in the air) and then 'offline' (thanks to covert self-stimulating cycles that engage much of the same machinery used in the ecologically primary case).

Outstanding questions remain. Exactly how does the loop of verbal self-stimulation work, such that it can really influence thought and reason in ways that go beyond the mere enhancement of memory? Does 'offline' self-directed inner speech rely on the same computational and representational resources as its overt counterpart [53]? Just how far, if at all, must we depart from the model of some kind of Central Executive if we are to do justice to the strong cognitive role of language?

The attraction is that by looking beyond the Pure Translation view we are able to treat language as an aspect of thought, rather than just its public reflection. This is a shift that might require, for its most satisfying completion, the simultaneous abandonment of the seductive image of the inner Central Executive where all the 'real thinking' happens. Eliminate the Central Executive, replace Pure Translation with the appeal to complex, distributed co-ordination dynamics, and we begin to reveal an alternative image of the 'wordful mind' itself. This is a mind populated by loops without leaders, that defies any simple logic of inner versus outer, or of tool versus user: a mind where words really work.

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References

1 Varela, F. *et al.* (1991) *The Embodied Mind,* MIT Press
2 Clark, A. (1997) *Being There: Putting Brain, Body and World Together Again,* MIT Press
3 Gallagher, S. (2005) *How the Body Shapes the Mind,* Oxford University Press
4 Wheeler, M. (2005) *Reconstructing the Cognitive World,* MIT Press
5 Smith, L. and Gasser, M. (2005) The development of embodied cognition: six lesson from babies. *Artif. Life* 11, 13–30
6 Iverson, J. and Thelen, E. (1999) Hand, mouth and brain. In *Reclaiming Cognition: The Primacy of Action, Intention and Emotion* (Núñez, R. and Freeman, W.J., eds), pp. 19–40, Imprint Academic
7 Berk, L.E. (1994) Why children talk to themselves. *Sci. Am.* 271, 78–83
8 Sterelny, K. (2003) *Thought in a Hostile World: The Evolution of Human Cognition,* Blackwell
9 Clark, A. (2005) Word, niche and super-niche: how language makes minds matter more. *Theoria* 20, 255–268
10 Laland, K.N. *et al.* (1999) Niche construction, biological evolution and cultural change. *Behav. Brain Sci.* 23 (1: Whole issue)
11 Norman, D. (1993) *Things That Make Us Smart,* Perseus Books
12 Dennett, D. (1996) *Kinds of Minds,* Basic Books
13 Hutchins, E. (1995) *Cognition In The Wild,* MIT Press
14 Dennett, D. (1991) *Consciousness Explained,* Little Brown
15 Dennett, D. (1998) Reflections on language and mind. In *Language And Thought: Interdisciplinary Themes* (Carruthers, P. and Boucher, J., eds), pp. 162–183, Cambridge University Press
16 Fodor, J. (1987) *Psychosemantics: The Problem of Meaning in the Philosophy of Mind,* MIT Press
17 Fodor, J. (1998) Do we think in Mentalese: remarks on some arguments of Peter Carruthers, *Critical Condition: Polemical Essays on Cognitive Science and the Philosophy of Mind*, pp. 63–74, MIT Press
18 Carruthers, P. (2002) The cognitive functions of language. *Behav. Brain Sci.* 25, 657–726
19 Hermer-Vazquez, L. *et al.* (1999) Sources of flexibility in human cognition: dual-task studies of space and language. *Cognit. Psychol.* 39, 3–36
20 Frankish, K. (2004) *Mind and Supermind,* Cambridge University Press
21 Wilson, R.A. (2004) *Boundaries of the Mind: The Individual in the Fragile Sciences – Cognition,* Cambridge University Press
22 Sutton, J. (2002) Cognitive conceptions of language and the development of autobiographical memory. *Lang. Commun.* 22, 375–390
23 Menary, R. *Cognitive Integration. Attacking The Bounds of Cognition*, Macmillan (in press)
24 Boysen, S.T. *et al.* (1996) Quantity–based inference and symbolic representation in chimpanzees (*Pan troglodytes*). *J. Exp. Psychol. Anim. Behav. Process.* 22, 76–86
25 Thompson, R.K.R. *et al.* (1997) Language-naive chimpanzees (*Pan troglodytes*) judge relations between relations in a conceptual matching-to-sample task. *J. Exp. Psychol. Anim. Behav. Process.* 23, 31–43
26 Waxman, S.R. and Markow, D.B. (1995) Words as invitations to form categories: evidence from 12- to 13-month-old infants. *Cogn. Psychol.* 29, 257–302
27 Colunga, E. and Smith, L.B. (2003) The emergence of abstract ideas: evidence from networks and babies. *Philos. Trans. R. Soc. Ser. B.* 358, 1205–1214
28 Yoshida, H. and Smith, L.B. (2005) Linguistic cues enhance the learning of perceptual cues. *Psychol. Sci.* 16, 90–95
29 Smith, L.B. *et al.* (2002) Object name learning provides on-the-job training for attention. *Psychol. Sci.* 13, 13–19
30 Dehaene, S. (1997) *The Number Sense,* Oxford University Press
31 Dehaene, S. *et al.* (1999) Sources of mathematical thinking: behavioral and brain imaging evidence. *Science* 284, 970–974
32 Feigenson, L. *et al.* (2004) Core systems of number. *Trends Cogn. Sci.* 8, 307–314
33 Donald, M. (1991) *Origins of the Modern Mind,* Harvard University Press
34 Jackendoff, Ray. (1996) How language helps us think. *Pragmatics Cogn.* 4, 1–34
35 Bermudez, J. (2003) *Thinking Without Words,* OUP
36 De Villiers, J.G. and de Villiers, P.A. (2003) Language for thought: coming to understand false beliefs. In *Language in Mind: Advances in the Study of Language and Thought* (Gentner, D. and Goldin-Meadow, S., eds), pp. 335–384, MIT Press
37 Dreyfus, H. and Dreyfus, S. (2000) *Mind Over Machine,* Free Press
38 Fodor, J. (1994) *The Elm and the Expert,* MIT Press
39 Kelso, S. (1995) *Dynamic Patterns,* MIT Press
40 O'Brien, G. and Opie, J. (2002) Radical connectionism: thinking with (not in) language. *Lang. Commun.* 22, 313–329
41 Elman, J.L. (2004) An alternative view of the mental lexicon. *Trends Cogn. Sci.* 8, 301–306
42 Carpenter, G. (2001) Neural-network models of learning and memory: leading questions and an emerging framework. *Trends Cogn. Sci.* 5, 114–118
43 Elman, J. (1995) Language as a dynamical system. In *Mind as Motion* (Port, R. and van Gelder, T., eds), MIT Press
44 O'Brien, G. and Opie, J. (2002) Internalizing communication: commentary on Carruthers' 'The cognitive functions of language'. *Behav. Brain Sci.* 25, 657–726
45 Barsalou, L.W. (2003) Abstraction in perceptual symbol systems. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 358, 1177–1187
46 Baddeley, A. (1986) *Working Memory,* Clarendon Press
47 Reisberg, D. (2001) *Cognition,* Norton & Co
48 Smith, E. (2000) Neural bases of human working memory. *Curr. Dir. Psychol. Sci.* 9, 45–49
49 Carruthers, P. (1998) Thinking in language. In *Language and Thought* (Boucher, J. and Carruthers, P., eds), Cambridge University Press
50 Goldin-Meadow, S. and Wagner, S.M. (2005) How our hands help us learn. *Trends Cogn. Sci.* 9, 234–241
51 Goldin-Meadow, S. (2003) *Hearing Gesture: How Our Hands Help Us Think,* Harvard University Press
52 McNeill, D. (2005) *Gesture and Thought,* University of Chicago Press
53 Wheeler, M. (2004) Is language the ultimate artifact? *Language Sciences* (Special issue: Distributed Cognition and Integrational Linguistics, edited Spurrett, D.) Vol. 26, No. 6
54 Shallice, T. (2002) Fractionation of the supervisory system. In *Principles of Frontal Lobe Function* (Stuss, D.T. and Knight, R.T., eds), pp. 261–277, Oxford University Press