

# Language is primarily a tool for communication rather than thought

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Language is a defining characteristic of our species, but the function, or functions, that it serves has been debated for centuries. Here we bring recent evidence from neuroscience and allied disciplines to argue that in modern humans, language is a tool for communication, contrary to a prominent view that we use language for thinking. We begin by introducing the brain network that supports linguistic ability in humans. We then review evidence for a double dissociation between language and thought, and discuss several properties of language that suggest that it is optimized for communication. We conclude that although the emergence of language has unquestionably transformed human culture, language does not appear to be a prerequisite for complex thought, including symbolic thought. Instead, language is a powerful tool for the transmission of cultural knowledge; it plausibly co-evolved with our thinking and reasoning capacities, and only reflects, rather than gives rise to, the signature sophistication of human cognition.

Language is estimated to have emerged in humans between 100,000 and 1,000,000 years ago<sup>1</sup>. The functions of language and the causal drivers in its origins have long been fiercely debated across diverse fields, including philosophy, linguistics, cognitive science, evolutionary biology and anthropology. Two broad hypotheses have dominated this discussion, although they are not mutually exclusive. One proposal is that language primarily serves a communicative function—it enables us to share knowledge, thoughts, and feelings with one another<sup>2–7</sup>. Another proposal is that language mediates thinking and cognition<sup>8–13</sup>. The specific hypotheses about the role of language in thinking have ranged from strong claims that language is necessary for all forms of (at least propositional) thought<sup>14,15</sup>, to weaker claims that language may only be critical for, or can facilitate, certain aspects of thinking and reasoning<sup>9,16</sup>, and claims that language helps scaffold certain kinds of learning during development but may no longer be needed in mature brains<sup>12,17,18</sup> (Box 1).

From an evolutionary fitness standpoint, both the communicative and the cognitive functions of language could provide adaptive advantages. An ability to accurately transmit information would plausibly facilitate cooperative behaviours such as hunting, scavenging and long-distance travel, and enable passing of knowledge and skills to offspring (cultural transmission). An improved reasoning capacity would plausibly enable more sophisticated planning and decision making, creation of better tools and better problem-solving abilities. However, hypotheses about the evolutionary origins of cognitive traits are notoriously challenging to evaluate<sup>19</sup>. The primary evidence about the lives of early hominins comes from sparse archaeological records. Brains do not fossilize, and even if they did, only coarse information about brain function could be gleaned from brain size, shape and anatomy. Moreover, certain traits may evolve for one reason but subsequently serve a different function owing to changes in the species' ecology: a phenomenon known as exaptation<sup>20</sup>. As a result of these challenges, we do not aspire to make strong claims about the evolutionary origins

of language. We do, however, make an argument about the function of language in modern humans and discuss optimization pressures that have shaped language.

At least some variants of both the language-for-thought and the language-for-communication proposals make testable predictions about human cognitive and neural architecture and about the properties of human languages. Do any forms of thought—our knowledge of the world and ability to reason over these knowledge representations—require language (that is, representations and computations that support our ability to generate and interpret meaningfully structured word sequences)? If some forms of thought require language, then linguistic mechanisms should be obligatorily engaged for at least those types of thinking and reasoning, and those types of thought should not be possible without language. If language is a tool for communication, then language should show hallmarks of efficient information transfer. Until recently, these predictions have been difficult to evaluate. However, over the past two decades, knowledge and tools have become available that have shed critical light on the function of language. First, substantial advances have been made in deciphering the neural architecture of language, providing a clear 'target' for evaluating the engagement of language-processing mechanisms during various forms of thought. Second, massive corpora of diverse languages have become widely available, along with a suite of powerful computational tools, often based on information theory<sup>21</sup>, for rigorously characterizing linguistic systems. As a result, the time is now ripe to take stock of current evidence on the big and important questions of the function of language and its role in human cognition.

## The language network in the human brain

Our knowledge of language encompasses knowledge of regularities at all levels of linguistic structure, from sounds to sentences, and a

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Box 1

## Many flavours of the language-for-thought hypothesis

A comprehensive review of prior claims about the role of language in thinking is outside the scope of this Perspective (for reviews, see for example<sup>9,10,12,16,71,178–182</sup>). However, we emphasize the diversity of perspectives on this issue and the complexity of the theoretical landscape. Proposals about the role of language in thinking vary along at least four dimensions (sample quotes and reasons why the idea that we use language to think appeals to many are presented in the Supplementary Information). First, proposals vary in the scope of the effects of language on thought: from claims that all of thought (at least all propositional thought) requires linguistic representations to claims that only certain kinds of thinking do. The second dimension concerns the *degree of importance* of language for thought, from claims that linguistic representations are necessary for thinking (such that without access to these representations, thinking is not possible) to claims that they only augment or facilitate thinking (that is, enable faster and/or more accurate performance on some target thinking task). The third dimension has to do with the *nature of linguistic representations* that are at play. Some proposals emphasize features that are common to all natural languages, including words and syntactic structure. Other proposals instead focus on features that are specific to particular languages—for instance, whether a language has a word for a particular concept or marks a particular grammatical distinction (Supplementary Information). Finally, proposals vary as to the *timing* of the effects of language on thought, with some proposals arguing that linguistic representations are necessary or helpful for the development of thinking abilities, and others arguing that linguistic representations continue to be important for thinking even in fully mature brains.

Stronger claims, such as accounts whereby all forms of thought require linguistic representations, are of course the easiest to

falsify. For accounts whereby only certain kinds of thought require linguistic representations, it is critical to clearly define the scope of the relevant kinds of thought—and ideally, to suggest particular paradigms that engage those forms of thinking—to render the hypotheses empirically testable. In cases where specific proposals have been articulated (for example, in refs. 9,72,74), they have not found empirical support in neuroscientific investigations, and some of the behavioural effects cannot be unambiguously attributed to the language network for example, ref. 70). Indeed, as discussed in this Perspective, at least for mature brains, there is at present no unequivocal empirical support for any form of thinking requiring linguistic representations (words or syntactic structures).

Similarly, for accounts whereby linguistic representations facilitate thinking, it is critical to delineate the conditions under which such effects should be observed and to describe their nature and—ideally—putative neural mechanisms. Current bodies of evidence for potential facilitative effects of language on thinking and potential roles of language in the development of certain cognitive capacities are complex and controversial (further details in Supplementary Information). It seems clear that we can use language to compress analogue signals into symbolic representations (for example, reducing a visual array of nine objects to ‘nine’<sup>183</sup>; see ref. 173 for a recent proposal on the role of information compression in human thinking). However, these representations need not be specifically linguistic: they could be symbolic but non-linguistic (for example, ‘9’), and the use of symbolic non-linguistic representations does not engage linguistic resources (for example, mathematical reasoning elicits no response in the language brain areas and is preserved in individuals with severe aphasia<sup>51,77–79</sup>).

large set of form–meaning mappings<sup>22,23</sup> (meanings of morphemes, words and constructions). Using this knowledge, we can both convey our thoughts to others and infer others’ intended meanings from their utterances. Language production and language understanding are supported by an interconnected set of brain areas in the left hemisphere, often referred to as the ‘language network’<sup>24–27</sup> (recently reviewed in ref. 28) (Fig. 1a; Box 2 describes its relationship to the ‘classic model’ of the neurobiology of language).

Two properties of the language network are important for the discussion of the function(s) of language. First, the language areas exhibit independence of input and output modalities—key signatures of representational abstractness. First, during comprehension, these brain areas respond to linguistic input across modalities (spoken, written or signed<sup>29–32</sup>). Similarly, during language generation, these areas are active regardless of whether we produce our messages by speaking or writing<sup>33</sup>. The fact that these areas support both comprehension and production<sup>33,34</sup> (Fig. 1a) suggests that they are likely to store our linguistic knowledge, which is needed to both encode and decode linguistic messages. The abstractness of the language network’s representations suggests that this network corresponds to what Hauser, Chomsky and Fitch, in an influential piece on language evolution<sup>35</sup>, referred to as “the faculty of language in the narrow sense” or an “abstract computational system” that is separate from lower-level speech perception and speech articulation mechanisms (Box 2).

Second, the language areas represent and process both word meanings and syntactic structure—two components of language that are important to the language-for-thought hypotheses (Box 1). In particular, evidence from diverse experimental and naturalistic paradigms

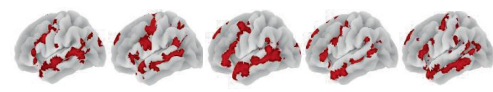
in functional MRI (fMRI), magnetoencephalography and intracranial recording studies has revealed that all areas of the language network are sensitive to word meanings and to inter-word syntactic and semantic dependencies<sup>33,36–48</sup> (Fig. 1a).

Together, the abstractness of the linguistic representations in the language network and the sensitivity of the network to linguistic meaning and structure make it a clear target for evaluating hypotheses about the role of language in thought and cognition (Box 3).

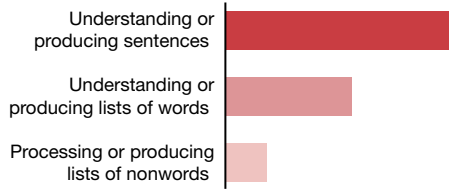
### Language is not necessary or sufficient for thought

The ontology of human cognition and the nature of mental representations that mediate thought (Box 3) remain active areas of research. Broadly, thought encompasses our knowledge of the world (including particular domains, such as knowledge of the physical properties of objects or knowledge of social agents) and reasoning over these knowledge representations, which includes making inferences and predictions. Aside from reasoning about particular knowledge domains, reasoning can involve cross-domain integration of information (an important ingredient of analogical reasoning<sup>49</sup>) or be domain-general, abstracted away from any particular domain. Domain-general reasoning is often linked to the notion of fluid intelligence<sup>50</sup>. Because language-for-thought hypotheses vary in what aspects of thought or cognition language is supposed to be critical or helpful for (Box 1) and our goal is to evaluate this idea broadly, we discuss evidence from diverse paradigms that engage thinking and reasoning. Moreover, empirically, all aspects of thought tested so far behave similarly with respect to their recruitment of linguistic resources.

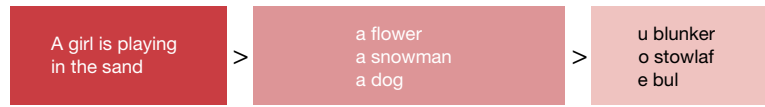
### a Sample language networks in individual brains



#### Responses in the language areas



### Understanding language (by listening or reading)



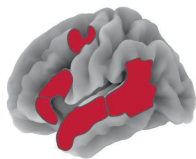
### Producing language (by speaking or writing)



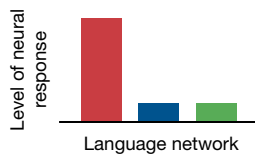
Interpretation: sensitivity to sentence structure

Interpretation: sensitivity to word meanings

### b Language network

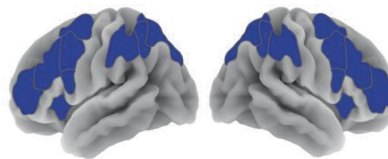


**Supported functions:**  
Language comprehension  
Language production

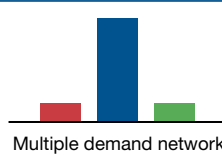


### Some networks that support thinking and reasoning

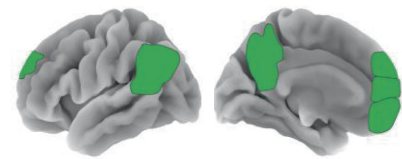
#### Multiple demand network



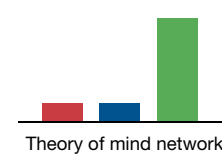
**Supported functions:**  
Executive functions  
Novel problem solving  
Mathematics  
Some forms of reasoning  
Computer code comprehension



#### Theory of mind network



**Supported functions:**  
Social reasoning  
Mentalizing



**Fig. 1 | The language network and its relationship to other cognitive networks.** **a**, The language network in the human brain. The language network supports computations that are related to lexical access and syntactic structure building during both comprehension and production across modalities, which suggests that the representations that this network operates over are abstract. Given that access to words and syntactic structures has been argued to be critical for aspects of thinking, this brain network is a clear target for evaluating language-for-thought proposals. Top left, the language network in five sample individuals. These activation maps were obtained with fMRI using a language localizer paradigm, which contrasts language processing and a perceptually similar control condition<sup>30</sup>. The brain areas in these maps show more neural activity during the critical, language-processing condition compared with the control condition. Bottom left, a schematic representation of the response profile of the language network (for example, as measured by fMRI) to understanding or producing sentences, lists of unconnected words and lists of nonwords<sup>30,33,36,40,47</sup>. A stronger response to sentences than word lists is generally taken to suggest engagement of a brain region in combinatorial (syntactic and semantic) computations, a requirement for processing sentences but not lists of words; a stronger response to word lists than nonword lists is taken to suggest the engagement of a brain region in accessing

word meanings, a requirement for processing real words but not nonwords. Right, sample stimuli used in brain imaging experiments to investigate responses to sentences, lists of words and lists of nonwords in comprehension (top row) versus production (bottom row). **b**, Language and thought are dissociated in the human brain. Left, a schematic representation of the response profile of the language network (for example, as measured by fMRI). This network responds strongly to language comprehension and production, but not to non-linguistic tasks that require thinking and reasoning (for example, ref. 77). The core regions of the language network are shown schematically in red on a brain template (sample individual activation maps are shown in **a**). Right, schematic representation of the response profiles of two networks that support thinking and reasoning (for example, as measured by fMRI). The multiple demand network (shown schematically in blue on a brain template) responds to diverse demanding cognitive tasks, including executive function tasks, novel problem-solving tasks, and mathematical and logical reasoning, but not to language or social reasoning (for example, ref. 76). The theory of mind network (shown schematically in green on a brain template) responds during social reasoning, but not to language or demanding executive function tasks (for example, ref. 86).

If language mediates some forms of thought, then those forms of thought should not be possible in the absence of language because they should critically depend on linguistic representations (the ‘necessity of language for thought’ argument). Moreover, the presence of language (or an intact linguistic ability) should be associated with the capacity for those forms of thought (the ‘sufficiency of language for thought’ argument). We discuss these points in turn.

### Language is not necessary for any tested forms of thought

The classical approach for making inferences about brain-behaviour associations and dissociations is to examine individuals with brain damage or disorders. If linguistic ability mediates our ability to engage in certain forms of thought, then linguistic impairments should be associated with concomitant difficulties in those aspects of thinking

Box 2

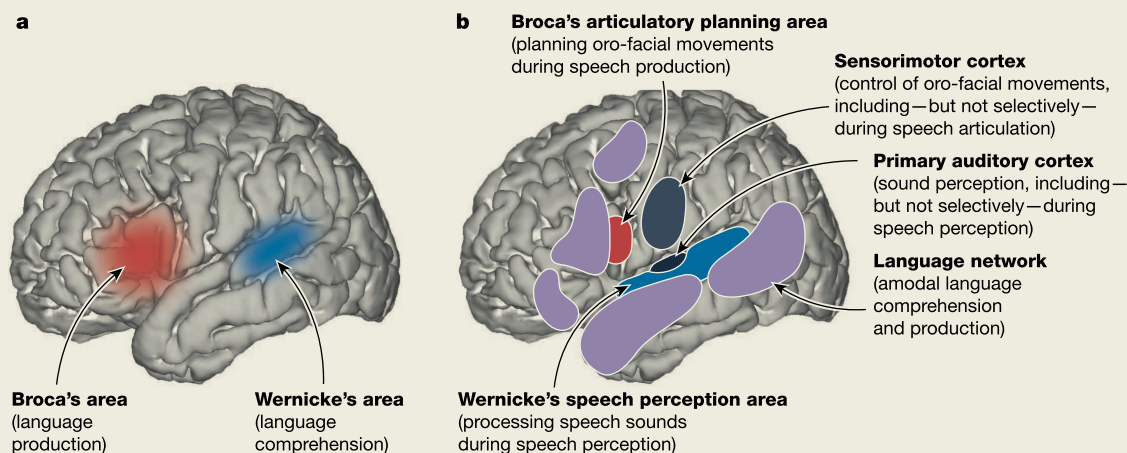
# From the classic model of the neurobiology of language to where we are now

Many textbooks continue to use the classic model of the neural basis of language, which was proposed by Wernicke<sup>184</sup> and elaborated and revised by Lichteim and Geschwind<sup>24,185</sup>. This model consists of two cortical areas—Broca’s area in the inferior frontal cortex and Wernicke’s area in the posterior superior temporal cortex—which are argued to support language production and comprehension, respectively, and which are connected by a dorsal fibre bundle (the arcuate fasciculus) (panel a). This model has received criticism over the years<sup>27,186,187</sup>—but, although incomplete, the classic model correctly captures key aspects of the neurobiology of language. We believe that much of the confusion about Broca’s and Wernicke’s areas has resulted from frequent conflation of *speech* (the form of spoken language) and *language* (the abstract system of form-to-meaning mappings) in experimental designs and scientific discourse, and predominant reliance in human cognitive neuroscience on anatomical rather than functional definitions of brain areas.

As described in the original sources, the brain areas that were discovered by Broca and Wernicke support speech motor (articulatory) planning and speech perception, respectively. Current neuroscientific evidence strongly supports the existence of an articulation-selective area in the inferior frontal cortex<sup>188–192</sup> (panel b, red) and of an area selective for speech perception in the superior temporal gyrus<sup>193–197</sup> (panel b, blue). In contrast to the language network areas, these areas are not sensitive to linguistic meaning, only to the surface properties of linguistic signals<sup>28</sup>. Adding function

into these areas’ names (for example, ‘Broca’s articulatory planning area’ and ‘Wernicke’s speech perception area’) and using validated ‘localizer’ paradigms to separate these areas from nearby functionally distinct areas is likely to lead to progress and alleviate confusion<sup>28</sup>.

Absent from the classic model are the ‘higher-level language areas’, which store abstract linguistic knowledge and support comprehension and production, as discussed in ‘The language network in the human brain’ (Fig. 1a and panel b, purple). There is a straightforward explanation for the absence of these areas from the early proposals of the neurobiology of language. The early evidence about brain–behaviour relationships came from reports of selective deficits following brain damage. Because Broca’s and Wernicke’s areas are relatively circumscribed and specialized for particular functions, their damage is more likely to lead to deficits (given that no other brain areas support these functions). By contrast, the higher-level language network is distributed across extensive portions of the left temporal and frontal cortex (Fig. 1a and panel b, purple), with different language regions exhibiting similar functional profiles<sup>28</sup> (alternative proposals are described in refs. 27,198,199). As a result, in contrast to speech articulation and speech perception areas, no individual part of the high-level language network may be critically needed for linguistic function. Indeed, circumscribed lesions to the language network do not lead to severe or long-lasting deficits, although the posterior temporal component, which is adjacent to the speech perception area, may be relatively more important<sup>200</sup>.



**Classic and current models.** **a**, The classic model of the neurobiology of language. **b**, A model based on the current knowledge of neurobiology of language (alternative proposals are described in refs. 27,198,199). This updated model still includes Broca’s (articulatory planning) area<sup>188–192</sup> and Wernicke’s (speech perception) area<sup>193–197</sup>, but additionally includes a set of frontal and temporal

areas that jointly support high-level language comprehension and production<sup>28</sup> (also see Fig. 1a). For context, we also show primary auditory cortex, which is likely to provide input to Wernicke’s (speech perception) area, and sensorimotor cortex, to which Broca’s (articulatory planning) area is likely to provide input<sup>189,190</sup>.

and reasoning. The evidence is unequivocal—there are many cases of individuals with severe linguistic impairments, affecting both lexical and syntactic abilities, who nevertheless exhibit intact abilities to engage in many forms of thought—they can solve mathematical problems<sup>51,52</sup>, perform executive planning and follow non-verbal

instructions<sup>53</sup>, engage in diverse forms of reasoning, including formal logical reasoning, causal reasoning about the world and scientific reasoning<sup>54–58</sup>, to understand what another person believes or thinks and perform pragmatic inference<sup>53,56,59–62</sup>, to navigate in the world<sup>63</sup>, and to make semantic judgements about objects and events<sup>64–70</sup> (Fig. 1b).

## Box 3

### Open questions

Our understanding of human linguistic and cognitive capacities and the relationships between them remains incomplete. Here we highlight a few open questions.

(1) What is the nature of *linguistic representations* that the language-selective brain network stores and the *computations* that it performs during comprehension and production? Recent advances in artificial intelligence—the development of neural network models that excel at language<sup>201</sup>—have provided language researchers with a suite of powerful tools to probe the neural codes of linguistic processing<sup>48,202–205</sup> (reviewed in ref. 206). These tools, combined with the increasing sophistication of neural recording approaches<sup>207,208</sup>, should enable advances in our understanding of the human language system in the coming years.

(2) Does our *thinking* rely on *symbolic representations*<sup>209–212</sup>, *sub-symbolic or connectionist representations*<sup>213,214</sup>, or some combination of these? How do representations that mediate abstract thought arise from the biological neural networks that are our brains<sup>215,216</sup>? Are any thought-related computations and the underlying neural circuits distinctly human, or do humans simply have more neural and cognitive resources<sup>163,173</sup> that lead to greater sophistication?

(3) How does the language network *develop* as children learn language? What cognitive functions do brain areas that are selective for language by age four<sup>92,93</sup> support before language is acquired? Although a number of studies have investigated responses to speech in newborn and infant brains<sup>217–219</sup>, the functional changes that happen in the brain during the second half of the first year of life and during toddlerhood (age 6 months to 3 years), when children begin to link words to meanings and to use language communicatively, remain unknown because experimentation with spatially precise brain imaging approaches such as fMRI is challenging at this age.

Importantly, in these studies, researchers carefully and systematically assessed the individuals' linguistic abilities to ensure that the deficit concerns linguistic ability, including lexical and syntactic processing, and not the lower-level perceptual or motor abilities<sup>71</sup>.

This body of evidence challenges both general claims about the importance of language for thought (Box 1), and a number of specific proposals about the critical role of language in particular kinds of thinking, including mathematical reasoning<sup>72</sup>, cross-domain information integration<sup>9,73</sup> and categorization<sup>74</sup>. Despite losing their linguistic ability, some individuals with severe aphasia are able to perform all tested forms of thinking and reasoning, as evidenced by their intact performance on diverse cognitive tasks. They simply cannot map those thoughts onto linguistic expressions, either in language production (they cannot convey their thoughts to others through language) or in understanding (they cannot extract meaning from others' words and sentences) (Fig. 1b). Of course, in some cases of brain damage, both linguistic and (some) thinking abilities may be affected, but this is to be expected given the proximity of the language system to other high-level cognitive systems<sup>75,76</sup>.

Neuroimaging evidence complements the evidence from individuals with brain damage. Using tools such as fMRI, we can identify the language areas in intact, healthy brains and then examine the response in those areas while individuals engage in tasks that require different forms of thought. In 'The language network in the human brain', we defined a clear target for evaluating such hypotheses: the language network, a set of brain areas that are ubiquitously engaged when

we understand and produce language<sup>28</sup> (Fig. 1a). Responses in this network to diverse non-linguistic inputs and tasks have been examined, and the evidence demonstrates that all regions of the language network are largely 'silent' during all tested forms of thought, including mathematical reasoning<sup>77–79</sup>, formal logical reasoning<sup>80,81</sup>, performing demanding executive function tasks such as working memory or cognitive control tasks<sup>77</sup>, understanding computer code<sup>82,83</sup>, thinking about others' mental states<sup>84–86</sup>, and making semantic judgments about objects or events<sup>69,70,87</sup>. Instead, these tasks engage other brain areas that are non-overlapping with the language network (Fig. 1b), although they sometimes lie in close proximity to the language areas<sup>75,76</sup>. It remains possible that future work will uncover some thinking tasks that will engage language areas and that will prove challenging for patients with aphasia, but no such tasks have been found so far.

Some language-for-thought hypotheses specifically concern cognitive development (Box 1). According to these hypotheses, language (or, in some accounts, symbolic representations more generally) may be critical for the development of certain kinds or ways of thinking<sup>12,17,18,88,89</sup>. Some support for this idea comes from studies in which teaching children or non-human primates words or symbols for certain concepts (for example, the concept 'same') or assigning labels in a way that highlights the task-relevant dimension of the world (for example, drawing attention to object size by labelling a bigger object 'daddy' and a smaller one 'baby') can lead to success on certain relational reasoning tasks<sup>18</sup>. Others have argued that training young children on certain syntactic constructions (for example, complement clauses) can result in their ability to pass theory of mind tasks<sup>17,90,91</sup>. However, reasons for skepticism exist. First, recent evidence suggests that the dissociation between the language network and systems that support thinking and reasoning is already present in young children<sup>92,93</sup> (Box 3), which contradicts the possibility that at an early developmental stage thinking relies on linguistic resources. And second, some children growing up with no access to language can nevertheless reason in complex ways.

In particular, some deaf children who are born to hearing parents grow up with little or no exposure to language, sometimes for years, because they cannot hear speech and their parents or caregivers do not know sign language. Lack of access to language has harmful consequences for many aspects of cognition<sup>94,95</sup>, which is to be expected given that language provides a critical source of information for learning about the world<sup>96,97</sup>. Nevertheless, individuals who experience language deprivation unquestionably exhibit a capacity for complex cognitive function: they can still learn to do mathematics, to engage in relational reasoning, to build causal chains, and to acquire rich and sophisticated knowledge of the world<sup>98,99</sup> (also see ref. 100 for more controversial evidence from language deprivation in a case of child abuse). In other words, lack of access to linguistic representations does not make it fundamentally impossible to engage in complex—including symbolic—thought, although some aspects of reasoning do show delays<sup>101,102</sup>. Thus, it appears that in typical development, language and reasoning develop in parallel (see 'Communication and thought in humans and animals' for concordant evidence from brain evolution).

Finally, it is worth mentioning that pre-verbal infants<sup>103</sup> and many animal species—including non-human primates<sup>104–108</sup>, corvids<sup>109,110</sup>, elephants<sup>111</sup> and cephalopods<sup>112,113</sup>—exhibit impressive inferential and problem-solving abilities, apparently without language, further bringing into question the necessity of language or a language-like system for complex thinking<sup>114,115</sup>.

#### Intact language does not imply intact thought

The evidence discussed above suggests that all types of thought tested to date are possible without language. Next, we discuss the other side of the double dissociation between language and thought: contrary to the view that language mediates thinking, an intact language system does not appear to entail intact reasoning abilities. Evidence from both

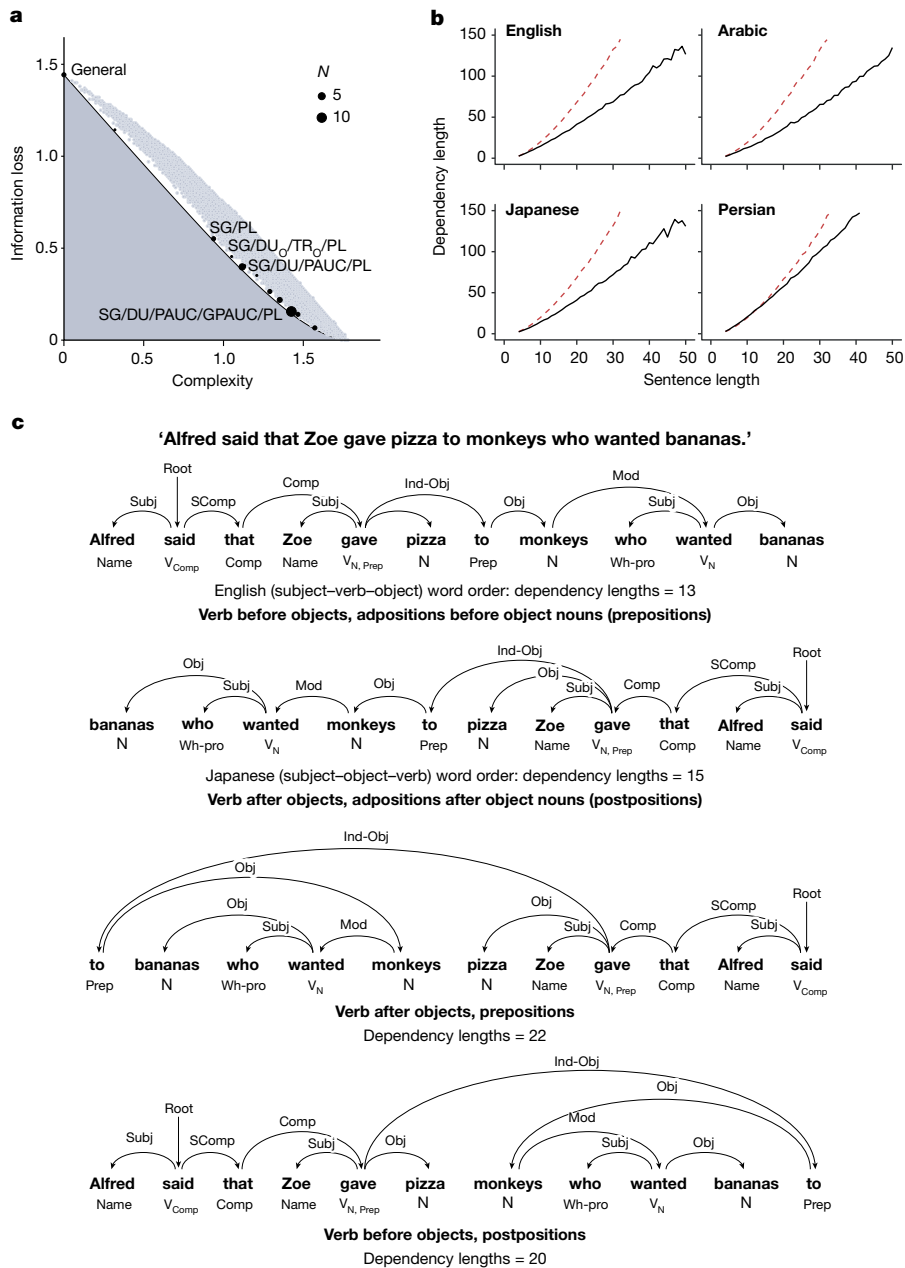


Fig. 2 | See next page for caption.

developmental and acquired brain disorders suggests that intellectual impairments can be present even when linguistic abilities are largely intact. For example, several genetic disorders are characterized by varying degrees of intellectual disability (Down syndrome and Williams syndrome, among others), yet the linguistic abilities of people with these disorders appear to be close to typical. Even if subtle linguistic deficits are observed, the foundational capacities for processing word meanings and linguistic structure building—the capacities that figure in the language-for-thought hypotheses—are intact<sup>116–118</sup>. Some neuropsychiatric disorders, such as schizophrenia, affect the ability to think and reason, but again spare language<sup>119</sup>. Finally, many individuals with acquired brain damage exhibit difficulties in reasoning and problem solving but appear to have full command of their linguistic abilities<sup>58</sup>. In other words, having an intact language system does not bring with it ‘for free’ an ability to think: thinking capacities can be impaired in the presence of intact language (see ref. 120 for related arguments from large language models).

### Language is an efficient communication code

Having reviewed the evidence against the role of language in thought, we next discuss evidence that communicative forces have shaped the form that language takes<sup>2–7</sup>. An efficient communication code should be easy to produce and understand, while being robust to noise<sup>21</sup> (environmental or resulting from imperfect processing mechanisms), and it must be learnable by people. As we discuss next, human languages—both spoken and signed—exhibit all these properties, and these properties manifest at all levels of linguistic structure, including sounds, words and syntax.

We acknowledge that some of these properties are not uniquely predicted by the language-for-communication view. However, the supposed absence of communicative features of language has long been used by some advocates of the language-for-thought hypothesis as evidence against the communicative function of language<sup>121</sup>, so it is important to summarize the now abundant evidence for

**Fig. 2 | Human languages are shaped by communicative pressures.**

**a**, Words across many semantic domains trade-off between complexity and informativeness. This pattern is as predicted for efficient communication systems (here, shown for the domain of grammatical number markers<sup>135</sup>). Attested inventories (black dots; sizes correspond to the number of languages with a given inventory ( $N$ )) and unattested systems (grey dots) are plotted in the space of all possible grammatical systems. Systems that achieve optimal trade-offs lie along the Pareto frontier (solid line); the shaded region below the line shows trade-offs that are impossible to achieve. DU, dual; GPAUC, greater paucal (a bunch); PAUC, paucal (a few); PL, plural; SG, singular; TR, trial. Optional values are shown with the subscript 'o'. **b**, Languages minimize syntactic dependency lengths cross-linguistically<sup>146</sup>. Observed average dependency lengths (black lines in each graph) for sentences of 1 to 50 words across four typologically diverse languages, based on analyses of large language corpora. For each sentence in the corpus, a single value was computed by summing the lengths of all dependencies as shown in **c**. The red dashed line shows a random baseline created by first scrambling the words, preserving the hierarchical dependency structure and disallowing crossing dependencies, and then recomputing dependency lengths<sup>146</sup>. All lines are fitted using a generalized additive model. Across languages (ref. 146 for data from 37 languages), the observed dependency lengths fall below the random baseline, suggesting that languages evolve to make dependencies shorter, presumably to facilitate production and comprehension. **c**, Examples of minimization of syntactic

dependency lengths in different languages. Top row, syntactic dependency structure for a subject–verb–object word order language (for example, English). Verbs appear before object nouns; prepositions appear before object nouns. Here and in the other examples, the syntactic category of a word is shown under each word and the relationships between words are shown with directed arcs; the type of the relationship is marked above each arc. The total dependency length of a sentence is the sum of all dependency distances—for example, the dependency between 'Alfred' and 'said' is 1; for dependencies between non-adjacent words, the dependency length is the number of intervening words plus 1. For this sentence, there are 7 local dependencies of length 1 and 3 dependencies of length 2, for a total sentence dependency length of  $7 + 6 = 13$ . Second row, syntactic dependency structure for a subject–object–verb word order language (for example, Japanese). Verbs appear after object nouns; prepositions (postpositions) appear after object nouns. Two word orders that rarely occur in natural languages, putatively because they introduce long-distance dependencies: in the third row, verbs appear after object nouns, and prepositions appear before object nouns; in the fourth row, verbs appear before object nouns, and prepositions (postpositions) appear after object nouns. Comp, complementizer; Ind-Obj, indirect object; Mod, modifier; N, noun; Obj, object; root, the root of the sentence; SComp, sentence complement; Subj, subject;  $V_{Comp}$ , verb taking a complementizer argument;  $V_N$ , verb taking a noun argument;  $V_{N,Prep}$ , verb taking a noun and a preposition argument; Prep, preposition; Wh-pro, wh-pronoun (for example, 'who').

the robust presence of these features cross-linguistically. Moreover, some of the communicative features are difficult to explain under the view that language is used primarily for internal thought.

Starting from the lowest level of linguistic structure, the *sounds* of a language are spread out in phonetic space<sup>122,123</sup>, which enables them to carry information in a way that is robust to corruption from noise and facilitates perception and comprehension. Sound repertoires of languages appear to also be shaped by factors that affect articulatory ease for different sound classes, including physical environments<sup>124</sup> and diet-related changes in the anatomy of the articulatory apparatus<sup>125</sup>.

With respect to *word forms*, languages preferentially re-use short and efficient words and within-word sound sequences<sup>126</sup>. Moreover, frequent and low-information words tend to be short<sup>127</sup>. These properties enable ease of word retrieval in production and comprehension (frequent words are easier to access from memory) and for articulatory ease (short words are less energy-costly, and repeated sound sequences can be stored as chunks in motor memory, reducing articulatory planning costs<sup>128</sup>).

In terms of *word meanings*, words optimize communicative efficiency through a trade-off between complexity (the cost of acquiring or representing the meanings) and informativeness (how precisely and unambiguously the words select their meanings). One example is kinship terms<sup>129</sup>: languages choose different solutions along the optimal frontier defined by the trade-off between having simple versus informative meanings (for example, words that pick out unique members of a family tree, such 'maternal grandmother'). The efficiency that characterizes natural languages means that it is typically not possible to make a real language's kinship system much simpler without having it convey less information, or vice versa. Similar results have been reported for colour terms<sup>130,131</sup> and season words<sup>132</sup>, and closed-class words and grammatical markers<sup>133–136</sup> (Fig. 2a). Lexical systems also show hallmarks of adaptation to specific communicative needs, more densely covering the parts of a conceptual space that a given community needs<sup>137,138</sup>.

*Syntax* is the component of language that has been the most controversial in the discussions about whether languages are optimized for efficient communication. Syntax specifies how words combine to enable the expression of a vast number of meanings—the 'infinite use of finite means'<sup>139</sup>. The defining properties of syntax—hierarchy and composition—are probably the result of the very same pressures mentioned in the context of word meanings above: the pressure for

simplicity (critical for learnability) and the pressure for expressiveness (critical for effective communication)<sup>5,140–142</sup>.

Moreover, various syntactic patterns in the world's languages can also be explained by combining communicative and cognitive pressures. A prime example is the tendency of languages to minimize the lengths of dependencies between words. In any given sentence, words are assembled—according to the rules of the grammar—to form a larger meaning. For example, the sentence 'Lana ate five apples', has a dependency between 'five' and 'apples', but there is no link between 'Lana' and 'five' because those words are not directly related in the meaning. Longer-distance connections (connections with more intervening words) increase difficulty of production and comprehension, as measured behaviourally<sup>143,144</sup> or with brain imaging<sup>39,45</sup>. Plausibly owing to this cognitive cost, languages have evolved to become more efficient for processing—that is, use—by minimizing dependency lengths<sup>145,146</sup> (Fig. 2b,c). This functional pressure in a grammar to keep dependencies local explains several universal tendencies in word orders<sup>147,148</sup>.

Other examples concern the order of basic elements—the subject (the agent, roughly), verb and object (the patient of the action, roughly)—within a sentence to convey complex meanings. The subject–object–verb order, which is the most common across the world's languages (approximately 47% of languages—for example, Japanese, Persian and Hindi), appears to be a cognitively natural default: speakers of diverse languages use this order when gesturing event meanings<sup>149</sup>, and emergent sign languages have this order<sup>150,151</sup>. Gibson et al.<sup>152</sup> have further offered a communicative explanation for the shift of some languages from the default (subject–object–verb) order to the second most common order, subject–verb–object (approximately 41% of languages—for example, English, Ukrainian and Mandarin). In particular, in the subject–verb–object order, the listener can use positional cues—whether a given noun appears before or after the verb—to reconstruct who is doing what to whom in the presence of information loss during communication<sup>153,154</sup> (refs. 155–157 describe other word-order generalizations that follow from similar pressures).

One common argument against the idea that language has evolved as a communication system is the prevalence of ambiguity: most words have multiple meanings, and many (especially longer) sentences have many possible dependency structures. Chomsky, for instance, has long argued that the existence of ambiguity implies that language is used primarily for thought rather than communication, because

## Perspective

ambiguous signals would impede communication<sup>121</sup>. However, the existence of ambiguity in human language is actually not expected under the language-for-thought view, given that our thoughts do not seem ambiguous. By contrast, the existence of ambiguity in language is a natural prediction of communicative accounts of language. That is, ambiguity can be mathematically shown to be communicatively useful: not only does it allow speakers to leave out information that listeners already know (for example, from the context), but it enables the re-use of short, easy-to-produce linguistic forms<sup>158</sup>. A system that allows no ambiguity would require a much bigger lexicon and grammar than those of human linguistic systems, and such a system would need to use long words and sentences to convey even simple meanings. For example, an artificial language that was constructed to remove ambiguity<sup>159</sup> proved to be so complicated as to be unlearnable by humans and has been undergoing rounds of revision to allow for learnability. Moreover, the existence of words with multiple related senses (such as ‘water’ used as a drink and as a verb) has been argued to support learning, since acquisition of one meaning will help with acquisition of a related one<sup>160</sup>. In this way, the capacity for multiple form–meaning mappings is likely to be useful for maintaining a rich lexicon.

We acknowledge that some of these properties of human languages may also have non-communicative explanations. For example, compositionality in language may simply reflect pre-existing compositionality in thought, or even in lower-level, perceptual and motor systems<sup>161</sup>—although this idea is still contrary to the language-for-thought hypothesis, as the directionality is reversed.

### Communication and thought in humans and animals

Across species, interactions with conspecifics require a communication system—that is, mechanisms for perceiving and emitting signals and a store of signal-to-meaning associations. The communication system of humans is unquestionably complex, but did language endow us with a new form of reasoning (Box 1), or does language simply reflect the independent sophistication of human thoughts? In this Perspective, building on prior theorizing and bringing in evidence from the past two decades, we have argued that language appears to not be necessary for any forms of thought tested so far, and that language is not sufficient for thought. Furthermore, on the basis of the evidence that many features of natural languages appear to be optimized for efficient information transfer, we have argued for communication being the primary function of language.

The view that language is simply a communication system aligns with a continuity view of human evolution<sup>162,163</sup>. In this view, the properties of human language—including its complexity—may result from the multifaceted landscape in which it has evolved, where the system must be useful (able to express the internal contents of the human mind) and learnable, and humans should be able to process language with the idiosyncratic strengths and limitations of pre-existing cognitive and neural systems. The contrasting alternative—that language is the substrate for thinking—implies a sharp discontinuity between our species and others. This alternative view centres language—perhaps innately—as the mechanism of change, and the mechanism that endowed humans with a novel representational format for mental computations.

Why does an intimate relationship between language and thought have an intuitive appeal to many? Some are attached to the idea that humans are superior in the animal kingdom (that is, they differ qualitatively, not just quantitatively, from other animals<sup>164</sup>), even though scientific evidence suggests strong biological similarities between humans and non-human animals<sup>165,166</sup>. Another reason may be linked to the desire for parsimony in explaining differences between humans and non-human animals (additional reasons are provided in Supplementary Information). In particular, humans differ from other animals in the sophistication of their communication system as well as their

thoughts and cognition. A parsimonious account favours a single-factor explanation—for instance, humans evolved language, and the change in cognition was simply a consequence of this. However, evidence from human brain evolution instead suggests parallel increases in the sophistication of multiple cognitive systems.

Relative to the brains of other animals, including non-human primates, the association cortex—which houses mental processes above and beyond perception and motor control—has expanded substantially and disproportionately in the human brain<sup>167</sup>. The association cortex spans frontal, temporal and parietal lobes and, in humans, comprises multiple large-scale networks—ensembles of brain areas that jointly support some aspect of cognition<sup>75</sup>. The language network<sup>28</sup> is just one of these networks. Significant progress has been made in characterizing several other networks that support human cognitive abilities, including those underlying the non-linguistic tasks discussed in ‘Language is not necessary or sufficient for thought’. For example, the network sometimes referred to as the ‘multiple demand’ network, supports diverse goal-directed behaviours, including novel problem solving, and damage of this network leads to impairments in fluid intelligence<sup>168</sup> (Fig. 1b). Mathematical and logical reasoning and the processing of computer code also draw on the multiple demand network<sup>78–83</sup>. Other such networks include the ‘theory of mind’ network, which supports social reasoning, including mentalizing or thinking about others’ thoughts<sup>169</sup> (Fig. 1b) and the ‘default’ network, whose functions remain debated, with some linking its regions to episodic projection into the past or future<sup>170</sup> and others linking them to spatial cognition and reasoning<sup>171</sup>. At least some of the networks have homologues in non-human animal brains<sup>172</sup>—the correspondences in functional architecture across species is an ongoing effort in neuroscience. Importantly, however, multiple brain networks have expanded over the course of human evolution, and this expansion was associated with increases in diverse cognitive abilities<sup>173</sup>. Whether this expansion proceeded in a truly parallel fashion, or whether the emergence or expansion of one network critically drove the expansion of other networks is not known, but the former possibility is perhaps more plausible given that diverse cognitive abilities probably increased the probability of survival—including social sophistication (being able to model the minds of others), the ability to infer causal structures in the world, flexible problem solving and planning for the future, and better communicative ability. Regardless of the exact timeline and order of the expansion of different cognitive networks in the brains of modern humans, the language network—which supports our ability to communicate with conspecifics—is sharply distinct from the networks that support our abilities to think and reason, which makes the idea that language mediates thinking unlikely.

### Conclusions

In sum, we have reviewed work from the past two decades that has helped to clarify the function of language in modern humans and its role in human cognition. Evidence from aphasia research suggests that all tested forms of thought are possible in the absence of language, and fMRI evidence suggests that engaging in diverse forms of thinking and reasoning does not recruit the language network—a set of brain areas that represent and process word meanings and syntactic structure during language comprehension and production. Moreover, intact linguistic abilities do not entail intact thinking abilities. Together, this evidence suggests that language is unlikely to be a critical substrate for any form of thought. Although access to words, syntactic structures or non-linguistic symbols can facilitate performance on certain cognitive tasks (Box 1), language is doubly dissociated from thinking and reasoning (compare with Box 3 for open questions about the nature of linguistic and thought-mediating mental representations). We have also reviewed a body of work that has shown that diverse properties



of human languages render them easy to produce, easy to learn and understand, concise and efficient for use, and robust to noise. Many of these cross-linguistic tendencies—including the tendency to minimize dependency lengths, the preferences for particular word orders, and the prevalence of ambiguity—are difficult to account for under the view that language is used for internal thought and without appealing to how language is used and processed.

Considering the evidence in tandem, we have argued that language serves a primarily communicative function and reflects, rather than gives rise to, the signature sophistication of human cognition. Instead of providing the key substrate for thinking and reasoning, language likely transformed our species by enabling cross-generational transmission of acquired knowledge. Language is uncontroversially a tremendously useful tool for knowledge transmission. The cumulative effect of this transmission—knowledge building on knowledge—along with increased sophistication of our social and problem-solving abilities is plausibly what enabled us to create human civilizations<sup>174–177</sup>. Although our review shows that all tested forms of thought are apparently possible without language, it is unlikely that our species' success would have been possible without the cumulative culture that was enabled by the external usage of language.

1. Barham, L. & Everett, D. Semiotics and the origin of language in the Lower Palaeolithic. *J. Archaeol. Method Theory* **28**, 535–579 (2021).
2. Hockett, C. F. The origin of speech. *Sci. Am.* **203**, 88–97 (1960).  
**A classic overview of the relationship between key features of human language and communication systems found in other species, with a focus on distinctive and shared properties.**
3. Jackendoff, R. & Pinker, S. The faculty of language: what's special about it? *Cognition* **95**, 201–236 (2005).
4. Hurford, J. R. *Language in the Light of Evolution: Volume 1, The Origins of Meaning* (Oxford Univ. Press, 2007).
5. Kirby, S., Cornish, H. & Smith, K. Cumulative cultural evolution in the laboratory: an experimental approach to the origins of structure in human language. *Proc. Natl Acad. Sci. USA* **105**, 10681–10686 (2008).  
**This behavioural investigation introduces an experimental paradigm based on iterated learning of artificial languages for studying the cultural evolution of language; the findings suggest that languages evolve to maximize their transmissibility by becoming easier to learn and more structured.**
6. Seyfarth, R. M. & Cheney, D. L. *The Social Origins of Language* (Princeton Univ. Press, 2018).
7. Gibson, E. et al. How efficiency shapes human language. *Trends Cogn. Sci.* **23**, 389–407 (2019).
8. Chomsky, N. *The Minimalist Program* (MIT Press, 1995).
9. Carruthers, P. The cognitive functions of language. *Behav. Brain Sci.* **25**, 657–674 (2002).  
**This comprehensive review discusses diverse language-for-thought views and puts forward a specific proposal whereby language has a critical role in cross-domain integration.**
10. Gentner, D. & Goldin-Meadow, S. *Language in Mind: Advances in the Study of Language and Thought* (MIT Press, 2003).
11. Majid, A., Bowerman, M., Kita, S., Haun, D. B. & Levinson, S. C. Can language restructure cognition? The case for space. *Trends Cogn. Sci.* **8**, 108–114 (2004).
12. Vygotsky, L. S. *Thought and Language* (MIT Press, 2012).
13. Lupyán, G. The centrality of language in human cognition. *Lang. Learn.* **66**, 516–553 (2016).
14. Davidson, D. in *Mind and Language* (ed. Guttenplan, S.) 1975–1977 (Oxford Univ. Press, 1975).
15. Dummett, M. *Origins of Analytical Philosophy* (Harvard Univ. Press, 1994).
16. Gleitman, L. & Papafragou, A. in *The Cambridge Handbook of Thinking and Reasoning* (eds Holyoak, K. J. & Morrison, R. G.) 633–661 (Cambridge Univ. Press, 2005).
17. de Villiers, J. in *Understanding Other Minds: Perspectives from Developmental Cognitive Neuroscience* (eds Baron-Cohen, S. et al.) 83–123 (Oxford Univ. Press, 2000).
18. Gentner, D. in *Language in Mind: Advances in the Study of Language and Thought* (eds Gentner, D. & Goldin-Meadow, S.) 3–14 (MIT Press, 2003).  
**This position piece articulates one version of a language-for-thought hypothesis, whereby human intelligence is due to a combination of our analogical reasoning ability, possession of symbolic representations, and the ability of relational language to improve analogical reasoning abilities.**
19. Buller, D. J. *Adapting Minds: Evolutionary Psychology and the Persistent Quest for Human Nature* (MIT Press, 2005).
20. Gould, S. J. & Vrba, E. S. Exaptation—a missing term in the science of form. *Paleobiology* **8**, 4–15 (1982).
21. Shannon, C. E. A mathematical theory of communication. *Bell Syst. Tech. J.* **27**, 379–423 (1948).  
**This article introduces a formal framework for systems of information transfer, with core concepts such as channel capacity, and lays a foundation for the field of information theory.**
22. Goldberg, A. E. *Constructions: A Construction Grammar Approach to Argument Structure* (Univ. Chicago Press, 1995).

23. Jackendoff, R. *Foundations of Language: Brain, Meaning, Grammar, Evolution* (Oxford Univ. Press, 2002).
24. Geschwind, N. The organization of language and the brain: language disorders after brain damage help in elucidating the neural basis of verbal behavior. *Science* **170**, 940–944 (1970).
25. Friederici, A. D. Towards a neural basis of auditory sentence processing. *Trends Cogn. Sci.* **6**, 78–84 (2002).
26. Bates, E. et al. Voxel-based lesion-symptom mapping. *Nat. Neurosci.* **6**, 448–450 (2003).
27. Hagoort, P. The neurobiology of language beyond single-word processing. *Science* **366**, 55–58 (2019).
28. Fedorenko, E., Ivanova, A. I. & Regev, T. I. The language network as a natural kind within the broader landscape of the human brain. *Nat. Rev. Neurosci.* **25**, 289–312 (2024).
29. Neville, H. J. et al. Cerebral organization for language in deaf and hearing subjects: biological constraints and effects of experience. *Proc. Natl Acad. Sci. USA* **95**, 922–929 (1998).
30. Fedorenko, E., Hsieh, P.-J., Nieto-Castañón, A., Whitfield-Gabrieli, S. & Kanwisher, N. A new method for fMRI investigations of language: defining ROIs functionally in individual subjects. *J. Neurophysiol.* **104**, 1177–1194 (2010).
31. Vagharchakian, L., Dehaene-Lambertz, G., Pallier, C. & Dehaene, S. A temporal bottleneck in the language comprehension network. *J. Neurosci.* **32**, 9089–9102 (2012).
32. Regev, M., Honey, C. J., Simony, E. & Hasson, U. Selective and invariant neural responses to spoken and written narratives. *J. Neurosci.* **33**, 15978–15988 (2013).
33. Hu, J. et al. Precision fMRI reveals that the language-selective network supports both phrase-structure building and lexical access during language production. *Cereb. Cortex* **33**, 4384–4404 (2022).
34. Menenti, L., Gierhan, S. M. E., Segaert, K. & Hagoort, P. Shared language: overlap and segregation of the neuronal infrastructure for speaking and listening revealed by functional MRI. *Psychol. Sci.* **22**, 1173–1182 (2011).  
**This fMRI investigation establishes that language comprehension and language production draw on the same brain areas in the left frontal and temporal cortex.**
35. Hauser, M. D., Chomsky, N. & Fitch, W. T. The faculty of language: what is it, who has it, and how did it evolve? *Science* **298**, 1569–1579 (2002).
36. Pallier, C., Devauchelle, A. D. & Dehaene, S. Cortical representation of the constituent structure of sentences. *Proc. Natl Acad. Sci. USA* **108**, 2522–2527 (2011).
37. Bozic, M., Fonteneau, E., Su, L. & Marslen-Wilson, W. D. Grammatical analysis as a distributed neurobiological function. *Hum. Brain Mapp.* **36**, 1190–1201 (2015).
38. Rodd, J. M., Vitello, S., Woollams, A. M. & Adank, P. Localising semantic and syntactic processing in spoken and written language comprehension: an activation likelihood estimation meta-analysis. *Brain Lang.* **141**, 89–102 (2015).
39. Blank, I., Balewski, Z., Mahowald, K. & Fedorenko, E. Syntactic processing is distributed across the language system. *NeuroImage* **127**, 307–323 (2016).
40. Fedorenko, E. et al. Neural correlate of the construction of sentence meaning. *Proc. Natl Acad. Sci. USA* **113**, E6256–E6262 (2016).
41. Nelson, M. J. et al. Neurophysiological dynamics of phrase-structure building during sentence processing. *Proc. Natl Acad. Sci. USA* **114**, E3669–E3678 (2017).
42. Fedorenko, E., Blank, I. A., Siegelman, M. & Mineroff, Z. Lack of selectivity for syntax relative to word meanings throughout the language network. *Cognition* **203**, 104348 (2020).  
**This fMRI investigation establishes that every part of the language network that is sensitive to syntactic structure building is also sensitive to word meanings and comprehensively reviews literature relevant to the syntax selectivity debate.**
43. Giglio, L., Ostarek, M. O., Weber, K. & Hagoort, P. Commonalities and asymmetries in the neurobiological infrastructure for language production and comprehension. *Cereb. Cortex* **32**, 1405–1418 (2022).
44. Heilbron, M., Armeni, K., Schoffelen, J. M., Hagoort, P. & De Lange, F. P. A hierarchy of linguistic predictions during natural language comprehension. *Proc. Natl Acad. Sci. USA* **119**, e2201968119 (2022).
45. Shain, C., Blank, I. A., Fedorenko, E., Gibson, E. & Schuler, W. Robust effects of working memory demand during naturalistic language comprehension in language-selective cortex. *J. Neurosci.* **42**, 7412–7430 (2022).
46. Desbordes, T. et al. Dimensionality and ramping: signatures of sentence integration in the dynamics of brains and deep language models. *J. Neurosci.* **43**, 5350–5364 (2023).
47. Shain, C. et al. Distributed sensitivity to syntax and semantics throughout the language network. *J. Cogn. Neurosci.* **22**, 1–43 (2024).  
**This fMRI investigation establishes distributed sensitivity to cognitive demands associated with lexical access, syntactic structure building and semantic composition across the language network.**
48. Tuckute, G. et al. Driving and suppressing the human language network using large language models. *Nat. Hum. Behav.* **8**, 544–561 (2024).
49. Gentner, D. Structure-mapping: a theoretical framework for analogy. *Cogn. Sci.* **7**, 155–170 (1983).
50. Duncan, J. *How Intelligence Happens* (Yale Univ. Press, 2012).
51. Varley, R. A., Klessinger, N. J., Romanowski, C. A. & Siegal, M. Agrammatic but numerate. *Proc. Natl Acad. Sci. USA* **102**, 3519–3524 (2005).  
**Patients with acquired damage to the language network display aphasia and linguistic deficits (including severe grammatical difficulties) but perform at the level of neurotypical control participants on diverse numerical reasoning tasks.**
52. Klessinger, N., Szczerbinski, M. & Varley, R. Algebra in a man with severe aphasia. *Neuropsychologia* **45**, 1642–1648 (2007).
53. Lecours, A. & Joanette, Y. Linguistic and other psychological aspects of paroxysmal aphasia. *Brain and Language* **10**, 1–23 (1980).
54. Kertesz, A. in *Thought Without Language* (ed. Weiskrantz, L.) 451–463 (Oxford Univ. Press, 1988).
55. Varley, R. & Siegal, M. Evidence for cognition without grammar from causal reasoning and ‘theory of mind’ in an agrammatic aphasic patient. *Curr. Biol.* **10**, 723–726 (2000).
56. Siegal, M., Varley, R. & Want, S. C. Mind over grammar: reasoning in aphasia and development. *Trends Cogn. Sci.* **5**, 296–301 (2001).

57. Varley, R. In *Cognitive Bases of Science* (eds Carruthers, P. et al.) 99–116 (Cambridge Univ. Press, 2002).
58. Woolgar, A., Duncan, J., Manes, F. & Fedorenko, E. Fluid intelligence is supported by the multiple-demand system not the language system. *Nat. Hum. Behav.* **2**, 200–204 (2018).
59. Dronkers, N. F., Ludy, C. A. & Redfern, B. B. Pragmatics in the absence of verbal language: descriptions of a severe aphasic and a language-deprived adult. *J. Neurolinguistics* **11**, 179–190 (1998).
60. Varley, R., Siegal, M. & Want, S. C. Severe impairment in grammar does not preclude theory of mind. *Neurocase* **7**, 489–493 (2001).
61. Apperly, I. A., Samson, D., Carroll, N., Hussain, S. & Humphreys, G. Intact first- and second-order false belief reasoning in a patient with severely impaired grammar. *Soc. Neurosci.* **1**, 334–348 (2006).
- A person with acquired damage to the language network and consequent aphasia exhibits linguistic deficits but performs at the level of neurotypical control participants on theory of mind tasks.**
62. Willems, R. M., Benn, Y., Hagoort, P., Toni, I. & Varley, R. Communicating without a functioning language system: Implications for the role of language in mentalizing. *Neuropsychologia* **49**, 3130–3135 (2011).
63. Bek, J., Blades, M., Siegal, M. & Varley, R. Language and spatial reorientation: evidence from severe aphasia. *J. Exp. Psychol.* **36**, 646 (2010).
64. Caramazza, A., Berndt, R. S. & Brownell, H. H. The semantic deficit hypothesis: Perceptual parsing and object classification by aphasic patients. *B. Lang.* **15**, 161–189 (1982).
65. Chertkow, H., Bub, D., Deaudon, C. & Whitehead, V. On the status of object concepts in aphasia. *Brain Lang.* **58**, 203–232 (1997).
66. Saygin, A. P., Wilson, S. M., Dronkers, N. F. & Bates, E. Action comprehension in aphasia: linguistic and non-linguistic deficits and their lesion correlates. *Neuropsychologia* **42**, 1788–1804 (2004).
67. Jefferies, E. & Lambon Ralph, M. A. Semantic impairment in stroke aphasia versus semantic dementia: a case-series comparison. *Brain* **129**, 2132–2147 (2006).
68. Dickey, M. W. & Warren, T. The influence of event-related knowledge on verb-argument processing in aphasia. *Neuropsychologia* **67**, 63–81 (2015).
69. Ivanova, A. A. et al. The language network is recruited but not required for nonverbal event semantics. *Neurobiol. Lang.* **2**, 176–201 (2021).
- In this fMRI study, semantic processing of event pictures in neurotypical individuals engages the language network, but less than verbal descriptions of the same events; however, individuals with acquired damage to the language network and consequent aphasia perform at the level of neurotypical control participants on a non-verbal semantic task.**
70. Benn, Y. et al. The language network is not engaged in object categorization. *Cereb. Cortex* **33**, 10380–10400 (2023).
71. Varley, R. Reason without much language. *Lang. Sci.* **46**, 232–244 (2014).
72. Dehaene, S., Spelke, E., Pinel, P., Stanescu, R. & Tsivkin, S. Sources of mathematical thinking: behavioral and brain-imaging evidence. *Science* **284**, 970–974 (1999).
73. Hermer, L. & Spelke, E. Modularity and development: the case of spatial reorientation. *Cognition* **61**, 195–232 (1996).
74. Lupyan, G. Extracommunicative functions of language: verbal interference causes selective categorization impairments. *Psychon. Bull. Rev.* **16**, 711–718 (2009).
75. Braga, R. M., DiNicola, L. M., Becker, H. C. & Buckner, R. L. Situating the left-lateralized language network in the broader organization of multiple specialized large-scale distributed networks. *J. Neurophysiol.* **124**, 1415–1448 (2020).
- This fMRI investigation of the language network establishes this network as one of the intrinsic large-scale networks in the human brain, distinct from nearby cognitive networks.**
76. Fedorenko, E. & Blank, I. A. Broca's area is not a natural kind. *Trends Cogn. Sci.* **24**, 270–284 (2020).
77. Fedorenko, E., Behr, M. K. & Kanwisher, N. Functional specificity for high-level linguistic processing in the human brain. *Proc. Natl Acad. Sci. USA* **108**, 16428–16433 (2011).
- This fMRI investigation finds that arithmetic addition, demanding executive function tasks and music processing do not engage the language areas, thus establishing their selectivity for linguistic input over non-linguistic inputs and tasks.**
78. Monti, M. M., Parsons, L. M. & Osherson, D. N. Thought beyond language: neural dissociation of algebra and natural language. *Psychol. Sci.* **23**, 914–922 (2012).
79. Amalric, M. & Dehaene, S. A distinct cortical network for mathematical knowledge in the human brain. *NeuroImage* **189**, 19–31 (2019).
80. Monti, M. M., Osherson, D. N., Martinez, M. J. & Parsons, L. M. Functional neuroanatomy of deductive inference: a language-independent distributed network. *NeuroImage* **37**, 1005–1016 (2007).
81. Monti, M. M., Parsons, L. M. & Osherson, D. N. The boundaries of language and thought in deductive inference. *Proc. Natl Acad. Sci. USA* **106**, 12554–12559 (2009).
- This fMRI investigation finds largely non-overlapping activations of brain regions to language processing and logical processing, thus establishing the selectivity of language areas for linguistic input over logic statements.**
82. Ivanova, A. A. et al. Comprehension of computer code relies primarily on domain-general executive brain regions. *eLife* **9**, e58906 (2020).
83. Liu, Y. F., Kim, J., Wilson, C. & Bedny, M. Computer code comprehension shares neural resources with formal logical inference in the fronto-parietal network. *eLife* **9**, e59340 (2020).
84. Paunov, A. M., Blank, I. A. & Fedorenko, E. Functionally distinct language and theory of mind networks are synchronized at rest and during language comprehension. *J. Neurophysiol.* **121**, 1244–1265 (2019).
85. Paunov, A. M. et al. Differential tracking of linguistic vs. mental state content in naturalistic stimuli by language and theory of mind (ToM) brain networks. *Neurobiol. Lang.* **3**, 413–440 (2022).
86. Shain, C., Paunov, A., Chen, X., Lipkin, B. & Fedorenko, E. No evidence of theory of mind reasoning in the human language network. *Cereb. Cortex* **33**, 6299–6319 (2023).
87. Sueoka, Y., Paunov, A., Ivanova, A., Blank, I. A. & Fedorenko, E. The language network reliably “tracks” naturalistic meaningful non-verbal stimuli. *Neurobiol. Lang.* [https://doi.org/10.1162/nol\\_a\\_00135](https://doi.org/10.1162/nol_a_00135) (2024).
88. Piaget, J. *The Language and Thought of the Child* (Harcourt Brace, 1926).
89. Gentner, D. & Loewenstein, J. In *Language, Literacy, and Cognitive Development: The Development and Consequences of Symbolic Communication* (eds Amsel, E. & Byrnes, J. P.) 89–126 (Lawrence Erlbaum Associates, 2002).
90. Appleton, M. & Reddy, V. Teaching three year-olds to pass false belief tests: a conversational approach. *Soc. Dev.* **5**, 275–291 (1996).
91. Slaughter, V. & Gopnik, A. Conceptual coherence in the child's theory of mind: training children to understand belief. *Child Dev.* **67**, 2967–2988 (1996).
92. Hiersche, K. J., Schettini, E., Li, J. & Saygin, Z. M. (2022). Functional dissociation of the language network and other cognition in early childhood. Preprint at [bioRxiv](https://doi.org/10.1101/2022.08.11.503597) <https://doi.org/10.1101/2022.08.11.503597> (2023).
93. Hiersche, K. J. *Functional Organization and Modularity of the Superior Temporal Lobe in Children*. Masters thesis, The Ohio State University (2023).
94. Hall, W. C. What you don't know can hurt you: the risk of language deprivation by impairing sign language development in deaf children. *Matern. Child Health J.* **21**, 961–965 (2017).
95. Hall, M. L., Hall, W. C. & Caselli, N. K. Deaf children need language, not (just) speech. *First Lang.* **39**, 367–395 (2019).
96. Bedny, M. & Saxe, R. Insights into the origins of knowledge from the cognitive neuroscience of blindness. *Cogn. Neuropsychol.* **29**, 56–84 (2012).
97. Grand, G., Blank, I. A., Pereira, F. & Fedorenko, E. Semantic projection recovers rich human knowledge of multiple object features from embeddings. *Nat. Hum. Behav.* **6**, 975–987 (2022).
98. Jackendoff, R. How language helps us think. *Pragmat. Cogn.* **4**, 1–34 (1996).
99. Jackendoff, R. *The User's Guide to Meaning* (MIT Press, 2012).
100. Curtiss, S. *Genie: A Psycholinguistic Study of a Modern-day Wild Child* (Academic Press, 1977).
101. Peterson, C. C. & Siegal, M. Representing inner worlds: theory of mind in autistic, deaf, and normal hearing children. *Psychol. Sci.* **10**, 126–129 (1999).
102. Richardson, H. et al. Reduced neural selectivity for mental states in deaf children with delayed exposure to sign language. *Nat. Commun.* **11**, 3246 (2020).
103. Spelke, E. S. *What Babies Know: Core Knowledge and Composition*, Vol. 1 (Oxford Univ. Press, 2022).
104. Cheney, D. L. & Seyfarth, R. M. *How Monkeys See the World: Inside the Mind of Another Species* (Univ. Chicago Press, 1990).
105. Herrmann, E., Call, J., Hernández-Lloreda, M. V., Hare, B. & Tomasello, M. Humans have evolved specialized skills of social cognition: the cultural intelligence hypothesis. *Science* **317**, 1360–1366 (2007).
106. Tomasello, M. & Herrmann, E. Ape and human cognition: what's the difference? *Curr. Dir. Psychol. Sci.* **19**, 3–8 (2010).
107. Fischer, J. *Monkeytalk: Inside the Worlds and Minds of Primates* (Univ. Chicago Press, 2017).
108. Krupeny, C. & Call, J. Theory of mind in animals: current and future directions. *Wiley Interdiscip. Rev. Cogn. Sci.* **10**, e1503 (2019).
109. Shimizu, T. Why can birds be so smart? Background, significance, and implications of the revised view of the avian brain. *Comparat. Cogn. Behav. Rev.* **4**, 103–115 (2009).
110. Güntürkün, O. & Bugnyar, T. Cognition without cortex. *Trends Cogn. Sci.* **20**, 291–303 (2016).
111. Hart, B. L., Hart, L. A. & Pinter-Wollman, N. Large brains and cognition: where do elephants fit in? *Neurosci. Biobehav. Rev.* **32**, 86–98 (2008).
112. Godfrey-Smith, P. *Other Minds: The Octopus and the Evolution of Intelligent Life* (William Collins, 2016).
113. Schnell, A. K., Amodio, P., Boeckle, M. & Clayton, N. S. How intelligent is a cephalopod? Lessons from comparative cognition. *Biol. Rev.* **96**, 162–178 (2021).
114. Gallistel, C. R. Prelinguistic thought. *Lang. Learn. Dev.* **7**, 253–262 (2011).
115. Fitch, W. T. Animal cognition and the evolution of human language: why we cannot focus solely on communication. *Philos. Trans. R. Soc. B* **375**, 20190046 (2020).
116. Yamada, J. E. & Marshall, J. C. *Laura: A Case Study for the Modularity of Language* (MIT Press, 1990).
117. Rondal, J. A. *Exceptional Language Development in Down Syndrome* (Cambridge Univ. Press, 1995).
118. Bellugi, U., Lichtenberger, L., Jones, W., Lai, Z. & St George, M. The neurocognitive profile of Williams syndrome: a complex pattern of strengths and weaknesses. *J. Cogn. Neurosci.* **12**, 7–29 (2000).
119. Little, B. et al. Language in schizophrenia and aphasia: the relationship with non-verbal cognition and thought disorder. *Cogn. Neuropsychiatry* **24**, 389–405 (2019).
120. Mahowald, K. et al. Dissociating language and thought in large language models. *Trends Cogn. Sci.* **28**, 517–540 (2024).
121. Chomsky, N., Belletti, A. & Rizzi, L. In *On Nature and Language* (eds Belletti, A. & Rizzi, L.) 92–161 (Cambridge Univ. Press, 2002).
122. Schwartz, J. L., Boë, L. J., Vallée, N. & Abry, C. The dispersion–focalization theory of vowel systems. *J. Phonetics* **25**, 255–286 (1997).
123. Diehl, R. L. Acoustic and auditory phonetics: the adaptive design of speech sound systems. *Philos. Trans. R. Soc. B* **363**, 965–978 (2008).
124. Everett, C., Blasi, D. E. & Roberts, S. G. Climate, vocal folds, and tonal languages: Connecting the physiological and geographic dots. *Proc. Natl Acad. Sci. USA* **112**, 1322–1327 (2015).
125. Blasi, D. E. et al. Human sound systems are shaped by post-Neolithic changes in bite configuration. *Science* **363**, eaav3218 (2019).
126. Dauriche, I., Mahowald, K., Gibson, E., Christophe, A. & Piantadosi, S. T. Words cluster phonetically beyond phonotactic regularities. *Cognition* **163**, 128–145 (2017).
127. Piantadosi, S. T., Tily, H. & Gibson, E. Word lengths are optimized for efficient communication. *Proc. Natl Acad. Sci. USA* **108**, 3526–3529 (2011).
128. Levelt, W. J. *Speaking: From Intention to Articulation* (MIT Press, 1993).
129. Kemp, C. & Regier, T. Kinship categories across languages reflect general communicative principles. *Science* **336**, 1049–1054 (2012).
- This study provides a computational demonstration that the kinship systems across world's languages trade off between simplicity and informativeness in a near-optimal way, and argue that these principles also characterize other category systems.**

130. Gibson, E. et al. Color naming across languages reflects color use. *Proc. Natl Acad. Sci. USA* **114**, 10785–10790 (2017).
131. Zaslavsky, N., Kemp, C., Regier, T. & Tishby, N. Efficient compression in color naming and its evolution. *Proc. Natl Acad. Sci. USA* **115**, 7937–7942 (2018).
132. Kemp, C., Gaby, A. & Regier, T. Season naming and the local environment. *Proc. 41st Annual Meeting of the Cognitive Science Society* 539–545 (2019).
133. Xu, Y., Liu, E. & Regier, T. Numeral systems across languages support efficient communication: From approximate numerosity to recursion. *Open Mind* **4**, 57–70 (2020).
134. Denić, M., Steinert-Threlkeld, S. & Szymanik, J. Complexity/informativeness trade-off in the domain of indefinite pronouns. *Semant. Linguist. Theor.* **30**, 166–184 (2021).
135. Mollica, F. et al. The forms and meanings of grammatical markers support efficient communication. *Proc. Natl Acad. Sci. USA* **118**, e2025993118 (2021).
136. van de Pol, I., Lodder, P., van Maanen, L., Steinert-Threlkeld, S. & Szymanik, J. Quantifiers satisfying semantic universals have shorter minimal description length. *Cognition* **232**, 105150 (2023).
137. Clark, H. H. in *Context in Language Learning and Language Understanding* (eds Malmkjr, K. & Williams, J.) 63–87 (Cambridge Univ. Press, 1998).
138. Winter, B., Perlman, M. & Majid, A. Vision dominates in perceptual language: English sensory vocabulary is optimized for usage. *Cognition* **179**, 213–220 (2018).
139. von Humboldt, W. *Über die Verschiedenheit des Menschlichen Sprachbaues* (1836).
140. Hurford, J. R. *Linguistic Evolution Through Language Acquisition: Formal and Computational Models* (ed. Briscoe, E.) 301–344 (Cambridge Univ. Press, 2002).
141. Smith, K., Brighton, H. & Kirby, S. Complex systems in language evolution: the cultural emergence of compositional structure. *Adv. Complex Syst.* **6**, 537–558 (2003).
142. Piantadosi, S. T. & Fedorenko, E. Infinitely productive language can arise from chance under communicative pressure. *J. Lang. Evol.* **2**, 141–147 (2017).
143. Gibson, E. Linguistic complexity: locality of syntactic dependencies. *Cognition* **68**, 1–76 (1998).
144. Lewis, R. L., Vasishth, S. & Van Dyke, J. A. Computational principles of working memory in sentence comprehension. *Trends Cogn. Sci.* **10**, 447–454 (2006).
145. Liu, H. Dependency distance as a metric of language comprehension difficulty. *J. Cogn. Sci.* **9**, 151–191 (2008).
146. Futrell, R., Mahowald, K. & Gibson, E. Large-scale evidence of dependency length minimization in 37 languages. *Proc. Natl Acad. Sci. USA* **112**, 10336–10341 (2015).  
**This investigation of syntactic dependency lengths across 37 diverse languages suggests that dependencies are predominantly local cross-linguistically, presumably because non-local dependencies are cognitively costly in both production and comprehension.**
147. Dryer, M. S. The Greenbergian word order correlations. *Language* **68**, 81–138 (1992).
148. Hahn, M., Jurafsky, D. & Futrell, R. Universals of word order reflect optimization of grammars for efficient communication. *Proc. Natl Acad. Sci. USA* **117**, 2347–2353 (2020).
149. Goldin-Meadow, S., Wing, C. S., Özyürek, A. & Mylander, C. The natural order of events: how speakers of different languages represent events nonverbally. *Proc. Natl Acad. Sci. USA* **105**, 9163–9168 (2008).
150. Senghas, A., Kita, S. & Özyürek, A. Children creating core properties of language: evidence from an emerging sign language in Nicaragua. *Science* **305**, 1779–1782 (2004).
151. Sandler, W., Meir, I., Padden, C. & Aronoff, M. The emergence of grammar: systematic structure in a new language. *Proc. Natl Acad. Sci. USA* **102**, 2661–2665 (2005).
152. Gibson, E. et al. A noisy-channel account of crosslinguistic word-order variation. *Psychol. Sci.* **24**, 1079–1088 (2013).
153. Levy, R. A noisy-channel model of human sentence comprehension under uncertain input. In *Proc. Conference on Empirical Methods in Natural Language Processing* 234–243 (2008).
154. Gibson, E., Bergen, L. & Piantadosi, S. T. Rational integration of noisy evidence and prior semantic expectations in sentence interpretation. *Proc. Natl Acad. Sci. USA* **110**, 8051–8056 (2013).  
**This behavioural investigation demonstrates that language comprehension is robust to noise: in the presence of corrupt linguistic input, listeners and readers rely on a combination of prior expectations about messages that are likely to be communicated and knowledge of how linguistic signals can get corrupted by noise.**
155. Futrell, R., Levy, R. P. & Gibson, E. Dependency locality as an explanatory principle for word order. *Language* **96**, 371–412 (2020).
156. Hahn, M. & Xu, Y. Crosslinguistic word order variation reflects evolutionary pressures of dependency and information locality. *Proc. Natl Acad. Sci. USA* **119**, e2122604119 (2022).
157. Hahn, M., Futrell, R., Levy, R. & Gibson, E. A resource-rational model of human processing of recursive linguistic structure. *Proc. Natl Acad. Sci. USA* **119**, e2122602119 (2022).
158. Piantadosi, S. T., Tily, H. & Gibson, E. The communicative function of ambiguity in language. *Cognition* **122**, 280–291 (2012).
159. Quijada, J. A grammar of the Ithkuil language—introduction. *ithkuil.net* [https://ithkuil.net/00\\_intro.html](https://ithkuil.net/00_intro.html) (accessed 27 February 2022).
160. Srinivasan, M. & Rabagliati, H. The implications of polysemy for theories of word learning. *Child Dev. Perspect.* **15**, 148–153 (2021).
161. Bizzi, E. Motor control revisited: a novel view. *Curr. Trends Neurol.* **10**, 75–80 (2016).
162. Darwin, C. *On the Origin of Species—A Facsimile of the First Edition* (Harvard Univ. Press, 1964).
163. Herculano-Houzel, S. The remarkable, yet not extraordinary, human brain as a scaled-up primate brain and its associated cost. *Proc. Natl Acad. Sci. USA* **109**, 10661–10668 (2012).
164. White, L. T. The historical roots of our ecologic crisis. *Science* **155**, 1203–1207 (1967).
165. King, M. C. & Wilson, A. C. Evolution at two levels in humans and chimpanzees. *Science* **188**, 107–116 (1975).
166. Chimpanzee Sequencing and Analysis Consortium. Initial sequence of the chimpanzee genome and comparison with the human genome. *Nature* **437**, 69–87 (2005).
167. Buckner, R. L. & Krienen, F. M. The evolution of distributed association networks in the human brain. *Trends Cogn. Sci.* **17**, 648–665 (2013).  
**This review presents the evidence for the disproportionate expansion of the association cortex relative to other brain areas in humans.**
168. Duncan, J., Assem, M. & Shashidhara, S. Integrated intelligence from distributed brain activity. *Trends Cogn. Sci.* **24**, 838–852 (2020).
169. Saxe, R. & Kanwisher, N. People thinking about thinking people: the role of the temporo-parietal junction in “theory of mind”. *NeuroImage* **19**, 1835–1842 (2003).
170. Buckner, R. L. & DiNicola, L. M. The brain’s default network: updated anatomy, physiology and evolving insights. *Nat. Rev. Neurosci.* **20**, 593–608 (2019).
171. Deen, B. & Freiwald, W. A. Parallel systems for social and spatial reasoning within the cortical apex. Preprint at *bioRxiv* <https://doi.org/10.1101/2021.09.23.461550> (2021).
172. Mitchell, D. J. et al. A putative multiple-demand system in the macaque brain. *J. Neurosci.* **36**, 8574–8585 (2016).
173. Cantlon, J. & Piantadosi, S. Uniquely human intelligence arose from expanded information capacity. *Nat. Rev. Psychol.* **3**, 275–293 (2024).
174. Tomasello, M. *The Cultural Origins of Human Cognition* (Harvard Univ. Press, 2009).
175. Boyd, R., Richerson, P. J. & Henrich, J. The cultural niche: Why social learning is essential for human adaptation. *Proc. Natl Acad. Sci. USA* **108**, 10918–10925 (2011).
176. Henrich, J. *The Secret of Our Success: How Culture is Driving Human Evolution, Domesticating Our Species, and Making Us Smarter* (Princeton Univ. Press, 2016).
177. Heyes, C. *Cognitive Gadgets* (Harvard Univ. Press, 2018).
178. Gumperz, J. J. & Levinson, S. C. (eds). *Rethinking Linguistic Relativity* (Cambridge Univ. Press, 1996).
179. Piaget, J. *Language and Thought of the Child: Selected Works*, Vol. 5 (Routledge, 2005).
180. Gleitman, L. R. & Papfragou, A. in *Cambridge Handbook of Thinking and Reasoning* (eds Holyoak, K. & Morrison, R.) 2nd edn (Oxford Univ. Press, 2016).
181. Fedorenko, E. & Varley, R. Language and thought are not the same thing: evidence from neuroimaging and neurological patients. *Ann. NY Acad. Sci.* **1369**, 132–153 (2016).
182. Gentner, D. Language as cognitive tool kit: How language supports relational thought. *Am. Psychol.* **71**, 650 (2016).
183. Frank, M. C., Everett, D. L., Fedorenko, E. & Gibson, E. Number as a cognitive technology: Evidence from Pirahã language and cognition. *Cognition* **108**, 819–824 (2008).
184. Wernicke, C. The aphasic symptom-complex: a psychological study on an anatomical basis. *Arch. Neurol.* **22**, 280–282 (1869).
185. Lichteim, L. On aphasia. *Brain* **7**, 433–484 (1885).
186. Poeppel, D., Emmorey, K., Hickok, G. & Pyllkänen, L. Towards a new neurobiology of language. *J. Neurosci.* **32**, 14125–14131 (2012).
187. Tremblay, P. & Dick, A. S. Broca and Wernicke are dead, or moving past the classic model of language neurobiology. *Brain Lang.* **162**, 60–71 (2016).
188. Hillis, A. E. et al. Re-examining the brain regions crucial for orchestrating speech articulation. *Brain* **127**, 1479–1487 (2004).
189. Flinker, A. et al. Redefining the role of Broca’s area in speech. *Proc. Natl Acad. Sci. USA* **112**, 2871–2875 (2015).
190. Long, M. A. et al. Functional segregation of cortical regions underlying speech timing and articulation. *Neuron* **89**, 1187–1193 (2016).
191. Guenther, F. H. *Neural Control of Speech* (MIT Press, 2016).
192. Basilakos, A., Smith, K. G., Fillmore, P., Fridriksson, J. & Fedorenko, E. Functional characterization of the human speech articulation network. *Cereb. Cortex* **28**, 1816–1830 (2018).
193. Obleser, J., Zimmermann, J., Van Meter, J. & Rauschecker, J. P. Multiple stages of auditory speech perception reflected in event-related fMRI. *Cereb. Cortex* **17**, 2251–2257 (2007).
194. Mesgarani, N., Cheung, C., Johnson, K. & Chang, E. F. Phonetic feature encoding in human superior temporal gyrus. *Science* **343**, 1006–1010 (2014).
195. Norman-Haignere, S., Kanwisher, N. G. & McDermott, J. H. Distinct cortical pathways for music and speech revealed by hypothesis-free voxel decomposition. *Neuron* **88**, 1281–1296 (2015).
196. Overath, T., McDermott, J., Zarate, J. & Poeppel, D. The cortical analysis of speech-specific temporal structure revealed by responses to sound quilts. *Nat. Neurosci.* **18**, 903–911 (2015).
197. Norman-Haignere, S. V. et al. A neural population selective for song in human auditory cortex. *Curr. Biol.* **32**, 1470–1484.e12 (2022).
198. Hickok, G. & Poeppel, D. The cortical organization of speech processing. *Nat. Rev. Neurosci.* **8**, 393–402 (2007).
199. Friederici, A. D. The cortical language circuit: from auditory perception to sentence comprehension. *Trends Cogn. Sci.* **16**, 262–268 (2012).
200. Wilson, S. M. et al. Recovery from aphasia in the first year after stroke. *Brain* **146**, 1021–1039 (2023).
201. Radford, A. et al. Language models are unsupervised multitask learners. *OpenAI blog* **1**, 9 (2019).
202. Jain, S. & Huth, A. Incorporating context into language encoding models for fMRI. In *Proc. 32nd International Conf. Neural Information Processing Systems* (eds Bengio, S. et al.) (Curran Associates, 2018).
203. Schrimpf, M. et al. The neural architecture of language: Integrative modeling converges on predictive processing. *Proc. Natl Acad. Sci. USA* **118**, e2105646118 (2021).
204. Caucheteux, C. & King, J. R. Brains and algorithms partially converge in natural language processing. *Commun. Biol.* **5**, 134 (2022).
205. Goldstein, A. et al. Shared computational principles for language processing in humans and deep language models. *Nat. Neurosci.* **25**, 369–380 (2022).
206. Tuckute, T., Kanwisher, N. & Fedorenko, E. Language in brains, minds, and machines. *Annu. Rev. Neurosci.* <https://doi.org/10.1146/annurev-neuro-120623-101142> (2024).
207. Paulk, A. C. et al. Large-scale neural recordings with single neuron resolution using NeuroPixels probes in human cortex. *Nat. Neurosci.* **25**, 252–263 (2022).
208. Leonard, M. K. et al. Large-scale single-neuron speech sound encoding across the depth of human cortex. *Nature* **626**, 593–602 (2024).
209. Fodor, J. A. *The Language of Thought* (Crowell, 1975).
210. Fodor, J. A. & Pylyshyn, Z. W. Connectionism and cognitive architecture: a critical analysis. *Cognition* **28**, 3–71 (1988).
211. Rule, J. S., Tenenbaum, J. B. & Piantadosi, S. T. The child as hacker. *Trends Cogn. Sci.* **24**, 900–915 (2020).

212. Quilty-Dunn, J., Porot, N. & Mandelbaum, E. The best game in town: the reemergence of the language-of-thought hypothesis across the cognitive sciences. *Behav. Brain Sci.* **46**, e261 (2023).
213. Rumelhart, D. E., McClelland, J. L. & PDP Research Group. *Parallel Distributed Processing, Vol. 1: Explorations in the Microstructure of Cognition: Foundations* (MIT Press, 1986).
214. Smolensky, P. & Legendre, G. *The Harmonic Mind: From Neural Computation to Optimality-Theoretic Grammar Vol. 1: Cognitive Architecture* (MIT Press, 2006).
215. Frankland, S. M. & Greene, J. D. Concepts and compositionality: in search of the brain's language of thought. *Annu. Rev. Psychol.* **71**, 273–303 (2020).
216. Lake, B. M. & Baroni, M. Human-like systematic generalization through a meta-learning neural network. *Nature* **623**, 115–121 (2023).
217. Dehaene-Lambertz, G., Dehaene, S. & Hertz-Pannier, L. Functional neuroimaging of speech perception in infants. *Science* **298**, 2013–2015 (2002).
218. Pena, M. et al. Sounds and silence: an optical topography study of language recognition at birth. *Proc. Natl Acad. Sci. USA* **100**, 11702–11705 (2003).
219. Cristia, A., Minagawa, Y. & Dupoux, E. Responses to vocalizations and auditory controls in the human newborn brain. *PLoS ONE* **9**, e115162 (2014).

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