Verbal Development, Behavioral Metamorphosis, and the Evolution of Language

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Abstract

Building on Skinner's theory of verbal behavior, research over the last few decades confirmed verbal speaker operants, added the role of the listener, added the identification of speaker and listener interaction between and within individuals, and identified verbal behavior developmental cusps. Meanwhile, comparative biology focused on how and why language evolved in *Homo sapiens*. Findings about differences in behavior that neurotypical children demonstrated in their verbal development, and even more so in research that identified and established missing verbal behavior cusps, suggested changes analogous to metamorphosis. These striking changes in stimulus control found in the onset of cusps from the preverbal to the fully verbal child led us to an expansion of the concept of metamorphosis from morphology to the domain of behavior. The major findings of this comparative perspective are presented here as they have led us from experimental analyses of verbal development to metamorphosis as complex verbal behavior transformation and finally to a novel hypothesis about the evolution of language based on the concepts and research described here. To our knowledge, this is the first formulation of verbal development as behavioral metamorphosis in the context of evolutionary developmental biology.

Keywords Evolutionary developmental biology · Verbal behavior development · Bidirectional Naming (BiN) · Behavioral metamorphosis

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Behavioral Metamorphosis

Transformation of the caterpillar into a butterfly may have more in common with verbal development and its evolution than one might suppose. In Figure 1, the life cycle of a swallowtail butterfly (*Papilio glaucus*) is compared with the stages of verbal development. Such a radical change of form from one stage to the next in the life history of an organism is called *complete metamorphosis*. The word is of Greek origin—*meta* (change) and *morphe* (form)—with changing form as the key notion. In the swallowtail, the egg (larva) transforms into the caterpillar, then the pupa, which finally turns into an adult butterfly. *Incomplete metamorphosis* is a type of metamorphosis in which an insect hatches from an egg and then goes through several immature stages that look like small versions of the adult and get slightly bigger with age, with the insect finally molting into the adult form. All of these changes in body form are examples of what is called a *phenotype* in biology, which is the set of observable characteristics of an individual conceived as the interaction of its genotype with the environment.

Although the phenomenon of metamorphosis is widespread among insects (think of a maggot turning into a fly) and amphibians (a tadpole changing into a frog), in popular culture the process of metamorphosis is still considered a kind of magic or rebirth of the soul in a new living form, a subject for fiction rather than science.

Studies of neurotypical children and those with minor or severe language delays have led us to this unexpected comparison, in which the evolution of the biological process of metamorphosis is seen as an ancestral phenotype enabling verbal development in *Homo sapiens* (Greer, Pohl, Du, & Lee Moschella, 2017). Metamorphosis may have been supported by the process of exaptation, in which features or behaviors acquired in one context are coopted in a different one, such as the essentially modern vocal tract that hominins possessed for hundreds of thousands of years prior to being employed verbally in the vocal communication of *H. sapiens*. The debate about the origins of metamorphosis has only recently begun among evolutionary biologists (Nielsen, 2000; Ryan, 2011; Williamson & Vickers, 2007). Despite some dissension about the definition of the phenomenon, biologists agree that the various stages of complete metamorphosis are so radical a transformation that we must assume powerful evolutionary advantages for its occurrence across taxa and repeated selection in the history of multicellular life (Bishop et al., 2006). With respect to underlying mechanisms, recent neuroendocrinological research indicates that hormones play a significant role in the transcription of certain genes at different metamorphic stages (Buchholz, 2015; Stenzel & Huttner, 2013; Zoeller, 2012). Mention should be made here of a remarkable case of “Welsh-sparing dysphasia,” which was clearly related to underactive thyroid hormones in a bilingual patient (Rice, Boregowda, Williams, Morris, & Okosieme, 2013). In current theory, the young discipline of evolutionary developmental biology (or “evo-devo”) recognizes metamorphosis as extreme life-stage modularity of distinctively different morphological units and relatively independent functions that occupy distinctively different niches and discusses it in terms of classical natural selection theory.

It is important to note in this context that—although regularly overlooked in evolutionary developmental discussions of the subject (e.g., Bishop et al., 2006; West-Eberhard, 2003)—a coherent alternative formulation of the origin of metamorphosis exists beyond Darwinian natural selection, to which we return in the concluding

Figure 1: Behavioral metamorphosis demonstrated in verbal behavior development milestones. There is a continuum of change within each stage and experientially learned stimulus control propels behavioral metamorphosis across stages. For example, the child in larvae stage is very different from someone who lacks this stimulus control, and also very different from someone who comes under the stimulus control that results in the emergence of the cusps listed in the listener stage.

section. Given this background, the reader will not be surprised to hear that no mention is made of metamorphosis in the vast literature on the evolution of language (Deacon, 1997; Fitch, 2010). This presumably results from the circumstance that metamorphosis has rarely been conceived as a radical transformation of *behavior* as opposed to morphology, and for this reason the phenomenon has gone largely unnoticed in mammals or is referred to metaphorically at best. Thus, commenting on the birth of Haeckel's child (Darwin, 1911), Charles Darwin noted that "A young child, and the same when nearly grown, sometimes differ almost as much as do a caterpillar and

butterfly.” Many others have followed Darwin in this metaphorical usage of the term metamorphosis in mammalian development.

Two notable exceptions published in 1980 merit our attention. Zoologists Scott and Nagy (1980) devoted a chapter to behavioral metamorphosis in the development of social behavior in dogs. At approximately two weeks of age, they observed a brief transition period during which the puppy regularly went through “a metamorphosis in behavior,” so that within five or six days it developed many of the patterns of behavior adapted to adult life. For example, the puppy begins to wag its tail at the sight of people or animals at a distance, and playful fighting appears in the form of pawing and mouthing between litter mates. Thus, from a wormlike creature that does little but suckle, sleep, and eliminate, the puppy’s behavior has been transformed to adult social behavior within a few days predictably during the second to the third week of life.

In the same year, developmental neurobiologist Ronald Oppenheim (1980) published an editorial in *Developmental Psychobiology* entitled “Metamorphosis and Adaptation in the Behavior of Developing Organisms.” Oppenheim’s reflections on the term “metamorphosis” in the context of mammalian development are remarkable and of direct relevance to the argument presented here. He begins by noting that: “Metamorphosis has long been an appealing metaphor for describing and understanding development in organisms which strictly speaking do not undergo true metamorphic changes such as are seen in insects and amphibians” (p. 353). In a footnote to this opening statement, Oppenheim points out that in his view, metamorphosis is more than just a metaphor of development in what he calls “nonmetaphoric” animals. In contrast to the commonly held assumption that the dramatic nature of the transformations that many of the insects and amphibians undergo are fundamentally different and therefore can tell us little about the ontogeny of birds and mammals, Oppenheim argues that precisely *because* of their temporal acceleration and condensation, such forms represent an exaggeration of developmental processes common to most animals and adds that, “For this reason, ontogenetic adaptations and the striking modifications of structures and functions in larval animals may represent an exceedingly useful model of related phenomena in other animals in which the changes are not so clearly revealed” (p. 355).

In the following sections, we attempt to show that behavioral metamorphosis is not only real, but may indeed be an essential part of the biological makeup of the development of verbal behavior.

Evolution of Verbal Behavior

In the present formulation we maintain that verbal development in humans, grounded in behavioral metamorphosis, has enabled the transformation of a hominin signaling system into one of *symbolic communication* in man. The key evolutionary components of this profound transformation of communication in *H. sapiens*, which sets language apart from all known communications systems (Fitch, 2010), are captured by bringing four lines of evolutionary theorizing together as follows.

First, although Darwin understood both natural and sexual selection, a type of behavior that troubled him to the end of his life was when an individual sacrifices its resources or even its life to help another individual in so-called “altruistic behavior.” Following the modern synthesis of evolutionary biology in mid-20th century, the

breakthrough in explaining altruistic behavior came when Hamilton (1964) published the first formal quantitative analysis of kin selection, which was to become the famous central theorem of *inclusive fitness theory*, expressed as the inequality $Br > C$ (or the Benefit to kin, as diluted by their fraction of relatedness r , must exceed the Cost to self). Thus, Hamilton's rule, which predicts that social behavior evolves under specific combinations of relatedness, benefit, and cost (together with Darwinian natural and sexual selection), constitutes a third subtype of selection called *kin selection*. It is worth mentioning that the eminent evolutionary biologist, Mary Jane West-Eberhard (2003), compares the significance of Hamilton's work to the scientific bonanza released by the work of Watson and Crick on DNA.

Second, a central issue in the evolution of cooperation that applies to all taxa in which cooperation between individuals has evolved and, in particular, to the evolution of language in *H. sapiens*, is that each individual possesses both altruistic and cheating tendencies, which also accrue in all verbal episodes. Trivers (1971) has presented a widely accepted model, notably in which kin selection is ruled out, to account for the selection of what has come to be known as *reciprocally altruistic behavior*. Reciprocally altruistic behavior is typically invoked in situations during which cooperation occurs between individuals who are not related, and therefore enables interlocking of verbal behavior between individuals in the majority of episodes that constitute human verbal communication.

Third, it was Hamilton's work that led Trivers (1974) to his deep insight of the inevitability of *parent–offspring conflict* during development as a result of parental, usually maternal, investment. Unfortunately, parent–offspring conflict as a basic dimension of the parent–child relationship has gone unnoticed by developmental psychology. The principle maintains that the enormous difference in size, strength, and experience between the child and its parents effectively selects in the child continuous behavioral manipulation of its parents in order to induce more investment than the parents are willing to give. At the same time, natural selection favors parental attentiveness to any signals from its offspring that notify them of their offspring's current condition. Due to the long duration of the sizable physical and behavioral inequality between caretakers and their children, parent–offspring conflict selects in the child ever subtler forms of behavioral manipulation of its parents such as surprise, astonishment, ingratiation, deception, irritation, and provocation. From an applied behavior-analytic perspective, increased realization by parents, therapists, and teachers of the inevitability of parent–offspring conflict could facilitate the induction of behavioral metamorphosis in many children (Schlomer, Del Guidice, & Ellis, 2011).

Fourth, when drawn together, the three threads of evolutionary theorizing presented above allowed Fitch (2004) to advance a formulation of the selection of what he has aptly called “mother tongues,” defined as “systems of communication that have evolved in the context of kin selection” (p. 275). By exploring the intersection between kin selection and communication theory, Fitch has presented an as yet little-appreciated hypothesis of the evolution of language as a kin-selected communication system, particularly (but not exclusively) between parents and their offspring as follows.

From the perspective of kin selection theory, the evolution of effective communication between kin needs to satisfy Hamilton's inequality, $C < Br$. Fitch (2004) points out that the physiological costs of human speech are so low that they are almost unmeasurable, because air as the source of energy for speech is part of resting metabolism and

not a cost of vocalization. It therefore presumably plays no major role in the evolution of spoken language.

In dealing with the obvious difficulty of the mother-tongue hypothesis to explain the fact that most language today is not used predominantly to communicate among kin, Fitch (2004) employs Trivers's (1974) model of *reciprocally altruistic behavior* as explained above.

Some of the most important characteristics of human language can be explained from an evolutionary perspective in the context of kin-selected communication systems. The mother tongue hypothesis—namely, that language primarily evolved in a context of kin communication—not only provides a good overall fit to much of the existing data but a solution to some serious problems left standing by other models. Fitch (2004) concludes by noting that, “The advantage of this posited selective force over the sexual selection assumed by earlier workers is twofold. First, it accords with the fact that language learning begins in early childhood rather than at puberty, and second, it is expressed in both sexes rather than preferentially in males” (p. 292).

Recent neurodevelopmental findings may provide an important hinge between the mother-tongue hypothesis and the experimental work on the development of verbal behavior in the next section. The former suggests that *specific* early language exposure—often referred to as conversational units, verbal episodes, or dialogic interaction between caregiver and child—is associated with *specific* variation in children's neuroanatomical development (Romeo et al., 2018). Turning to behavior, in this context we propose that Horne and Lowe's (1996) account of the development of naming (see Figures 5, 7 and 9 in Horne & Lowe, 1996) and its subsequent empirical validation by Greer et al. (2017), provide the behavioral counterpart to current evolutionary theorizing on kin-selected communication systems and the findings referred to here on the development of underlying neuroanatomical connectivity.

Based on the foregoing synthesis, we hypothesize that in *H. sapiens*, protracted parental, usually maternal, and often *alloparental* care—defined as a particular mode of childrearing called “cooperative breeding” in which mothers regularly rely on groupmates to help protect, care for, and provision their unusually slow-maturing children (Hrdy, 2009)—has set the stage for the selection of a behavioral phenotype that has enabled the evolution of verbal behavior. This novel behavioral phenotype has been identified as the *bidirectional operant* (Greer & Du, 2015; Greer & Speckman, 2009). With respect to verbal development in the context of Fitch's (2004) mother-tongue account, we focus on the prerequisite developmental cusps that lead to the cusp of *bidirectional naming* (BiN) as a higher-order functional relationship between the child's own speaker–listener behavior and classes of objects and events (Horne & Lowe, 1996; Longano & Greer, 2014; Miguel, 2016) on the one hand, and verbal episodes or conversational units between individuals on the other. In support of this hypothesis, in the following section we provide empirical support for the Horne and Lowe (1996) account of the development of naming on the basis of studies in children with developmental delays, as well as studies that document the acceleration of the onset of BiN in neurotypical children (Greer et al., 2017). Readers will recognize the pathbreaking legacy that B. F. Skinner and his seminal treatise on *Verbal Behavior* (Skinner, 1957) has left us in providing the theoretical blueprint for many of the experimental analyses of verbal behavior and its development referred to in the following section.

Verbal Behavior Development

Research findings resulting in the identification of verbal milestones (i.e., verbal developmental cusps) in children with and without communication delays are complementary to evo-devo analyses of *H. sapiens* and nonhuman primates (Pohl, 1983, 1984; Tomasello, 2008). Researchers focused on the development of verbal behavior (Greer & Ross, 2008; Greer & Speckman, 2009) have identified procedures for the identification of, and interventions to establish verbal developmental cusps. Behavioral-developmental cusps are changes in behavior and stimulus control that allow individuals to learn things they could not learn before, or learn them faster, and in some cases learn them by contacting the elementary principles of behavior in ways they could not before the cusp is established (e.g., learn from observing the consequences received by others). In the case of verbal development, cusps often result from the learning of new reinforcers (i.e., newly conditioned reinforcers). For example, the establishment or enhancement of adult attention as reinforcers for behavior maintenance or learning new objectives results in the emission of and increases in bidirectional verbal operants between children and adults initiated by children (see Schmelzkopf, Greer, Singer-Dudek, & Du, 2017).

The establishment of these cusps allow children to (a) contact lexical (i.e., forms of languages) and nonlexical (i.e., nonlanguage specific) vocal and nonvocal verbal stimuli (Donahoe and Palmer, 2004; Greer & Ross, 2008; Michael, 1993; Michael, Palmer, & Sundberg, 2011; Miguel, 2016), (b) respond to the stimuli as a listeners (Hayes, Barnes-Holmes, & Roche, 2001; Greer, Chavez-Brown, Nirgudkar, Stolfi, & Rivera-Valdes, 2005a; Moon, Lagercrantz, & Kuhl, 2013), and (c) produce verbal behavior that affects listeners' behavior (Miguel, Petursdottir, & Carr, 2005; Rehfeldt & Root, 2005; Ross & Greer, 2003; Ross, Nuzzolo, Stolfi, & Ntarelli, 2006; Tsiouri & Greer, 2003; Williams & Greer, 1993). By definition, verbal developmental cusps: (a) accelerate rates of learning, (b) make new learning possible, and in some case, (c) lead to social learning milestones. The cusps resulting from the learning of social reinforcers are pivotal. Several studies show (a) the critical role of social reinforcement and (b) interventions that can establish social reinforcement (Eby & Greer, 2017; Lawson & Walsh, 2007; Schmelzkopf et al., 2017). Current evidence suggests how particular experiences make it possible for children to learn language incidentally from a developmental trajectory that leads to the joining of what is initially developmentally independent listener and speaker behavior. The following examples show how one cusp, simple bidirectional naming (Horne & Lowe, 1996; Miguel, 2016), allows a child to learn word/object relations incidentally. The research underlying the description of the reinforcement sources for the examples are cited above and described later.

A mother and child who does not talk yet simultaneously see a brilliantly blue bird and the child points excitedly to the bird and the mother says, "That's a blue bunting." After this experience or repeated experiences with seeing the bird and hearing the spoken word, the child can point to the bird when asked, "Where is the blue bunting?" Also, she may point to pictures of blue buntings when other pictures of other birds are present and asked to do so. The mother does not necessarily need to provide reinforcement. Of course, the child cannot look at the bird and say its name at this point. How did the child learn the word for the bird as a listener without direct instruction? One approach would be to attribute this to a psychological learning acquisition device;

alternately, the existence of learned and embedded reinforcement for looking at the bird and the learned and embedded reinforcement for listening to the mother's speech are the reinforcers that teach the listener response from experiences like this. The listener repertoire expands exponentially with experiences, and the reinforcement implicit in the experiences serves to "teach" word/object relations. The learned and embedded reinforcers are the verbal developmental cusps that make the incidental learning possible.

As the child continues to have experiences and build her listener repertoire, once she learns to talk, the listener joins the speaker because of the rotation of the two responses to the same stimuli. Listening as an observing operant response and speaking as a different response for a range of stimuli, come under the same stimulus control. The two responses to the same stimuli become equivalent, so to speak. In order for these rotation experiences to join the listener and speaker a number of prerequisite cusps need to be in the child's developmental history. (See Greer and Speckman, 2009; Greer and Du, 2015; and Greer and Longano, 2010 for a detailed description of this sequence.)

Many of these experiences lead to the learning or conditioning of new reinforcers. Although the term *conditioned reinforcement* is traditional, for the purposes of this article we will alternately refer to conditioned reinforcers as *learned reinforcers*, emphasizing the evidence showing the role of experientially learned reinforcers in establishing verbal development.

Special experimental methodology has been used to identify that the learned reinforcers are the source of several critical cusps. The research methods for identifying and establishing these new reinforcers and their relation to cusps involve first showing that prior to some intervention children are missing cusps that are the dependent variables (e.g., engaging in conversational verbal episodes or initiating tacts with adults). At the same time, preintervention tests are done comparing existing stimuli that reinforce learning other behavior or maintenance of previously learned behavior, such as candy or toys, with certain stimuli that are not reinforcers such as adult attention. When this experimental analysis shows that the stimuli (e.g., adult attention and praise) do not act to reinforce either learning or maintenance the stage is set for the intervention. During the intervention, intervention procedures involve establishing the targeted stimuli as reinforcers for learning and maintenance (e.g., adult attention). The criterion for the establishment of the stimuli as reinforcers involve demonstrating that the stimuli (e.g., adult attention) do now show the stimuli (e.g., adult attention) now function to reinforce learning or maintaining previously learned behavior as effectively as the initial preferred stimuli (e.g., candy or toys) did prior to the intervention. Once the new reinforcement is established or learned, postintervention measures of the cusp repertoire are done (e.g., measures of conversational exchanges and tacts as dependent variables). Evidence of the onset of the cusp occurs when these postintervention measures show major changes in what children can learn or do. For example, in the research on changes in adult reinforcement, the establishment of reinforcement for adult attention in the intervention resulted in dramatic increases, or first instances of, bidirectional conversational exchanges between children and adults. This change is evidence that new repertoires emerged and that the source was the establishment or enhancement of adult attention as a newly learned reinforcing stimulus for initiating social verbal behavior. One might say that the adult behavior is now an automatic reinforcer. However, in this case, the term automatic is not tautological, because the

change in the stimulus control was empirically demonstrated (see Schmelzkopf et al., 2017, and Eby & Greer, 2017, for the evidence related to adult attention). Examples of the methodology and evidence for the relation between the establishment of conditioned reinforcers as cusps can be found in Du, Broto, and Greer (2015), Greer, Pistoljevic, Cahill, & Du (2011), Greer and Singer-Dudek (2008), Greer, Singer-Dudek, Longano, & Zrinzo (2008), Longano and Greer (2014), Pereira-Delgado, Greer, Speckman, and Goswami (2009), and Schmelzkopf et al. (2017).

There are several cusps that have resulted from establishing new reinforcers. See Greer and Du (2015) for a more complete description of that research. We describe a few examples herein. Children who did not initially demonstrate generalized visual match to sample (MTS), acquired the match to sample stimulus control for 144 visual stimuli after 2-dimensional print symbols were conditioned as reinforcers for observing responses (Greer & Han, 2015). Visual MTS is a preverbal but foundational cusp for verbal behavior in that these children are not yet verbal but MTS is a prerequisite for becoming verbal. Children without visual MTS lack listener and speaker behavior and may lack canonical babbling, which is what Skinner (1957) referred to as “parroting” (pp. 58–59). However, even for children who are not yet verbal, the establishment of visual MTS is foundational to the evolvment of verbal behavior (see the butterfly figure for the preverbal foundations). Several studies have shown either emergence of generalized visual MTS (Du et al., 2015; Greer & Han, 2015) on accelerated rates of learning MTS following establishment of these stimuli as reinforcers for observing responses (e.g., Pereira-Delgado et al., 2009; Speckman, Longano, & Syed, 2017). In another example of newly conditioned reinforcers as a cusp, Greer et al. (2011) found that the establishment of adults’ voices as a reinforcer for children with limited listener responding resulted in significant changes in rate of learning discriminations involving listening to speech, as well as, enhanced observing responses to others (see Figure 1). Although several studies cited above have shown the role of multiple exemplar instructions (MEI) across speaker and listener responding for training sets of visual stimuli (rotation of speaker and listener response to the same stimuli) in the establishment of BiN, the underlying prerequisite that appears to be necessary for the rotation experiences to be effective is the establishment of visual stimuli as conditioned reinforcers for observing (e.g., looking at the blue bunting in the earlier example) and vocal speech as reinforcers for simultaneously listening to speech sounds (e.g., listening to what the mother says).

Longano and Greer (2014) showed that children who did not demonstrate BiN did so as a result of the establishment of visual stimuli and speech stimuli as conditioned reinforcers for observing responses. First, they identified preschoolers who did not demonstrate BiN, and for whom the MEI procedure was not effective. At the same time, they determined the children’s preferences for, and reinforcement value for, listening to words or choosing to look at visual stimuli produced using two computers. This resulted in measures of preferences for one of the stimuli over the other. That is, either the participants preferred to (a) to listen to recorded words spoken by the experimenter presented with a blank screen, or to (b) look at contrived cartoon-like symbols presented on the screen. In the intervention, the preferred stimulus was then paired with the nonpreferred stimulus such that the participants looked at presentations of the cartoon figures while hearing the spoken words on a computer screen. After pairing sessions, the participants were tested on the acquisition of tacts (the recorded

words). Tact acquisition with 100% accuracy was set as the criterion for mastery of the pairing sessions. Following the pairing procedure, probes were conducted to test for preference of recorded words, visual stimuli, or the simultaneous stimuli presentation of speech and visual stimuli (i.e., hearing the word for the visual stimulus as the visual stimulus was presented over choosing presentations of single stimuli). Data were also collected on the voluntary emission of echoics as the children received the pairing sessions. The participants' emitted more echoics as they increased choosing the simultaneous presentations (i.e., high positive correlations). After the reinforcement intervention criterion was achieved, participants demonstrated BiN in laboratory and classroom probes. For the children for whom MEI had not been successful, BiN was established as a function of the conditioning intervention and MEI was not necessary.

As noted above, prior studies on the establishment of BiN demonstrated that multiple exemplar instruction, involving rotating speaker and listener responses with training sets of stimuli, resulted in establishment of BiN (e.g., Fiorile & Greer, 2007; Greer & Du, 2015; Greer, Stolfi, & Pistoljevic, 2007; Greer, Stolfi, Chavez-Brown, & Rivera-Valdez, 2005b; Rosales & Rehfeldt, 2007). However, intensive tact instruction intervention also resulted in BiN (e.g., Pistoljevic & Greer, 2006). Thus, there may be several ways in which BiN is established. Perhaps the prerequisite reinforcement control must be present for both responses. The Longano and Greer (2014) article suggested that the fundamental source was the conditioned reinforcement for visual and speech stimuli as it results in observing responses for BiN (Longano & Greer, 2014). This interpretation also follows from the several cusps that resulted from the instantiation of learned reinforcers as cited in the literature.

Findings from verbal development complement other evidence from comparative psychology, neuroscience, hominin paleontology, linguistics, and sign language studies (Fitch, 2010). For example, one of the cusps that have been identified is the reinforcement stimulus control for collaboration (Darcy, 2017). This cusp is identified as the point of development when children will work together for common outcomes. This involves the learning of collaborative reinforcers, where the acts of collaboration result in each person being reinforced. In this process, the social collaboration is necessary for a preferred reinforcer. The social payoff may involve a primary reinforcer or a toy. This type of *social reinforcer* may be regarded as *contractual* in nature as opposed to the effect of social *contact* alone. However, the process of collaborating acts, in some cases, to condition the social properties of other individuals (Darcy, 2017; Stolfi, 2005), resulting in the learning of social *contact* reinforcers. In social contact reinforcers, the learned reinforcers are embedded in the social interaction.

Another instance of a verbal developmental cusp occurs when a child begins to respond as a listener, whereas first-speaker responses remain independent of being a verbal listener. For this developmentally early cusp, the reinforcement is the correspondence between what is heard and what is emulated (i.e., parroting or canonical babbling; Pelaez, Virues-Ortega & Gewirtz, 2011). Note that emulation differs from imitation (e.g., Skinner's use of the term "echoic" rather than the word "imitation"). Imitation involves seeing and doing, whereas in emulation one does not see a process but rather observes the outcome. Learning to produce the effect (e.g., an echoic) involves trial and error. The reinforcement for the trial and error process of producing the echoic is the production of responses that are reinforced by a listener (e.g., Ross & Greer, 2003; Tsiouri & Greer, 2003, 2007) rather than the acoustical correspondence in

canonical babbling (e.g., Sundberg, Michael, Partington, & Sundberg, 1996; Yoon & Bennet, 2000).

One type of reinforcement for the production of speech sounds has functions like those in song and is not verbal or symbolic. The point-to-point reproduction reinforcement function becomes verbal for the child's speech-sound production when reinforcement shifts from acoustic correspondence (producing the same sounds is the embedded and learned reinforcer) to communicative verbal functions as a reinforcer (i.e., mand or tact reinforcers). When the acoustical properties of speech sounds reinforce the production of speech sounds, the correspondence between what the child says and what the child has heard acts as the automatic embedded reinforcer. However, at some point the reinforcement shifts to reinforcement for producing speech sounds to affect the behavior of a listener. The listener then "mediates" or assists the speaker as in the listener "passing the bread" to the speaker (Skinner, 1957). The speech sounds are no longer parroting or canonical babbling.

As the child comes into contact with new reinforcement conditioning experiences, the initially separate speaker and listener responses are joined. Interested readers could refer to Greer and Speckman (2009) and Greer and Longano (2010) for more detail on the process and evidence. Nevertheless, for the purposes of this article let it suffice to note that the development of reinforcement for verbal interactions accelerate and lead to the *joining of the listener- and speaker-within-the-skin* (Greer & Longano, 2010; Home & Lowe, 1996; Skinner, 1957). Skinner used this term to refer to instances where we talk to ourselves overtly or covertly. Preschool-age children who demonstrate the joining of the speaker and listener repertoires talk aloud to themselves particularly in solitary play. Lodhi and Greer (1989) found that typically developing 5-year-old children alternate speaker and listener resulting in episodes in which (a) the speaker role is reinforced by responses from (b) the listener role and (c) vice versa. The child talks to a play object such as a doll and the imagined person/object responds as a listener. This is followed, in turn, by the original listener role functioning as a speaker, and then the original speaker role as a listener. Each role is reinforced by the behaviors of the other role. This interaction has been identified as a conversational unit between individuals also in several studies and is likely the predecessor to the speaker-within-the-skin episodes (Donley & Greer, 1993; Eby & Greer, 2017; Schmelzkopf et al., 2017). This interaction constitutes bidirectional operants between individuals whereas the child's self-talk, as described above, is a bidirectional operant within the child's own skin, where each role interacts with the other. Skinner points out that at some point speaking aloud is punished and becomes covert and he and others argue this results in covert "verbal thinking" (Keohane & Greer, 2005, but see Rachlin, 2018, for a different argument). Verbal development evidence suggests that the outcomes of these behaviors are learned reinforcers and is described in detail in Greer and Du (2015). Studies of the relation between BiN and "thinking" are described in the research summarized by Miguel (2018). The work we describe in the present article is focused on how children come to be verbal and demonstrate bidirectional operants between individuals and within the skin. An extensive research program is focused on how BiN is related to problem solving. Recent unpublished dissertations suggest that the findings of the two research objectives appear to be converging (Frank, 2018; Morgan, 2018): Findings from the experiments in the dissertations show strong correlations between the degree of BiN and properties of derived relations (Morgan, 2018) and scores on the *Boehm*

Test of Basic Concepts 3rd Edition-Preschool Version (BTBC3-P; Boehm, 2001; Morgan, 2018).

The listener and speaker are also joined within the skin in BiN. The onset of the verbal cusp of BiN enables the learning of word/object relations as listener and speaker without direct instruction (e.g., Carnerero & Pérez-González, 2015; Greer et al., 2005a, 2005b; Greer & Speckman, 2009; Kobari-Wright & Miguel, 2014; Miguel, 2016; Pérez-González, García-Conde, & Carnerero, 2011; Pérez-González, Cereijo-Blanco, & Carnerero, 2014; Rosales-Ruiz & Baer, 1997; Speckman-Collins, Lee Park, & Greer, 2007). Once BiN is demonstrated, bidirectional operants between individuals and bidirectional operants in self-talk are present. This new stimulus control enables verbal/language self-editing or “thinking” (Greer et al., 2017; see Figure 1, Butterfly). The bidirectional operants set the stage for the learned reinforcement functions that then extend to print control in reading and writing and likely as well to more complex stimulus relations (e.g., Jennings & Miguel, 2017; Ma, Miguel, & Jennings, 2016; Morgan, 2018).

The four major advances in verbal development shown in the butterfly figure result from major changes in stimulus control that accrue as a result of experiences that, in turn, allow children to contact still other stimulus controls. In Rosales-Ruiz and Baer’s (1996, 1997) original formulation of behavioral developmental cusps, the emphasis was on the onset of new behaviors (e.g., crawling, walking) that lead to contact with novel stimuli. Subsequent research over two decades added *changes in stimulus control that result from experiences as key to the advancement of children’s verbal behavior* (Greer & Du, 2015). For example, children may emit point-to-point correspondence between heard speech and their own. In the example of parroting or canonical babbling, the correspondence between what is heard and what children produce vocally is the reinforcing stimulus (i.e., producing the matching speech sounds is the reinforcer). However, at the point when the child comes to learn to be reinforced by having an effect on the behavior of a listener towards, for example, gaining something (e.g., “pass the bread”), the reinforcing stimulus is the obtainment of bread. The response effort for producing speech is easier, as described above, and is the newly learned reinforcing stimulus control and newly learned motivation condition (Michael, 1993). The cusp results from the new stimulus control and motivating condition as follows: (a) the newly learned reinforcers or stimuli that follow the behavior, (b) the motivating conditions that result from the newly learned reinforcers, and (c) the antecedent stimuli that are selected by the reinforcers (i.e., discriminative stimuli and conditional stimuli). The trajectory of acquiring new stimuli that select behavior result in the metamorphosis from preverbal to fully verbal. This analysis of communicative behavior provides a perspective that is completely compatible with biology and does not rely on intervening psychological constructs.

Each of the several cusps plays developmentally important roles. However, the group of cusps that lead from preverbal foundational cusps to the stimulus control that is characteristic of the four major verbal metamorphoses is key (see Figure 1). Each of these stages result in very different individuals. Each stage results in transformations in stimulus control. The emergence of bidirectional operants (i.e., the butterfly) is, we believe, the onset of becoming truly verbal. This is made possible by the learned stimulus control involved in behavioral metamorphosis, during successive stages of verbal development. Each of these stages presumably results in structural changes in

the brain, as is suggested in recent correlational investigations of the emergence of the neural bases of specific language structures in young children related to the separate development of children's listener and speaker behavior, and traditionally discussed in terms of speech perception and speech production, respectively (Skeide & Friederici, 2016; Romeo et al., 2018). Verbal development research offers neural scientists the opportunity to do true experiments. That is, measures of brain activity before and after the establishment of cusps provides the means for determining functional relations between the establishment of language development and measures of brain activity (Greer & Du, 2015; Pohl, 1979).

The existing benefits of this work include (a) improved educational prognosis for children with autism (Greer et al., 2011; Maffei, Singer-Dudek, & Keohane, 2014), (b) the acceleration of observational and imitational learning of neurotypical children (Greer, 2009; Novak & Pelaez, 2004; Rosales-Ruiz & Baer, 1997), including neurotypical children from impoverished language environments (Hart & Risley, 1995; Hrachuk, Greer & Longano, 2018), and (c) the role of development of verbal behavior cusps in learning or *not learning* to read (Tsai & Greer, 2006).

Conclusions

Two major conclusions can be drawn from our synthesis of verbal development, behavioral metamorphosis, and the evolution of language. First, we maintain that *functional language development is a behavioral homologue of structural metamorphosis*. This means that the child's verbal development in predictable stages is a *functional equivalent of structural metamorphosis* regularly seen in amphibians and insects, such as the complete morphological transformation in the swallowtail depicted in Figure 1. *Homology* in our case is not to be confounded with a metaphor but refers to a common ancestry or evolutionary origin of a *developmental process of stage progression* in genetically different organisms, in distinction to the homology of the *structure* as exemplified, for instance, in the wings of bats and arms of humans.

Based on the experimental analyses described in the previous section, if one accepts our hypothesis, a potentially far-reaching implication emerges for evolutionary biology. Given (a) DNA sequencing data that suggest *hybridogenesis*—or the transfer of half the genome to the next generation in some animals that are hybrids between species—as a causal mechanism for major and relatively rapid structural change through horizontal transfer of genes between different taxa across the evolutionary tree (Syvanen & Ducore, 2010), and (b) a recently published field study of *natural hybridization* (defined as the inbreeding of individuals from two distinct populations) in Darwin's finches (Wagner, 2018) and an extraordinary paleogenetic finding of a first-generation Neanderthal-Denisovan hybrid (Slon et al., 2018), *the theory of hybridization* (as the only universal explanation of metamorphosis throughout all of the animal kingdom) deserves serious consideration from evolutionary developmental biology regarding the origin of metamorphosis and *the transformation of morphological into behavioral metamorphosis* in particular. Indeed, Williamson's theory of hybridization (Williamson, 1992, 2003; Williamson & Vickers, 2007) may receive unexpected experimental support by the findings presented here on verbal development as behavioral metamorphosis. By the same token, during the next decade we may witness the

assemblage of major parts of the puzzle of language and its development into a comprehensive and coherent theory of the evolution of symbolic behavior. This could include a deeper understanding of why *sapiens* is the only extant species of the genus *Homo* (Greer et al., 2017).

Second, once verbal development is conceived as behavioral metamorphosis in the context of lexical and nonlexical verbal behavior, we should expect to see cross-fertilization between two subdisciplines of biology: *evolutionary developmental biology* and *developmental verbal behavior analysis*. Evolutionary developmental biology, for example, could look for homologues of behavioral metamorphosis in the development of birdsong (Greer et al., 2017). It could also study the retention of learning across various stages of insect metamorphosis apart from what has already been experimentally demonstrated in the moth (Blackiston, Casey, & Weiss, 2008). The discovery of relational operants in nonhuman species would give empirical support to Hayes & Sanford's (2014) assertion that "When viewed as a contextual behavior science, behavior analysis is part of evolution science" (p. 112). Earlier studies of functional asymmetry of the auditory system in baboons (Pohl, 1983, 1984) could now be related to clinical investigations (Pohl, 1979) and developmental studies of functional auditory asymmetry in neurotypical children (Pohl, Grubmüller & Grubmüller, 1984) on the basis of the development of verbal behavior (Greer & Ross, 2008; Greer & Speckman, 2009). Finally, with a view to the future, children's acquisition of programming languages can be conceived as yet another manifestation of behavioral metamorphosis and analyzed within a verbal behavior development framework.

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