

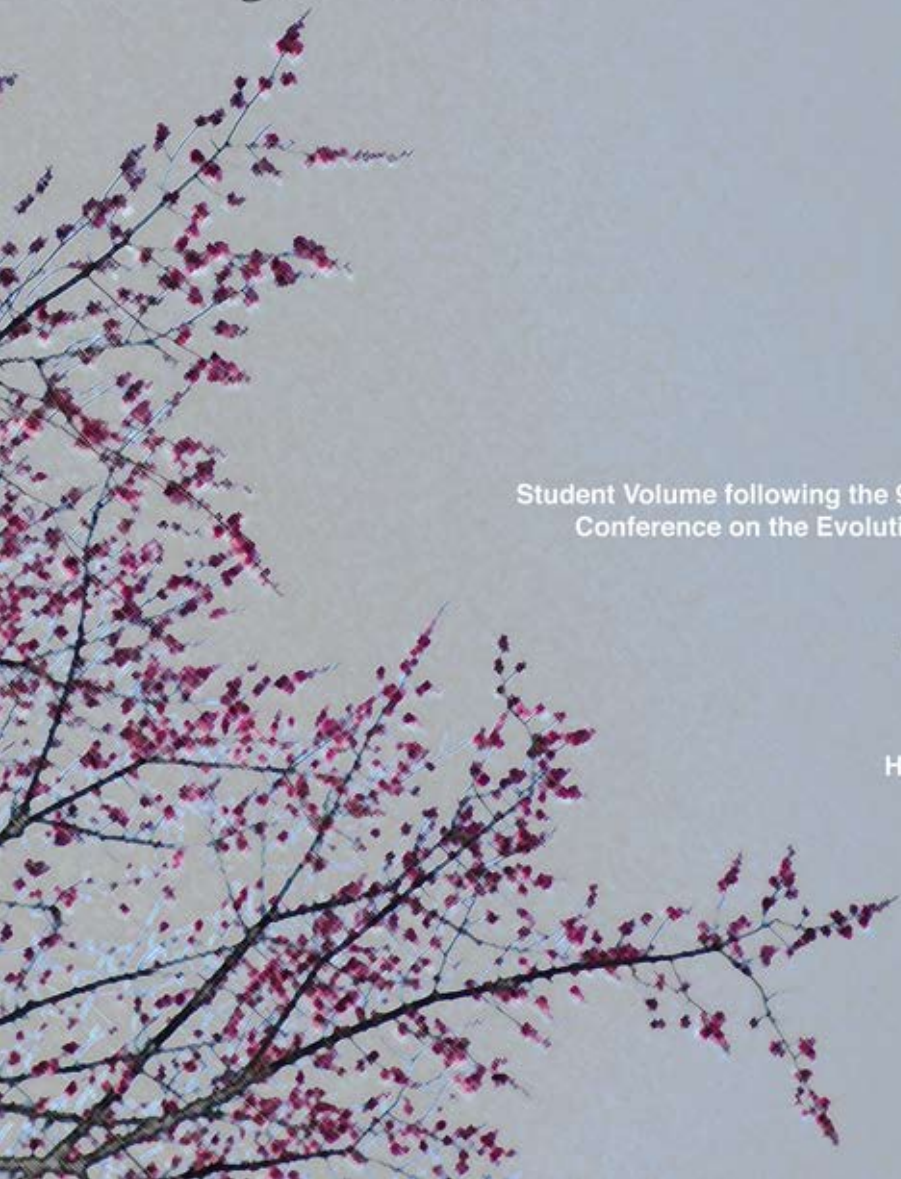
The Past, Present and Future



of Language Evolution Research

Student Volume following the 9th International
Conference on the Evolution of Language

Edited by
Luke McCrohon
Bill Thompson
Tessa Verhoef
Hajime Yamauchi



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Preface

The 9th International Conference on the Evolution of Language was held in Kyoto, Japan, between the 13th and 16th of March 2012. Following the conference, students who had presented papers were given the opportunity to submit papers on topics related to either the past, present or future of language evolution research.

A total of 19 submissions were received, of which 15 were chosen for inclusion in this volume by a process of peer review. The accepted papers span a wide range of topics and methodologies, providing a cross section of current research in evolutionary linguistics.

The preparation of this volume was financially supported by the *Japan Evolutionary Linguistics Forum (JELF)* and indirectly through the contributions of other Evolang sponsors. In addition to these organizations, thanks are due to the following individuals for their assistance:

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THE GESTURE THEORY OF LANGUAGE ORIGINS: CURRENT ISSUES AND BEYOND

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This paper explores the gesture theory of language origins and two alternative accounts based on the recent empirical evidence. Research from diverse fields suggests that gestures must be the key to understanding the evolution of language. Future research possibilities are also discussed.

Various theories have been proposed to explain the origins of human language. Many early studies focused on the evolution of non-speech vocalization into spoken language, i.e., vocal theories of language origins. A less known yet appealing alternative account is the gesture theory of language origins, which posits that human language began as gestures rather than vocalization. Codillac (1746/1971) was one of the first scholars to speculate that language in its infancy was not speech per se, but involved movements using the entire body. Although this somewhat counterintuitive theory has been continuously advocated for centuries by several scholars (e.g., Armstrong & Wilcox, 2007; Jóhannesson, 1950; Kelly et al., 2002; Paget, 1944; Rizzolatti & Arbib, 1998), it did not attract enough attention. With the advancement of research methods, however, recent studies in humans and other animals have provided empirical support for the importance of gestures in the evolution of language. Non-speech vocalization is not a sufficient foundation of language, and gestures must be taken into account to obtain a full picture of how language emerged.

1. Vocal Theories of Language Origins

Since the majority of the human populations use speech as the primary means of linguistic communication, it seems natural to think that spoken language evolved from less sophisticated forms of vocalization, more specifically, something similar to the vocal calls of other primates. For example, the vervet monkeys in East Africa use various vocal calls to communicate the presence of different predators such as leopards, eagles, or snakes (Cheney & Seyfarth, 1990). Their vocalization is not mimicry of the sound each predator makes, and

in this sense, their calls may be considered as reasonably arbitrary symbols similar to human language. However, the arbitrary symbols used by other animals and the vocabulary used in human language are largely different in their sizes (Tomasello & Zuberbühler, 2002).

Although animal vocal calls exhibit some variability, they are inflexible and only convey information about fixed situations. Their use is often limited to survival, e.g., avoiding predators, defending against aggressors, and discovering food (Tomasello & Zuberbühler, 2002). Furthermore, primate signals do not seem to have representational content; instead, they simply seem to reflect some characteristics of the environment or of the signaler's state. Cross-fostering studies found some modifications in the acoustic patterns of macaques' vocal calls (Masataka & Fujita, 1989; Owren, Dieter, Seyfarth, & Cheney, 1993); however, these modifications were limited to subtle changes in existing calls. Attempts to induce chimpanzees to say words by raising them in human families have also failed (Kellogg & Kellogg, 1933; Hayes, 1951).

In addition, vocalization in other primates is mostly non-voluntary and almost like a reflex to internal and external stimuli (Arbib, 2005; Tomasello, 2008). Non-human primate vocalizations are mainly emotional (e.g., Goodall, 1986), relying on the limbic system, whereas human speech is largely controlled by the cortex. According to Lieberman (2012), fossil evidence also suggests evolutionary changes in the human vocal tract such as the location of the larynx and pharynx. The supralaryngeal vocal tract (SVT), the airway above the larynx, was not fully developed for speaking until 50,000 years ago. Computer modeling studies also demonstrated that, with the range of tongue shapes that monkeys are able to make, it would be impossible for them to articulate certain vowels that are critical for human speech (Lieberman, Klatt, & Wilson, 1969; see Boe, Heim Honda, & Maeda, 2002 for an opposing view).

The evolutionary pathway from vocalization to speech seems less plausible especially when our closest relatives in the primate family have a quite limited ability to produce speech sounds. Although they exhibit outward resemblance, animal vocalization and human speech may be completely different systems.

2. Gesture Theory of Language Origins

While non-human primates almost completely fail to acquire spoken words, they are capable of learning various manual signs. For example, the chimpanzee Washoe acquired 132 manual signs within 51 months of training and even combined the signs to form sequences (Gardner & Gardner, 1978). Patterson (1978) also reported that her gorilla Koko acquired 100 signs in 30 months (see also Greenfield & Savage-Rumbaugh, 1990 for the case of bonobos). Their signs are not considered as language due to the lack of formal syntax; nevertheless, great apes exhibit remarkable signing abilities. Unlike their vocal calls, gestural communication of chimpanzees and other apes is socially and

cognitively complex and flexible (e.g., Liebal, Call, & Tomasello, 2004). These facts necessarily lead us to speculate that our hominid ancestors might have been better at gesturing than speaking as well.

The discovery of the mirror neuron system further boosted attention to the gesture theory. In the early 1990s, a group of Italian researchers identified unique neurons in area F5 in the ventral premotor cortex of a monkey. These neurons discharged when the monkey executed a particular action or when it observed another individual executing a similar action (di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992). Since the first discovery of these “mirror neurons,” extensive research identified other regions that possibly belong to the “mirror system” in humans, including Broca’s area (Iacoboni et al., 1999; Koski, Wohlschläger, Bekkering, Woods, & Dubeau, 2002). Rizzolatti and Arbib (1998) speculated that the neural circuits involved in language processing evolved as an elaboration of the mirror system (see also Arbib, 2005). According to their claim, the “proto-Broca” area was initially used for action recognition, and later extended its function to action imitation and to language. Cerebral lateralization of language and its relation to handedness may also suggest that manual gestures were the dominant form of communication (Hews, 1973). During vocalization, more right-hand gestures can be observed than left-hand gestures in humans and chimpanzees (Kimura, 1973; Hopkins & Cantero, 2003).

One of the most common refutations to the gestural theory is: If language evolved from gestures, why are spoken languages dominant in the modern world? The gesture theory claims that language began as gestures, and was gradually dominated by speech due to the advantages of speaking over signing. Spoken language frees the hands for other activities, and requires much less energy than gestures. In addition, speech allows for communication across distances as well as in the dark (Corballis, 2009). While most signers do not use speech sounds in their communication, speakers of any language seem to use gestures as a supplementary communicative tool (McNeil, 1992). Perhaps gesturing became non-dominant over time due to its higher flexibility and capability to supplement other modalities such as speech (Goldin-Meadow & McNeil, 1999).

The notion that language evolved from gestures seems very plausible. However, since humans split away from great apes well before the origination of language, cross-species research can only provide speculation. Even though our closest relatives are better at signing than speaking, their signing abilities are still limited and not comparable to human language.

3. Merging the Two Theories

Communication systems of other primates are considerably different from that of humans; thus there must have been an intermediate state that filled the gap in

the evolution of language. What theorists disagree on is whether gestures or vocal calls are the missing piece. But, do we need to choose one or the other? Instead, we may want to consider the possibility that gestures emerged together with other communicative tools. In other words, speech and gesture may have simultaneously evolved (McNeill, Bertenthal, Cole, & Gallagher, 2005).

Donald (1991) speculated that *Homo erectus*, an immediate predecessor of today's humans, used mimesis for communication. Mimesis is the voluntary use of one's body as a representational device, and this broad term embraces a range of behaviors such as pantomimes, facial expressions, and vocalization (Zlatev, 2002). In the absence of language, using various strategies to communicate messages appears to be most natural. For instance, if an individual is trying to convey the information that "his father is feeling sad," using a facial expression would be the easiest way. If he wants to inform others about the unknown animal sounds he heard, he may want to use vocalization to mimic the sound. Language could have been a multimodal system from its advent.

Even among those people who cannot speak or use a formal sign language, mimesis naturally emerges. Some researchers suggest that deaf children of hearing parents who are not exposed to sign language develop "homesigns" that possess many properties of language (e.g., Goldin-Meadow & Feldman, 1977). Congenitally blind children also spontaneously develop speech-accompanying gestures (Iverson, Tencer, Lany, & Goldin-Meadow, 2000). Further, anyone with normal speech can naturally use bodily gestures and speech sounds even when he is situated among speakers of an unknown language. These spontaneous acts can be regarded as another strong piece of evidence for the mimesis theory of language origins.

4. Future Research

Regarding the origins of human language, I have discussed three possibilities: vocalization, gesture, and the combination of the two. Although evidence suggests that gestures are the key component of our communication, the possibility of vocalization as the sole origins cannot be fully eliminated. However, advances in neuroscientific techniques may let us settle the debate.

Further improvement in the spatial and temporal resolution of brain imaging techniques, for instance, may help us examine whether the language areas and the mirror system indeed recruit the same neurons in a meaningful way. In fact, there has been an extensive discussion about whether the human mirror system actually participates in language processing (de Zubizaray, Postle, McMahon, Meredith, & Ashton, 2010). De Zubizaray et al. observed similar activation in Broca's area with action words, unrelated words, and non-words as well as hand-, face-, and foot-related words. From these results, they concluded that activation of Broca's area did not reflect the motor aspect of the area, but rather its general role of sequencing information. Their claim can be a serious

challenge to the core premise of the gesture theory. However, with the current fMRI technology, we could only discuss the topological “similarity” of brain activations.

Fortunately, new methodologies are continuously being developed. For instance, after decades of cumulating indirect evidence, mirror neurons in the human brain were recorded directly for the first time (Mukamel, Ekstrom, Kaplan, Iacoboni, & Fried, 2010). Extracellular activity was recorded from 1177 cells while human participants executed or observed hand grasping actions and facial emotional expressions. A significant proportion of neurons in supplementary motor area and hippocampus responded to both observation and execution of these actions. The study successfully informed us that more regions are involved in the human mirror neuron system than previously imagined. If these new methods are adapted to language research, we may be able to determine whether gestures and language in fact share common neural substrates in a critical way.

In addition to the neuroscientific research, interdisciplinary collaboration among biology, psychology, computer science, archaeology, and many other areas is much needed to tackle this convoluted yet fascinating problem. Moving beyond speculation is especially challenging in this research area; however, with rigorous efforts, we can continue to improve our speculative theory.

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GRADUAL VERSUS ABRUPT VIEWS IN EVOLANG CONFERENCES PAST AND PRESENT

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A long debate has existed over whether language evolved gradually through incremental changes over a long period of time, or abruptly through genetic mutation. At the most recent Evolang Conference in Kyoto, Japan, this issue was readdressed by Jim Hurford in his talk on not only the gradual evolution of language, but of syntax. In the first Evolang held in Edinburgh in 1996, the audience and contributors were less diverse in views and backgrounds as they are today. At Kyoto especially, a varied crowd (including those who align themselves with biolinguistics) were present. Biolinguistics take the line that language might have arisen by mutations, in an abrupt fashion. This paper looks at the first as well as most recent Evolang proceedings that concern the gradualist/abruptist debate, to look at how the discussion has changed.

1. Introduction

In the many models of language's origin and evolution, both gradual and abrupt approaches are common. In the 16 years of biennial Evolang conferences, it can be expected that with the discipline's increasing popularity and breadth of participation, that this issue has undergone changes in support. Even with recent advances in genetics, neurolinguistics and zoological studies, the case has not simply been of one view coming out as consensus. The broadened interest of researchers into language origins, especially the increased discussion from linguists and the new field of biolinguistics, means that views are in fact more varied than they were a decade and a half ago. Indeed, it is clear in comparing the first and most recent proceedings of these conferences that the debate, though not often directly addressed but always implied, remains a rift between distinct camps.

2. The First Evolang Conference Proceedings

The result of the first Evolang conference was a proceedings edited by Jim Hurford, Michael Studdert-Kennedy and Chris Knight, called *Approaches to the Evolution of Language* (1998, henceforth *Approaches*). In the Introduction, Knight notes the gradual versus abrupt debate as a central question in evolutionary linguistics: “Did complex, syntactical speech emerge in a relatively sudden ‘leap’? Or can gradualist models explain its evolution?” (p. 9) The papers in *Approaches* have an emphasis on primate ancestry and comparative analysis of primate groups as a model of early human societies (including issues of altruism, group size, theory of mind, and grooming). Most models of language evolution assume a gradualist view outright, or propose models that by their nature are necessarily gradualist.

Throughout the first proceedings, language as a gradually evolving versus an abruptly appearing phenomenon is a heavily debated issue. Most discussions surround whether or not language evolved from animal communication and cognition (continuous), or a distinct and unique mechanism in human behaviour (discontinuist). The discontinuous stance is called “antievolutionary” in one article in *Approaches* (Ulbaek 1998), and indeed most evolutionary linguists of the time saw Cartesian/Chomskian theorists as having dismissed evolution’s role in the origin of language.

Articles with gradually evolving language as a central theme appear in many of the articles in *Approaches*. In Jean Aitchison’s article, “On discontinuing the continuity-discontinuity debate”, she notes how dichotomies are often useful for focussing attention within wide ranging topics, particularly at the beginning stages of research. She suggests that the continuity-discontinuity debate should be phased out, evoking language’s ‘mosaic evolution’, where some aspects might have strong continuity and others little, and therefore it is not a helpful way of framing the discussion. She then speaks of new dichotomies, which can serve as ‘stepping stones’: one being the gradualism versus abruptism question.

Merlin Donald writes of “the obligation on theorists in this field to build credible bridges between primate cognition and human language, and to purge any implied saltation or evolutionary miracles from their proposals.” (p. 45) He argues for a gradual evolution of language because, “language is the most complex of human skills; the simpler ones [components the author suggests] probably came first. Even protolanguage could not have evolved before the central executive apparatus had reached a certain point.” (p. 57)

Robert Worden summarises the sentiment of many writers in *Approaches*, saying,

“...it seems highly unlikely that the whole human language faculty – with its capacity for unbounded meaning structures, complex syntax, robust production, understanding and learning, links to the auditory channel and to other meaning structures in the brain – could be specified in a mere 5,000 bytes of information. Therefore we should look for theories in which language did not arise de novo in the human brain, but is based in pre-existing animal cognitive faculties.” (pp. 150-151)

He calls this an ‘evolutionary speed limit’.

In “Catastrophic evolution: the case for a single step from protolanguage to full human language”, Derek Bickerton has an interesting view of language's evolution – for while he is a supporter of the gradual evolution of language in that he posits multiple steps evolving through biological and cultural evolution (Bickerton 1998, 2009), he insists that the acquisition of fully modern syntax would have been a single step process through the acquisition of a single rule. This view of language developing slowly at first is prolific in language evolution models, but often takes on an abrupt view when it comes to syntax. It can be associated with now mostly unfavoured ideas about an Upper Palaeolithic cultural revolution in Europe (a more gradual accumulation of cultural and material complexity originating over tens or hundreds of thousands of years earlier is now more favoured (McBrearty 2007)).

Generally, *Approaches* contains models of language evolution which either outwardly support or implicitly suggest a gradual evolution of language, and in addition, denounce abrupt theories. The issue of gradual versus abrupt models of language evolution is central to this proceedings, contra the most recent proceedings from the 2012 Evolang conference.

3. Proceedings of the 9th International Conference

At the Kyoto Evolang conference and in Proceedings 9, the issue of abrupt versus gradual language evolution is less directly addressed, but still assumed as one or the other by most authors in their models. The major difference between the two proceedings is that by the 2012 volume, the conference and discipline itself have undergone a great increase in breadth and depth of participation; research areas have emerged in such topics as birdsong, pointing, neurological studies, the internet and language, historical linguistics, and multitudes of computer modelling studies of various aspects of language development. Another obvious difference between the two proceedings is their size: while the

first proceedings included just 25 papers, the 9th included 51 full papers as well as 84 abstracts.

It could be anticipated that the 9th proceedings would include much more nativist approaches to language evolution models, because of the increasing numbers of biolinguists participating in the discipline and presenting at Evolang 8. Biolinguistics is an approach to language origins with an emphasis on the biological and evolutionary origins of language. It is often aligned with the Chomskian school of linguistics evoking an evolved language faculty and striving to understand the principles underlying mental recursion. Noam Chomsky himself was originally set as a keynote speaker for the Kyoto conference, but would later be replaced by Massimo Piatelli-Palmarini, another linguist who aligns himself with the biolinguistics perspective of language as mutation. At the conference he spoke against the seminal gradualist Pinker and Bloom (1991) paper about language as a product of natural selection, and instead looked to Fibonacci sequences as a possible origin of some parts of language structure (Piatelli-Palmarini & Uriagereka 2008). An abstract or paper by Piatelli-Palmarini does not appear in the proceedings.

Most papers that appear in the 9th proceedings, if supporting one or another view, do support a gradual emergence of language as papers in *Approaches* did. However, it is a markedly less directly addressed issue than it had been previously. Arbib (2012, p. 3) illustrated his gradual model of language evolution and correlated it with archaeological events in the record, which conforms to a gradualist version of difference stages in the evolution of language as evidenced by the material culture. Gil (2012, p. 134) discussed a single element of language structure, predication, and how it might have emerged, evoking that different structures of language emerged at different times, and not all at once as part of a macromutational package.

Hurford (2012, p.165), however, opens the discussion of gradual evolution of language to a greater resolution by supporting the gradual evolution of syntax, contra Bickerton in his *Approaches* paper. This can be perhaps seen as a turning point in the discussion of the gradualist versus abruptist debate, as gradualism itself is being considered in an even more gradualist way.

Only two articles in the 9th proceedings were found to overtly reject a model of gradual language evolution and favour an abruptist view, and both of these were abstracts. “Recent archaeological evidence suggests much earlier emergence of UG” (Ike-Uchi 2012), supports the language-as-mutation view, and “No words without syntax no syntax without words” (Rosselló et al 2012), rejects the possibility of a protolanguage stage, à la Bickerton (1996), and supports both syntax and phonology appearing simultaneously in language.

In sum, the 9th proceedings less directly addressed the gradualism versus abruptism debate, but at the same time put forth a less unified view compared with the first proceedings. This is likely to be because of the increased participation in discussions of language's origins from different disciplines.

4. Conclusion

We can reflect on the different approaches to the question of gradualism versus abruptism by considering Jean Aitchison's suggestion in the first proceedings. The dichotomy of language as having a gradual or abrupt origin is one that has helped researchers frame questions and focus issues. With the ever broadening discipline, evolutionary linguistics is growing not only in interest and participation numbers, but in the different kinds of research backgrounds and collaborations between disciplines, the research areas being explored and questions being asked.

While the field is not at a consensus when considering the issue of gradualism versus abruptism, we can clearly see that the source of the division is rooted deeper in broader issues of views on what language is and how it works. Most language evolution models can be seen to adhere to either a nativist Chomskian approach versus an evolutionary/cognitive approach. The proceedings of the Evolang conferences stand as a record of how issues such as the gradualist versus abruptist debate has changed through the years.

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THE ORIGIN OF LANGUAGE AND MUSIC – COMMON OR SEPARATE? A NEUROSCIENTIFIC APPROACH

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As capacities unique to human beings, language and music share a few parallels. Concerning their origins, there have been different positions for several centuries. Recently developed neuroscientific technologies offer new opportunities to investigate this topical issue in connection with a comparative approach by providing new evidence and generating new hypotheses. Currently, more evidence from the non-western tradition is also needed to enrich these results.

1. The Topical Issue of whether the Origin of Language and Music are Common or Separate

The question of a common or separate origin of language and music, which was the centre of hot debates between philosophers and scientists from the seventeenth to the nineteenth century, is now being examined using tools and technologies (Besson & Schön, 2003).

The first fact tying the origin of language and music together is that these two domains differentiate human beings from other species. This alone would seem to hint that there is some connection in evolutionary origin. As far as language is concerned, Bickerton (1995) argued that an animal only has a primary representational system, which is described as “on-line thinking”. On the contrary, humans have both a primary representational system and a secondary representational system, which is glossed as “off-line thinking”. In this way, humans free themselves from the “here and now”. For music, Patel (2008) proposed that animals’ “music” is only the consequence of auditory capacity; it is not the music we know as humans. Despite of some traits of language-like and music-like processing in other species in biological evolution, these two domains are species-specific to humans in a strict way. As Bickerton (2009:62) stated “They are both universal in the human species and both unique

to it. Each is distinguished by having structure that is complex as well as rule-governed, and by being potentially infinite and open-ended”.

The second fact tying the origin of language and music together is the parallels between them, which provide a very useful starting point for examining possible evolutionary pathways. In spite of strong divergences at the level of meaning, significant common points exist in these two domains in their grammatical structure and phonology. First of all, we perceive the sounds as a sequence of pulses in both – in language as syllables, in music as notes (Fenk, 2009). Secondly, both language and music are hierarchically structured signals (Fitch, 2006). Unlike animal vocal communication systems they are recursive generative phrasing systems (Hauser et al., 2002). Thirdly, both language and music show rhythm and intonation. Musical and linguistic phrases can undergo changes in conveyed emotion through variation in pitch, amplitude, tempo, rhythm, etc. (Patel et al., 1998a).

Owing to the above reasons, scholars have been discussing language and music together from an evolutionary perspective (e.g. Fitch’s (2010) design features of music and language). The questions of whether they share a common origin and which one came first become central topics in this discussion.

2. Historical Research on the Origin of Language and Music

2.1. Possible Relations of the Origin of Language and Music

Concerning the evolutionary relationship between language and music, there are four possibilities. First, language and music could have had different ancestors, and then evolved individually and separately in a parallel style, as illustrated in (1.1). Second, one common ancestor could have split into language and music respectively, as illustrated in (1.2). Third, language and music could be descendents of a common ancestor, and language was a precursor of music as illustrated in (1.3). Fourth, language and music could have been descendents of a common ancestor, but music was a precursor of language, as illustrated in (1.4).

2.2. Historical Research on the Origins of Language and Music

Historically, several outstanding contributors to this field must be mentioned. Rousseau, one pioneer who paid attention to the origin issue between language and music, was a strong advocate of the view that they share some common ancestor and that language evolved out of music for the sake of a rational organization of human societies (Rousseau 1781). Darwin’s conjecture of 1871 also argued for a common origin, but considered that music evolved out of the primate’s reproductive calls and that language was first (Darwin 1871).

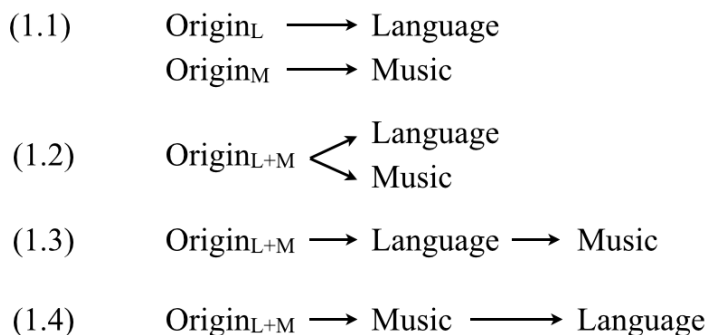


Figure 1: Four possible evolutionary relationships between language and music (small letter of L and M represents language and music respectively).

Recently, with the increasing interest in comparative research on language, music, and the brain, the opinions about this origin issue are more apparently controversial. Noam Chomsky proposes that music, like mathematics or the structure of the natural number system, is an evolutionary derivative of the language faculty. Brown supports a similar position and argues (2001) that music and language are homologous functions that evolved from a common ancestor that embodied their shared features, something he refers to “musilanguage” system. In contrast, researchers such as Pinker (1997), Jackendoff (2009) and Bickerton (2009) remain doubtful of language theories that connect language with music in human evolution. Pinker (1997) dismisses music as being of no adaptive purpose. Jackendoff points out structural differences in both domains and raises doubts about a comparative approach because “at the moment we don’t have a properly laid out account of even one other capacity against which to compare language and music.” (Jackendoff 2009: 203). He suggests further that language and music should be completely different and have no real common evolutionary history. Bickerton is skeptical about tracing the origins of language back to only one main cause or “single umbrella theory”. He clarifies his position in a very succinct and direct way: “A single source for music and language becomes highly unlikely” (2009:64).

The evolution of language and music will benefit from comparative and experimental approaches (Fitch 2010; Arbib 2012). The up-to-date technologies in connection with a comparative paradigm offer promising possibilities to test and investigate theories of language and music evolution empirically. In the following discussion we’ll focus on a neuroscientific perspective for such endeavor.

3. Revisit this Topical Issue with a Neuroscientific Approach

3.1. *Bridging the Gap between the Origin Issue and Neuroscience*

“The relevant hypothesis of neural resource and the origin” proposed in this paper intends to bridge the gap between the origin issue and neuroscience. The central idea is that the overlapping of neural resources used by language and music is related to the degree of commonality in origin. The “neural resource” in this hypothesis is the neural networks and mechanisms that are involved in the processing of language or music.

This current neuroscientific approach is a necessary complement to the well-known philosophical, linguistic and musical approaches. In general, philosophy isn’t concerned with empirical research. Linguistics and musicology traditionally focuses on the features of language or music. The neuroscientific approach would offer promising comparative empirical evidence of the neural processes necessary for language and music, which can not be provided by linguistics, musicology or even philosophy. The identification of functional architecture obtained from neurological research is going to be an integral part in investigating the origin issue.

With respect to the four possible evolutionary relations proposed above, the “relevant hypothesis” is included four testable predictions. These are what language and music look like in the brain if they come from the same origin, if they come from different origins, if language comes first in their evolution, and if music comes first respectively. Considering that this paper in particular points out the necessity of combining neuroscience and evolution for arguing a same or different origin and how this can be investigated empirically, we are going to discuss the first and second possibilities of the hypothesis below. These are what the neural resource in the brain will be when music and language have a common origin versus a different origin.

Ecology states that species which come from the same ancestor will have common properties. Archaeobiology holds the idea that the correspondent organs are similar among species if they originate from a same source. By analogy with ecology or archaeobiology, neuroscientifically, if language and music have a common origin, they will share similar neural resources. Such an idea can be illustrated as figure (2.1). Language and music originate from the same ancestor. They have separate but overlapping resource requirements which are in the same system. Dotted lines mean language neural resources and music neural resources are open to each other.

Conversely, if language and music derivate from different origins, they will have separate and distinctive neural resources which may or may not reside in the same system. Such idea can be illustrated as figure (2.2). Language and music originate from different ancestors. Their neural resources are separate and distinctive. Dotted lines mean the question of the same system is open.

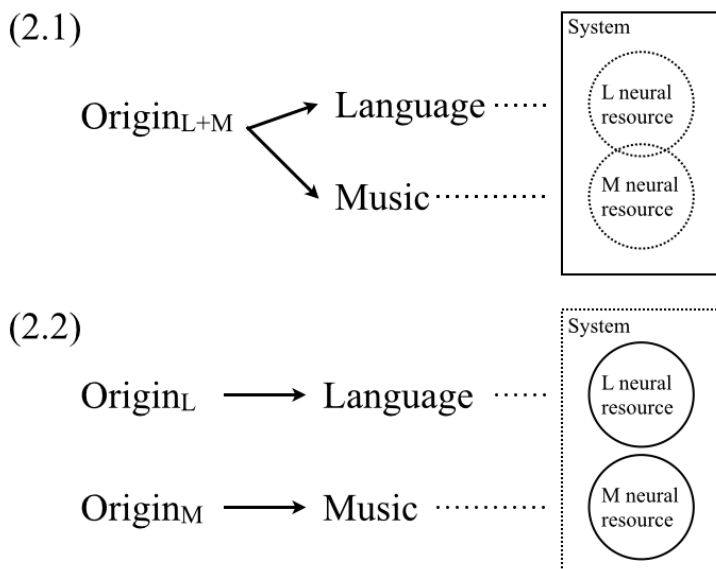


Figure 2. The relevant hypothesis of neural resource and the origin

3.2. *Neuroscientific Research Results*

As mentioned at the beginning, the question of a common or separate origin of language and music is now being examined using new tools and technologies. One of the most promising avenues is functional brain imaging (Besson & Schön, 2003), which is aimed at understanding the functional activity of the brain activity.

Three arrangements for localization of music and language have been reported in a review by Wallin, Merker & Brown (1999) where the authors argue that “music and language share cerebral representation; that they have overlapping representations in the same hemisphere; and they have corresponding (i.e. homologous) localizations in the opposite hemisphere.” Wallin, Merker & Brown (1999) also point out that “the relationship between the cerebral localization of music and language is essential for understanding the evolutionary relationship between these two important human functions”.

A series of experiments mainly using the event-related brain potential methods were conducted to compare different levels of processing in language and music. Patel et al. (1998b) claimed that ERP data argued against the language-specificity of the P600 and suggested that some aspects of syntactic processing are shared between these two domains. He proposed a novel hypothesis where linguistic and musical syntactic processing engage different cognitive operations, but rely on a common set of neural resources for structural

integration in working memory. Koelsch, Gunter, Wittfoth & Sammler (2005), confirmed that the processing of musical syntax interacts with the processing of linguistic syntax. Besson & Schön (2003) got three conclusions from their series of ERP experiments: their results favour language specificity for semantics; while in terms of syntax, but general cognitive resources for syntax; Furthermore, analysis of the temporal structure led to similar effects in language and music.

In addition, Masess et al. (2001) found out with MEG and source analysis that incongruent music was processed in Broca's area. This finding strongly offers the evidence that musical syntax is processed in the area where language is processed too.

3.3. Tentative Conclusion

The evidence from previous neuroscientific studies tends to support the idea that language and music share a common origin. However, whether the neural resources on which they rely have split completely is still undecided. A comparative approach in connection with the neurosciences seems necessary to provide new data and insights to address this issue. One additional issue is that almost all the empirical studies are based on both Western language and Western music. More evidence from the non-western tradition is needed to test and develop our tentative conclusion.

4. Remarks

The parallels between language and music motivate researchers to explore whether they have a common origin. After several centuries of investigation, the modern neuroscientific technologies offer new opportunities to investigate this topical issue. Various linguistic and musical systems in different cultures are required in this investigation. Finally, the fundamental point in combining neuroscience and evolution is to build a comprehensive theory to improve the approach to the investigation of the origin relations between language and music.

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CULTURAL EVOLUTION, COMPRESSION AND THE BRAIN

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The influence of cultural evolution on the way linguistic structure emerges is increasingly being studied with the use of laboratory experiments. This method has generated a vast amount of data in the past few years and in this paper a selection of the results is reviewed. The focus is on the emergence of compressible and predictable systems, which appears to be a prevalent result of cultural transmission experiments. These results are assumed to be a reflection of general cognitive biases. To reach a deeper understanding of the nature of these biases or where they may come from, exciting results from the field of computational neuroscience are reviewed and it is suggested that an integrative framework combining cultural evolution research and neuroscience would benefit the field of language evolution.

1. Introduction

Recent developments in the field of language evolution have shown an increased interest in the adoption of experimental methods. This trend follows a period in which it was recognized that language should be viewed as a complex adaptive dynamical system (Steels, 1997; Brighton & Kirby, 2001), and computer simulations were used to show the importance of social and cultural processes for language evolution dynamics (e.g. Steels (1997), Brighton and Kirby (2001), Kirby and Hurford (2002)). Now the findings of such computer simulations are being replicated in the laboratory with human participants. Focussing on the method of iterated learning (Kirby & Hurford, 2002), this paper reviews some of the experimental work in the light of an overarching theme in their results: compressibility and predictability (Brighton & Kirby, 2001; Smith & Wonnacott, 2010). Then, some findings from the field of computational neuroscience are discussed that could help to explain the results of iterated learning experiments.

2. Experimental iterated learning and compression

In this paper the focus is on the method of experimental iterated learning. Iterated learning simulates how behaviors such as language are culturally transmitted. This mechanism has been studied with computer models through agent-based simulations (Kirby, 2001; Brighton & Kirby, 2001; Kirby & Hurford, 2002; Kirby,

Smith, & Brighton, 2004) and mathematical analyses (Griffiths & Kalish, 2007) and it has been demonstrated that cultural transmission plays an important role in how languages are shaped. Kirby, Cornish, and Smith (2008) introduced a method in the field of language evolution which allowed them to replicate the findings of computer models in the laboratory by doing iterated learning experiments with human participants. In this method a transmission chain of learners is created by exposing participants to input data that is created on the basis of the learning-outcome of their predecessors in the experiment. The development of the system that is being transmitted can be closely investigated and it reveals how individual (cognitive) biases cumulatively influence this system. Kirby et al. (2008) demonstrated the emergence of compositional syntactic structure using this method. The utterances in these languages were typed strings referring to objects that differed in shape, color and movement. With an increasing number of iterations of learning and reproduction, the compositional structure in these languages cumulatively increased and the languages became easier to learn. At the end almost all words of one of the languages were composed of three syllables, where each syllable consistently coded one of the three dimensions in the meaning space. This regularity made it possible for participants to even predict the words for objects they had never been exposed to during training. This is a first example of how iterated learning results in a language that is predictable and efficiently coded. We could argue that iterated learning in general leads to emerging behaviors that are predictable and for which the knowledge or information can be coded efficiently. In the following more examples will be reviewed to strengthen the observation that compressibility appears to be a recurring theme.

Real and Griffiths (2009) studied the development of an artificial language consisting of spoken sequences of syllables as words for objects, where each object was associated with one of two different words with a certain probability. Participants' knowledge of the learned language was tested by asking them to select one of the two words as the right one with a forced choice task. Based on the responses of one participant, the probabilities of the word-object pairings for the input-language for the next person were determined. After some iterations of this procedure it became clear that synonymy in the languages disappeared. The unpredictable variation in the word-object relations got regularized, yielding the languages more compressible and efficient.

A similar loss of unpredictable variation was found by Smith and Wonnacott (2010) in artificial languages with morphological variability. Here, participants learned and reproduced sentences describing a scene involving either one cartoon animal or a pair of the same cartoon animals. Plurality was indicated with two different markers that were both used in combination with each of the nouns referring to the cartoon animals, but with different frequencies. This made the use of plural marking unpredictable and irregular. In the language that was passed on to the next participant, the produced sentences from the previous person were used.

After repeated iterations of learning and production, the variability in plural marking did not disappear in all languages, but it did become more regular. The nouns ended up being used exclusively with one of the two plural markers, which made the system more predictable. Conditional entropy was used as a direct measure of unpredictability and this value was shown to cumulatively decrease significantly with increasing number of iterations.

Studying the emergence of phonological combinatorial structure, Verhoef, de Boer, and Kirby (2012) used artificial whistled languages in which participants produced utterances with a slide whistle. The continuous whistled signals did not refer to any meanings, but a set of whistle words needed to be memorized and recalled. The recalled productions of one participant were used as the input set for the next. After ten transmissions from participant to participant, combinatorial structure emerged in the sets of whistles. A discrete set of basic building blocks could be identified in the sounds and these were reused and combined in a predictable way. Figure 1 shows an example of a set of whistles that emerged as part of an emerging language in this study. Quantitatively, a cumulative decrease of entropy over the reuse of basic elements could be measured in the languages, indicating that equally large languages could be described using fewer basic elements. The whistled systems therefore became more constrained and predictable as well as more compressible.

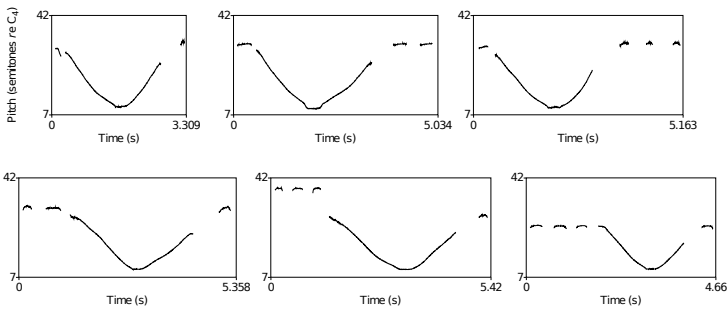


Figure 1. Fragment of a set of whistles plotted as pitch tracks that emerged through cultural transmission in the experiment of Verhoef, de Boer and Kirby (2012). Basic elements can be identified that are systematically recombined.

Very similar results were found with the use of continuous visual signals (del Giudice, 2012). Languages in these experiments consisted of scribbled signals created with a stylus on a digitizing pad. After transmission from participant to participant, the signals started to share an increasing amount of basic units and the systems became easier to learn and recall. Even when the signals were paired

with meanings, the emergence of signal-internal structure could be observed. It did not seem to be the case that the form-meaning mappings became more iconic, or started to have increasingly transparent semiotic relations. Instead, the systems appeared to become more learnable as a result of an increase in reuse of basic elements and an increase in compressibility of the signals (del Giudice, 2012).

The experimental iterated learning method has not only been used to study language evolution dynamics, but has also been applied to other cognitive tasks including category learning. Griffiths, Christian, and Kalish (2008) used the iterated learning paradigm to study human inductive biases for learning different types of category structures. They used a set of category structures for which it had previously been shown that the difficulty of learning these structures could be predicted by the incompressibility of the member concepts (Feldman, 2000). The concepts in these studies were ‘amoebas’ that contained a nucleus which differed according to three binary features: shape, size and color. In the iterated learning study (Griffiths et al., 2008), participants were presented with examples from categories of amoeba and were asked to select an hypothesis (choosing from a number of different completions of the set) that they thought best described the underlying category structure. New input data was generated following the distribution of the chosen types of category structures in a participants’ responses. The results showed that those category structures that Feldman (2000) found to be more easily learned and for which the member concepts are more compressible, were increasingly chosen across generations of iterated learning. This reflects a bias towards these more compressible structures and shows that human learning and generalizing from a few examples results in categories of amoebas that can be more efficiently coded.

These experiments all demonstrate how structured behavior evolves culturally and comes to reflect human cognitive biases and constraints on learning, memory and production (Griffiths & Kalish, 2007; Kirby & Hurford, 2002; Christiansen & Chater, 2008; Deacon, 1997). After they have been transmitted over a number of experimental generations, human overgeneralization causes transmitted systems to become regularized. For theories about language evolution these studies provide important evidence in favor of ideas suggesting that linguistic structure is shaped by the brain (Christiansen & Chater, 2008; Deacon, 1997) and emerges as a compromise between compressibility and expressivity (Kirby, 2012).

3. Compression and the brain

The experiments discussed in the previous paragraph indicate that linguistic structure may be the result of an evolutionary process in which languages gradually adapt to be learnable by their users (Kirby et al., 2008), but it also seems to reflect a general tendency of the brain to compress information and make predictions. Some of the computer models about iterated learning have incorporated this idea, using models that implement inductive learning strategies such as minimal de-

scription length learning (Brighton & Kirby, 2001; Brighton, 2005) or Bayesian prediction (Griffiths & Kalish, 2007). These models are formed by making realistic abstractions of what we think the brain does and successfully simulate behavior of participants. To gain a deeper understanding of what it is exactly about the human brain that leads to the observed iterated learning results and to learn more about the nature of relevant cognitive biases or where these biases may come from, it may be informative to look at some interesting results from the field of neuroscience.

The idea that brains encode information efficiently is not at all new. Many years ago Barlow (1961) already proposed that efficiency plays a role in the coding of sensory information and at present many brain theories and learning models exist that are based on this assumption (see for instance Chater and Vitányi (2003), Olshausen and Field (2004), Schmidhuber (2009), Friston (2010)). In the domain of cognitive processing, Chater and Vitányi (2003) present a review of studies that link cognitive tasks with efficient coding and discuss empirical evidence in line with their ‘simplicity principle’. These studies encompass all kinds of cognitive and perceptive tasks, including linguistic processing. This principle has been applied to model language acquisition as well (Onnis, Roberts, & Chater, 2002). For decades neuroscientists have studied the hypothesis that compression and simplicity are important principles in neural processing with advanced computational techniques and precise measurements of neural responses of for instance cats, rats, monkeys and rabbits (as reviewed by Olshausen and Field (2004)). The studies that seem to be of particular interest to us are those in which it is demonstrated that brain processes are adapted to encode natural stimuli most efficiently.

A large body of work on this has been dedicated to the visual domain and more recently similar results have been found for auditory signals. Simoncelli and Olshausen (2001) review work in which the efficient coding principle is tested in visual systems. They give an overview of the regularities and statistical structure that can be found in natural images (such as mountains, rocks, trees) and present many examples of quantitative evidence in which these regularities are linked with structured neural responses. The main approach in this field is to create a model, and to adjust the parameters in such a way that the model optimally encodes the input data, for instance a set of images. Optimality is usually some measure on how well the input data can be reconstructed from the coded data. The resulting representations are then compared with real neural data. Olshausen and Field (1996, 1997) for instance define a model in which images are encoded using linear combinations of basis functions. The set of functions is updated in the direction of an optimally efficient code. Properties of the basis functions that emerge as the final solution resemble those of single cell receptive fields in the early visual (V1) system (Olshausen & Field, 1996, 1997), suggesting that these receptive fields encode natural stimuli efficiently.

In the auditory domain similar methods have been used (Lewicki, 2002; Smith

& Lewicki, 2006). Smith and Lewicki (2006) used a model that encoded sounds as a set of basis functions. These functions could have different shapes, lengths and onset times and they were optimized so that they encoded natural sounds (such as animal vocalizations, rain, cracking twigs) most efficiently. In parallel, response functions were computed for auditory nerve fibre measurements of a cat listening to the same set of sounds. The set of basis functions that emerged in the computational model was compared to the set from the actual brain measurements and these were found to be remarkably similar. This suggests that the cat brain encodes the structure present in natural sounds in an efficient way. Interestingly, Smith and Lewicki (2006) performed the same procedure with their model to find a set of functions optimized for the sounds of human speech. What they found was very similar to the results with natural sounds, namely that the basis functions that efficiently encode speech also closely resemble auditory response functions of a cat. This suggests that the sounds used for speech are likely adapted to the efficient auditory coding of the mammalian brain. Comparable results have recently been found with another efficient coding model for speech and comparisons with neural structures higher up the auditory pathway, as measured in cats and gerbils (Carlson, Ming, & DeWeese, 2012).

4. Discussion

In this paper several cultural transmission experiments are shown to be linked with a prevalent tendency towards compressibility and efficient coding. It has been suggested that this tendency reflects the way transmitted systems adapt to human biases (Griffiths & Kalish, 2007; Kirby & Hurford, 2002; Christiansen & Chater, 2008; Deacon, 1997). To find out more about the exact nature of such biases and where they may come from, we looked at the field of neuroscience, in which principles about simplicity and efficient coding are widespread. The study by Smith and Lewicki (2006) in particular provides convincing evidence in favor of the view that the sounds used in language are adapted to the (mammalian) auditory cortex. Since it is implausible that cat auditory processing has evolved to efficiently encode human speech, we may well assume that the sounds used in speech have adapted to be efficiently coded by the brain. Likewise, it is expected that linguistic structure at other levels of organisation has adapted to general cognitive ‘simplicity’ biases (Chater & Vitányi, 2003) and is shaped in such a way that it is compressible. The study by Smith and Lewicki (2006) provides an exciting example of direct evidence of adaptation through cultural evolution and even though this has so far only been shown for very early processing and sound primitives for speech, it is a promising avenue for further research. Following this direction we should try to formulate experiments and create biologically plausible models that can provide this kind of evidence for other levels of organisation in linguistic structure as well.

As Deacon (1997, 2009) shows, researchers have not been able to associate

human language behavior with a unique change or difference in brain anatomy as compared to non-human ancestors. Instead it is likely that a large variety of systems, with perhaps different functions in our ancestors, contributed to and are involved in modern human linguistic behavior. The study by Smith and Lewicki (2006) is a brilliant example of how such a homologous system (involving auditory processing in this case) can be linked to efficient coding of speech sounds in non-human species. There may be other aspects of language processing and learning for which it is possible to demonstrate preferences or efficient coding in homologous systems inside non-human mammalian brains. The method of demonstrating such efficiency by predicting properties of measurable brain responses through computational modeling of optimally efficient coding is a path that deserves exploring. Especially in the case that we can show this effect for cognitive processing of (linguistic) compositional and combinatorial structure, this would be compelling evidence against language-specific biological adaptations and must indicate a strong influence of general cognition and cultural evolution. In addition, this may be a direction that can potentially reveal relevant differences between human and non-human processing. Perhaps it is therefore time for an integrative framework combining the study of cultural transmission, the systems that emerge from it and the neuroscientific study of efficient coding in the brain.

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THE CHIMP CHALLENGE: VISUAL WORKING MEMORY IN CHIMPS AND HUMANS

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Matsuzawa (2012) presented work at Evolang demonstrating the working memory abilities of chimpanzees. (Inoue & Matsuzawa, 2007) found that chimpanzees can correctly remember the location of 9 randomly arranged numerals displayed for 210ms - shorter than an average human eye saccade. Humans, however, perform poorly at this task. Matsuzawa suggests a semantic link hypothesis: while chimps have good visual, eidetic memory, humans are good at symbolic associations. The extra information in the semantic, linguistic links that humans possess increase the load on working memory and make this task difficult for them. We were interested to see if a wider search could find humans that matched the performance of the chimpanzees. We created an online version of the experiment and challenged people to play. We also attempted to run a non-semantic version of the task to see if this made the task easier. We found that, while humans can perform better than Inoue and Matsuzawa (2007) suggest, chimpanzees can perform better still. We also found no evidence to support the semantic link hypothesis.

The limited-hold memory task (Inoue & Matsuzawa, 2007, hereafter I&M) is a game where the participant sees a random array of numerals displayed on a screen in a random configuration. The numerals are masked after a short latency. The participant must then press the masking symbols in the order suggested by the symbols that they cover (see figure 1). If they pressed all the displayed numbers in the correct order (e.g. ordinal ascending) then they get a reward. If they press one out of sequence, the trial ends and no reward is given. In I&M, two chimps and 9 humans were tested. One of the chimps, Ayumu, completed about 80% of trials correctly, regardless of latency. Humans and the other chimpanzee, Ai, performed worse at lower latencies, scoring between 20-40% at 210ms. The differences between the chimpanzees might be due to age (Ayumu was younger) or, interestingly, because Ai had been language-trained, while Ayumu had not. Mat-

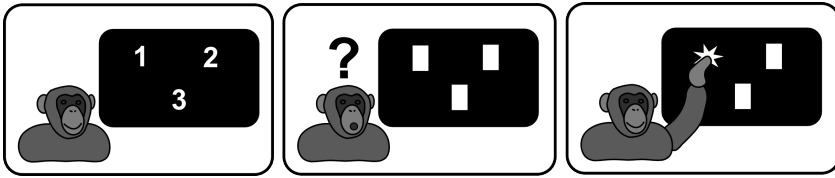


Figure 1. The experimental setup: Symbols are presented then masked. The participant attempts to select the masked symbols in their correct sequence.

suzawa suggested that the semantic links possessed by humans puts extra pressure on working memory, making the task difficult. Matsuzawa speculated that this kind of visual ability is adaptive for chimpanzees, who regularly fight with other groups and need to keep track of where many attackers are at once, while ranking them by threat level.

210ms is at the limit of the time a human eye can move from from central to peripheral stimuli (Bartz, 1962), which means that a human should not be able to fixate all numbers on the screen before they are masked. Humans can produce ‘express saccades’ at 100ms if their visual field is blank before the stimuli appears rather than if there is a central fixation point displayed up until the stimulus appears (Fischer & Ramsperger, 1984, but see Kingstone & Klein, 1993 for an alternative hypothesis). This is known as the ‘gap effect’ and the conditions for express saccades are essentially met in the limited hold task. However, chimpanzees do not exhibit a ‘gap effect’, performing equally well in both conditions (Kano, Hirata, Call, & Tomonaga, 2011), so the success of chimpanzees at the limited hold task cannot be because of this. Kano and Tomonaga (2011) demonstrate that while both species have similar saccade latencies in the gap condition, chimpanzees make more fixations per second and have shorter fixation durations than humans, making them more effective at visual scanning. Kano and Tomonaga suggest that humans and chimpanzees have different strategies for resolving competition between central and peripheral stimuli.

Silberberg and Kearns (2009) suggested that the chimpanzees were benefitting from more practice with the task. The results in I&M came from 500 trials for chimpanzees but only 50 trials for humans. After extensive training, the human participants in Silberberg and Kearns (2009) were performing comparably with Ayumu for 5 numerals. However, there are reports of chimpanzees performing correctly 80% of the time with 8 numerals at 210ms (Matsuzawa, 2009).

1. Eidetic Memory

The study of the ability to recall intricate visual images or eidetic memory has a long history. (Sperling, 1960) discovered that the number of letters that participants could correctly recall seeing in an array presented for a short amount of

time did not differ as a function of the latency. Later studies of ‘informational persistence’ showed that the identity of a symbol shown for a short amount of time could be held between 500ms, while the location of that symbol could only be held for 150-300ms (Loftus & Irwin, 1998; Luck & Hollingworth, 2008). It is the second type of memory that appears to be weak in humans in the limited-hold memory task.

However, there are individuals with very good eidetic memory. Up to 15% of children have good eidetic memory^a, but this declines in adulthood (Haber & Haber, 1988). There are some adult individuals with extraordinary eidetic memory. Stephen Wiltshire can draw extremely complex and accurate pictures of cityscapes from memory (and without sketching). Wiltshire would presumably perform similarly to Ayumu on the limited-hold memory task. Interestingly, Wiltshire’s language development was delayed. However, there are other adult individuals with strong eidetic memory who also have good phonological memory (e.g. ‘Elizabeth’, see Stromeyer & Psotka, 1970). There are also human individuals with highly superior autobiographical memory, but normal visual reproduction memory (LePort et al., 2012)^b.

With regards to the semantic hypothesis, (Lupyan & Spivey, 2008) find that adding semantic information actually improves visual search. Participants had to identify a target symbol amidst similar distractor symbols. Pointing out that the symbols could be seen as ‘2’s and ‘5’s rotated 90 degrees improved participants’ performance on the task. However, this task measured visual identification, not on the recall of location. An alternative (but not mutually exclusive) hypothesis is that humans have evolved an advanced phonological working memory, trade-off against a visual working memory (see Hurford, 2010). A further hypothesis is that Ayumu has developed synaesthetic associations between number and colour (Humphrey, 2012). Synaesthetic associations in humans usually involve learned sequences of stimuli and there is evidence that having colour associations can aid recall (Gross, Neargarder, Caldwell-Harris, & Cronin-Golomb, 2011).

2. The QHImp Qchallenge

We adapted this task to run online, using a similar layout and look to the original experiments (coded in javascript and HTML). You can see the implementation at <http://www.correlation-machine.com/qhimp/>. In order to attract participants, we presented the experiment as a game called the *QHImp Qchallenge* (Quick-Hold Improvement Challenge). In order to give participants practice with the game there were three ‘modes’ in which to play. ‘Arcade mode’ presented increasingly

^a2-15% of children aged 6-10 shown a detailed picture that was then removed could accurately describe the picture and did so in the present tense, suggesting that the visual perception was still accessible to them.

^bSee amazing autobiographical memory <http://tiny.cc/qjsk8w>

difficult trials starting with a single symbol at a long latency, then decreasing the latency while increasing the number of symbols. ‘Challenge mode’ started with 9 symbols for 3 seconds and decreased the latency slowly to 210ms. ‘Chimp mode’ presented 9 symbols for 210 milliseconds. To proceed to the next level of difficulty, participants had to choose all symbols in the current trial in the correct order. If participants made a wrong choice, the trial would end and they would ‘lose a life’. Once all their ‘lives’ were lost, the game ended and they would have to start again. Participants gained an arbitrary number of points for passing each level and there was a ‘leaderboard’ which displayed the players with the highest scores.

The stimuli were always sequential and started from the first in the set. Therefore, if there were 4 numerals on the screen, these would always be 1, 2, 3 and 4. In I&M, the stimuli set was sampled randomly, so there were possible gaps in the sequence. As a reviewer pointed out, this makes the task more difficult, since participants can’t always infer the identity of a symbol by exclusion. We’re currently addressing this issue (see section 4).

2.1. Stimuli

There were five sets of stimuli. First, as in I&M, numerals from 1 to 9. We also attempted to choose sets of symbols without semantic links. We used letters arranged alphabetically from a to i, shades of colour from red to white to green^c, a set of arbitrary symbols (presented in the same arbitrary order for all participants) and directional arrows arranged clockwise (see figure 2). We asked participants to choose a player name and recorded the participant’s responses. Because this program would be run on a range of computers, operating systems and web browsers, the actual latency time could not be guaranteed to match the intended latency time. Therefore, the actual latency time was recorded.

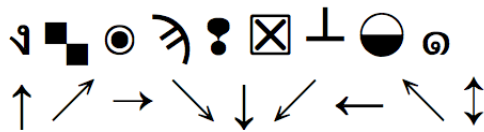


Figure 2. Two sets of non-semantic symbols used in the experiment.

^cThe range had to be fairly broad to support easily recognisable differences between the shades

Table 1: Results of a linear regression testing how various factors predict performance.

Factor	Estimate	t-value	p-value	
Number of previous trials	1.08E-04	42.836	<0.00001	***
Numerals displayed	-4.73E-02	-17.098	<0.00001	***
Saccade Distance	-2.54E-03	-5.892	<0.00001	***
Latency	2.37E-05	3.004	0.00267	**
Order (top to bottom)	-2.06E-02	-1.86	0.06295	.
Order (left to right)	-2.76E-03	-0.25	0.80266	

2.2. Participants

Participants were recruited online using blogs and twitter. No monetary incentive was offered. Around 170 participants took part in our experiment (identified by names they chose themselves), completing a median of 24 trials each (range between 1 and 3382). A total of around 16,500 trials were recorded over one month. Although there were ways participants could cheat, since we could not observe them directly, the incentive to do so was low and we found no evidence of cheating after checking the average trial completion time for each participant.

3. Results

Although the results of this experiment are difficult to compare to the original experiment, the first question was whether the humans in the current experiment were any better than those in I&M. Figure 3 shows the results for all participants

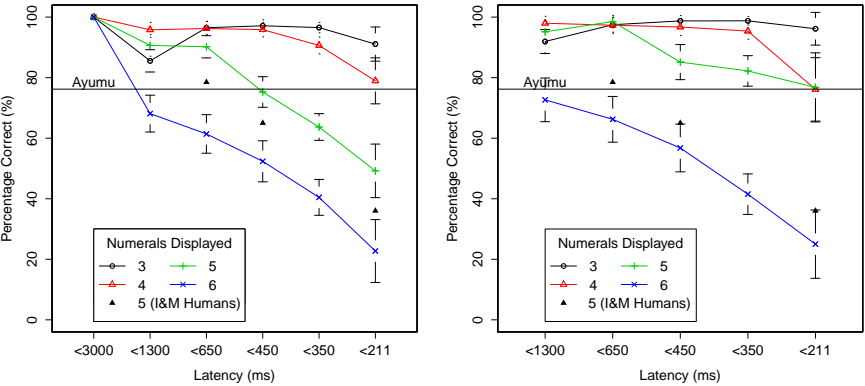


Figure 3. Results for the experiment with 95% confidence intervals for numeral stimuli for all participants (left) and for the best 66 participants (right). The solid horizontal line indicates Ayumu's performance and the solid triangles indicate the performance of the humans on 5 numerals from I&M.

for a range of latencies and number of numerals displayed. While humans appear to be performing slightly better than the human participants of I&M, they are clearly not performing as well as Ayumu at 210 ms. However, there were a large individual differences in performance. Looking at players who got over 75% of their trials correct on five numbers (at all latencies), a different picture emerges (figure 3). 66 participants have a mean within 5% of Ayumu’s performance for 5 numerals shown for 210 ms or less. This result is qualitatively different from that of I&M. The best overall player at 210ms latency got 80% of his trials correct on 6 numerals (5 trials) and 60% of his trials correct on 7 numerals (5 trials). The best player for 9 numerals at 210ms only got 18% of their trials correct (174 trials). Ayumu, whose performance is unaffected by latency up to 8 numerals, still appears to be better than humans at this task.

Out of 2347 attempts at choosing 9 numerals at 210ms latency, 75 were successful (3%). Although humans’ performance is much lower than Ayumu’s, humans are choosing the correct numeral at a rate greater than chance up to 7 numerals (figure 4). Interestingly, humans choose the first numeral correctly about 80% of the time, which is comparable to Ayumu’s performance on all 9 numerals. This suggests that humans can *identify* symbols at this latency (as in Sperling, 1960), but cannot retain the *location* of these symbols for very long.

Finally, we used some post-hoc tests to look at various factors that make the task hard for humans. The proportion of numbers guessed correctly in a trial was entered as the dependent variable into a linear regression model. The independent variables were the number of numerals displayed, the actual latency time, the game ‘mode’ and how many previous trials the participant had played. We also

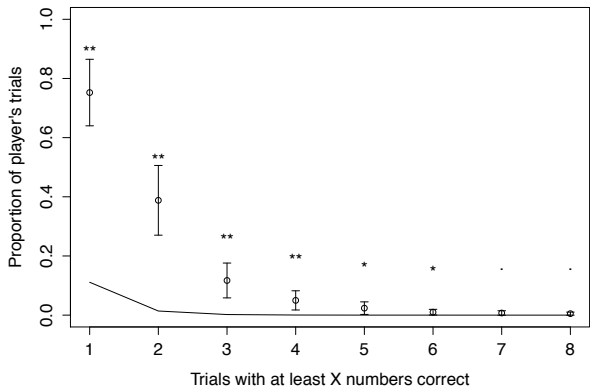


Figure 4. Results for 9 numerals displayed for 210ms or less. The solid line represents the level of success predicted by chance. Note that once the player chooses 8 numbers correct, there is only one numeral left to choose from. Symbols above means give significance above chance. **: $p < 0.001$, *: $p < 0.01$, .: $p \approx 0.05$.

measured how difficult the layout of the numerals might have been to remember. The saccade distance measured the cumulative distance between each numeral in order, assuming that a shorter saccade trajectory would allow more numerals to come within fixation. Also, numerals presented in order from top to bottom or from left to right might make the task easier (measured using Damerau Levenshtein distance).

The results are shown in table 1. As expected, the number of numerals displayed and how much practice the participant had (number of previous trials) were significant factors. However, the latency predicted less of the variation in performance than the saccade distance, suggesting that humans were attempting to fixate the individual numerals. How ordered the numerals were from top to bottom was only a marginally significant predictor.

3.1. *Non-Semantic Symbols*

We compared the proportion of symbols guessed correctly in each trial over the different stimuli types. Contrary to the predictions of the semantic link hypothesis, 10% fewer symbols were guessed correctly per trial on average from the non-semantic stimuli compared with the numeral stimuli ($t=19.04$, $p < 0.0001$, linear regression controlling for number of symbols displayed, latency, mode, number of previous trials played, saccade distance and ordering, model accounting for 54% of the variance, see figure 5). No participant performed significantly better with

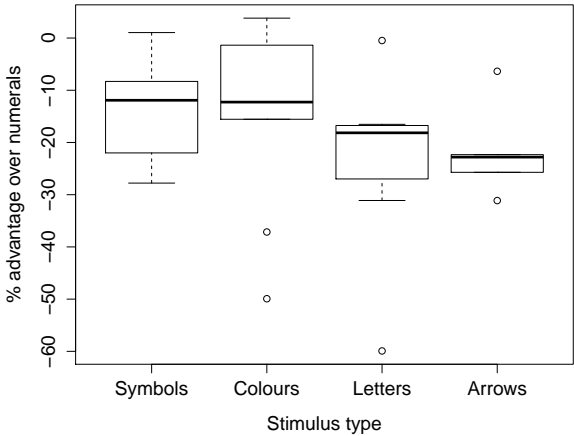


Figure 5. Percentage difference in performance within trials between numeral and non-semantic stimuli for 5 symbols displayed.

any of the non-semantic stimuli than the numerals. However, the results are not entirely clear-cut. Two participants did show a small, non-significant improvement with colour stimuli. In light of the synaesthetic hypothesis (Humphrey, 2012) it may be useful to test this further. Also, one participant also showed a small, non-significant improvement with the arbitrary symbols. The poorer performance could be due to the non-semantic stimuli being less familiar than numerals or perhaps the participants forged semantic links between non-semantic stimuli during training.

4. Future Research

In collaboration with the Living Links Research Centre in the Edinburgh Zoo, we have installed a version of this experiment in the Living Links Science Exploration Zone, an area for visitors to the zoo to interact with and learn about different research projects. This installation addresses several issues with the previous experiment. Firstly, as in I&M, we use non-sequential stimuli, where the numbers displayed will be drawn from a random sample from one to nine. We are also gathering data on the age of the participants. Since eidetic memory in humans declines in adulthood (Haber & Haber, 1988), and performance of chimps on this task is said to decrease with age (Humphrey, 2012), it will be useful to determine how age affects performance in humans. Finally, this installation consists of a single machine, so the dimensions and layout of the screen will be standard across participants, and timings can be measured with greater accuracy.

5. Conclusion

This study found evidence that humans can perform better than suggested in I&M in the limited-hold memory task. However, human performance is still below that of chimpanzees. This difference appears to stem from an inability to keep the *location* of symbols in working memory. We found no evidence to support the hypothesis that semantic links with the symbols were interfering with the task.

The methodology harnessed the power of online crowdsourcing of participants. We hope that this experiment demonstrates that empirical results can be brought to bear on research questions rapidly and cost-effectively, without the attendant ethical issues with utilising online labour markets. The results are available to download at: <http://www.correlation-machine.com/qhimp/data/>.

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THE EVOLUTION OF LANGUAGE FROM TWO COMPARATIVE VIEWS

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In research on language evolution, two kinds of *uniqueness* play an important role: human uniqueness and language uniqueness. Although these two are often intertwined in research discourse, they should be investigated as two different concepts. This paper reviews two kinds of comparative research to develop a conceptual framework investigating the evolution of language in terms of human uniqueness and language uniqueness. 1) Two different models examining cognition of humans and non-human animals provide opportunities to investigate the evolution of human uniqueness in very wide field. 2) By investigating similarities and differences of uniquely human cognitive systems or domains (e.g. language and music), language uniqueness and its evolution should be examined. Based on findings from these two kinds of comparative research, I suggest that evolution of language should be investigated in terms of human uniqueness including the ability of processing hierarchical structure with natural language complexity as well as systems handling with unique linguistic components like propositional meaning and phonemes.

1. Introduction

In language evolution research, there is a deep confusion in using the term “language” (cf. Hauser et al., 2002): some scholars use a wider conception of the term “language” in the sense of a communication system including syntax, semantics, and pragmatics, while others like Chomsky refer to a far narrower meaning such as computational mechanisms central to linguistic syntax. In spite of such a wide variety of interpreting “language”, there seems to be a general agreement that language is a complex system including a range of interacting subsystems. Moreover, most researchers agree that some of these subsystems or some connections between them are unique to human cognition or to language. The most important point is that uniqueness of human cognition (human uniqueness) and language uniqueness should be investigated as two different concepts although research on language evolution and questions of human uniqueness are often strongly intertwined. The view-point that the birth of

language caused a transition from non-human animals to humans is problematic (Hauser, 2009). To investigate the evolution of human uniqueness and language uniqueness, the well-known framework of Hauser, Chomsky, and Fitch (2002) (hereafter HCF) is discussed and updated, at first. Then, this paper reviews two kinds of comparative research: comparative research between species (e.g., humans and non-human animals) giving insight into human uniqueness, and that between uniquely human cognitive systems or domains (e.g., language and music) revealing language uniqueness.

2. Updating the framework of Hauser, Chomsky, and Fitch (2002)

HCF delineate two concepts of *the faculty of language (FL)*: *the faculty of language in the broad sense (FLB)* including all aspects of *FL* and *the faculty of language in the narrow sense (FLN)* involving only those components unique to humans and to human language. In their framework, HCF attempted to investigate two questions “What is uniquely human?” and “What is unique to language?” in terms of *FLN*, i.e. in terms of uniquely human and specifically linguistic features of *the faculty of language*. As a candidate belonging to *FLN*, they emphasize the uniquely human property of language’s *discrete infinity* provided by *recursion*, which is assumed to yield the rich expressive and open-ended power of human language by interacting at minimum with the following two *interface systems*: the sensory-motor (S-M) interface system as a mechanism of externalization (e.g. phonology) and the conceptual-intentional (C-I) interface system as some interpretative mechanisms (e.g. semantics and pragmatics) (cf. Hauser et al., 2002; Chomsky, 2010). However, their claim on *recursion* as unique to humans and unique to language seems not to be sustained. While HCF claim that *recursion* is included in *FLN*, there are many evidences against this claim: *recursion* in general referring to “a procedure that calls itself”, or to “a constituent that contains a constituent of the same kind” (Pinker & Jackendoff, 2005) seems not to be unique to language, but domain-general (cf. Deacon, 2003; Pinker & Jackendoff, 2005; Hauser, 2009; Brattico, 2010; Jackendoff, 2011; see Fitch, 2010b and Martins, 2012 for discussions of this term). Moreover, as HCF already remarked, even the possibility that *recursion* in general exists in animals remains open (cf. Jackendoff, 2011). That is, another framework giving us possibilities to investigate *recursion* in more domain-general terms and to reconsider components included in *FLN* is required.

The first step in developing such a framework can be made by discriminating the language capacity relevant to language evolution research in a more specific way as Jackendoff (2010) did: 1) “things necessary to language

that have required *no* changes from the ancestral genome”; 2) “innovations in the human lineage that are essential to language or language acquisition but that serve purposes more general than language”; 3) “aspects of language that are unique to humans, that are used exclusively for language or language acquisition, and that resulted from some alteration or specialization of preexisting primate structures or capacities”; 4) “aspects of language that require something altogether new and unprecedented in the primate lineage”. This classification takes up some evolutionary considerations not explicitly addressed by HCF. Jackendoff (2010) points out the specificity question: “What aspects of the language capacity in the mind/brain are special for language, and what aspects make use of more general capacities?” That is, research on language evolution should focus on 3) and 4). In this framework, *recursion* seems to belong at the best to 2), i.e. unique to humans, but not unique to language. That is, *recursion* should be investigated beside the use of pointing for drawing attention, the capacity for detailed imitation of other’s actions, and a fully developed theory of mind (cf. Jackendoff, 2010) not in terms of language uniqueness, but, if any, in terms of human uniqueness. By differentiating human uniqueness and language uniqueness, this framework opens up new possibilities to investigate the evolution of language. In the following, these two concepts are discussed and specified within two kinds of comparative research.

3. Two kinds of comparative research

3.1. *Comparative research between humans and non-human animals*

One wide spread comparative approach concerning human uniqueness is that using artificial grammar learning (AGL) methods based on the Chomskyan framework of natural language complexity (Chomsky hierarchy). The basic assumption of this research approach is that processing of natural languages involves at least processing of structures with the complexity of context-free grammars (phrase structure grammar complexity) because natural languages include hierarchically nested self-embedding structures whose complexity is beyond that of regular grammars (cf. Chomsky, 1963). “Natural languages go beyond purely local structure by including a capacity for recursive embedding of phrases within phrases” (Hauser et al., 2002). Empirical studies suggest that no other primates than humans can process this level of complexity in the auditory domain (e.g. Fitch and Hauser, 2004). That is, the ability to process phrase structure grammar complexity in the auditory domain appears to be uniquely human among primate species. This is the main reason why HCF regarded

recursion as the most important component of language evolution. However, homologous traits are not the only relevant source of evolutionary data (cf. Hauser et al., 2002). Recently, AGL is also used to compare processing abilities of humans with songbirds showing that the latter are able to recognize acoustic patterns with the A^nB^n grammar complexity, i.e. a grammar complexity beyond regular grammars (Gentner et al., 2006). It is even assumed that neural circuits of human speech and birdsong are analogous (Berwick et al., 2013).

Another comparative research approach independent of AGL methods provides an additional view of human uniqueness. Both humans and apes are species capable of imitating actions of other individuals, while monkeys have little capacity of imitation. Concerning the way of imitation and the complexity of imitated actions, there are some differences between the imitation capacities of humans (complex imitation) and apes (simple imitation). For example, humans are able to recognize quickly that a novel action consists of known actions associated with appropriate sub-goals, whereas apes need months of observation and trial-error learning (cf. Arbib, 2011). This ability to recognize known actions in novel actions seems to be an advantage for humans. Comparable abilities of imitation or action-related tasks in humans and apes also exist in tool use. Apes, but not monkeys, can use tools for insect ‘fishing’ or nut cracking, whereas *making* stone tools appeared in the late stage of human evolution (cf. Fitch, 2010a). Arbib (2011) regards tool making as a hierarchical skill consisting of several complexities corresponding to imitation skills, and proposed a connection between the archaeological records of hominid tools (Oldowan, Archeulean, and Middle Stone Age) and the evolution of the *language-ready brain*. Here, the capacity to handle hierarchical structures with deep embedding again seems to be a keystone of the evolution of human uniqueness, which even enables us to design Swiss army knives by embedding tools within tools (cf. Hauser, 2009).

Based on the comparison of the ability to process hierarchical structures with natural language complexity using AGL methods as well as the way of human and non-human primate tool use, Hauser (2009) emphasizes that “only humans have evolved the capacity to use one object for many functions, and to combine objects that each have a different functional role in order to solve novel problems”. While animal tools consist of a single material and never include more than one functional component, a pencil, one of human simple tools, consists of four combined materials (graphite, wood, metal and rubber) and is used for several functions like writing, erasing, holding up hair or poking a friend (cf. Hauser, 2009). As humans use tools for different functions, they make use of *recursion* for a wide range of functions such as communication

(language), culture (music), and technology (tools). He suggests that even birds using *recursion* in their vocal imitation or learning cannot use this operation in other domains or for other functions. That is, *recursion* as such is not characteristic of human uniqueness: it is its domain-general property and flexible functional use that is uniquely human. This seems to mirror the possibility HCF left open: “the modular and highly domain-specific system of recursion may have become penetrable and domain-general” (Hauser et al., 2002). Based on the idea of Hauser (2009), Boeckx (2012) introduced the concept of “Human Cognition in the Narrow sense” and claimed that “the ability to systematically transcend the boundaries of modular thought and engage in cross-modular concept formation” is uniquely human. To sum up this section, the ability of processing (generating or parsing) hierarchical structures with complexity of natural human languages across domains seems to be one of the candidates for *human uniqueness*.

3.2. *Comparison of uniquely human cognitive systems or domains*

The nature of such a domain-general ability to process hierarchical structure with a certain complexity and the way it is *put into use* in each domain can be investigated through the comparative approach of cognitive systems like language and music. Some theoretical linguistic approaches considering language and music as *faculties* emphasize the similarity or even identity at a deeper theoretical level of both cognitive systems (cf. Katz & Pesetsky, in review; Roberts, 2012): their components handling hierarchically organized structures tend to be emphasized as their strong similarities or even identity. For example, the hierarchical organization of metrical structure in both domains seems to share some principles (cf. Lerdahl & Jackendoff, 1983; Fabb & Halle, 2012 – but note some formal differences between these accounts in terms of *grouping*). Moreover, syntactic structure of language and rhythmic-harmonic structure of music make use of recursive headed hierarchies in which each constituent has a head, and other dependents are modifiers or elaborators of the head (cf. Jackendoff, 2009). This general view is supported by current neuroscientific research. Patel (2008) introduced the idea of a resource-sharing framework with the ‘shared syntactic integration resource hypothesis’ (SSIRH) at its center: he proposes that the syntactic integration processes of language and music rely on the same neural resource. His hypothesis got some support from current imaging studies (e.g. Koelsch, 2012). For example, functional neuroimaging studies using chord sequence paradigms showed that music-syntactic processes, such as linguistic syntactic processes, involve several

regions in and near Brodmann area 44 (BA 44) bilaterally (cf. Koelsch, 2011). Koelsch (2011) also notes that this part of Broca's area is involved not only in linguistic and musical syntactic processing, but also in processing action sequences. That is, some cognitive operations overlap in syntactic processes of language and music, but they also seem to be shared with processing of other structures based on long-distance dependencies involving hierarchical organization (phrase-structure grammar) (cf. Koelsch, 2011). Similarly, Jackendoff (2009) claimed, that complex action makes use of a headed hierarchy, too. That is, the components of language and music processing, i.e. headed hierarchy or their shared neural resource, are used in a wide range of domains and therefore domain-general.

By focusing on differences between such cognitive systems as language and music, this comparative approach gives us hints on uniqueness of each cognitive system, e.g. language uniqueness. For example, Jackendoff (2009) stresses structural and functional differences and proposes independence of these cognitive systems. Especially, concerning 'meaning', both systems differ from each other: language encodes propositional meaning and has a tight connection to conceptual structure, while music has mainly to do with tension-relaxation patterning or affect (cf. Jackendoff, 2009). Moreover, he proposes that syntactic categories like N(oun) or V(erb) fail in musical prolongational structure (for discussion, see also Patel, 2008). Another point to note is that even in the highly similar domain of rhythm based on metrical structure, language and music differ from each other in relation to periodicity: the systematic patterning of sound in terms of timing, accent, and grouping in regular periodic pulse called *isochronous rhythm* relating strongly to the capacity of synchronization appears to be unique to music (Patel, 2008). For language, phonology based on the smallest meaning differentiating elements (phonemes) would be its additional unique feature (Pinker & Jackendoff, 2005). Such theoretical considerations of different architectures for language and music are mainly supported by cognitive neuropsychology. Peretz (2012) emphasizes a "modular view" of music and language focusing on their *functional specialization* and *domain-specificity* instead of *informational encapsulation* as key properties of modularity by referring to reports of selective impairment in language and music recognition. Such studies imply differences in the neural circuits of language and music as well. Further formal analyses and empirical studies on such unique systems of language and music will give us a near insight into *language uniqueness*.

4. Perspectives on human uniqueness and language uniqueness

Getting started with the discussion about *recursion* introduced by HCF as *FLN*, i.e. unique to humans and unique to language, we discussed *uniqueness* of this operation. Because *recursion* in general is not unique to language, but widespread in human cognitive systems such as music, the discussion focused on human uniqueness. As comparative approaches between species show, the ability of processing (generating or parsing) hierarchical structure with the complexity of natural languages across domains seems to be a candidate for human uniqueness. That is, this ability would fit category 2) within the classification of Jackendoff (2010) at the moment. The fact that no other primates than humans, but birds are able to process complex hierarchy (especially A^nB^n sequences) in the auditory domain implies the convergent evolution of this ability (Berwick et al., 2013). If this holds true, the ability of processing complex hierarchy would be an innovation in human cognitive systems unprecedented in the primate lineage. This would also be supported by the fact that vocal imitation plays an important role in the acquisition of language in humans and song in birds, while no other primates possess this ability (Hauser et al., 2002). However, this is not the only way to explain the emergence of *recursion*. The comparative approach based on the ability of (manual) imitation may argue against this position. If this is true, the ability to process hierarchical complexity of natural human languages evolved from the ancestral capacity in the primate lineage and would originate from some capacity existing in primate lineage as the other uniquely human aspects like the use of pointing for drawing attention, the capacity for complex imitation, and a fully developed theory of mind are. It is possible that *recursion* was used in the social and spatial domains (cf. Jackendoff, 2011; Martins, 2012). For the moment, this question remains open for future discussion.

Additionally, the important notion made through the comparative approach between human cognitive systems is that focusing on the domain-general uniquely human ability alone cannot solve the puzzle of language evolution. That is, one should focus on the interaction between uniquely human mechanisms and the other unique linguistic subsystems or *interface systems* like phoneme-based phonology and propositional semantics which can be classified as 3) or 4). Whether they belong to 3) or 4) and which features of language additionally can be classified as belonging to these categories are questions which should be examined theoretically and empirically by the two comparative approaches discussed here. Only by investigating the nature of the unique systems of language and their interactions with domain-general uniquely human

capacities, one of which is the ability to process hierarchical structure with natural language complexity across domains, one will get a nearer insight into the whole story about the evolution of language.

5. Conclusion

The framework of HCF provided the starting point to investigate the evolution of language in terms of *FLN*, i.e. aspects unique to humans and unique to language. However, the way specifying *recursion* as belonging to *FLN* and the lack of the possibility to examine human uniqueness and language uniqueness as two different concepts should be updated. In this paper, I reviewed two kinds of comparative research important for the investigation of language evolution in terms of human uniqueness and language uniqueness as two different concepts. At first, focusing on human *uniqueness*, the paradigm of comparative studies on humans and non-human animals was introduced. By discussing evidence from different models studying human and non-human animal cognition, it was shown that processing of hierarchical structures with natural language complexity across domains is a key component of human uniqueness which can be examined by focusing on homologous as well as analogous traits. However, the evolution of language cannot be investigated by studying human uniqueness alone. The second comparative approach concerning the two different cognitive systems language and music based on formal theoretical and neuroscientific considerations showed that this uniquely human component is broadly shared in human cognitive systems. That is, investigating such a domain-general, uniquely human core mechanism alone is not enough to explain the evolution of language: the evolution of language should be investigated in terms of human uniqueness and mechanisms unique to each system. To investigate the emergence of mechanisms unique to language, it is proposed that one should focus on differences between language and other cognitive systems such as music. Here, further analyses of language and music focusing on their differences are required in future research. For now, phoneme-based phonological systems and propositional semantic systems are candidates for language uniqueness. The evolution of language should be examined by clarifying how the domain-general uniquely human core mechanisms interact with these specific linguistic systems in the faculty of language. Investigating the nature and its emergency of both human uniqueness and language uniqueness will guide us on the way towards an answer to the question “Why is language the way it is?”

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INTER-SPECIES COMPARATIVE RESEARCH IN VOCAL LEARNING: POSSIBILITIES AND LIMITATIONS

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Animal models are increasingly used to study human speech and language. In the light of understanding both language evolution and individual language acquisition these models are highly valuable, provided that a valid comparative framework is used. In the past few decades non-invasive methods such as MRI have become available for human as well as small animal brain research. The aim of this review is twofold, exploring both (1) how cross-species research can inform questions about language evolution and (2) how recently developed non-invasive neuro-imaging techniques can be applied in inter-species comparative studies.

1. Animal models of human speech and language

1.1. *What can animal vocal learning tell us about language?*

With approximately 4000 species, oscine songbirds represent the largest group of vocal learners in the animal kingdom. These songbirds learn to produce their song by imitating the vocalizations of their parents. In contrast, among primates, evidence for vocal imitation learning has only been found in humans (Egnor & Hauser, 2004). The limited vocal learning abilities in our closest relatives complicates the study of vocal learning from the perspective of common descent. Species that show vocal learning (also comprising hummingbirds, parrots (Pepperberg, 2002), cetaceans, pinnipeds, bats (Janik & Slater, 1997) and possibly elephants (Poole et al., 2005)) differ greatly from humans in both brain and behavior. Moreover, birdsong, which is the most studied model for human language, is highly limited in its productivity and symbolic representation and does not show duality of patterning like human language (Hockett, 1966). It has been claimed that songbirds show some combinatorial potential (e.g. Gentner et al., 2006), however, these findings are disputable (Stobbe et al., 2012; van Heijningen et al., 2009). This limits the ways in which findings from birdsong

studies can be extrapolated to human language. In order to arrive at an interesting and informative comparison between birdsong and human language, one should clearly limit studies to behavioral mechanisms that, at some level, have been shown to be comparable between species. Several aspects of the zebra finch song learning process, like the memorization of the target song during the sensory phase (Eales, 1985) and motor practice or “babbling” during the sensorimotor phase (Marler, 1970), show such interesting similarities to theories of human speech learning (Doupe & Kuhl, 1999). For these behaviors, songbird studies can add to the understanding of neural mechanisms underlying the development of speech in human infants and of vocal learning in humans. Many other aspects of language, like the ability of symbolic reference, can be found in other lineages like parrots (e.g. Pepperberg, 2002) and non-human primates (Pollick & de Waal, 2007). Studies of these abilities, combined with studies of vocal learning, can help to establish which abilities underlying human language can be found in other species and which abilities are uniquely human.

1.2. *Different brains, similar mechanisms*

Both at the behavioral and the neural level, similarities between species can be informative, but studies showing parallels on both levels are most convincing. Behavioral studies have established birdsong as a learned behavior (Thorpe, 1958) and have shown which environmental and internal factors influence its acquisition (e.g. Fundabiki & Konishi, 2003). Recently, song and speech learning has been compared using similar behavioral methods (Gobes et al., 2009 ; Ter Haar et al., 2009). In contrast, studies of the songbird brain have primarily used invasive methods such as electrophysiology and IEG expression to study the neural substrates underlying these behavioral traits (see Bolhuis & Gahr, 2006 for a review). Due to these types of studies much knowledge is gained about the neural substrates of birdsong learning and the song system and many apparent similarities to human language acquisition and its neural substrates have been noted (Doupe & Kuhl, 1999). However, these methods might highlight different neural mechanisms from those found using the non-invasive methods typically applied in human research. For example, electrophysiological research in non-human primates have led to the discovery of mirror neurons (Rizzolatti et al., 1996). Songbirds have also been shown to possess auditory forebrain neurons that are both activated during song production and listening to the same song (Prather et al., 2008). Here, songbirds can inform questions about the role of mirror neurons in vocal learning and the

use of songbird (and primate) fMRI in combination with electrophysiology can aid the validation of human fMRI results.

Songbird studies aiming to understand vocal learning processes in humans search for common neural or genetic mechanisms to explain common behavior, but direct comparisons between the neural substrates of human language and birdsong development have yet to be made. In order to achieve a sound comparison between species, ideally, the same experimental methods are used. Because studies of human brain function typically involve non-invasive neuro-imaging methods such as EEG or (functional) MRI, the Bio-Imaging Lab has taken the approach to implement fMRI in Zebra Finches (Boumans et al., 2007). Because fMRI has also been established in non-human primates (Logothetis et al., 1999) the neural correlates of vocal learning and memory can now be effectively compared between songbirds, non-human primates and humans.

When aspiring more direct comparisons between the neural mechanisms underlying vocal learning in bird and humans, the large structural differences between the mammalian and avian brain have to be taken into consideration. Birds do not have a cortex and their brain is structured in nuclei rather than lamina and there are different views as to how the birdbrain and the mammalian brain evolved from a common ancestor, implicating different homologies between brain structures (Jarvis et al., 2005). However, even if there is no consensus about the common descent of specific neural structures, functional analogies can also inform us about convergence on the neural level. For example, the basal ganglia play a crucial role in birdsong learning (Brainard & Doupe, 2000), while infant language learning studies revealed mainly cortical components (e.g. Gervain, et al., 2008). Thus, although the brain of a songbird differs significantly from ours and does not show the same architecture as a mammalian brain, similar neural mechanisms may drive the development, perception and production of learned vocalizations.

2. Comparative studies: challenges and considerations

2.1. fMRI in songbirds: mapping development

Due to its non-invasiveness, using fMRI to study birdsong learning has several advantages. Firstly, we can compare the development of the neural substrates for vocal learning in songbirds and humans. Secondly, because animals are not sacrificed after the experiment, longitudinal studies are possible and finally, the whole brain can be studied, which facilitates the study of large-scale brain changes. This technique thus enables us to longitudinally follow birdsong

development in the same individuals and compare these data to fMRI data on human language development or auditory perception and memory in non-human primates.

In recent years, auditory fMRI in zebra finches have revealed highly specific responses to species-specific sounds (Boumans et al., 2008), the bird's own song (Poirier et al., 2009) and the song of the bird's father, which was learned during development (van der Kant et. al., in press). More recently, the technique to acquire auditory fMRI data from juvenile zebra finches has been developed (van der Kant et al., to be submitted). Birds can be measured as early as 20 days post hatching, which enables us to map neural substrates of song learning in both the sensory and the sensorimotor period. This first fMRI study using juvenile zebra finches has confirmed the role of the auditory midbrain nucleus in birdsong learning and has shown changes in lateralization of tutor song selectivity during development, which might be reminiscent of the laterality changes found in human infants during language development.

Although the results seem promising, there are still some practical limitations to this comparative approach. One of these is the need for anesthesia when collecting fMRI data from small songbirds. Non-human primates like macaques (Petkov et al., 2006; 2008) as well as pigeons (De Groof et al., 2013) can be measured in an awake state after a significant amount of training. However, fMRI in awake zebra finches has yet to be established and the skittish nature of these small songbirds might complicate training. Furthermore, the extensive training periods required for awake animal fMRI experiments limit the possibilities for developmental studies. Although anxiety is less of an issue in human subjects, children can only participate in MRI experiments in a non-clinical setting when they are at least six years old, well past the start of language acquisition. However, Near Infrared Spectroscopy (NIRS), like fMRI, is based upon a hemodynamic signal. However, this signal is measured using infrared light directly on the scalp and thus does not involve a confined space, a magnetic field or radio-frequency pulses. This method can therefore be used at very early ages, even in newborns (Gervain et al., 2008).

2.2. What can non-human primates tell us about language?

Although non-human primates, like chimpanzees, do not show vocal imitation learning, there are several examples of comprehension learning and usage learning (e.g. alarm calls in vervet monkeys (Seyfarth et al., 1980)) in non-human primates. The study of apes and monkeys can add to the understanding of human language development in several ways. They can serve as a non-vocal

imitation learning control species when comparing vocal learning in humans and birds and additionally they can provide insights into other behaviors that might have contributed to human language evolution, like auditory processing (Petkov et al., 2006), gesture (Pollick & de Waal, 2007), joint attention (Carpenter & Tomasello, 2006) and symbolic reference (Ribeiro et al., 2006). Because non-human primates are genetically relatively close to the human species, they may possess general learning mechanisms that were adapted to sub-serve language in human evolution. By comparing humans to both songbirds and non-human primates, mechanisms we might have in common with either vocal learners or non-vocal learners can be identified.

An interesting study by Jarvis and colleagues (Jarvis et al., 2012) has used this approach on the genetic level, comparing levels of parvalbumin, a calcium-binding protein in vocal learning and non-vocal learning birds. Petkov and colleagues (2008) used auditory fMRI in macaques to show that some auditory regions in the monkey temporal lobe are preferentially activated by conspecific sounds and even by the voice of individual conspecifics. In zebra finches, auditory fMRI studies have shown selectivity for conspecific song and the song of individual birds in the auditory midbrain nucleus, the avian homologue of the inferior colliculus (Poirier et al., 2009; van der Kant et al., in press). Here, primate research suggests that some brain functions that are important in vocal learning were in place before vocal imitation developed in the human lineage.

3. Conclusions

The aim of the present paper was to sketch a framework in which different animal models can be used to inform questions about the neural underpinnings of human language evolution and language acquisition. Furthermore, some of the methodological challenges faced in comparative research studying both human and animal brains have been discussed.

Since the advent of neuroimaging research, important steps have been taken to optimize the methods available for several species important to studies of vocal learning. The technical developments of the last decade have created possibilities for inter-species comparative research on vocal learning using brain imaging techniques. fMRI can now be used in anesthetized songbirds and both awake humans and primates, enabling us to longitudinally study vocal learning in both humans and songbirds and compare this to perception of species-specific signals in non-vocal learning species.

As a next step, comparing the neural substrates of learned versus non-learned communication signals in birds and primates might reveal some of the

convergent neural substrates of vocal learning across the primate and bird lineages. Furthermore, developmental studies within the same individual creates possibilities to compare the developmental trajectory of vocal learning across species.

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FOXP2 MEDIATES OPERANT SELF-LEARNING NECESSARY FOR LANGUAGE DEVELOPMENT

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FOXP2 is a transcription factor involved in gene regulation and neural plasticity. It is of particular interest as it was discovered as the first gene to have a relationship with the development of language. At Evolang IX, FOXP was shown to affect operant learning in *Drosophila*. This finding suggests that the development of language is a form of operant learning through vocal and auditory systems. I hypothesize that functional auditory and vocal systems, integrated via FOXP2, are required for a species to be able to access complex vocal language.

1. Language is Operant Learning

Acquisition of speech, and other non-reflexive sound production, is a form of operant learning. As I have previously shown, for children to acquire spoken language non-referent, reflexive vocalizations are controlled and conditioned into novel vocalizations (i.e. babbling) and further conditioned into complex speech (Green et al., 2012). I hypothesize that the ability to receive feedback and make appropriate modifications in this context is predicated upon functional vocal and auditory systems and therefore if either system functions incorrectly, speech and all other operant sound production will be affected. For example, post-lingually deafened adults experience deterioration in speech over time (Cowie et al., 1982). Similarly, songbirds show degradation in song after surgical deafening (Woolley et al., 1997). I further hypothesize that FOXP2 is the coordinator of the interactions between hearing and speech development.

2. FOXP2

Forkhead-box protein P2 (FOXP2) is a transcription factor encoded by the FOXP2 gene. FOXP2 is comprised of a forkhead-box DNA-binding domain, polyglutamine tracts, a zinc finger, and a leucine zipper. These are common motifs by which a transcription factor binds to DNA to regulate other genes.

FOXP2 is known to regulate CNTNAP2, a gene associated with specific language impairment, among dozens of other genes (Vernes et al., 2008).

3. Mutations in FOXP2 Result in Failure to Develop Language

FOXP2 was the first gene discovered to have a relationship with the development of language. A family with mutations in the FOXP2 gene, without cognitive or motor limitations, had marked communicative disabilities (Vernes et al., 1998). Vernes et al. showed that individuals with FOXP2 mutations have difficulty achieving the oral coordination necessary for speech (in addition to their other linguistic deficits).

4. FOXP2 in Non-Human Primates

FOXP2 is one of few genes that vary between humans and other primates. Enard et al. have shown two amino-acid changes in the FOXP2 gene are present in human lineage after diverging from chimpanzees. In contrast, one synonymous amino-acid change is present in orangutan lineage, but no other primates present any variants from chimpanzees (Enard et al., 2002). This human variant is fundamental and proposed as a *sine qua non* of primate language.

Diller and Cann point out that these amino-acid changes may not be an immediate precursor to language development, a position consistent with this theory (Diller et al., 2009). I hypothesize that FOXP2 is necessary for the development of all complex vocal communication including protolanguage. Improved vocal control then increases the selective advantage of further speech-related developments such as the vocal tract and ear ossicle optimization seen in both Neanderthals and humans.

4.1. *Neanderthal Language*

Neanderthals have a vocal tract that is adequate for phonation as summarized by Johansson (2012). A Neanderthal hyoid bone was found (Arensburg et al., 1989) in addition to two hyoid bones of likely ancestors of Neanderthals (Martinez et al., 2008) which closely resemble the hyoid of the modern human. These findings suggests a vocal tract adequate for speech.

As summarized by Johansson (2012), increased perception of sounds in the 2-4 kHz range has occurred during human evolution. Minor changes in the ear ossicles account for this increased sensitivity (Martinez et al., 2004). This change is not present in ape ears. However, Neanderthals likely possessed this increased sensitivity as ear ossicles found have no significant differences from those of the modern human (Quam & Rak, 2008).

Neanderthals were found to possess the modern FOXP2 (Krause, 2007). Benitez-Burraco et al. (2012) discussed the gene's possible involvement in language as involvement in oral coordination related to language (White, 2010) or as a regulator of the language network/s. In contradistinction, I propose that FOXP2 is involved in oral coordination related to language **and** as a regulator of the language network/s.

With adequate speech and hearing organs as well as modern FOXP2, Neanderthals possessed all the necessary requirements for language development. FOXP2 allows for fine motor control of the speech organs while the advanced sound perception allows for focused feedback. FOXP2 mediates this relationship allowing for the Neanderthal to make minute changes in vocalization to create distinct syllables and furthermore complex speech.

5. Operant Learning in *Drosophila*

The relation between FOXP2 and language is likely related to operant learning. *Drosophila*, for example, show complete absence of self-corrective operant learning with an RNAi-mediated knockdown of the FOXP gene (Mendoza et al., 2012).

6. FOXP2 in Songbirds

Bird song is relevant to human speech as it is composed of rhythmic, stressed structures with varied intonation and is produced by conditioned and controlled vocalizations (Asano, 2012). During the song-learning period, the zebra finch, an age-limited song-learner, has higher levels of FOXP2 in Area X. Interestingly, canaries, seasonal song-learners, have seasonal increases of FOXP2 in Area X (Haesler et al., 2004). As shown by Haesler et al. (2007), knockdown of FOXP2 in the zebra finch causes a variable and inaccurate song. This finding suggests that FOXP2 allows for the production of stable, accurate song. I hypothesize that FOXP2 mediates operant self-learning in this context, allowing the bird to regulate song and detect differences from its song and the tutor song more accurately.

According to a study by Schulz et al., knockdown of FOXP2 in Area X of the zebra finch causes a decrease in the spine density of newly generated spiny neurons: where FOXP2 is expressed (Schulz et al., 2010). This decrease reduces the number of synaptic pathways in Area X, reducing the plasticity and the bird's song learning ability.

A study by Teramitsu et al. (2012) has shown that deafened zebra finches do not have a deficit in basal FOXP2 levels; however, a correlation between singing and FOXP2 levels was only present in hearing birds (Teramitsu et al.,

2010). This finding suggests that FOXP2 and hearing are directly related. Hearing allows for auditory feedback of song production and FOXP2 mediates the relationship between this feedback and song production. I hypothesize that the basal levels of FOXP2 do not increase in deaf birds due to the absence of feedback necessary for the operant self-learning acquired through FOXP2.

7. Discussion

Hominid FOXP2 allows for fine coordination of the speech organs. Increased auditory perception in the 2-4 kHz range has given early humans the ability to detect slight differences between vocalizations (Johansson, 2012). FOXP has been shown to affect operant self-learning in *Drosophila* (Mendoza et al., 2012). This finding suggests that the modern FOXP2 mediates the relationship between the greater control of the speech organs and the increased auditory perception of early humans by allowing them the ability to self-correct vocalizations.

I hypothesize that FOXP2 increases oral coordination by the operant self-learning it allows. The advanced auditory perception of modern humans allows for distinction between vocalizations with only minute differences. Through operant self-learning FOXP2 allows humans to vocalize and analyze the sound produced, then to use this analysis to produce a slightly different sound. If the desired sound is not achieved, then another slightly different sound can be produced. I hypothesize that FOXP2 allows for humans to understand the effects of different motions vocally and achieve the greater coordination through conditioning as seen in the previously aphonic reconstructed children that I discussed (Green et al., 2012).

I propose that the increased ability for speech production and perception mediated by self-correction via FOXP2 is the necessary prerequisite for complex spoken language.

8. Future Directions

To further understand the relation between vocal and auditory systems and FOXP2, a series of experiments could help to delineate the feedback loops. Songbirds, as previously mentioned, are an ideal model for study due to the similarity of bird song to human speech. Separating out hearing from song can be accomplished by a surgical deafening of the birds (Teramitsu et al., 2012; Wooley et al., 1997). More complex techniques are required to separate song from hearing.

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COGNITION, USAGE, AND COMPLEX SYSTEMS: EVOLVING THEORIES OF LANGUAGE AND THEIR RELEVANCE FOR EVOLUTIONARY LINGUISTICS

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The view of language as a complex adaptive system has come to be one of the most important frameworks guiding research in evolutionary linguistics. Importantly, the complex adaptive system of language is itself a product of the interaction of three complex adaptive systems operating on three different timescales: The ontogenetic timescale of language learning and acquisition, the glossogenetic timescale of language change, and the phylogenetic timescale of biological evolution. In the future, one of the main desiderata of evolutionary linguistics will be to unravel this complex web of interactions. In this paper, I give a brief overview of this emerging consensus. In addition, I argue that cognitive-functional and usage-based approaches in linguistics, which emphasize the importance of the dimensions of actual language usage and cognitive and social factors in language acquisition, processing, change, and evolution present an important addition to the emerging view in evolutionary linguistics of language as a complex adaptive system.

1. Introduction

In their groundbreaking 1990 paper, Pinker & Bloom praised language as evidencing clear signs of ‘adaptive complexity.’ From their generative nativist perspective, this term – used to designate a “system composed of many interacting parts where the details of the parts’ structure and arrangement suggest design to fulfill some function” (Pinker & Bloom, 1990:709) – of course referred to the gradual evolution of a domain-specific biological system dedicated to language. As natural selection is the only mechanism capable of producing such adaptive complexity in the biological realm, it seemed clear that such a capacity could only have evolved through processes of gradual Darwinian evolution.

It can be argued that this line of reasoning led Pinker & Bloom and many researchers in their wake to adopt a perspective that tended to overemphasize the *phylogenetic* dimension of domain- and language-specific biological changes. Due to this perspective, it could be argued, many other potentially important processes that come to bear on the question of language origins were not dealt with to the same degree. In particular, their line of reasoning did not take into account, and tended to draw attention away from, two other important dimensions of language evolution: (1) the contribution of domain-general and non-language-specific cognitive and neural mechanisms, as stressed, for example, by cognitive scientists like Lieberman (e.g. 2006) and cognitive-functional linguists like Bates (e.g. Bates & MacWhinney, 1989), Tomasello (e.g. 2003) and Langacker (e.g. 1987); and (2) the *glossogenetic* dimension of language: the fact that language itself is a dynamic medium that evolves, adapts and changes continually whenever it is used and replicated in cultural and social-interactive settings (Hurford 1990; Croft 2000).

This of course is a fact long known to historical linguists. But in the context of language evolution it opens up the exciting possibility that the hypothesized biological evolution of language-specific neuronal mechanisms was not the main factor in language evolution. From this perspective, language was shaped by the brain and adapted to non-language specific cognitive mechanisms and processes in order to ‘survive’ (Christiansen & Chater, 2008; Deacon 1997; Kirby 1999). It also poses the following two questions: a) what role might glossogenetic processes of cultural/linguistic transmission and language change have played in the emergence of linguistic structure and complexity? And b) how were they combined with domain-general capacities and processes of human interaction (Bybee 1998, 2010; Kirby 1999; Heine & Kuteva, 2007)?

Over the last years, these two previously neglected dimensions have gained in recognition and importance in language evolution research. More specifically, they feed into an evolving and emerging view of language as a *complex adaptive system* embedded in and coupled with a multiplicity of social, cognitive, diachronic, and interactive factors (Beckner et al., 2009; Hruschka et al., 2009; Kirby 2012; Steels 2011).

I argue that a view of language as deeply rooted in the socio-cognitive and cultural dimension and in actual language use will become more important in the future. Namely, it promises to be able to integrate and synthesize a wide variety of approaches and research on the evolution, change, and acquisition of language (Beckner et al., 2009; Hruschka et al., 2009).

I will first present the emerging consensus of language as a complex adaptive system before arguing that the modern school of Cognitive Linguistics

has important contributions to make to this evolving theory of language (evolution). I thus set out to give a brief outlook of what kinds of questions will prove to be important in the future of evolutionary linguistics if it takes a complex adaptive systems perspective.

2. Language as a Complex Adaptive System

As outlined in the introduction, language is consistently being viewed as a complex adaptive system that arises through complex interactions of multiple factors located on multiple timescales. According to Kirby (2012:590f.), there are three timescales whose dynamic interactions determine the emergence of the complex adaptive system of language:

1. The *ontogenetic timescale* of individual learning and individuals acquiring a language, which is influenced by a variety of cognitive constraints, processing factors, learning biases, social scaffoldings and other mechanisms (e.g. Beckner et al., 2009)
2. The *glossogenetic timescale* of cultural transmission and historical language change in dynamic populations, which is determined by social and cognitive factors as well as emergent properties of the transmission process (e.g. Deacon 1997; Hruschka et al., 2009; Kirby 2012)
3. The *phylogenetic timescale* of the biological evolution of the species and of the multi-component suite of skills and motivations that enables language learning and production in modern humans (e.g. Tomasello 2003, 2008; Christiansen & Chater, 2008)

Importantly, these three dimensions themselves also constitute complex adaptive systems determined by a variety of interacting factors. This evolving framework – which Kirby (2012:591) and Steels (2011:340) term *evolutionary linguistics* – guides the multidisciplinary analysis of the complex interrelation of the forces that are involved in the acquisition, processing, development and transmission of language.

Extending the position of Pinker & Bloom, such a view of evolutionary linguistics suggests the biological evolution of language can be understood as but one of three systems exhibiting ‘adaptive complexity’:

“Learning, cultural transmission, and biological evolution are all complex adaptive systems. In other words, they are processes involving a number of interacting parts which give rise to emergent properties that show the appearance of design” (Kirby 2012:590).

Language, as well as individual languages, is thus shaped by a multiplicity of factors, including constraints of body, brain and environment. Christiansen & Chater (2008), for example, discuss the importance of multiple interacting constraints shaping the glossogenetic evolution of language structure. These include constraints from the nature of thought, constraints arising from the perceptual and motor machinery underlying language, cognitive constraints of learning and processing, and pragmatic constraints. As Steels (2011) adds, these constraints give rise to language structure through processes of dynamic alignment and self-organization in embodied interactions. In addition, languages are also shaped by the specific nature of the process of cultural transmission and selection (e.g. Kirby 2012, Steels 2011) and by emergent properties of semiotic constraints, discourse factors and other cultural conventions (e.g. Deacon 2012).

Studying the complex conditions and dynamic interactions in which these emergent properties (and therefore language) arise can be seen as one of the most important trends characterizing present evolutionary linguistics. This approach will continue to be highly important in the future of the field.

3. Language, Usage, and Cognition

The view of language discussed in the previous section is highly compatible with *cognitive-functional* and *usage-based approaches* to language (Geeraerts & Cuyckens, 2007; Beckner et al., 2009). These form an important part of the complex adaptive system view of language. Thus, they are also highly relevant for evolutionary linguistics.

In particular, cognitive-functional and usage-based approaches highlight a number of important insights regarding the nature of language and its cognitive, embodied, and social-interactive bases. These approaches stress that language as a mental and neuronal phenomenon is based on abstracted patterns and schematizations from actually occurring instances of dynamic language usage in richly interactive social settings (Beckner et al., 2009; Bybee 2010).

The foundations of language processing, acquisition and change are seen as based on domain-general and non-language specific processes and capacities. These include, on the one hand, our socio-cognitive capacities and motivations for cultural learning, imitation, sharing and directing attention, having joint goals and commitments, understanding social conventionality, social perspective-taking, and others (Tomasello 2003, 2008). On the other hand, language is seen as relying on general cognitive capacities such as conceptualization, categorization, chunking, entrenchment, routinization,

analogy, schema formation, sequential processing, planning, automatization, generalization, statistical analysis, pattern recognition, focusing and shifting attention, viewing a scene from different perspectives, conceptualizing a situation at varying levels of abstraction, and others (e.g. Beckner et al. 2009; Bybee 2010; Ibbotson 2011; Langacker 1987; 2008).

Language users employ these capacities to derive schematized patterns of varying degrees of abstraction from usage events in order to build up their communicative inventories. As research on grammaticalisation has shown, these capacities not only shape language acquisition and use but are also responsible for diachronic processes of language change. They also continue to shape the structure of language and the emergence of new structural patterns (Bybee 2010; Heine & Kuteva, 2007).

What is more, within the Cognitive Linguistics and complex adaptive systems framework the evolutionary emergence of language as a structured inventory of constructions of differing complexity and schematic abstraction is explicated with recourse to these domain-general cognitive and socio-cognitive capacities (e.g. Bybee 1998, 2010; Heine & Kuteva, 2007; Hruschka et al. 2009). This then places the emphasis in investigations of the evolution of language on the evolution of the cognitive and social mechanisms described above in richly social and dynamic interactive settings and symbolic niches (Sinha 2009).

It is of course an open question to what extent any of these capacities can be considered ‘uniquely human’ in any meaningful way (see e.g. Pleyer 2012). However, it can be argued that the suite or ‘conspiracy’ of these (socio-) cognitive capacities enabling language is uniquely human: “the uniqueness emerges out of an interaction involving small differences in domain-nonspecific behaviors” (Elman 1999:25).

4. Cognition and Construal

In Cognitive Linguistics, language is seen as a dynamically changing, structured inventory of form-meaning pairings (constructions) with varying degrees of abstraction. These are tightly linked to shared encyclopaedic and contextual knowledge for their dynamic interpretation and enable speakers to construe or ‘package’ the same situation in alternative ways for purposes of communication and social interaction (Beckner et al., 2009; Croft & Cruse, 2004). In a given communicative situation, speakers thus have to choose from a number of possible construals which select and highlight certain aspects of a cognitive representation and thus create different ‘windows of attention’; these direct

attention to certain portions of a situation and background others (Croft 2007; Talmy 2000; Langacker 1987; 2008; Radden & Dirven, 2007).

The construal operations available to a speaker of a given language are of course a matter of individual diachronic development. However, according to Croft (2007:349f.) there are three universal factors that influence the individual choice of construal and the way experience is verbalized in a particular usage event. First of all, the choice of construal depends on the interlocutors' communicative goals in discourse. In interaction, humans display an 'irreducible semantic communicative drive' (Núñez 2012) that takes place in multi-modal, real-time, face-to-face interaction. This drive can be seen as the foundation of linguistic perspective-setting and -sharing and as the motor of the creation of complex conceptual perspectival construals underlying and motivating symbol production and convention (cf. Núñez 2012). As a second factor, Croft mentions the constraint that the human perceptual and cognitive apparatus favours certain categorizations and construals over others. Certain entities, e.g. ones that are easily perceptually and cognitively individuated, lend themselves to certain construals rather than others and thus guide the choice of the speaker. For example, it is easier to construe bigger pieces of gold using a count noun ('gold nugget(s)') whereas it is easier to construe very small pieces of gold using a mass noun ('gold dust') (Radden & Dirven, 2007:6). Lastly, construals can be constrained by dominant cultural conventions of the speech community. The conventional imagery and construal operations embodied in the lexical and grammatical organisation of a given language, and their possible prototypical and metaphorical extensions, thus determine the set of perspectival construals available to speakers. These then influence to a significant degree their options in construing a scene from a certain perspective (Langacker 1987:39).

The linguistic processes of conceptualization employed by human beings are thus embodied in the dynamic patterns of language usage of individual speech communities. The construals and the linguistic constructions that instantiate them are of course unique to each language. Croft & Cruse (2004: Ch. 4), however, argue that all linguistic construal operations can be seen as distinct cognitive processes that are manifestations of four basic cognitive abilities: attention/salience, judgement/comparison, perspective/situatedness and constitution/Gestalt.

5. Cognitive Linguistics, Complex Systems, and Converging Perspectives

The perspective on the factors shaping the origin and evolution of construal operations described in the previous section presents an important contribution to the complex adaptive systems view of language evolution. Of course there are many more factors and constraints that are relevant to the development of construal operations. In addition, the factors investigated by Cognitive Linguistics need to be spelt out in more detail so that they can be integrated with converging evidence from other disciplines (Evans 2012)

In general, it thus seems like a highly worthwhile enterprise for the future to bring these considerations into closer contact with other work on factors influencing the development of language structure and function. From the perspective of evolutionary linguistics, relevant work that should be integrated with Cognitive-Linguistic research includes, for example, work from psycholinguistics (e.g. Barr & Keysar, 2006; Gibbs & van Orden, 2012), computer modelling and robotics (e.g. Kirby 1999, 2012; Steels 2011, 2012; see also Croft 2011, Diessel 2011), quantitative linguistics (e.g. Köhler 2005; Zipf 1949) and of course complex systems research on language dynamics more generally (e.g. Baronchelli et al., 2012).

Within quantitative linguistics, for example, Reinhard Köhler's (e.g. 2005) "synergetic linguistics" explicitly treats language as a complex adaptive system and endorses "a view of language as a psycho-social phenomenon and a biological-cognitive one at the same time" (p. 760). As can be seen, for example, in the work of Ferrer-i-Cancho and colleagues presented at the 9th Evolang (Ferrer-i-Cancho 2012; Baixeries et al. 2013) the investigation of the role of statistical patterns in the evolution of language is an active area in evolutionary linguistics. This of course also speaks in favour of expanding and complementing Cognitive-Linguistic research with work done in the areas of research mentioned above. Moreover, complex systems research like that featured in Baronchelli et al. (2012) or Steels (2011, 2012) also lends support to the Cognitive-Linguistic emphasis on the social and socio-cognitive dimension of language. Therefore, it should be incorporated into Cognitive-Linguistic investigations of the evolution of perspectival construal operations and their foundations.

The theoretical and analytical considerations of Cognitive Linguistics can thus be seen as an important addendum feeding into parallel theoretical proposals on the forces shaping language acquisition, transmission, processing, and evolution discussed in the previous sections. In turn, however, Cognitive

Linguistics can also profit from taking into account converging evidence from evolutionary linguistics.

6. Conclusion

The evolving theories of language discussed in this paper call for a research programme that explores how the general cognitive capacities discussed above evolved to interact in such a way as to enable the emergence of language as a dynamic interaction-, usage- and population-based phenomenon. One of the key questions for a future evolutionary linguistics driven by a complex adaptive system perspective and informed by Cognitive-Linguistic considerations will thus be the following: how did these domain-general capacities evolve in tandem with the complex adaptive systems of a) ontogeny and b) cultural and diachronic linguistic change to yield the complex adaptive system of language? As the 9th Evolang has shown, this project is well underway and produces exciting new research from a variety of perspectives, including computational, experimental, psychological, and linguistic work, and surely will continue to do so in the future.

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FOUR FOR ONE
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**FOUR DIFFERENT STUDIES RESULTING IN ONE CONCEPT
CALLED MULTIPLE-NETWORK-POPULATION**

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Language evolution and networks are frequently discussed topics in current research. A combination of recent articles on language evolution and networks should lead to an idealized conceptualization of possible further research. The articles are the basis for our concept of language evolution presented here. This concept, we call it Multiple-Network-Population, is influenced by language change and language contact with respect to social structures. We design a possible way in which the interaction and connection of languages and their evolution can be studied.

1. Introduction

Recent literature has discussed the relations between networks and language evolution. In the following we will examine possible relations between different approaches - all presented at the EvoLang IX in Kyoto - to language evolution and networks. All the articles presented in this paper probe into possible effects of network structures on language evolution. The article by Mühlenbernd and Franke studies the effect of local network properties on learning and non-learning and the evolution of language regions (see section 2). Schulz, Whittington, and Wiles deal with the change of language in socially structured populations. In an agent based model, they examine how successful social interaction between agents affects the evolution of concepts and lexicons (see section 3). The proposal offered by Bachwerk and Vogel differs in a crucial point from Mühlenbernd and Franke (2012). Instead of taking links between agents as fixed Bachwerk and Vogel enable agents to form new ties and strengthen existing ones (see section 4). Last but not least Gong, Tamariz, and Jäger follow an approach similar to the one taken by Mühlenbernd and Franke. They investigate how individual preferences and different kinds of networks may affect linguistic diffusion (see section 5).

In what follows, we will propose a combination of the four articles above. The combination of different ideas from the articles leads to a representation of a concept called *Multiple-Network-Population* (see section 6). This concept should

be seen as a conceptualization for further studies which are well grounded on a frequently discussed topic. Applying the methodologies proposed in the articles in a certain manner, we may come close to a picture which shows how different languages may interact or form connections to each other. The concept is based on the idea of language evolution and language change with respect to social structures. We combined the articles in a, for us, logical way to show these ideas inside one network and in several independent networks, which could be connected to each other and form a population.

Scott-Phillips, Tamariz, Cartmill, and Hurford (2012) show that the relation between networks and language evolution is currently in the discussion of the field. So our proposal presents a currently applied research methodology and suggests a possible application of it.

2. Signalling conventions

The study of signalling games run on social networks has been intensively studied. The article by Mühlenbernd and Franke investigates the conditions in a network for the evolution of language; local network properties triggering conventionalization and local properties of learners and non-learners. For their analysis Mühlenbernd and Franke run a Lewisian signalling game on a structured population.^a Depending on their relative position in the network nodes can be called *globetrotters* or *family men*. These names are suggestive regarding their position in the network. A node is called *family man* if it is well embedded in local structure and does not have many global connections. A *globetrotter* on the other hand is characterized the other way round. High connectedness also characterizes a globetrotter. These positions in the network are formally defined by high or low values of e.g. *degree centrality* or *individual clustering*. Degree centrality simply indicates how well a node is connected in terms of direct connections. Individual clustering measures how many nodes, that are neighbours to node *i*, are also neighbours.^b The simulations were run with two different learning dynamics; reinforcement learning with limited memory and best-response.^c

In line with recent work, the authors found that for small world networks the number of language regions is small whereas their size is relatively big. “A language region is a maximal subset of agents that have acquired the same language that forms a connected subgraph.” (Mühlenbernd & Franke, 2012, p. 246) They also discovered that the *average clustering* and the *transitivity* value of a language region was higher than the expected average for a connected subgraph. Mühlenbernd and Franke therefore conclude that a cliquishness supports

^aThe structure of the population is called a β -graph. A β -graph is a ring-network where each node is connected to its k nearest neighbours. Based on the probability β each node gets rewired. (Watts & Strogatz, 1998) The algorithm for this construction method is called *Watts-Strogatz algorithm*.

^bFor a more formal and in depth definition of these terms see chapter 2 of Jackson (2008).

^cFor an overview over these dynamics see Skyrms (2010).

the evolution of a local language. An important result concerned the relation between learners *vs.* non-learners, border agents *vs.* interior agents and globetrotters *vs.* family men. For both learning dynamics the following general picture arises: “learners tend to be family men border agents tend to be globetrotters” (Mühlenbernd & Franke, 2012, p. 247). In other words, a good embedding in a local dense structure helps to acquire a language successfully. On the other hand, the well-connectedness of agents communicating with different regions poses problems for learning a language. Mühlenbernd and Franke also observe that high connected family men tend to establish a language region, i.e. they are the first agents acquiring a language and classical family men are going to stabilize these regions. The later an agent adopts a language, the more it shows the properties of a globetrotter. Probably the most striking result of Mühlenbernd and Franke’s study is, that the influence of the learning dynamics on local network properties characterizing the regional success in learning is relatively small. (Mühlenbernd & Franke, 2012). But nevertheless conventions arise faster for best response learners than for reinforcement learners.

3. Social effects of language change

The article of Schulz et al. presents how social interaction among agents affects language change. As a significant factor in society, language can undergo changes over time. Language contact is an external social factor which influences the language change. An effect of language contact is language competition. In language competition, two languages are spoken but the individuals choose one language over the other one. (Schulz et al., 2012) The interaction of two populations can lead to different situations: First, if the populations have a shared knowledge about the languages, they start borrowing words from the other language and create a mixed language. Second, if the populations have no shared knowledge about the language, a pidgin may emerge. (Schulz et al., 2012)

The type of model for investigating language evolution, used in this article, is an agent-based model. In such models the populations are allowed to develop shared lexicons. These lexicons can have meaningful referents and allow for investigating changes in meaning and word use over time. The model contains two populations of agents for studying the impact of different social interactions on the lexicon and it is based on the Lingodroid project (Schulz, Wyeth, and Wiles (2010)). “The Lingodroids are agents that explore a spatial environment and interact socially to construct shared lexicons for spatial concepts.” (Schulz et al., 2012, p. 313) To account for the social aspect in the interaction the different groups have an additional parameter called *influence*.

Social interaction between the agents allows them to form concepts and lexicons. The agents are geared to form lexicons of place names (also called *toponyms*), distances and directions. An interaction between the agents takes place in a grid world. Two randomly chosen agents interact through conversations.

Firstly, they use a conversation to create a shared lexicon for toponyms. This enables the agents to describe locations in a world. Secondly, they use a conversation and the shared lexicon of toponyms to create a shared lexicon for distances and directions. If one of the conversations fails, the learning process fails. Otherwise, the lexicon is updated. While updating the lexicon, the agents store the new learned words. They memorize these words in three lexicon tables, one table for each category. Additionally, component parts of concepts are stored. The grid squares are for instance the concepts for the toponyms. The results of this study show that social interaction influences the language of a community. Both high and low influence values allow the acquisition of new words, whereas high influence leads to a faster establishment of words in the community. It was also shown that language competition has an effect on language change. (Schulz et al., 2012)

4. Finding friends among agents

In the model of Bachwerk and Vogel, agents can adapt their social ties to other agents based on the success of performed interactions. Generally, in agent-based models the social ties between the agents are fixed and cannot be changed. An agent can neither deepen his friendship to another agent, nor break off an existing friendship. So in line with other research Bachwerk and Vogel use a *social dynamic network* for their population. A dynamic network is based on dynamic interactions. Therefore, the model contains also dynamic ties between the agents. The dynamic ties should shed light on the decisions of the agents during individual interactions and how these interactions may influence the social structure of the population. (Bachwerk & Vogel, 2012) The task of the agents is to form a lexicon.

The agents have a few cognitive skills, e.g. the ability to observe and individuate events. These skills are assumed and more or less widely accepted to be the minimal preconditions for the appearance of language. The agents need to interact with each other until they achieve their goal. The goal of the agents is to agree on a lexicon which allows them to consistently understand each other in the future. The agents need to be able to access alternative information in order to learn the meaning-form mappings that are used by others. While interacting with each other, the agents need to agree on two things: Firstly, the entities which they talk about and secondly, the relation between the entities. If the agents agree, the communication succeeded and the goal is achieved. With a successful interaction, the strength of the relationship is updated. The probability of future interactions between the agents is based on the strength of the relationship. At some threshold, when the strength of the relationship reaches a certain weight, the agents are called *friends*. The number of friends an agent can have is not limited. An additional parameter allows the adjustment of the agents' ties.

In a first run, the agents are allowed to adjust their ties dynamically, i.e. there are no predefined connections between agents. In this case, it does not matter if

the agents are able to adjust their ties effectively or not, they all perform nearly the same. To improve the results in a second run, the strength of all social ties were set at the beginning to the same equally high value. This has the effect that the agents begin to cut ties relatively soon. This leads to a redistribution of communication preferences to the more popular communication partners. By making friends and having a closer relationship to others, the structure in the network changes and more clusters will arise. (Bachwerk & Vogel, 2012)

5. Individuals vs. society

The article by Gong et al. deals with social and individual effects on linguistic diffusion. Their main goal is to observe combinations of speaker's and hearer's preferences and social constraints affecting linguistic diffusion. Gong et al. run a Polya urn diffusion model on different types of networks. A Polya urn can be thought of an urn containing different types of balls.^d The maximal proportion of a particular type of balls at a certain point in time in the whole population is the dependent variable for the statistical analysis performed by Gong et al.. A high proportion should indicate a high degree of diffusion.

A general observation for all networks concerns the influence of a speaker's or hearer's preference: Linguistic diffusion is supported by hearer's preference. For just one interaction the preference of speaker or hearer behave the same, regarding to the distribution of variants. Whereas if multiple interactions and an iteration over actions are taken into account the picture differentiates. It can be said that a speaker's preference is *self-centered*, whereas hearer's preference is *other-centered*. Self-centering means to dictate its own preference and other-centring to be more likely to comply with others preference. So the hearer's preference is more efficient for linguistic diffusion. The efficiency increases by taking one-speaker-multiple-hearer interactions into account. (Gong et al., 2012) Turning to the effect of networks on diffusion means taking structural network properties into account. Gong et al. observe that a high *level of centrality* (how centralized is the structure of the network) supports linguistic diffusion. The *average degree* (number of edges per node) of a network does not work as good as the level of centrality as an indicator for the degree of diffusion. Nevertheless, for one-speaker-multiple-hearer interactions the average degree does a good job. The network property *average shortest path length* (the average smallest number of edges connecting any two nodes) yields a combined effect of the previous two properties.

To sum up: Gong et al. probe in their article the relations between network characteristics and linguistic diffusion on the one hand and on the other hand, the relation between individual preferences, i.e. hearer's or speaker's preference, and

^dAn agent is constructed as a Polya urn containing V tokens belonging to a particular type $v_1, v_2, \dots v_i$.

linguistic diffusion.

6. Multiple-Network-Population

We want to propose a union between the different papers presented above. A combination of relevant facts from the studies leads to an example for language change with respect to certain social factors and language contact. This combination can be used to construct what we call *Multiple-Network-Population*. This Multiple-Network-Population reflects a population which includes smaller networks. These networks are connected with each other, some stronger some weaker. Within these networks, there are several agents. Some agents interact with agents in other networks and some agents stay within their own network.

In the article of Mühlenbernd and Franke the concept of globetrotters and family men and additionally the concept of border and interior agents are relevant for our purpose. The idea is to create several independent networks. Within these networks different language regions arise during communications. The different language regions emerge from the signalling game and the learning dynamics. During the simulations, some agents become interior agents and some border agents. Each network is interpreted as representing a particular language and the language regions within a network as variants of it.

The starting point of the model of Schulz et al. (2012) are two separate populations, or in our case, different networks. The agents of the populations do not need to share knowledge about the language they speak. If they speak different languages, a pidgin may emerge. Agents are allowed to be bilingual. Schulz et al. choose the agents for the conversations randomly. We want to transfer this idea to several networks we created with the concept of Mühlenbernd and Franke. The small networks contain interior and border agents. The latter ones are agents on the border of a language region. We want to choose only border agents of different networks randomly. These two agents interact with each other through the three types of conversations stated in Schulz et al.. The agents do not speak the same language, therefore a pidgin can arise where the agents create a shared lexicon. Through the shared lexicon, the agents connect with each other and so do several networks. The connection of the several networks leads to the construction of a whole population.

In Bachwerk and Vogel (2012) the agents interact with other agents with a probability based on the connection strength. The interior agents in the networks get a default strength. They are surrounded by other agents, speaking the same language. Therefore, the learning success is high and they get a high default strength. The connection strength between border agents is linked to the size of the lexicon. The greater the lexicon, the greater the strength between them, but it can never be as high as the connection strength to interior agents. A great strength between the border agents leads to closer connected networks. The conversations stated

in Bachwerk and Vogel leads to closer connections between agents. One agent can choose another agent to interact with. This choice is based on the connection strength between one agent and its neighbors. The probability is higher, that the agent chooses the neighbour with a greater strength. After a successful conversation, the connection strength is updated and the relation between the agents get closer.

In line with Gong et al. (2012), we are now able to look at the influences that certain agents may have on the evolution of the communication in a network. The aspect of linguistic diffusion plays a crucial role in the study of Gong et al.. We think of a diffusion of languages, not only of variants. For our purpose, the focus lies on the communications between border agents. As shown in Gong et al. (2012), different individual preferences affect the spread of different languages. Depending on the preferred type, interior agents can also adopt this language. This may lead to a complete change within one network. With the results offered by Gong et al., we are also able to somehow predict the spread of a pidgin language, since certain structures support diffusion whilst others do not.

As it can be seen, the combination of the several facts presented in the articles may lead to a closer look an a whole Multiple-Network-Population. Each article represents a part of it and in a combination these ides may lead to a new and broader view on language change within sub-networks and on an overall network i.e. the population. More precisely the population is represented by several small networks. The networks are connected with each other. Through the connection of the networks a pidgin language emerges and can spread out. For our purpose, border agents and interior agents build a social structure within a network. The language change occurs with respect to the social structures, because only border agents are affected by the conversations we modelled with respect to Schulz et al. (2012). The changes in tie strength based on Bachwerk and Vogel (2012) changes the connection between every kind of agent. Therefore, the social structure does not affect the interaction or the connection strength. With respect to the social structure, the border agents may be affected faster by language change than interior agents. Altogether, this support the research on language contact affecting language change from an evolutionary perspective.

7. Conclusion

One might ask what the results of these considerations could be. At first, this may be an example of different studies working together and yielding new results. All these four studies deal with parts of language evolution and how language contact may influence its evolution. Some kind of social interaction also plays a crucial role. As Gong et al. have shown, individual preference plays are central for the spread of linguistic variants. On the other hand, Bachwerk and Vogel and Mühlenbernd and Franke displayed the key role of network structure for the emergence of a language. We think that this represents the competition of social

structure and individual preference very well. But as we hope to have demonstrated this competition can be fruitful. Additionally the general topic of network and language evolution is already well grounded so that it can be a solid base for further research. Last but not least, we wanted to illustrate that a combination of the studies is potentially able to draw a picture of how languages and communities of speakers have previously interacted.

We are aware that the way we presented our idea above is not the only way to combine the articles and the models contained therein. Another combination of these approaches may lead to different results. We have just chosen one possible combination to work with, because it seemed to be the most logical one for our purpose. Subsequent work may illustrate the validity of this approach.

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EVALUATING THE ROLE OF QUANTITATIVE MODELLING IN LANGUAGE EVOLUTION

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Models are a flourishing and indispensable area of research in language evolution. Here we highlight critical issues in using and interpreting models, and suggest viable approaches. First, contrasting models can explain the same data and similar modelling techniques can lead to diverging conclusions. This should act as a reminder to use the extreme malleability of modelling parsimoniously when interpreting results. Second, quantitative techniques similar to those used in modelling language evolution have proven themselves inadequate in other disciplines. Cross-disciplinary fertilization is crucial to avoid mistakes which have previously occurred in other areas. Finally, experimental validation is necessary both to sharpen models' hypotheses, and to support their conclusions. Our belief is that models should be interpreted as quantitative demonstrations of logical possibilities, rather than as direct sources of evidence. Only an integration of theoretical principles, quantitative proofs and empirical validation can allow research in the evolution of language to progress.

1 Introduction

It is clear that modelling has gained in importance in studies of language evolution. For example, at the latest International Conference on the Evolution of Language (Evolang IX), from a total of 83 talks, 19 (23%) reported results from quantitative models. These models make hypotheses about events in the past that are no longer observable, and explore whether these premises could lead to conclusions compatible with the current state of matters. They are, therefore, often able to give

insights into the potential stages and mechanisms involved in the emergence of language. For instance, computer models have played an important role in demonstrating that cultural transmission, in the absence of strong biological constraints, can be seen as a plausible mechanism leading to language universals (Kirby, 2001). Quantitative models also generally require greater “clarity and rigor” (Hurford, 2002) than non-quantitative theorizing and “enforce explicitness in the formulation of an explanation” (Christiansen & Kirby, 2003).

Despite the potential benefits of using quantitative tools to model language evolution, there are important pitfalls that can arise from taking models as direct evidence to support or refute specific theoretical frameworks. This practice has generated an unwarranted confidence that modelling can provide data similar in quality to experimental work (Cangelosi & Parisi, 2001). In this paper, we argue that this is a dangerous conclusion. With examples from recent literature, we show how different scenarios rendering different conclusions can be coherently modelled, without an obvious procedure to assess which one better approximates the reality it is built to simulate. We think models should only be used as an intermediate step between theory and experiments. Given this, we examine the role of empirical data in justifying these models.

2 The Problem of Diversity

One of the potential problems of treating models as equivalent to empirical tools is that too far a range of situations can be plausibly modelled. For instance, consider the debate regarding the relative weight of biological and cultural evolution in shaping language structure. Some models have suggested that the distribution of different languages in a population reflects the (innate) priors of individual agents (Burkett & Griffiths, 2010; Griffiths & Kalish, 2007). Other models propose instead that weak innate biases are sufficient for languages to become established in populations, since mechanisms of cultural transmission have the power to amplify weak biases (Kirby, Dowman, & Griffiths, 2007; Smith, 2009). One important assumption of these models is how, given a set of different hypotheses\languages, agents select which hypothesis\language better explains the utterances they are exposed to. The role of innate biases seems to be emphasized when agents are assumed to choose a language proportionally to its probability in the posterior hypothesis space; and the effects of innate biases are minimized when agents are assumed to choose disproportionately more often the language with the highest probability in the hypothesis space. As Smith (2009) points out, “the true nature of human hypothesis selection strategy is ultimately an empirical question”. This should be kept in mind when interpreting the results of different models (Burkett & Griffiths, 2010; Griffiths & Kalish, 2007; Kirby et al., 2007; Smith, 2009) which have different assumptions and support contrasting conclusions about language evolution.

The broader problem is that the same mathematics can be used to argue from opposite theoretical views, such as the idea of an innate universal grammar and the notion of a pure cultural evolution of language (Griffiths, Kalish, & Lewandowsky, 2008; Nowak, Komarova, & Niyogi, 2001). Furthermore, models with completely different mechanistic principles can generate very similar outputs. For instance, both the principles and parameters and the iterated learning frameworks can be used to agree with the same data in historical linguistics (Niyogi & Berwick, 1997; Reali & Griffiths, 2009).

Further examples of model flexibility abounded during Evolang IX. While Baronchelli et al. (2012) argue that cultural change is too fast for biological evolution to play a role in the structure of languages, McCrohon (2012) demonstrates that some aspects of language resistant to change may be targets of biological evolution. This diversity of scenarios would not be problematic, if the models were taken as demonstrations of logical possibilities instead of direct sources of evidence. Unfortunately, statements from the conference proceedings suggest more than the mere demonstration of logical possibilities: "Cultural transmission renders the biological evolution of strong domain-specific innate constraints unlikely" (Thompson, Smith, & Kirby, 2012); "Only adaptations for flexible learning combined with continual cultural evolution can reconcile the diversity of languages, with the biological uniformity of their speakers" (Baronchelli, Chater, Pastor-Satorras, & Christiansen, 2012); "duality of pattern emerges as a consequence of pure cultural dynamics" (Tria, Galantucci, & Loreto, 2012).

We are aware that modelling research in all disciplines usually draws conclusions under the tacit assumption that these are only valid within the theoretical scope of a specific modelling framework. However, given the particularly multidisciplinary readership of language evolution research, the connection between model results and empirical reality should always be stated. Given that several alternative scenarios can be all coherently modelled, there is a fundamental problem in assessing which model among the many provides a better description of the mechanisms involved in language evolution. This assessment is impossible without external instruments of validation.

3 Model Validation

There are two general ways to assess the validity of quantitative models. A first, obvious method is the comparison of the model outcomes with the reality it exemplifies. Whenever a model is inconsistent with observable facts, then a reformulation of the model is necessary. For instance, if a certain model attempts to simulate the establishment of conventionalized communication systems, then the failure to do so generally argues against its validity. This method of validation is not, however without pitfalls. As mentioned above, both the principles and parameters and the iterated learning frameworks can be used to fit the same historical data.

Moreover, the problem of using only historical data is further demonstrated by other disciplines such as social sciences and economics, where models built to fit past data failed to predict future outcomes. Such failures render these models poor approximations of reality and reflect the disregard of important variables, the reliance on false assumptions or the impossibility to adequately describe a complex system with few minimalistic equations.

A second method to assess the validity of models is to check whether assumptions and selected parameters hold against empirical inquiry. For example, in classical (normative) microeconomics, agents (humans) are assumed to be rational decision-makers. Research in psychology has proven this assumption wrong (Kahneman & Tversky, 1979). Recent models on iterated decision-making (Camerer, Ho, & Chong, 2004) do incorporate these assumptions of irrationality and cognitive limitations, fitting well both *empirical evidence on processes' outcomes* and, crucially, *mechanistic constraints leading to such outcomes*.

3.1 Examples from Social Sciences

There is a basic, widespread family of models that can be found, explicitly or tacitly used, both in the language evolution literature and in the social sciences. Both areas engage themselves in the hard task of modelling and predicting states of complex systems characterized by a number of unobservable variables. Markov models, in all their simplicity and flavours, are a building block of applied mathematics. Simplicity and elegance are a tacit, golden rule of modelling. However, these come at a cost: few parameters can, if any, only capture the most basic forces in a complex system. It is therefore important for modellers to always keep in mind this essentiality vs. depth of scope trade-off when interpreting model results. Moreover, the failure of a model to predict an event in another discipline should instigate caution in drawing inferences on the evolution of language using a closely related modelling technique.

An interesting example of this is a modelling study by Schrodtt (2000) investigating conflict patterns in the former Yugoslavia war. The panel data consist of weekly reports about the magnitude of the conflict (low vs. high) over a period of 8 years. Two hidden Markov models are created, corresponding to low and high conflict magnitudes. Independent variables include several possible predictors of conflict (ranging, for instance, from demonstrations to ethnic expulsions). The goodness of the model is then evaluated as the ability of a time pattern of events to be attributed to - therefore explained by the model of - high or low conflict periods. The results suffer from an issue common to such models: accuracy (how well an outcome is predicted), sensitivity (how uncertainty propagates from assumptions to results) and precision (variability in replicated forecasts) of the model have to be traded for one another. Here, for instance, 80% accuracy corresponds to 25% sensitivity and 60% precision, while a model with 92% short-run (near future) accuracy has only 30% precision. The forecasting horizon emerges as a fourth

parameter in assessing the goodness of Schrod's model. This is extremely common in any model containing a time component: the closer in time the prediction, the higher its reliability. Results on forecasting horizon from other disciplines appear particularly relevant to language evolution research: Language models deal with time spans which are several orders of magnitude greater than the critical time horizons in the social sciences.

As another parallel, it is interesting to mention what Cowles (1932) reports on the ability of economic models to forecast future market developments, notably at a time when mathematical economics was starting to develop. Cowles, an advocate of mathematical accuracy in economics, reviews 45 different attempts at predicting stock markets, made by just as many prestigious agencies and financial publications. He compares these forecasts to null statistics achievable by pure chance and finds little difference between these two ways of predicting unknown events. "The most successful records are little, if any, better than what might be expected to result from pure chance. There is some evidence, on the other hand, to indicate that the least successful records are worse than what could reasonably be attributed to chance." (Cowles, 1932)

Twelve years later, as modelling techniques advance, Cowles (1944) finds evidence of some predictability in stock prices. He claims that "A simple application of the "inertia" principle, such as buying at turning points in the market after prices for a month averaged higher, and selling after they average lower, than for the previous month, would have resulted in substantial gains for the period under consideration". Paraphrasing, a Markov process with three states and one month lag was better than chance in suggesting fruitful investments. These simple models have since then been replaced by more complex ones, which became the standard college-level tuition in finance and whose basic assumptions were in turn criticized down to the bone (Hudson & Mandelbrot, 2004). What happened to stock market forecasting is already history.

Our point is that if a specific technique used in modelling language has demonstrated lack of robustness or predictive power when used in other disciplines, researchers should be cautious in interpreting the result of their model. To make matters worse, language evolution models are designed to predict only past, rather than future events. Hence, if different evolution models fit the historical data equally well, it may be impossible to refute these models based on their outcome. This renders the selection and validation of *a priori* assumptions even more fundamental. Within the field of language evolution, this empirical validation comes from historical linguistics, psychology, biology and demographics. In the next section we will discuss a paradigmatic example of this interaction between models and empirical data: the iterated learning model.

3.2 Iterated Learning Model

The “iterated learning model” (Kirby, 2001) involves a meaning space, a signal space, a learner and a teacher. At each step of the model, the teacher agent produces a string. The learner tries to construct the most parsimonious mapping between meaning and symbols. It has been observed that there is a gradual regularization of this mapping over many steps of the model. The iterated learning model has been linked to two distinct sets of empirical tests.

The first source of empirical evidence supporting the iterated learning model comes from psychological experiments, in which people are asked to make signal-object associations (Kirby, Cornish, & Smith, 2008). The experiments show evidence of compositionality emerging spontaneously in an artificial language after a few iterations of cultural transmission, an outcome similar to previous simulation results. These experiments are important to demonstrate that language-specific features can emerge from cultural mechanisms (without the need of language-specific biological adaptations). However, they do not constitute a strong proof that evolution of language occurred due to these mechanisms alone. One reason to be cautious about these inferential jumps is raised by Littauer (2012): “Early language communities may have had different pressures on linguistic evolution and morphological complexity than modern languages, including differences in the amount of shared information. (...) Agreement is an integral part of language evolution, and the origin of agreement in protolanguage may not have followed the same paths as modern agreement formation processes”. In fact, the psychological experiments conducted to validate the model of iterated learning were performed on modern humans, while pre-linguistic hominids may have had different cognitive skills and biases. With this setup, one can investigate mechanisms of cultural transmission under the cognitive biases that are characteristic of modern humans, but one cannot assess whether the evolution of these biases in the hominin lineage might have changed the compositional features of our communication signals.

Still within experimental psychology, we can find other reasons warning against straightforward conclusions: When horizontal transmission (intra-generation) is included along with vertical transmission (inter-generation), the scenario of cultural evolution becomes more complex (Berdicevskis, 2012; Tamariz, Cornish, Smith, Roberts, & Kirby, 2012). For example, the need to negotiate meaning with conspecifics in horizontal transmission leads to low fidelity in vertical transmission (Berdicevskis, 2012), even in a scenario of a highly structured language (*contra* Kirby et al., 2008).

The second source of evidence comes from historical linguistics. Recently, Reali and Griffiths (2009) showed that three distinct language features can be explained by a neutral iterated learning model. These include the characteristics of verb regularization, Zipf’s law and the character of innovations in language. The authors propose that neutral models should be used as null models for language

dynamics. Their opinion is that if neutral models can be used to explain a particular characteristic of languages, then there is no need to appeal to selective forces. Recently, Blythe (2011) also justified that neutral models qualify as good null models for language dynamics. While this agreement of theory and data from historical linguistics might be both interesting and useful, the data is unfortunately over a time scale much smaller than that of language evolution. Since the evolution of the faculty of language refers to a period of time that goes back at least up to the last common ancestor between humans and chimpanzees, its (cognitive, ecological, cultural, etc.) context differs from that of the evolution of languages (object of concern for historical linguistics). Naturally, the theoretical model cannot be extrapolated to a different time scale and a different set of conditions.

4 Better Evaluation Techniques and Better Models

We think models can be useful if there are better common practices in their evaluation and validation. There is, however, the danger that modelling research will go towards increasingly complex models that rely on an increasing number of plausible hypotheses which rely on the intuition of the modeller. It is important to instead focus on identifying and limiting the hypotheses within these models and look for ways of testing them. As pointed out, a crucial method to evaluate models is to check whether both their *assumptions* and *mechanistic constraints* are supported by independent experimental research. This applies to a variety of assumptions usually only scrutinized by plausibility analyses. For instance, we should test how humans select hypotheses before assuming a particular strategy (Smith, 2009); and we should test whether humans display irrational biases or cognitive limitations on certain tasks before assuming they will behave as rational agents in processes involving those tasks (Camerer et al., 2004; Kahneman & Tversky, 1979). If it turns out that human behaviour departs from rationality, realistic models should incorporate these constraints.

An important point for modelling language evolution is the question of what biological/cognitive evolution means, and how it can be encoded in models. The evolution of language is the product of both biological and cultural evolution. The weight of each of these processes in shaping language structure is currently unknown. However, modelling discrete stages of biological evolution requires the incorporation of discrete cognitive constraints present in the populations evolving. For instance, while humans can encode hierarchical information in vocal utterances, it is unlikely that cats do so, even though both species can communicate vocally. It is unlikely that successive generations of cats communicating vocally will develop a hierarchical system of communication, even if this communication strategy would be the most efficient. A realistic model of evolution of vocal communication, from the last common ancestor between humans and cats up to the modern human, would need to somehow encode these cognitive constraints, and the evolution of these

constraints across successive generations of agents (Jones & Love, 2011). Cues about the processes underlying the evolution of these cognitive constraints can be obtained using a comparative approach, in which different species are experimentally tested in similar cognitive tasks, with the goal of identifying the cognitive constraints of each. Though it might be impractical to include such fine-grained information, perhaps some general law of ‘cognitive evolution’ will emerge from the comparative approach. This law could be incorporated in future models of language evolution.

5 Conclusion

In this paper we have suggested how a large variety of scenarios can be coherently modelled. Since different scenarios are achieved by selecting different parameters and assumptions, this selection process should be rigorously scrutinized. We have shown that leaving fundamental parameters out of models may bias the conclusions in order to meet previous theoretical assumptions. If computer simulations are taken as direct evidence to support particular theories over others, then there is a danger of the scientific process becoming circular. The role of experimental work is fundamental to validate both models’ results and assumptions. Finally, we note that it is not enough to check models against empirical data, but also to examine the relevance of this agreement to language evolution. Data relevant to the evolution of languages is not necessarily relevant to the evolution of the faculty of language. A wider range of validation techniques will be required.

We see quantitative modelling as an intermediate step between theory and experiment. It helps improve on theory by clarifying assumptions, adding insights and showing the plausibility of processes. It can help analyze available data and lead us to new sources of empirical evidence. It is then a worthwhile endeavour as long as it continues to interact with experiments and data. If the results of these models are carefully interpreted, they could play an important role in our understanding of language evolution.

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CONCILIATING MODERN EVOLUTIONARY THEORY AND LANGUAGE EVOLUTION RESEARCH

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In current language evolution research, it seems difficult for scholars to put together notions from linguistics and well-established research lines in evolutionary theory. Here we attempt a conciliation of these two fields in order to overcome some of the old dichotomies that have plagued it in recent years (e.g., linear vs. saltationist, or, to some extent, cultural vs. biological). We also assess the validity of approaches to evolutionary theory heavily dependent on natural selection. Those two things aim to contribute to the effort of building the foundations of the study of language evolution on the solid ground provided by notions and theories from biology and evolutionary theory, thus establishing the study of language evolution as a subfield of those two areas of knowledge.

1. Introduction

Scientific advances often come from uncovering a hitherto unseen aspect of things as a result, not so much of using some new instrument, but rather of looking at objects from a different angle. (Jacob, 1977: 1161)

In the present work we try to conciliate evolutionary theory and language evolution research. We think this is especially important for the latter field to relay on a good evolutionary framework. Many current approaches to language evolution are largely based on the application of the natural selection principle to a story that more or less can explain a targeted feature. However, this strategy often fails when the feature in question is shared by other species. That often raises the need for an evolutionary explanation of the feature, generally accomplished by means of a new story in which natural selection is again the only agent driving the evolutionary path of the feature.

Modern biology has since long abandoned that strategy. Nowadays, evolutionary theory recognizes the important role played by factors like mutation, genetic drift, migration, natural selection and developmental paths, as contributors to (our understanding of) organic evolution in general (West-Eberhard, 2003). Evolutionarily, some features are more clearly affected by one of those factors than others, but the most important fact is that modern

evolutionary theory does not rely on a single factor only anymore.

We would thus like to bridge evolutionary theory and language evolution research taking the current multidimensionality of the latter field, and somehow adopting it for the study of the origins and evolution of the human faculty of language. In doing so, the study of organisms according to evolutionary theory (strongly based in physics and biology) can provide formal tools, theories, and a bigger framework to the study of cognition in general, and language in particular. Such an approach has been proved suitable for cognition in recent years, and we think it will also be valid for the study of language. If language derives from (or relates strongly to) cognition, such an approach should be just as worth pursuing.

In particular, we consider especially important to introduce in the study of language evolution the points of view of the set of theories of Evolutionary Developmental Biology (aka evo-devo). In those theories, explanation does not center on the genes, but in the developmental paths and environmental factors affecting them. Additionally, this should not be considered as an opposite view to that offered by some works in evolutionary modeling. On the contrary, a theory of language evolution that is well grounded on evolutionary theory supposes an enhanced option for modeling, since some of the imported theoretical notions could have already been modeled for studies on organic evolution.

Finally, we think that the integration of well studied notions and principles from evolutionary theory could also be helpful in order to fill some gaps, or to put an end to long-standing debates like those regarding linear vs. non-linear growth, or the participation of culture in the development of the language faculty.

As it has been observed, “[S]cientific knowledge thus appears to consist of isolated islands. In the history of sciences, important advances often come from bridging the gaps.” François Jacob (1977:1162). Or to put it with a famous quote by Francis Borden: “Most advances in science come when a person for one reason or another is forced to change fields.”

In the second section we comment on the century-old problem of taking natural selection to be the only factor in evolution. The third section is devoted to a more embodied perspective that takes into account the whole organism, not just a single unrelated feature. The final section pretends to take some steps toward a conceptual integration of cognitive sciences that takes into account the developments and contributions that can be found in evolutionary theory. The ultimate goal is make language evolution research naturally become a subfield of evolutionary theory.

2. Darwin and Natural Selection

For many, it has been tempting to invoke a similar mechanism of selection to describe any possible evolution, whether cosmological, chemical, cultural, ideological or social. But this seems condemned to

fail from the outset. The rules of the game differ at each level. New principles have, therefore, to be worked out at each level. (Jacob, 1977:1163)

Natural selection is invoked once and again in many works on language evolution as the only factor driving the evolutionary process. It is important to note that it was not Darwin's intention to explain organic evolution by natural selection only. Such theoretical misinterpretation, however, rapidly spread across the society. Therefore, he included a note 6th edition (1871), in what he thought to be the "most conspicuous position – namely, at the close of the Introduction". Darwin stated there that "I am convinced that natural selection has been the main but not the exclusive means of modification" (Darwin, 1871). The time elapsed he observed that, "this has been of no avail. Great is the power of misrepresentation".

With the advent of the new Synthesis, lead by Dobzhansky, natural selection became again the great and – for some scholars –, the apparently unique factor in evolution. Thus, the *genocentric* perspective, according to which the genes had "all the relevant information" for an organism to develop, was fashionable for many years. Even today the research of the biological substratum of language is sometimes unfairly regarded as if the purpose was to show that *all we need* are genes which eventually encode grammar, or a single mutation, and therefore evolution acts *only* when "weaker" genes get weeded out through natural selection. This view was challenged in the 1970s and the 1980s when biologists started studying organic evolution taking into account the developmental patterns of the phenotypes. Because, it is well known at least since four decades, that it is on the phenotype that natural selection operates, not on the genotype, nor on the mutation rates (e.g., Deacon, 2010). The author insists in the single mutation theory, focusing the attention on Chomsky 1983, though neglecting Chomsky 2005).

Ploeger and Gallis (2011) have noted that evolutionary psychology emerges from the application of Darwinian principles, particularly natural selection, to explain cognitive and social development. Thus, sometime it has been followed the point of view adopted in evolutionary psychology and other different theories, which are based on just natural selection, or strongly focused on one single feature which triggers the selection pressure (e.g., Pinker & Bloom, 1990; Bickerton, 2010). In this view, mind and therefore, language, with all its related features, should not be separated from the rest of the organism, for otherwise we risk missing important information from other parts or mechanisms that might have also affected the evolutionary development of language. As Wagner and Wagner (2003) note: "*natural selection and other mechanisms of evolution, are holistic and unlikely to affect neural/mental features separately from other biological properties of the organism.*" (our stress)

3. On organic development

A product of cleavage in one chain can suddenly become an active element in another chain or even play a role in a completely different process. These products may serve as signals to connect chemically unrelated, but physiologically dependent, systems. (Jacob, 1977:1165)

It is accepted today that minor changes can trigger cascades of effects in the evolution of an organism. This is well known but seldom applied to language evolution. However, small changes can force divergent evolutionary paths. For example, although the genetic distance between chimpanzees and humans is not that big, the phenotypic expression of their genomes is quite different. That's because many small changes in each of the two genomes, in their expression and in their respective developmental tendencies have led each species to diverge greatly in many aspects. However, it should be recalled, that *de novo* changes are actually rare:

Novelties come from previously unseen association of old material. To create is to recombine. (Jacob, 1977:1163)

Hence, as Marcus (2006) and Marcus et al. (2012) have well observed, human language can be considered as *descent-with-modification* with respect to its genomic (and we add, “developmental”) history. It probably descends from a previous form of thought/communication so different in many aspects that perhaps should not be labeled as “language”. At several points of that history, many (probably subtle or even innocuous) changes accumulated until module(s) for thought and/or communication ended up being what we know today. This is probably what also happened to other processes that took place in the evolution of the human body, such as the face, the brain, the limbs, etc. Those sequences of linear progress can therefore be detected in the evolution of any species. But there are as well leaps from phenotype to phenotype. Not all the theoretically possible intermediate states of a feature are found in nature, nor must they be. This is something that was pointed out as early as 1979 by Pere Alberch and colleagues, who pursued the evolution of species by adopting the evolutionary and developmental perspective (Alberch, 1989; Alberch & Blanco, 1996; Alberch, Gould, Oster & Wake, 1979; Oster & Alberch, 1982), later to be known as *evo-devo*, recently adapted to language evolution by Balari & Lorenzo (2013).

3.1 On apes evolution and language

The previous comments lead us to reconsider the use of theoretic arguments just based on *fitness*, in evolutionary theories and in accounts where modern humans are always the species best adapted, the species better evolved, the ape that

evolved towards the best “communication system”. Apes evolved following different evolutionary paths. Today we find six great groups of apes. All of them share many traits, but also differ in many aspects. The adaptability of non-human traits should not be called into question just because they are not humans. Hence,

This permanent reshuffling of genetic elements provides tremendous potentialities of adaptation. (Jacob, 1977:1166)

Thus, the constant evolution of organisms leads to many different solutions, and species take or not advantage of the ones that either were already available to them, albeit for some other purpose, or are changes on them. Non-human apes did not evolve towards language. Nevertheless, their current existence is at least proof that language is not necessary for survival. Nonetheless, the use and usefulness of language – once it is a biological fact within our species –, should not be denied. For, as we said in the previous section, language as a (probably modern) phenotype has probably been a positive target of natural selection.

What is less certain is whether a specific need for developing language directly triggered the phylogenetic changes in the genome and/or the developmental trends of the species that made possible the emergence of the language faculty. In order for our species to evolve into our current modern human form, these changes – all of them – *had* to happen.

This is why the probability is practically zero that living systems, which might well exist elsewhere in the cosmos, would have evolved into something looking like human beings. (Jacob, 1977:1166)

This statement can be true even in the case of hybridization. In our history there are at least three episodes of *introgressive* hybridization with three different hominins: with Neandertals (Green et al., 2010), with Denisovans (Reich et al., 2011) and with an unknown African hominin (Hammer, Woerner, Mendez, Watkins, & Wall, 2011). “Introgression” means that two species partially interbreed, something really common even within mammals (Mallet, 2005, 2008). But this fact does not ensure at all that all four hominins already had language. There are many aspects that could prevent such a conclusion, and this is something we can learn from evolutionary studies: from differences in the genomic expression to different developmental trends. All these phenomena call for caution in our conclusions.

4. Towards the conceptual integration

If language is considered as the outcome of a language faculty, the study of its phylogenic evolution should be carried out by using the same tools that have been used in the study of the eye and vision, or of auditory perception. Therefore,

when classifying language-related features, notions from cladistics, like *homoplasy* (a convergent solution of unrelated species; e.g. wings in birds and bats) or *apomorphy* (a derived trait in a clade; e.g., loss of tail in apes), or *autapomorphy* (a derived trait particular of a species; e.g., loss of air sacs in *H. sapiens*, regarding apes) are useful both to delimit and classify the language-related features, and to unify the evolutionary terminology. Psychological capabilities that are attested in other species can be reflected into cladograms so that it becomes easier to see whether a particular aspect of our cognition is something completely new or it is rather shared (Kitching et al., 1998; Nadal et al., 2009; Barceló-Coblijn, 2012).

In principle, the study of language evolution demands the integration of many fields. This appears to be something difficult though not impossible, as it was difficult though not impossible for the project of cognitive sciences in the past century (Miller, 2003).

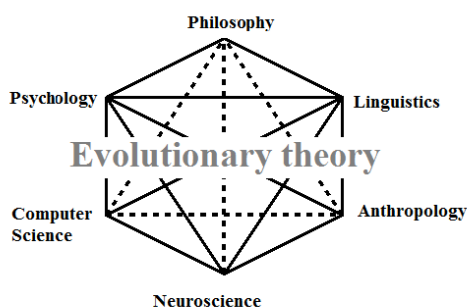


Figure 1: An adaptation of Miller's representation of Cognitive Science in order to capture our proposal for Language Evolution Research. Here all the fields of the hexagon are interrelated (for the sake of clarity, genetics is subsumed into Anthropology). All fields, however, take modern evolutionary theory into account.

Ultimately, the union of developmental studies of unique phenotypes in a myriad of species will result in a more thorough model of the groundwork the brain was built upon. (Konopka & Geschwind, 2010)

The study of language leads to the study of the brain, and this to the study of cyto-architecture, the study of neurons. The comparative method allows us to apply what we already know from these studies to the study of other species, and altogether can be enriched by genetics and modeling.

Why should language be a feature so different that escapes any explanation

based on biological and physical arguments (something that does not deny the inclusion and possible intervention of cultural factors)? We find no reason to prevent an approach to the language faculty that takes the fields in figure (1) into account, while maintaining coherence with modern evolutionary theory.

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BEYOND “NEUROEVIDENCE”

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In the study of what makes human language different from animal communication systems, it is readily apparent that the crucial change involves the human brain. Over the past few decades, there have been several methodological advances in the neuroscience that have applications for explaining how human language could have arisen out of animal behavior. Use of neuroscience findings and methods can advance the field by inspiring new lines of inquiry, constraining the hypothesis space, and grounding evolutionary scenarios within a precise and rigorously testable framework.

1. Introduction

While there are many animal species that exhibit complex communication systems, which can include both vocal and gestural components (Tomasello, 2006; Marino et al., 2007), both innovation and social learning (Poole, Tyack, Stoeger-Horwatch, & Watwood, 2005; Rendell & Whitehead 2001), it is clear that there is no nonhuman animal which possesses a human-like language. The characterization of what makes human languages unique potentially includes parity, displacement, recursion and infinite generativity, combinatorial expression, symbolic content, logical structure, or some combination of these (Arbib, 2005; Bickerton, 2009; Chomsky, 1965; Deacon, 1997; Locke, 1706). However, which of these are sufficient for a language capacity and how they arose remains an open question.

The scientific study of the evolution of language attempts to explain how human language came to be different from other animal communication systems. The one thing we can be sure of is that this explanation must necessarily include some difference between human brains and the brains of other animals, because it has been demonstrated that human language is not sufficiently explained only as an external or cultural phenomenon. Animals raised with humans in encultured environments, even those with explicit training in a human-like communication system, do not master language (Savage-Rumbaugh, McDonald, Sevcik, Hopkins, & Rubert, 1986; Arbib, Liebal, & Pika, 2008). Furthermore, current evolutionary scenarios for the evolution of language all include changes

in cognition, whether this is stated explicitly or not. Simply put, you can't talk about languages without talking about brains.

However, the reasons to include what is sometimes dismissively described by linguists as “neuroevidence” extend beyond its central position in the question of what language is and how it began. This perspectives piece will consider three of these in turn, after a brief description of some common methods in cognitive neuroscience. First, new findings about brain structure and function can lead to the generation of new hypotheses about the nature and origin of language. Second, known facts about brains and neural processing can provide constraints on what is possible in constructing hypotheses of language origins. Third, and most importantly, including explicit hypotheses on what changed in human brains will force these hypothetical scenarios to organize themselves into neurologically plausible steps that can be tested empirically.

2. Some Common Methods

An older but still powerful method for constructing hypotheses about behavioral evolution is comparative neuroanatomy (see Deacon, 1997; Striedter, 2005). This particular method is based on correlating species differences in cognition with species differences in brain structure, connectivity, cytoarchitecture, cell types, and peripheral inputs. Modern methods include the use of viral vectors to insert DNA in specific pathways with imaging agents like green fluorescent protein, electrical modulators like bacterial rhodopsin, ion channel blockers like tetanus, or combinations of these, which allow for visualization and experimental manipulation of entire functional circuits (see Kinoshita et al., 2012).

A newer method used for cognitive neuroscience in humans involves the manipulation of atomic properties of water molecules to acquire non-invasive, in vivo structural and functional data on the brain (see Huettel, Song, & McCarthy, 2009). These methods include high resolution magnetic resonance imaging (MRI), functional imaging of neural activity using magnetic differences in oxygen-rich versus oxygen-poor blood (fMRI), and the mapping of white matter pathways using Brownian diffusion of free water (DTI). While older functional imaging studies tended to use large block designs to localize broad functions to large anatomical areas, newer studies have been innovative in combining one or more of these techniques to test hypotheses about the cognitive development (Finn, Sheridan, Hudson Kam, Hinshaw, & D'Esposito, 2010) and the acquisition of language (Brauer, Anwander, & Friederichi, 2011).

An exciting advance in the field of neuropsychology involves the use of strong magnetic fields to modulate localized neural activity in the human cortex, which is known as transcranial magnetic stimulation (TMS). TMS can be used to create temporary “lesions” in areas of cortex by inhibiting electrical activity, and has been shown to produce temporary aphasias in human participants (Stewart, Walsh, Frith, & Rothwell, 2001). A further benefit of TMS, beyond

that it is noninvasive and the deficits temporary, is that it can also be used to potentiate electrical activity, thereby allowing researchers to induce responses to stimuli that are normally too weak to elicit responses. This technique has already been used in the investigation of mirror neuron activity and human language (Iacoboni, 2009).

The newest methods in human cognitive neuroscience include the use of microarrays of electrodes placed directly on the cortical surface of awake, behaving humans. This has the drawback of being limited to clinical populations (almost entirely epileptics undergoing exploratory surgery), but offers the strong benefit of directly imaging neural activity in real time with millimeter resolution. While cortical microarrays have been used to study language comprehension in humans, these studies have not been explicitly grounded in an evolutionary framework (Edwards et al. 2010; Sahin et al., 2009).

3. Generating New Hypotheses About Language Origin

New findings in the neurosciences can be used to inspire new hypotheses about the neural processing of language comprehension and production, and how these capacities may have evolved. The most well-known example comes from a French anthropologist who documented language deficits in a patient with a lesion in the posterior inferior frontal gyrus (Broca, 1861). This finding began the scientific study of aphasias, where the different types of language deficits presented in patients with traumatic brain injuries presumably reflected the functions of the damaged areas (Lecours, Lhermitte, & Bryans, 1983). A modern application of Broca's discovery to the evolution of language involves using asymmetries in the endocasts of extinct hominins to infer the extent of laterality in language critical areas (Holloway, Broadfield, & Yuan, 2002).

A more modern example involves the discovery of what are now known as mirror neurons. These are pyramidal cells discovered by single-cell recordings in the premotor area of macaques that fire not only when the animal performs an action, but also when it sees or hears that action being performed by another (Rizzolatti & Sinigaglia, 2010). This finding generated views of language as mutual mindreading (Tomasello, 2005), mental simulation (Iacoboni, 2009), and modifications of pantomime (Arbib, 2005).

4. Providing Constraints on Theories of Language Origin

The process of discovery in science requires both creativity in the generation of multiple possible explanations for observed phenomena, and rigid standards for culling less-likely hypotheses from the body of scientific knowledge. However, the unconstrained number of possible explanations for any event will always be too numerous to test empirically, and so we use existing knowledge to constrain the number of hypotheses to entertain. Not having witnessed the evolution of a human-like communication system, there is little empirical evidence in that

domain to limit the number of potential evolutionary scenarios; for example, there is no empirical reason to require that displacement preceded symbolic reference in the origin of language (cf. Bickerton, 2009). There is, on the other hand, good evidence about what changed in human brains and how human language is processed, which makes neuroscience a useful resource in the generation of constraints.

One thing we know about human brain evolution is that humans likely possess direct cortical innervation of the nucleus ambiguus, the hindbrain motor nucleus that controls movements of the larynx via cranial nerve X (Jurgens, 2002). This allows a degree of dexterity in vocal movements in humans in much the same way that direct cortical projections to alpha motor neurons in the cervical spinal cord of capuchins allows for discrete finger movements (Bortoff & Strick, 1993). In nonhuman primates, no such direct innervation has been found, suggesting humans are the only primate whose larynges are not controlled exclusively by pattern generators in the brainstem (Deacon, 1997). This would account for why there have been no successful attempts by nonhuman primates to vocally imitate humans (Savage Rumbaugh et al., 1986). With this in mind, it is obvious that any scenario for the evolution of human communication must include an explanation of how this connection arose.

Another constraint comes from the neural circuits that control vocalizations in humans and in nonhuman animals. The typical mammalian vocalization circuit is limbic in nature, beginning in the anterior cingulate cortex, descending to the periaqueductal gray area in the midbrain, and finally ending in the medullary reticular formation (Jurgens, 2002). This particular processing path also appears to control vocalizations in dolphins and whales, even though the extent to which their vocalizations are voluntary and transmitted socially have been well documented (Manger, 2006; Marino et al., 2007). While humans retain the anterior cingulate system, voluntary aspects of vocalization appear to be controlled by circuits in the frontal and parietal cortices. The evolution of a unique system in humans must also be considered by any evolutionary scenario.

As a final example of constraints from neuroscience, most language evolution scenarios have focused on the “classic” language areas and how they may have arisen. However, we know from the study of gesture that human language is not only multimodal, but that different kinds of reference can be carried by each of these modalities (Kendon, 2004). Furthermore, functional imaging studies show that language comprehension creates widespread activation across many different areas of the brain outside the classic language areas, and that these depend on the form of reference in both the auditory or visual modality (Niederhut, 2012). Thus, it is not enough to only account for how Broca’s area may have transitioned from a motor planning area for grasping to one which seems crucial for parsing grammar, when it is clear that a much wider range of areas is necessary for language production and comprehension.

5. Testing the Consequences of Origin Theories

Just as there is no protolinguistic fossil record with which to constrain hypotheses on language evolution, there is no ongoing emergence of a human-like language from a formerly non-linguistic species that can be used to put origin scenarios to the test. Without a test by which we can cull less worthy hypotheses from the discussion space, language evolution studies must necessarily become an unwieldy mass of just-so stories. Luckily, we have access to the end result of what was produced biologically when the ability to learn language actually evolved, and we can compare what would be produced by any of these evolutionary scenarios with the actual human brain. Three examples from the conference in Kyoto will be given below.

Michael Arbib has here, and in the past, presented a laudably well-informed scenario for language evolution that uses pantomime as a bridge between non-communicative actions and what might be called a precursor to language (2012). The early steps of this process are: that nonhuman primates have the ability to imitate simple grasping actions; that humans become capable of grasping-based pantomime; and that pantomime becomes conventionalized into sign (Arbib, 2005). Nonhuman primates do not have mirror neurons that fire in response to pantomime, so Arbib's pantomime-based parity system for language depends on the ability to relate apparently directionless motions to nonpresent objects (Hickock, 2008). Although Arbib has not made this prediction, one might argue that this step requires a link between the mirror neurons in premotor cortex and neurons for identifying objects, perhaps in the inferotemporal cortex. In this case, we can predict that humans should show inferotemporal activation during pantomime in fMRI that is not present in simple grasping or nonsense arm movements.

Terrence Deacon presented a view of language evolution that went beyond the effects of natural selection to examine what happens when selection is relaxed and intrinsic constraints play a large role in the development of language ability and form (Deacon, 2012; Deacon, 2010). Briefly, domesticated species experience a masking of selection pressure on many traits, even if those traits are not selected for or even noticed by breeders. He draws a parallel between Bengalese finches, which show expanded functional connections as compared to the wild species, and a possible scenario in human evolution where early hominins were self-domesticated. If the analogy holds, we would expect unusual connectivity patterns in the human brain as compared to an early hominin. While we have no early hominins to test, we should also expect to see more exuberant functional connectivity in humans as compared to their close cousins, the chimpanzees. This could be tested using resting-state fMRI.

Rafael Núñez argued that early language-like communication systems would be founded on a semantic communication drive, which would require explicit spatial reference as a basis for shared meaning and comprehension (2012). This could explain, for example, why many natural utterances require

bodily referential gestures, and why etymologies for demonstratives are so difficult to construct. While Núñez did not describe what the neural networks underlying this capability would look like, or what changes would have occurred in it over time, it is likely that such a system would require the involvement of the occipitotemporal area (OT), which has been implicated in the comprehension of pointing gestures (Pierno et al., 2009). This suggests two possible tests. If we adopt the strong hypothesis, that all language is literally built on pointing-like deixis, then language comprehension should fail if OT is disrupted in a TMS study. If we adopt the weak hypothesis that many, but not all, natural utterances require some form of deixis (literal or metaphorical), then these particular utterances should recruit OT on a time scale somewhere around the premotor suppression (300ms post-stimulus) described by Edwards et al. using the electrode microarrays (2010).

6. Conclusion

The field of cognitive neuroscience has quickly grown in both its body of knowledge and its capabilities over the past few decades. By incorporating knowledge of and methods for neuroscience, evolutionary linguistics can gain a strong foothold in the possible and the testable. There are many potential scenarios for the evolution of language, and most of these have incremental steps that posit or at least imply discrete changes in the processing that occurs in the human brain. If these scenarios are explicitly framed in this manner, it would provide a concrete testing ground for the validity of these assertions in the market place of explanations.

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WHAT'S NEXT? A (POSSIBLE) AGENDA FOR EVOLUTIONARY LINGUISTICS AFTER EVOLANG 9

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Every two years researchers at Evolang bring together an impressive amount of evidence to unravel the puzzling phenomenon of language evolution. However, an overarching framework of how to integrate all these bits of data into a coherent theory, into a full picture, is missing. This paper proposes that the complex adaptive system framework can serve this purpose. The model of a 'language helix' is presented to illustrate the interaction between cognitive, social and linguistic factors in language change and evolution. The central idea is that language structures adapt to the niche of learner populations and are therefore 'shaped' to fit the social and cognitive needs of human beings. That is, the structural features of today's languages should be viewed as the product of the co-evolution of domain-general preadaptations for language and language as a cultural tool, rather than growing 'naturally' based on genetic encoding.

1. Introduction

The EVOLANG series of conferences on the "Evolution of Language" is extraordinary at least in one sense: It brings together an incredibly wide range of scientific subfields. Researchers of various backgrounds such as biology, physics, engineering, psychology, neuroscience, archeology, computer science and linguistics come together to convince each other of their new insights into the possible pathways along which the complex system of human language might have evolved. Although some of them would normally not even acknowledge that the other guys are actually doing "science".

What we have seen on Evolang9 in Kyoto ranges from baby-robots learning to produce human like vowels (Asada, 2012) and chimpanzees with impressive short-term memories (Matsuzawa, 2012) to the genetics of the language impaired KE family (Fisher, 2012) and language structures emerging from random strings (Kirby, 2012). Obviously, there is no lack of interesting input to tackle the long-lasting quest of how a communicative tool using sounds

and signs to encode abstract concepts could evolve in the first place. However, what is lacking is an overarching theory which integrates all these scattered bits of evidence into a coherent picture.

Attending the plenary talks as well as the oral presentations and poster sessions, one sometimes realized that researchers might not only disagree with a certain perspective but just speak in an entirely different scientific “language”. For example, when Asada (2012) baffled the audience by showing videos of how neural networks learn to produce vowel-like sounds, someone in the audience asked how that could explain the syntactic phenomenon of *wh*-movement. Clearly, researchers attending Evolang9 were not always on the same page.

Again, this shows that a unifying framework to integrate the multitude of evidence for language evolution is missing. In the following, it will be proposed that the *complex adaptive system* theory (Hawkins & Gell-Mann, 1992; Gell-Mann, 1994; Ritt, 2005; Beckner et al., 2009) applied to language could integrate all the different sources of evidence into a wider framework of historical language change and language evolution. To this end, the relevant sources of data will be shortly outlined by referring to research projects presented on Evolang9 (section 2). In section 3, it will then be sketched how the various bits of data could make sense from the perspective of language as a complex system, which in turn hinges upon another complex system: human cognition and its *preadaptations* to language.

2. The six data sources

First, it needs to be examined what are the potential sources of data that can help us understand what makes us humans so radically different from other species, so that our information encoding abilities could gradually evolve beyond that of any other basic communicative system found in other species. The potentially relevant subfields in this context are: **genetics**, **archeology**, **primate research**, **psychological experiments**, **computational modeling** and **linguistics**. To what extent have these been represented on Evolang9?

Simon Fisher discussed the “Molecular windows into speech and language” in his plenary talk about the **genetic** underpinnings of language (Fisher, 2012). The basic message that he wanted the audience to take away was that there is a huge gap in between genetic encoding of information by strings of amino acids and the phenotypic and behavioral outcome we are facing in linguistic studies. To unravel the myriads of interconnecting effects occurring between a concrete mutation in a DNA string and its impact on higher cognitive functions such as language (e.g. the prominent FOXP2 gene and its expression in brain circuits) is

a fascinating but daunting puzzle that is far from being solved. However, Fisher (2012) reported that FOXP2 (and other genes regulated by it) seem to have an effect on the outgrowth of neurites from neurons as well as the plasticity of synapses (i.e. the connections between neurons) in their target neural networks (Fisher, 2012: 438). Since these networks, or expression sites, are scattered all over the brain from the neo-cortex to basic circuits in the cerebellum, the evidence points towards domain general effects of FOXP2 upon the basic building blocks of human cognition, rather than domain specific effects on language processing alone.

It would be interesting to see how these genetic effects on the basic architecture of neural networks could be modeled by using computational networks. These have been applied to understand language processing ever since McClelland and Rumelhart (1986) and modified to deal with even complex linguistic tasks like learning case marking and word order (Lupyan & Christiansen, 2002). Perhaps *neural networks* could model what effects we should expect to occur if neurons are less interconnected. However, modeling of neural networks has not been strongly represented on this year's Evolang, although other **computational models** have been presented which were invoked to test the effect of population size and population structure on communicative systems (Thompson et al., 2012; Quillinan, 2012), to explain the emergence of bilingualism (Roberts, 2012) and to generally promote cultural transmission accounts to language evolution (Kirby, 2012).

These insights from computational models in turn seem to dovetail nicely with the effects found in **psychological experiments**. In iterated learning tasks artificial languages are learned by participants and the output of their performance is handed down to the next generation of learners (Smith & Thompson, 2012; Smith, Wonnacott & Perfors, 2012). Changes in the structures of the original artificial language can tell us what the predispositions are under which predictability, regularity and hence structure can arise in languages over several generations of learners. This can give rise to a new perspective on language universals. They might no longer be viewed as the reflections of hard-wired language acquisition devices but rather the outcome of general learning constraints shaping language structures over historical and evolutionary timescales (Christiansen & Chater, 2008).

Intriguingly, if languages adapt to the "niche" of human cognition throughout time (Lupyan & Dale, 2010), then it should be possible to find the traces of this shaping process in linguistic analyses of diachronic corpora (Bentz, Kiela & Hill, forthcoming), in language typology (Lupyan & Dale, 2010; Bentz & Winter, in print), in theories of language contact (McWhorter, 2007; Trudgill,

2011), in theories of linguistic performance (Hawkins, 2004), and quite generally in theories of language acquisition (Saffran, 2001, 2002, 2003) and processing. This opens up a whole new research area of diachronic **linguistics**, which has barely been represented on previous Evolang conferences (but see for example Delz et al., 2012, for a corpus based study of diachronic changes in German verb inflection).

Where linguistic data is not reliable or just not available, i.e. before ~3000 BC, the **archaeological** record of other human activities such as tool use and cave paintings may give additional hints when and how complex cognitive preadaptations for language emerged. Arbib (2012) for instance scrutinizes the cognitive underpinnings of problem solving strategies that might have linked tool use and language use in the evolutionary past of humans.

In this context, **primate research** can likewise give us a first impression of the cognitive ‘stages’ that our ancestors might have gone through on their way to the usage of complex visual and auditory symbols. Indeed, this strand of research has impressively been represented by Matsuzawa (2012), who showed that the “outgroup” of chimpanzees can teach us a lot about more sophisticated human cognitive abilities, and even more interestingly – about their limits. Namely, Matsuzawa (2012) argued with reference to a series of visual short-term memory tasks that chimpanzees can actually outperform humans recalling numbers that are spread on a computer screen and visible for less than a second.

On the other hand, humans have developed complex language, which does not rely on a unidimensional enhancement in only one specific cognitive skill. Rather, it seems that short and long-term memory as well as other cognitive abilities are involved in processing language. This might be interpreted as evidence that the evolution of language is not necessarily the outcome of a single evolutionary pressure for a complex system of communication, but that it is grounded in a multitude of different pressures shaping a set of *preadaptations* for language.

To unravel these evolutionary pressures and their adaptive outcome on biological/genetic as well as cultural/historical timescales we need a framework for evolutionary linguistics that allows us to combine the evidence of the *six sources of data* – genetics, primate research, archeology, psychological experiments, computational modeling and linguistics – without major contradictions. The next section will argue that the *complex adaptive system* (CAS) theory is the most promising framework for this purpose.

3. Language as a Complex Adaptive System

In a first attempt to apply the complex system theory to genuinely social phenomena like human language, Gell-Mann (1994: 51 pp.) proposed that the process of language learning should be seen in the light of complex adaptive system theory as well. Infants are faced with a multitude of speech strings they need to ‘break into’ in order to get a first grasp of their communicative purpose. In this early phase neural circuits already tackle the problem of finding the regularities and irregularities of syllable patterns and word boundaries (Saffran, 2001, 2002, 2003), which will later help to further categorize the building blocks of sentences and unravel their interdependence, i.e. learn grammar. This is in line with Gell-Mann’s (1994: 25) general working of a CAS. That is, a CAS uses *previous data* to form *schemata* (be it syllable structure, word boundaries, grammatical rules or constructions) by identifying regularities in the data and compressing them. These schemata then ‘unfold’ (e.g. in linguistic behavior) and face negative or positive feedback depending on the consequences of the interaction with the environment (e.g. whether communicative purposes are met or not). Based on the feedback the schemata can then be modified.

Against the backdrop of this very general sketch, the position paper by Beckner et al. (2009: 2) fleshed out the idea of language being an adaptive system by stating that: a) whenever language is used, there are multiple agents involved; b) language is adaptive in the sense that the agent’s linguistic output is based on past input, which is, however, not just repeated, but modified according to c) selective factors ranging from perceptual and processing constraints to social pressures. Hence, d) the features we find in today’s languages are a historical and evolutionary outcome of the interaction between social and cognitive effects.

Addressing the latter ones in particular, Christiansen & Chater (2008) showed how domain-general *sequential learning abilities* might have shaped language structures throughout time. This finding has important implications for research on the evolution of language in general. If it is true that language is ‘shaped by the brain’, i.e. that the features of today’s languages are shaped to fit the learning constraints of humans, then scrutinizing the evolution of language in the human lineage means finding the cognitive *preadaptations* which set the frame for the structures of a complex communication system. As a consequence, language structures would no longer be viewed as the ‘outgrowth’ of a set of specific language genes encoding a Universal Grammar, but rather as the gradual product of the co-evolution of two intertwined complex systems: human

cognition and the corpora of produced linguistic structures (for related views see Deacon, 1997, Haspelmath, 1999 and Ritt, 2005).

Figure 1 depicts the principal idea of a ‘diachronic language helix’, i.e. the interaction between the complex adaptive system of human neural circuits and a hypothetical ‘whole corpus’ of a language, i.e. all structures uttered at one point in time.

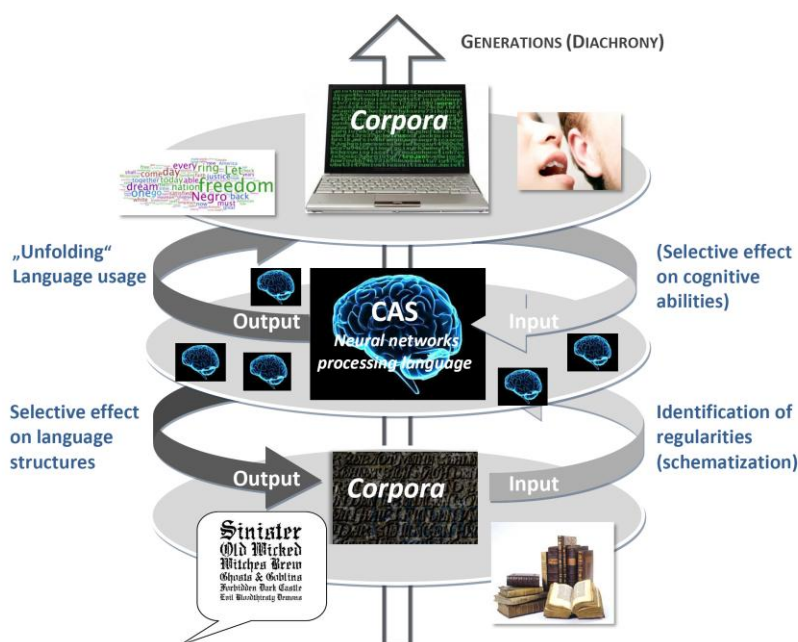


Figure 1. The ‘diachronic language helix’ of historical language change and language evolution.

Crucially, the diachronic pathway from one generation of corpora to another, as well as from one generation of language learners to another (represented by the neural networks involved in language acquisition) is shaped like a helix. This ‘language helix’ reflects the fact that the levels inserted here at three different stages are pure idealizations. Neither can a corpus of a language ever be complete and fully described at any point in time, nor are the language learners (i.e. agents) ever grouped into clear-cut generations. Hence, the shape of a helix is a) appropriate for representing the gradual and statistical nature of historical language change and language evolution, and b) it still captures the

somewhat paradoxical fact that there are similar and repetitive processes at play throughout time although they do never give rise to the exactly same outcome (which would be represented by a circle). For example, languages can lose some grammatical markers in an earlier stage of their development and later re-gain similar markers. The grammaticalization processes involved in the building of these markers might have similar cognitive and social underpinnings but they are very unlikely to give rise to exactly the same markers.

Another advantage of the helix is that it captures the mutual influence of both systems onto each other. On the one hand, learning constraints will shape the features found in the corpora of the next generation, on the other hand, the available input might also shape the linguistic abilities of learners – at least in ontogeny¹.

A subset of the utterances available at any point in time will be the input for a learner of the next generation. However, as noted earlier, a language learner will not just mechanically repeat the input utterances, but rather ‘filter’ these through individual learning constraints and social dependence. In this way, the next generation of corpora will be modified according to the needs or the ‘niche’ (Lupyan & Dale, 2010) of the population of learners. It is likely that these needs are not fixed, but might change more or less rapidly. For example, social linguists like Trudgill (2011), McWhorter (2007) and Wray & Grace (2007) have argued that populations with a lot of adult second language (L2) learners have different linguistic needs (e.g. less grammatical marking) than populations of native speakers. The account by Lupyan and Dale (2010) was a first attempt to prove this hypothesis by showing that there are negative correlations between population size and the occurrence of difficult grammatical features. Bentz and Christiansen (2010) argued that a linguistic adaptation of the L2 type might have taken place for Latin and the Romance languages as well as the Germanic languages (Bentz & Christiansen, submitted), and at this year’s Evolang Bentz and Winter (2012) have presented data which suggests that the relative number of L2 speakers can predict the numbers of case-marking paradigms in languages throughout the world.

All this evidence was brought forward to corroborate the framework of language as a complex adaptive system. In conclusion, this means that the features of today’s languages are the outcome of historical developments that have socially and cognitively shaped the symbolic systems of human languages.

¹ Christiansen & Chater (2008) have argued against phylogenetic biological adaptation for language structures, because these pose a ‘moving target’ for the relatively slow process of genetic encoding. However, both ontogenetic and phylogenetic adaptations would be in line with this model of a diachronic linguistic helix. For further discussions see Winter (2010).

Now, to what extent can the six data sources of section 2 be integrated into this model? On principal, there are at least two research areas that could be interesting for evolutionary linguists in this context: 1) trying to narrow down the cognitive *preadaptations* for language such as sequential learning abilities, which could tell us whether there is a universal core of all languages (albeit a domain-general one) and what it structurally looks like. This area will be most interesting for geneticists, psychologists and primatologists. 2) The next step would be to find out how language structures are then actually shaped by learning constraints and social factors in historical language change. This can be approached by corpus and typological studies, paired with iterated learning tasks. The data of these studies can in turn feed into more realistic computational models of the development and change of linguistic structures.

It goes without saying that these two potential strands of research are not strictly independent of each other but will always need mutual feedback and input. This way, both the evidence from empirical research as well as historical linguistics and corpus studies could nicely dovetail to establish a framework of language evolution that could win researchers from various disciplines.

4. Conclusion

This paper argued that it is about time to find an overarching theory that would bring together the various strands of evidence which have been carefully collected and presented at past Evolang conferences. At this point it seems that the *complex adaptive system* theory applied to language is the most promising candidate in this regard. It could integrate the data from genetics, primatology, psychology, computational modeling, archeology and corpus linguistics. This will help unravel the complex diachronic relationship between human cognition, social life and the usage of symbolic communication patterns.

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FROM THE SAVANNAH TO THE CLOUD: BLOGGING EVOLUTIONARY LINGUISTICS RESEARCH

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Over the last thirty years, evolutionary linguistics has grown as a data-driven, interdisciplinary field and received accelerated interest due to its adoption of modern research methodologies. This growth is dependant upon the methods used to both disseminate and foster discussion of research by the larger academic community. We argue that the internet is increasingly being used as an efficient means of finding and presenting research. The traditional journal format for disseminating knowledge was well-designed within the confines of print publication. With the tools afforded to us by technology and the internet, the evolutionary linguistics research community is able to compensate for the necessary shortcomings of the journal format. We evaluate examples of how research blogging has aided language scientists. We review the state of the field for online, real-time academic debate, by covering particular instances of post-publication review and their reaction. We conclude by considering how evolutionary linguistics as a field can potentially benefit from using the internet

1. Language Evolution Research: Then and Now

Darwin published *On the Origins of Species* in 1859, and it was this date, more than any other, that can be said to have been the beginning of evolutionary linguistics research. The 1,250 copies printed in the first edition of *The Origins* were all called for by the time the book hit the shelves, and many editions soon followed. The main venues for scientific research were then books, dissertations,

and the new format of scientific journals. Today, the monograph is seen mainly as a chance for a broader discussion, and dissertations are more a mandatory requirement for a doctorate than one in any number of large expositions published in a career. Current, cutting-edge research is published mainly in journal articles and conference proceedings. For language evolution, there are several journals which are seen as most relevant to language research: e.g. *Nature*, *Science*, *PNAS*, *ProcRoyalSocB*, *Human Biology*. In the past few decades, there have also been an increase in language-evolution focused conferences, the largest and most prestigious of which is unquestionably Evolang, started in 1996 in Edinburgh by Hurford, Studdert-Kennedy, and Knight (1996). Evolang serves as the best place to become aware of ongoing research, to draw lines in the sand regarding competing theories, and to disseminate one's own work.

However, conferences occur infrequently; Evolang occurs only biannually. Journals, with their notoriously slow review and publishing process, can delay research from being published for an equally long amount of time. Monographs or other research books can take even longer. This presents a problem; with many different teams and researchers working on similar research, it stands to reason that knowing the state of the field today, and not yesterday, is a must. This is increasingly difficult given the amount of research in the field and the slow publishing times. Furthermore, it is difficult to disseminate work in this subfield to the rest of academia, either because of publishing delays, or because conference proceedings are often not read outside of their particular subfield. This presents a problem for an interdisciplinary field such as evolutionary linguistics, which draws from various areas of research such as anthropology, neuroscience, linguistics, computer science, biology, and the evolutionary sciences, among others.

The most recent Evolang 9, which took place in March 2012 in Kyoto, differed from previous iterations of the conference in the amount of dialogue that took place online. This dialogue took place mainly on several web logs (*blogs*) set up by members of the conference, as well as on the micro-publication site Twitter.^a This digitalisation of the conference is representative of a sea change in the field of post-publication review. Instead of waiting several months, or longer, for a response to occur in writing, reviews of papers and presentations were available within as short a time as a couple of hours later online, and in some cases, live messages were posted during a presentation itself. These responses included a post and discussion concerning linguistic replicators (Roberts, 2012, March 14), a refutation of a claim regarding the relevance of jellyfish eyes to complexity in evolution (Winter, 2012, March 21), and an online game that tested the working memory of chimps and humans (Roberts, 2012, March 22).

The ability to immediately review research, and disseminate it to a wide audience is novel, and has wide-ranging implications. In this paper, we discuss the

^aTwitter. <http://www.twitter.com>

state of the field for online review and research dissemination using blogging, particularly involving the cultural evolution blog *Replicated Typo*.^b We discuss particular instances of blogging, including some posts during Evolang 9, which show the possibility of immediate review. Finally, we envision how the interdisciplinary field of language evolution research may change with these developing technologies.

2. The State of the Field for Academic Linguistics Blogging

Blogging offers new opportunities for academics to collaborate with researchers from other fields and integrate data easily, as it is free from the funding, time, and field-specific issues of traditional publication. However, the power to publish results and theories freely, and to provide and receive rapid feedback has both positive and negative potential implications. On the positive side, new ideas can be presented and discussed easily with progress potentially much faster than a traditional journal peer-review, as was the case at the Evolang conference. The internet also provides a forum to engage the public about ongoing research, which facilitates dissemination beyond the halls of academic conferences and universities, and the paywalls of publishers and libraries. However, on the negative side, ideas and comments can appear in public and affect research without being properly assessed. While well-thought out responses can alleviate such concerns, immediate responses outside of the considerable time frame of normal publication, and outside of anonymous peer review, could dilute the impact of relevant research. Discussion on the internet can also suffer because some academics are tentative to post their thoughts online due to a lack of protection on intellectual property, and in the absence of a reputable, widely used or recognised way of referencing ideas presented on the internet.

Blogs are a useful source for discovering current research and a forum for open peer review, whether open (from the public) or closed (from co-authors on drafts). Linguistics blogs have been around for many years, such as Language Log (Lieberman & Pullum, n.d.), but blogs dedicated to language evolution have emerged, too, such as Babel's Dawn, Shared Symbolic Storage, Culture Evolves!, Biolinguistics Blog, Replicated Typo (Bolles, n.d.; Pleyer, n.d.; Jordan, n.d.; Martn, n.d.; Winters, n.d.). While junior academics are prevalent in online discussions of linguistics, we note that well-established academics are also actively involved, e.g. Language Log, Culture Evolves!, Diversity Linguistics Comment, Vocalized/Vocalised, Language on the Move (Lieberman & Pullum, n.d., Jordan, n.d., Haspelmath, n.d., Hall-Lew, n.d., Piller & Takahashi, n.d.).

ReplicatedTypo.com, a community blog centred around cultural evolution, founded initially by Masters students at the University of Edinburgh, has received over 225,000 hits in 3 years (counts gathered using Wordpress Analytics) and

^bReplicated Typo. <http://www.replicatedtypo.com>

been awarded 8 editor's selections from ResearchBlogging.com.^c As well as reporting on recent publications and conferences, basic introductions to Linguistics, evolution, mathematical modeling and animal signaling have been written. The interests of the multiple authors are varied, but the central research theme - evolutionary approaches to language and culture - remains the same. Their aims as science bloggers on Replicated Typo are: to highlight and discuss new research on language evolution; to engage with the general public by presenting language evolution research in an accessible way; to be a platform for open science research into language evolution. Discussions of posts on the blog have led to revisions of research and discoveries of new avenues of research, as well as collaborations and clarifications of research by the authors of the studies reviewed. For example, a post about specific language impairment (Little, 2010, August 23) attracted comments from the original author, Dorothy Bishop (Bishop, 2010), and one post on the mapping of linguistic phylogenies to politics (Littauer, 2010, October 19) received a response from Simon Greenhill (Gray, Drummond, & Greenhill, 2009). Both Bishop's and Greenhill's responses allowed for public discussion between them and those commenting on their articles. This would either happen completely behind closed doors in the case of anonymous peer review, or over an extended period of time in the case of printed response letters.

3. Peer Review in the Blogosphere

There is no universal consensus on the method or acceptability of citing ideas from blogs. We argue that the devaluing of research and criticism appearing in open forums risks obstructing or hindering research. This is not merely a debate in Linguistics; examples are available elsewhere, such as the so called *#arsenicgate* scandal among evolutionary biologists (see Zimmer, 2011, December 2), where a paper chronicling arsenic-laced bacteria (Wolfe-Simon et al., 2010) was hyped by the media before publication, but condemned by many prominent science bloggers immediately afterwards for poor methodology. The authors responded by claiming that they would only respond to comments in peer-reviewed journals, sidelining the scientists who raised issues on public blogs (Shema et al, 2012).

A similar objection was raised by Jasmin & Casasanto (Lieberman, 2012, March 17) in response to a LanguageLog critique by Mark Liberman (Lieberman, 2012, March 13) of the robustness and size of their "Qwerty Effect" on language processing. The ensuing debate over statistical particulars included a serious concern over the ability of bloggers to damage the reputations of professional researchers, despite their peer-reviewed publications and regardless of the value of the critique. The quality standard of academic blogs is reasonable point of criticism, but could benefit from a consideration of the bigger picture. Arguably, this lack of enforced standards is a strength of the blog format, which simply results

^cResearch Blogging. <http://www.researchblogging.com>

in a higher overall volume of content, of varying quality. Blogs can therefore offer higher quantity and far better engagement, which is directly complementary to high-quality (though restricted) journal content. Though basic regulating standards are yet to be established, that blogs have enough wide-ranging influence to sway majority opinion against peer-reviewed articles is testament to their greater efficacy in disseminating knowledge and engaging the public. Misgivings about standards and plagiarism appear to concern blogs that are used to disseminating original works in progress, such as small-scale experiments and theoretical essays. While public access to experimental data, code or theoretical ideas may worry those protective of their contributions, public blogs are often a useful way to stake claim to an idea. Aside from this reassurance, it is important to highlight that methodological transparency is always desirable and more important for research itself than misguided sentiments over intellectual property; the idea that the research community need enact some “intellectual patent” is itself absurd and antithetical to academic advancement.

Another recent debate that has taken place online concerns Keith Chen’s work on the influence language has on economic decisions (Chen, submitted), which was discussed in the workshop on constructive models (Roberts & Winters, 2012). Chen demonstrated a robust correlation between whether people speak a language with a morphologically marked future tense and increased levels of smoking, drinking and obesity and less saving and pension provision. The paper was put online, and sparked much interest and media coverage, one online journalist writing “Want to end the various global debt crises? Try abandoning English, Greek, and Italian in favour of German, Finnish, and Korean.” (Fellman, 2012, January 1). Chen has recently also given a TED talk about this idea (see McManus, 2012, June 28). However, there have also been criticisms from bloggers. Geoffrey Pullum has criticised the typology that Chen uses (Pullum, 2012, February 9), and Mark Liberman has demonstrated with a simple model that correlations between unrelated cultural features are more frequent if the cultural features diffuse geographically (Liberman, 2012, February 12). Chen has also responded to these also through the medium of blogging (Chen, 2012, February 12). There have also been many comments from readers, with intellectual heavyweights are discussing an emerging hypothesis completely online before journal publication. Not only does this demonstrate the growing potential of blogs as a place where serious science is done, but also as an arena where academic debates can thrive with an immediacy that traditional journals do not offer.

4. Online Participation at EVOLANG

Ideas from Evolang were also discussed online. Andrew Smith (Smith, 2012) and Monica Tamariz (Tamariz, 2012) discussed the theory of cultural replicators. Both presentations were covered on Replicated Typo during the conference (Roberts, 2012, March 14, Roberts, 2012, March 20). This allowed people who were not

physically present at the conference to interact with the discussions. William Benzon, who was not present, wrote a lengthy response to the two views (Benzon, 2012, March 15). Together with technologies such as video conferencing, this changes the idea of conferences as insulated, static events to the possibility of conferences being platforms for a much wider range of interactions.

19 articles were published on Replicated Typo covering the proceedings of Evolang 9 (see Roberts, 2012, June 9), the majority of which were published before the conference had ended. Other blogs also covered the conference (e.g. Samuels, 2012, April 2, Alba, 2012, March 31). Twitter also recorded 128 tweets about the conference as it was running, many echoing the words of the speakers as they presented their research. This meant there were many more ways to interact with Evolang than ever before. One factor that has made this possible in the last few years is the proliferation of high speed internet and Wi-Fi as standard in conference venues and hotels. Tablet PCs, smaller laptops and smartphones also mean that it's easier access the web in the conference venue, and we noticed a shift in the apparent social acceptability of interacting with a computer while listening to a talk.

Continuous access to the internet also made it possible to check other research online during the talk and respond immediately with informed questions. In an extreme example, Gary Lupyan ran a short online experiment during the conference to counter a claim made by Massimo Piattelli-Palmarini (see Bodo Winter, this issue). In another example, an online experiment was coded during the conference that addressed Matsuzawa's demonstration of the working memory ability of chimps at Evolang (Matsuzawa, 2012), and the results are discussed in Quillinan & Roberts (this issue). Online connectivity is increasing the speed of interaction and academic progress at conferences. We also hope that this will encourage higher standards of academic accuracy in talks.

Experiments such as Quillinan & Roberts also allow for participation and engagement of the public in research that electronically crowd-sources participants. A similar style of public engagement and collaboration, known as citizen science, has been implemented in other fields to great effect in recent years. Projects such as Galaxy Zoo^d and Whale FM^e have gained popularity as the Research Excellence Framework in the UK calls for research to have greater engagement and impact.

Finally, Replicated Typo also offered authors the chance of posting short previews' of their talks a few weeks before the conference. This service can be beneficial because official abstracts for conferences are often not available before the conference starts, and the precise focus of a talk can change in the long gap between abstract submission deadlines and the first talk of the conference. In par-

^dGalaxy Zoo. <http://www.galaxyzoo.org/>

^eWhale.FM. <http://whale.fm/>

ticular, this gave less senior academics such as PhD and Masters students a chance to attract people to their talks, which was an important factor given the number of parallel sessions in this year's Evolang. In general, blogging allows researchers who are just starting to make a name for themselves and to network with other academics in the field. This is often a benefit for a young discipline like Language Evolution because researchers can often be physically isolated from others in the field. Indeed, Evolang 9 was the first time that some of the Replicated Typo bloggers had physically met, but the knowledge of each other from the blogosphere allowed them to immediately start interacting productively.

5. Academic Publication in the Future

Along with the rest of academia, the field of language evolution needs to change and respond to the growth of modern technology. Many journals publish their articles on the internet already with some journals existing solely online; for example, the Public Library of Science (PLOS) journals. Having journals online allows for the publication of code and data with the article, which journals like PLOS encourage, and this allows for other academics to replicate studies or build on existing work but online journals are still subject to the long process of peer review.

In recent years internet phenomena, such as blogs and social media, have started changing the way that some researchers are operating, especially as the traditional journal article is no longer the main method for disseminating research. As alluded to throughout this paper, there are many advantages to using the internet as a research tool. For legitimate change to occur, however, academics need to slowly embrace these new methods, by looking for research online, sharing their views in public prior to publication through commenting or social media, and blogging themselves. But while there are incentives, such as large amounts of readers, there are also drawbacks; "Unfortunately, most scientific output created on the Web goes unnoticed by current academic metrics, which measure scientific work published in 'conventional' academic literature." (Priem et al., 2010, October 26) The authors here believe that as academics use the internet as a tool for creation and dissemination of research, suitable new metrics will follow, such as Total Impact, which aggregates online presence from various sites.^f With new metrics that matter to hiring boards (and thus, jobs), the cycle may feedback until online publication is the norm.

Blogs can facilitate real-time academic debate as we saw in the examples in the paper during Evolang. Blogs are also almost exclusively open-source and allow for interaction with all users of the internet which goes some way to engaging the public with ongoing research. As well as a increase of the utilisation of blogs, we foresee that in the future journals may attempt to subsume the blog-comment

^fTotal-impact. <http://total-impact.org/>

format of blogs and make it available to their subscribers. This however will have its disadvantages where blog post succeed as it doesn't engage the public, as it will keep discussion between academics, and also doesn't all for open access. On the other hand, quality control is well established in the journal system, and this will have to be better accounted for and dealt with within the blogosphere; how to plan for quality control here is an open question.

In summary, the field is changing, as can be seen by the active online engagement at the Evolang conference, and beyond on popular research blogs. We hope that researchers will embrace blogging as more than a side front to traditional publications and private discussions, and will see them as an opportunity to showcase their ideas, to engage the public, and to bring the field of language evolution further along.

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The Past, Present and Future of Language Evolution Research

The 9th international conference on the Evolution of Language was held in 2012 from the 13th to 16th of March in Kyoto, Japan. This Student Volume is a peer reviewed collection of papers written by student participants at the conference. The volume is open access, published electronically on the Evolang website and distributed in print at Evolang10 in Vienna. The articles in this volume focus on the thematic area surrounding the past, present and future of research in language evolution.

