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Abstract

Categorical learning plays a foundational role in language development. By reviewing comparative studies on categorical learning in humans and nonhuman animals, we show that categorical learning displays evolutionary continuity across invertebrates and vertebrates. Great apes and parrots can be trained to produce categories of (proto-)language-like symbols in different modalities. From the neurological perspective, we show that as a conserved brain structure, the basal ganglia are involved in categorical learning across species, and language processing in humans. This raises the possibility that categorical learning is one of the crucial cognitive foundations for language evolution.

Keywords: categorical learning; language acquisition; language evolution; comparative perspective; neurological perspective

Introduction

Category formation is a central cognitive ability underlying human cognition. It guides action, thinking and expectations in decision making, planning, reasoning, and inference-making. For example, if I am told that all birds can fly, I will expect new members of the category bird that I encounter to be able to fly as well. So when hearing that a penguin is a bird, I would expect that they, too, can fly. However, upon learning that penguins can in fact not fly, I would need to adapt my category to include flightless (and therefore potentially less prototypical) birds. Category learning therefore is an ongoing, adaptive process throughout the lifespan (Horst & Simmering, 2015).

Categorical learning can be defined as the process of establishing equivalence classes of discriminable, non-identical entities (Sloutsky & Deng, 2019). It is also an important foundation of language development (Ibbotson, 2020). Given its central contribution to cognition and language, as well as language learning, it should also play an important role in approaches to language evolution (Hurford, 2007). Specifically, an evolutionary account of the cognitive foundations of language development and foundations needs to take into account research on categorical learning. Here we aim to shed light on the evolutionary origins of human categorical learning and its evolutionary roots shared with non-human animals. Bringing together comparative cognitive and behavioral data on the one hand, and data on the neurological bases of categorical learning on the other, we stress the importance of categorical learning in language evolution. The reviewed data suggest that categorical learning itself is a mosaic of underlying mechanisms, and that human categorical learning evolved to combine different processes of category formation. Our view fits in with a model of language evolution that describes language as a mosaic of different cognitive processes that form an integrated system (e.g. Gong, Shuai & Wu, 2018), with the individual elements having an evolutionarily continuous trajectory. We will first outline the role of categorical learning in language acquisition, before turning to its evolutionary and neural foundations.

The Role of Categorical Learning in Language Acquisition

Cognitive-linguistic approaches see language acquisition, processing, use, change, and evolution as based on domain-general cognitive capacities (Dąbrowska & Divjak, 2015; Xu & Taylor, 2021). Much work in this area has focussed on specifying the necessary cognitive abilities that it takes to talk (e.g. Bybee, 2010; Ibbotson, 2020; Tomasello, 2003) and that characterize the 'language-ready brain' (Arbib, 2012). These include socio-cognitive processes such as joint attention, pragmatic inference, and shared intentionality (Tomasello, 2003), as well as general cognitive processes such as neuromotor automation, chunking, cross-modal association, analogy, entrenchment, and inference-making (Bybee, 2010, 2012; Diessel, 2019; Schmid, 2020). One such process that is particularly important for language acquisition is that of categorical learning. Categorical learning is fundamental to language acquisition in a number of domains, such as the learning of sounds, words, and grammatical patterns. In all these domains, infants and young children learn the categories that are relevant for communicative purposes in their surrounding language(s).

In the domain of phonology, for example, at 6-8 months of age infants show universal speech perception and can distinguish non-native phonemic contrasts. For instance, at this age a Japanese infant can successfully distinguish /l/

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and /r/ phonemes (Kuhl, Stevens, Hayashi, Deguchi et al., 2006), and an English child can distinguish the Hindi dental /t/ from the retroflex /t/ (Werker & Tees, 1984). However, between 12-18 months language-specific speech perception starts to emerge and infants lose the ability to distinguish non-native phonemic contrasts (Galle & McMurray, 2014). This suggests that by this age, they start to become attuned to the phonemic categories relevant to their surrounding language(s), an instance of categorical learning.

Categorical learning is also foundational in the acquisition of semantics and word learning (Gelman & Roberts, 2018; Perszyk & Waxman, 2018). Starting in early infancy, infants display a rudimentary capacity to form categories (Deng & Sloutsky, 2015; Sloutsky & Deng, 2019). Infants first perceptually identify units constituting situations, entities, and events, which are then sorted into first conceptual categories by generalizing over individual instances (Hard, Tversky & Lang, 2006; Sloutsky, 2015). Within their first year of life, infants learn to establish early categories of events and objects that are sufficiently perceptually distinguishable, such as BOTTLE, DOG, RUN and SLEEP. These then guide their expectations about novel entities and situations These rudimentary categories develop parallel to more abstract categories, such as agency, causation, number, space, and relational patterns such as same/different (Baillargeon, Scott & Bian, 2016; Carey, 2009; Hespos, Gentner, Anderson & Shivaram, 2021). Some of these categories initially might develop independently of language, such as same/different (Hespos et al. 2021) and animate/inanimate (Rakison & Poulin-Dubois, 2001; Opfer & Gelman, 2011). One potential pathway towards these early abstractions is that children categorize perceptual input into prototypically structured image schemas, such as cause-motion, animate-motion, and self-motion (Mandler, 1992, 2004), based on the natural statistics of their (re)-occurence in the world. These image schemas serve as the conceptual primitives on which conceptual categories of animacy, inanimacy, and agency are constructed (Sloutsky, 2015). However, other categories might develop in tandem with and influenced by language. This is partly due to the function of words, which serve as invitations to form categories (Gelman & Roberts, 2018; Perszyk & Waxman, 2018), that is, as signals inviting the analysis of a particular conceptual space. As early as 3-4 months, infants show sensitivity to the fact that words denote categories (Ferry, Hespos & Waxman, 2010). By 12 months, infants successfully form object categories when they are exposed to the same novel word combined with a number of objects sharing similarities (Waxman & Markow, 1995). Children's emerging categories become increasingly rich as they develop and acquire language, and build up more and more complex taxonomies and networks of categories and relations between them (Clark, 2018; Sloutsky & Deng, 2019). Overall, infants and children show increasing abilities to acquire ever more complex and abstract categories (Sloutsky, 2015).

Categorical learning also plays an important role in the acquisition of grammatical patterns and more abstract constructions. Exposure to constructions also invites learners to form categories, just as words do (Goldberg, 2019). Children do this by generalizing over novel constructions based on statistical distributions of items in utterances. Just as for conceptual categories more generally, they then categorize items and constructions into hierarchies of more abstract and schematic constructions, such as NOUN PHRASE, PAST TENSE, or PASSIVE CONSTRUCTION (Goldberg, 2019; Ibbotson, 2020).

Overall, then, language represents a particularly important ostensive cue for categorical learning., and categorical learning and language development are intricately linked generally.

The Evolutionary Foundations of Categorical Learning–Comparative Perspective

Smith et al. (2016) present a comprehensive review on the debates about exemplar, prototype and rule theory of categorization, and emphasizes the profoundly important role of research on categorization of nonhuman animals to better understand the nature of categorization and its evolution. Exemplar theory posits that animals put the category exemplars they are confronted with in parallel as a whole but in separate memory traces, so new items will be compared to the exemplars and placed in the group where they are more similar. In prototype theory, animals form schematic representations that reflect the central tendency of the category, based on averaged experience over distinct exemplars. So if the new items animals encounter are similar enough to such an averaged representation they will be stored in the category. Cognitive neuroscience work has revealed that rules could be the representational vehicle for explicit categorical learning processes, especially in humans. The prototype-exemplar debates reveal evolutionary continuity across vertebrates, whereas the rules-exemplar debates suggest an evolutionary divergence between humans and nonhuman animals (Smith et al., 2016). Animal studies suggest that it is unlikely there is only one system in use. Rather, a multiple system theory seems to explain categorical learning better in terms of evolution (Smith et al., 2012). The precise role language plays in category learning in humans remains unresolved. In this section, we will review categorical learning research on birds and primates including humans, and extend it to invertebrates to show an evolutionary continuity in the framework of multiple system theory. We will focus on the visual and auditory modalities among all modalities found for categorical learning. We will provide evidence from a neurocognitive perspective highlighting the role of the cortico-basal ganglia circuits in the following section.

Invertebrates: Visual Categorization in Honeybees

The natural environment presents honeybees with complex affordances which require them to possess advanced sensory and perceptual abilities for food navigation. Zhang et al. (2004) demonstrated that honeybees are capable of categorizing complex visual objects. Four groups of visual stimuli were presented to bees for them to choose: landscapes, plant stems and two different types of flowers. The results showed that honeybees are successful in learning a match-to-sample task even with new stimuli, probably combining low-level features and configurational cues. Further analysis of the spatial power spectra of the stimuli hinted at the possibility that honeybees could refer to spatial frequency as one of the cues to classify natural scenes (Zhang et al., 2004). The spatial information has been found to be integrated with perceptual difference in categorization in honeybees, suggesting a dual-concept mechanism already present in invertebrates (Avarguès-Weber et al., 2012). The multi-concept processing acquired by such tiny brains of honeybees further brings about questions about the neural mechanism underlying it. We will discuss this in the following subsections and how this can be related to the mechanism in vertebrates.

Birds: Visual categorical learning in pigeons

Categorical learning has been recorded in pigeons for almost 60 years since Herrnstein & Loveland (1964)'s experiments. Later studies have demonstrated that pigeons are capable of categorically learning various classes of stimuli (see the review of Huber 2001), especially in the visual modality. For example, pigeons displayed categorical learning of pictures of trees, bodies of water, or a particular person (Herrnstein, Loveland & Cable, 1976). They can even distinguish paintings of Picasso and Monet (Watanabe, Sajamoto & Wakita, 1995). From an evolutionary point of view, the mechanism underlying pigeons' categorical learning has been compared with that of nonhuman primates and humans to explore an evolutionary trajectory across vertebrates.

The RB-II (rule-based and information-integration) dissociative tasks have served as good references for research on the cognitive mechanisms of categorical learning across species (Smith, Chapman & Redford, 2010). In RB tasks, two dimensions of stimuli are provided, in which by logical reasoning and hypothesis testing the category boundary will be detected. So, participants only need to attend to the rules to categorize the stimuli with information-telling dimension, and the other non-informative dimension could be ignored. On the other hand, in II tasks, information from both dimensions has to be integrated to discover the category boundary, and thus attention will broaden so that processing time may be longer and accuracy may be lower. RB-II dissociative techniques have been used to test categorical learning of pigeons, monkeys and apes, and humans. In pigeons, the results showed that there is no significant advantage of RB over II in speed and accuracy in both forward and backward learning (in contrast with primates including humans, see the following section) (Smith et al., 2011). Later modeling studies suggested that pigeons seemed to process RB and II tasks in a nonanalytic way for categorical learning (Smith et al., 2011). However, by extending the realm of the stimuli, Qadri et al. (2019) showed that pigeons can transfer RB rules to new stimuli, but might do so to a lesser degree. This suggests an evolutionary continuity of categorical learning in vertebrates at least for visual stimuli. Furthermore, since RB and II tasks are both linear (in square space), O'Donoghue et al. (2022) introduced a novel nonlinear category structure (in circular space) to investigate the difference of learning mechanisms between pigeons and humans (see O'Donoghue, Broschard & Wasserman (2020) for the advantages of nonlinear over linear tasks). The results also corroborate the proposal of evolutionary continuity of multiple system learning. We will discuss more about primates in the following sub-section.

Primates: Macaques, Capuchin Monkeys, and Humans

Similar RB-II dissociative tasks were also given to primates including humans to observe their categorical learning mechanisms. Both macaques and capuchin monkeys learned RB tasks faster and better than II tasks, with the latter being less sharp and sensitive learners than the former (Smith et al., 2010; 2012). Humans, on the other hand, use explicit-reasoning and hypothesis-testing processes to solve RB tasks much faster than II tasks. These results suggest that multiple system learning exhibits evolutionary continuity across primates. However, humans seem to show a more highly advanced ability in RB tasks than monkeys. The question is, what makes this advancement possible in humans? Is it language that makes the difference and what role does language play in RB task solving in humans? Are there other possible explanations? We will turn to categorical learning in the auditory modality next to give a possible explanation.

Categorical Learning in the Auditory Modality

To test whether birds possess multiple systems for categorical learning, two-dimensional stimuli with speech sound quality as one dimension and sex as the other were given to zebra finches and humans (Burgering, ten Cate & Vroomen, 2018). The results of two-dimensional stimuli processing showed that zebra finches most probably rely on exemplar-based memorization to generalize to new stimuli. However, the results of one-dimensional stimuli processing indicated that zebra finches also take advantage of rule-based learning. It shows that some species of birds exhibit a more analytical and integrative learning strategy (Burgering, ten Cate & Vroomen, 2018). In addition, Botskaris, Kriengwatana & ten Cate (2017) also showed that zebra finches could use the same learning methods for an auditory categorization task, suggesting that they could also use multiple systems for categorical learning. Furthermore, crows have been shown to possess categorical auditory working memory, which plays a crucial role in efficiently processing information and adapting to new environmental situations (Wagener & Nieder, 2020). Of note here is that zebra finches and crows are songbirds which belong to one of the three vocal production learning avian species, whereas pigeons are limited vocal learning birds. In the primate lineage, humans are the only vocal production learning species. In other words, songbirds to birds are like humans to primates. This raises the possibility that the high end of vocal production learning could be related to the RB transfer in new stimuli. Additionally, song learning in songbirds is also a good illustration of categorical learning in nature. Song learning and speech learning share the same developmental trajectory. Like human speech, birdsongs also exhibit hierarchical levels including notes, syllables, and motifs (Doupe & Kuhl, 1999). Birds need to learn how to categorize auditory units not only in learning the tutor songs (from their fathers) but also in the surrounding environment to distinguish singing purposes.

Symbol-Trained Birds and Primates

We have shown that categorical learning exists in birds and primates across modalities with results from laboratory experiments. If categorical learning displays evolutionary continuity, can animals be trained to learn categories found in human language? This part focuses on symbolic training on birds and nonhuman primates. Great Apes *Sign learning:* Initiated by Allen and Beatrix Gardner (1969), studies have been done on great apes learning signs based on signs from American Sign Language (ASL) produced by non-native hearing trainers. Chimpanzees, gorillas, and orangutans have all been reported to be able to learn a substantial number of signs, with a range of productive vocabularies reported in the peer-reviewed literature from 68 to 250, to over 1000 in other types of publications (see Lyn, 2012, for a review). For example, Washoe, who was only exposed to signs from ASL, managed to learn approximately 250 signs that she was said to combine spontaneously. There are also claims that she invented new sign combinations like ‘open food drink’ for a refrigerator (Fout & Mills, 1997), although these claims are highly disputed (Hurford, 2012; Neisser, 1983). Other recorded signing chimpanzees have also also been argued to lie with signs and refer to absent objects (Fout & Mills, 1997). As discussed above, signs function as invitations to form categories, and learning a sign also means either integrating the sign into an existing category or learning a new category. Sign learning in great apes can therefore be seen as evidence for categorical learning, although the difference between how categories connected to signs are represented in non-human great apes compared to human children is currently not known. Moreover, although bonobo Kanzi has been shown to exhibit some sensitivity to word order in spoken language, there is currently no evidence that symbol-trained great apes are capable of acquiring grammatical categories or categories based on hierarchical linguistic structure (Hurford, 2012; Rivas, 2005; Truswell, 2017). This is evidence that both great apes and humans exhibit categorical learning for some aspects of language, such as symbols, but that there are differences in the types of linguistic categories they can acquire.

Visual symbols: Apart from signs, great apes were also trained on visual symbols. One chimpanzee subject, Sarah, was initially taught using plastic, metal-backed tokens and a magnetic board, and then a typewriter-style keyboard. Sarah not only acquired the referential meanings of about 150 tokens but also constructed ‘sentences’ that were said to follow specific ordering principles, thereby exhibiting a kind of grammar in an artificial language. Moreover, she was able to categorize and name objects by color, shape, and size (Premack, 1977; Rumbaugh, 1977). Another chimpanzee, Lana, was reported to be able to use a keyboard with each key containing a lexigram, to produce grammatically correct sequences in an artificial grammar called Yerkish to request e.g. food and drinks. Like sign-learning chimpanzees, Lana is said to have invented combinations of learned lexigrams to describe new objects (Rumbaugh, 1977). However, just as with sign-learning chimpanzees, this interpretation is highly disputed and it is possible that these combinations are simply the result of trial-and-error (Kaplan, 2016).

Kanzi, on the other hand, has been shown to pick up lexigrams without explicit instruction. He can also combine two or three lexigrams into meaningful productions. Interestingly, he normally put the agent first followed by the action, and objects after the action (Greenfield & Savage-Rumbaugh, 1990), which suggests that he might have a rudimentary agent-patient concept. However, just as with sign-trained great apes, the current evidence with respect to categorical learning seems to indicate that great apes are able to associate objects, actions and some concepts with visual symbols, but that there is no clear evidence for their ability to learn grammatical categories.

Grey Parrots Parrots as one of the vocal production learning species have shown exceptional performance in the auditory-vocal modality of language training. A famous grey parrot, Alex, after training, could vocally tell 50 different objects apart. He was also reported to have concepts of category and relational reasoning (Pepperberg, 1999). Alex was also reported to produce speech patterns and coin new labels by reconstructing parts of labels, such as ‘banerry’ referring to an apple which actually is a combination of a taste (banana) and a shape (cherry) (Pepperberg, 1999). He could also distinguish minimal pairs, for example ‘want tea’ vs ‘want pea’, suggesting that he recognized the meaningful difference at the phonemic level instead of processing the whole words as inseparable units (Patterson & Pepperberg, 1998). References got mapped to new speech patterns after Alex had produced them by spontaneous play, which also resembled conventionalized sound-meaning mapping through interactions in humans (Pepperberg, 2011). Astonishingly, Alex exhibited word segmentation ability and phonological awareness. He extracted phonemes or morphemes out of acquired labels and reconstructed them into novel vocal patterns (Pepperberg, 2007). These data indicate that in the auditory-vocal modality, grey parrots perform even better than nonhuman primates in symbol learning and language related categorical learning.

Other animals Two dolphins have been demonstrated to understand both vocal and gestural utterances with different word orders (Herman et al., 1984). A sea lion was also shown to differentiate gestures with the opposite order of direct and indirect objects (Schusterman & Gisiner, 1988). Domestic dogs have also been shown to map sounds onto objects and understand them as verbal referents (Kaminski, Call & Fischer, 2004). Chaser, a border collie, has been shown to successfully learn 1022 object names and three common nouns representing categories (Pilley & Reid, 2011). However, no evidence of neither vocal nor gestural productions has been given on other animals resembling the abilities of great apes.

Taken together, comparative evidence has shown that categorical learning presents an evolutionary continuity across invertebrates and vertebrates. In addition, some animals can be trained to produce (proto-)language like vocal and gestural productions, and even different word orders, although disputes exist. We will discuss how categorical perception could be an important cognitive foundation for language evolution from the neurological perspective in the following section.

The Neural Bases of Category Learning

The basal ganglia are a complex collection of structures located beneath the cerebral cortex which serve a variety of important functions in human cognition. In particular, they play an integral role in the control and coordination of voluntary movements and procedural memory formation (Hikosaka et al., 1998). Additionally, these structures act on cognitive processes such as learning, attentional focus (van Schouwenburg et al., 2010), motivation (Ikemoto et al., 2008) and reward-seeking behaviors (Ikemoto et al., 2015). Disruptions in normal basal ganglia function have been associated with a variety of disorders such as Parkinson's disease and Huntington's disease, and also language related impairment (Garybiel, 2000). In this section, we will first review the functions of basal ganglia in categorical learning in animals including humans. We will further show how basal ganglia are also implicated in language processing. The data reviewed in this section suggest that the functions of the basal ganglia in categorical learning form an evolutionary continuity between humans and animals.

Basal Ganglia and Categorical Learning in Animals

As an evolutionary conserved brain structure, functions of the basal ganglia found in human beings are also detected in animals. Lesion studies in rats and monkeys that demonstrated the tail of the caudate is both essential and sufficient for visual discrimination learning provided the first behavioral and neuroscience evidence that the basal ganglia might be important in category learning (Ashby & Ennis, 2006). In an experiment conducted by Antzoulatos & Miller (2011), monkeys were trained to categorize a variety of abstract stimuli made up of many dots into two possible groups. The results showed that striatum activity was an earlier predictor of the corresponding saccade when they were able to learn particular stimulus-response correlations. The neurocomputational model replicates the results in Antzoulatos & Miller (2011) and confirmed the functions of basal ganglia in the categorization task.

In bees, similar to basal ganglia dopamine neurons, it has been suggested that the VUMmx1 may be the neural substrate underlying the process of visual information and guiding their behaviors (Schultz et al. 1997). It contains neurons which receive signals from the eyes, allowing the bee to recognize shapes, colors, edges, and movement. Moreover, the complex network of neurons in the basal ganglia also helps bees distinguish between different types of objects, such as flowers or dangerous predators. Chemicals located within the neurons further influence how a honeybee perceives its surroundings, and studies suggest that when these chemicals are altered, visual perception changes drastically. The understanding of these networks is essential for understanding a honeybee's behavior and decision-making abilities since these properties are heavily correlated to vision processing capacity (Menzel, 2001).

The basal ganglia of birds, such as the pigeon, have been studied extensively in recent years in order to better understand their role in visual categorization. Research has demonstrated that the avian basal ganglia are involved in a variety of more complex information processing tasks related to object recognition, navigation and sensory integration, showing sophisticated cognitive abilities similar to those found in large-brained mammals. Evidence suggests that the avian basal ganglia may underlie some specialized behaviors found only within bird species, emphasizing its importance for guiding general behavior across a variety of scenarios (Soto, 2014). Besides, in vocal learning birds, the pallio-striatal circuits have been shown to play a key role in vocal learning processes (Jarvis, 2007), which is one kind of categorical learning as we have mentioned above, and have been argued to be analogous (and maybe homologous) to human cortico-basal ganglia networks (Pfenning et al, 2014).

Basal Ganglia and Categorical Learning

Recent research has suggested that the basal ganglia also play a crucial role in categorical learning, or the ability to group similar stimuli into distinct categories (Ashby and Ennis, 2006; Seger, 2006). One key mechanism by which the basal ganglia are thought to contribute to categorical learning is through their involvement in reinforcement learning (Bar-Gad et al., 2003). The basal ganglia are known to be involved in the processing of rewards and punishments, and they have been shown to play a critical role in adjusting behavior based on the outcomes of previous actions. This reinforcement learning process is thought to be critical for the formation of categories, as it allows the brain to learn which stimuli are associated with positive outcomes and which are associated with negative ones.

Another way in which the basal ganglia are thought to contribute to categorical learning is through their involvement in working memory. The basal ganglia are known to be involved in the maintenance of information in working memory, and this ability is thought to be important for the formation of categories. When an individual is presented with a new stimulus, the basal ganglia are thought to help maintain this stimulus in working memory, allowing the individual to compare it to previously encountered stimuli and form a category based on the similarities and differences.

There is also evidence that the basal ganglia play a role in the ability to switch between different categories (Ashby and Ennis, 2006). Studies have shown that the basal ganglia, particularly the striatum, are involved in the ability to switch between different mental sets or task-rules (Cools et al. 2004). This ability is thought to be critical for flexible behavior and problem-solving.

In summary, the basal ganglia are a key brain region involved in the process of categorical learning. They are believed to play a critical role in the formation of categories through their involvement in reinforcement learning, working memory, and the ability to switch between different categories. Further research is needed to fully understand the mechanisms by which the basal ganglia contribute to categorical learning.

Basal Ganglia and Language Processing

In addition to the functions of the basal ganglia in categorical learning, it has also been shown that the basal ganglia are involved in language processing, specifically in controlling the initiation and selection of movements for speech production, modulating the automaticity and fluency of language output, regulating attention, and executive control processes involved in language production and comprehension, and facilitating the learning and retrieval of language patterns and structures (Zenon & Olivier, 2014). In terms of speech production, the basal ganglia play a crucial role in the initiation and selection of movements that are necessary for speech. This includes movements of the muscles used in speaking, such as the lips, tongue, and larynx. The basal ganglia work in conjunction with other brain regions to plan and execute the complex movements required for speech, allowing us to produce fluent speech..

The basal ganglia also play a role in modulating the automaticity and fluency of language output (Silveri, 2021). Automaticity refers to the ease and speed with which we are able to perform a task without conscious effort. Fluency refers to the smoothness of speech. Research has shown that the basal ganglia are involved in controlling the automaticity and fluency of language production.

In addition, the basal ganglia are involved in regulating attention and executive control processes involved in language production and comprehension (Hazy et al. 2007). This includes processes such as working memory, attention shifting, and inhibitory control, which are critical for our ability to understand and produce language. For example, when we listen to someone speaking, we need to be able to pay attention to what they are saying, store that information in our working memory, and then retrieve and use it when it is our turn to speak. The basal ganglia play a role in these processes, allowing us to effectively use language in everyday communication.

Finally, the basal ganglia are involved in facilitating the learning and retrieval of language patterns and structures. This includes the rules of grammar and syntax, as well as the vocabulary and semantic information associated with words (Kotz et al. 2003; Kotz et al. 2009). Research has shown that the basal ganglia are involved in the consolidation of new language information into long-term memory, allowing us to effectively recall and use that information in the future.

In conclusion, the basal ganglia play a critical role in language processing, specifically in controlling the initiation and selection of movements for speech production, modulating the automaticity and fluency of language output, regulating attention and executive control processes involved in language production and comprehension, and facilitating the learning and retrieval of language patterns and structures. These functions are essential for our ability to effectively communicate with others using language. We have shown in the previous sections that categorical learning exhibits an evolutionary continuity in invertebrates and vertebrates, and that the basal ganglia play a key role in categorical learning across species. Thus, it is highly possible that categorical learning supported by the functions of basal ganglia served as a foundational role in the process of language evolution.

Conclusion

This paper investigates the potential role of categorical learning in language evolution. Categorical learning is one of the necessary abilities for language acquisition in phonological, lexical, semantic and syntactic levels. By reviewing comparative studies on categorical learning in different animals, we show that it exhibits an evolutionary continuity across invertebrates and vertebrates. Trained with language-like symbols, great apes can produce and reconstruct signs, sending requests by using lexigrams with flexible structures. Grey parrots are capable of segmenting phonemes out of different phonetic labels and recombining them into new labels. This shows that animals possess the mechanism of categorical learning and also can be trained to acquire language related categories. From the neurological perspective, the involvement of the basal ganglia in categorical learning in animals and language in humans supports the evolutionary continuity of categorical learning in animals and further indicates the role of categorical learning in language evolution. In conclusion, integrating comparative and neurological perspectives on categorical learning can help elucidate the structure and evolution of this ability central to language development and evolution.

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