UNIVERSITÀ DEGLI STUDI DI SALERNO
DIPARTIMENTO DI SCIENZE POLITICHE E DELLA COMUNICAZIONE

Tesi di Dottorato di Ricerca in
Scienze del linguaggio, della Società, della Politica e dell'Educazione

LANGUAGE AS COMPLEX VERBAL BEHAVIOR: EXPERIMENTAL EVIDENCE AND POSSIBLE CLINICAL IMPLICATIONS

XXXIII Ciclo
Coordinatore: Ch.mo Prof. Filippo Fimiani

Tutor
Ch.mo Prof. Annibale Elia

Ch.mo Prof. Francesco Di Salle

Candidato
Michele Ianniello
Matr. 8801400069

Anno Accademico 2020/2021

TABLE OF CONTENTS

The data included in the present thesis are the product of the research activity I have conducted in a research group composed also by other PhD students, and parts of a manuscript this research group has worked on and that is being prepared for publication will be herein included.

Introduction

The present work deals with the convergence between the study of human language and the field of neurosciences. In particular, its conceptual framework is rooted in the behavior analytic approach, that diverges from the classical linguistic theories.

The behavioral conceptualization of language has been the subject of a book entitled *Verbal Behavior* and written by B.F. Skinner in 1957. In this volume, the author focuses his attention on the function of language, that is on the effect of every single act of talking (verbal operant) on the environment. Skinner's *Verbal Behavior* is, thus, an analysis focused on the functional aspects of the communication. He talks about language in terms of "controlling relations'', meaning a causal relation "*which includes the speaker's current motivational state, his current stimulus circumstances, his past reinforcements, and his genetic constitution"* (Skinner, 1957). In his work, only the objective dimensions of verbal behavior are taken into consideration and only objective, non-mentalistic and non-hypothetical aspects of language are explored.

In contrast with the Skinnerian ideas, there are other, more universally accepted, theories of language, among whom the one proposed by Chomsky has reached the widest notoriety.

Chomsky conceptualization was based on language structure, focusing on the syntactic and structural aspects of language than then on its function. His main contribution to linguistics is *Transformational Generative Grammar*, which is founded on an innatistic explanation of the acquisition of language and on a philosophy based on non-environmental arguments. For Chomsky, indeed, human brain is biologically programmed to learn language, so language skills are innate. (Barman, 2012).

That marks a clear difference between the formal approach to language and the behavioral one.

Neuroscience and language

The vast majority of the neuroscientific studies of language has originated from a cognitive and linguistic perspective and not from a behavioral one. Of course, from a behavioral perspective many language studies through neuroscience methods seem to not having focused on the right dependent variables, nor experimentally manipulated the right independent variables. As can be easily understood, if the framework of analysis is so distant as are behavioral and structural theories of language, even the experimental aims a neuroscience experiment based on structural language theories can pose appear to ask wrong questions and to accept wrong answers from a behavioral perspective. If a very divisive scientific theory can be recognized in the modern neurosciences, that is certainly the functional conceptualization of language.

From a behavioral perspective neuroimaging developed on cognitive theories sounds very distant, as well. Faux (2002) notes that cognitive neuroscience has attempted to localize traditional cognitive constructs in neuroanatomy, “however, too many proposed cognitive mechanisms are vague, unnecessarily complex, and amount to little more than inferred guesswork. Unobservable behaviors of the mind, like volition, central executive function, and mental imagery, do not enhance understanding of empirical brain operations” and “such terminology obscures more than clarifies”. (Faux, 2002, p. 171). To date, the science of behavior has produced an important work of analysis of public behavior and consequently a great number of effective procedures to modify it. At the same time, a notably high number of scientific papers have been published in the field of neurosciences in order to study the brain at different levels of analysis. Unfortunately, the two scientific communities have matured separately, and certainly without productive discussions on the topics in which they have both shown interest. This missed convergence has certainly limited behavioral analysis growth in the direction of incorporating the main achievements of neuroscience, but also neuroscience has not taken benefit from the scientific corpus of the science of behavior.

Already in *The Behavior of Organisms* (1938), B.F. Skinner wrote about the need to a "unified understanding of the laws of behavior and the laws of the nervous system", and in 1945 he remarked the value of bridging the gap between physiology and behaviorism (Pappalardo et al., 2019).

After Skinner, other behaviorists pointed out the role of neurophysiology "in every behavioral event" and began to talk about a "comprehensive science of behavior" (Moore, 2002) that could be able to explain how *the neural system mediate the functional relations between the public environment and the public behavior* (Pappalardo et al., 2019).

In this direction, Donahoe and Palmer described neurophysiological events related to behavior, such as the delivery of reinforcement[1], stimulus control[2] and memory.

In an article published in 2016, Ortu and Vaidya discussed the challenges of an integrated behavioral and neuroscientific perspective and analyzed brain responses within a behavioral framework. They discussed neuroplasticity, intended as the idea that the brain is "a flexible and continuously changing system" that reflects the changes that occur at the public level of behavior. However, the lower accessibility of the nervous system with respect to the domain of public behavior risks to endanger the possibility of a convergence between the science of behavior and neuroscience (Pappalardo et al., 2019).

The first scope of this work is then to show how neuroscience can converge with the study of high order language in a behavioral perspective, starting from the study of the "behavior of neurons and neural assemblies, which he refer to as "neural behavior".

---

[1] Reinforcement occurs when a stimulus immediately follows a behavior increasing the future frequency of that behavior.

[2] Stimulus control is intended as an environmental condition which alters the features of a behavior are altered by the presence or absence of a stimulus antecedent to that behavior.

The philosophical aim of the study produced in the context of this thesis is to discuss a convergence between neuroscience and behavioral science.

For this purpose, a series of functional Magnetic Resonance Imaging (fMRI) experiments were carried out. The analysis of the results allowed to understand brain functioning related to the emission of verbal behavior from a behavioral perspective and provided some conceptual tools to possibly develop new techniques to teach verbal repertoires, especially for individuals with language disabilities, as the ultimate goal of a line of research based on the study of the brain processes related to language.

From this point of view, the scope of these experiments is double: on one side to apply a behavioral perspective on what is already known about brain functioning related to language; on the other side deriving from neuroscientific results new ways to teach and therefore to improve the life of people with language impairment.

Chapter 1

Language as *verbal behavior*: Skinner's conceptual framework

In his influential article, "Psychology as the Behaviorist Views It," Watson (1913) wrote: Psychology as the behaviorist views it is a purely objective experimental branch of natural science. Its theoretical goal is the prediction and control of behavior. Introspection forms no essential part of its methods, nor is the scientific value of its data dependent upon the readiness with which they lend themselves to interpretation in terms of consciousness". (p. 158)

For Watson, in practice, the proper subject matter for psychology was not states of mind or mental processes but instead observable behavior. Moreover, since it is a natural science, the objective study of behavior should consist in the direct observation of the relationships between environmental stimuli (S) and the responses (R) that they evoke. For this reason, the Watsonian behaviorism became known as stimulus–response (S–R) psychology (Cooper, Heron and Heward, 2007) and it represented a first and important step towards a behavioral science to be considered as a natural science and not as a social one.

The further step was taken by B.F. Skinner, with the publication of *The Behavior of Organisms* in 1938. This book summarizes the laboratory research work conducted by Skinner from 1930 to 1937 creating to the Experimental Analysis of Behavior (EAB).

The Experimental Analysis of Behavior (EAB) is the basic research domain of the science of behavior, while Behaviorism is its philosophy. A further branch is represented by Applied Behavior Analysis (ABA) which is the application of the behavioral principles and of the derived technologies and strategies to improve socially significant behavior, thus impacting people's lives. EAB, Behaviorism and ABA are the three branches that constitutes the Behavior Analysis.

At that time, other psychologists and theorists postulated mediating variables inside the organism in the form of hypothetical constructs and cognitive processes, while Skinner instead, took a different way. He didn't follow these hypothetical constructs or presumed and unobserved entities that could not be manipulated directly and experimentally, instead he continued to look in the environment for the determinants of behavior that did not have apparent antecedent causes (Kimball, 2002; Palmer, 1998).

Hypothetical constructs — "theoretical terms that refer to a possibly existing, but at the moment unobserved process or entity" (Moore, 1995, p. 36) — can neither be observed nor experimentally manipulated (Mac Corquodale & Meehl, 1948; Zuriff, 1985). Free will, readiness, innate releasers, language acquisition devices, storage and retrieval mechanisms for memory, and information processing are all examples of hypothetical constructs that are inferred from behavior and not directly observable. Actually, Skinner (1953,1974) clearly indicated that could be a mistake to rule out events that influence our behavior only because they are not accessible to others (private events). He believed that using presumed and unobserved mentalistic fictions (i.e., hypothetical constructs) to explain the causes of behavior can't contribute to a functional analysis and comprehension (Cooper, Heron and Heward, 2020).

Skinner accumulated significant evidence about the fact that antecedent and consequent stimuli affect behavior by altering the momentary and future probability of its emission. The essential formulation for this notion is S–R–S (stimulus-response-stimulus), otherwise known as the three–term contingency.

With the three-term contingency, Skinner gave shape to a new paradigm. From a behavioral perspective, he achieved something revolutionary and no less profound for the study of behavior and learning than Bohr's model of the atom or Mendel's model of the gene (Kimball, 2002, p. 71). In fact, the operant three-term contingency is delineated as the primary unit of analysis of the behavior and represents a real conceptual breakthrough (Glenn, Ellis, & Greenspoon, 1992).

Through his research Skinner gained an incredible amount of experimental evidence enabling clear and powerful demonstrations of orderly and reliable functional relations between behavior and environmental events. Skinner systematically manipulated the arrangement of stimuli that preceded (antecedents) and followed (consequences) behavior in literally thousands of laboratory experiments from the 1930s until the 1950s. He could so discover and verify the basic principles of "operant behavior" that continue to provide the empirical foundation for behavior analysis today, producing undeniable results in the lives of thousands of people.

Other than being the founder of the experimental analysis of behavior, B. F. Skinner wrote also extensively on its philosophy, and his writings have been the most influential ones in both giving the practice coordinates of the science of behavior and in offering the application of the principles of behavior to new areas of intervention (Cooper, Heron and Heward, 2020).

Starting from the 1950s several researchers followed Skinner's example in using the methods of the experimental analysis of behavior to test whether the principles of behavior demonstrated in the laboratory with nonhuman subjects could be replicated and applied with humans too. Much of the early research with human subjects was so carried out in clinics or laboratory settings, giving the participants multiple benefits in terms of learning new behaviors.

For example, Bijou (1955, 1957, 1958) researched various principles of behavior both with typically developing subjects and with people affected by mental retardation. Baer (1960, 1961, 1962), instead, examined the effects of principles as punishment, escape, and avoidance contingencies on preschool children. Ferster and De Myer (1961, 1962; De Myer & Ferster, 1962) conducted a systematic study of the principles of behavior working with autistic children and Lindsley (1956, 1960) analyzed the effects of operant conditioning on the behavior of adults with schizophrenia.

This early research clearly showed that the principles of behavior are applicable to human behavior, and so these pioneer researchers set the conditions for the later development of applied behavior analysis as it is known today (Cooper, Heron and Heward, 2020).

In particular, the branch of behavior analysis that would later be called Applied Behavior Analysis (ABA) can be led back to 1959, year of the publication of Ayllon and Michael's paper titled "The Psychiatric Nurse as a Behavioral Engineer".

Applied behavior analysis became then the science in which the principles of behavior gave life to techniques, procedures and strategies applicable in real life, to improve socially significant behaviors, while experimentation is used to identify the determinants, called "variables of control" by behaviorists, responsible for behavior change.

Likely, the most socially significant and relevant aspect of human behavior involve verbal behavior. A series of skills like language acquisition, social interaction, academics, intelligence, understanding, thinking, problem solving, knowledge, perception, history, science, politics, and religion are all directly attributable to verbal behavior. On the other hand, many human problems or severe disabilities such as autism, involve the correct or wrong mediation of verbal behavior. So, verbal behavior plays a central role in most of the major aspects of human life, and in the laws, conventions and activities of a human society (Cooper, Heron and Heward, 2020).

With respect to the study of language, Skinner distinguished between the formal and functional properties of the single utterances (Skinner, 1957). The formal properties of the language belong to what is called “topography” (i.e., form, structure), whereas the functional properties involve the causes of the verbal responses. For Skinner a complete account of language must consider both of these elements, but his focus was on the functional aspects of the language rather than on the structural ones. From a more linguistic angle, the form of what is said can be measured by *(a) phonemes: the individual speech sounds that comprise a word; (b) morphemes: the units with an individual piece of meaning; (c) lexicon: the total collection of words that make up a given language; (d) syntax: the organization of words, phrases, or clauses in sentences; (e) grammar: the adherence to established conventions of a given language; and (f) semantics: what words mean (Barry, 1998;*

Owens, 2001). Moreover, Barry noted that, *the formal description of a language can be accomplished also by classifying words as nouns, verbs, prepositions, adjectives, adverbs, pronouns, conjunctions, and articles. Other aspects of a formal description of language include prepositional phrases, clauses, modifiers, gerunds, tense markers, particles, and predicates. Sentences then are made up of the syntactical arrangement of the lexical categories of speech with adherence to the grammatical conventions of a given verbal community. The formal properties of language also include articulation, prosody, intonation, pitch, and emphasis (Barry, 1998).*

It is a common mistake to consider that Skinner rejected the formal classifications of language. He did not argue *against* it but rather in favor of a new perspective able to explain where to search for the "causes" of language.

Classical theories of Language

There is a wide variety of theories of language which attempt to identify its determinants. These theories can be classified into three separate, but often overlapping, views: biological, cognitive, and environmental (Cooper, Heron and Heward, 2020).

The basic orientation of the biological theory is that language is a product of physiological processes and functions. Chomsky (1965), for example, argued that language is innate for humans. That is, human's language *abilities* are inherited and present at birth (innatism).

Together with Chomsky theory, also an extension to language of cognitive psychology theories is widely accepted (e.g., Bloom, 1968; Piaget, 1952).

Various proponents of the cognitive approach to language maintained that language is controlled by internal processing systems that "accept, classify, code, encode, and store verbal information" (Cooper, Heron and Heward, 2020).

It is not always easy to distinguish between the biological and cognitive standpoints as in the case of the cognitive metaphor of the storage as explanations of language behaviors, or the interchangeability between brain and mind terms (e.g., Chomsky, 1965).

Verbal Behavior

Skinner (1957) sustained that language is totally a learned behavior, and that it is *acquired, extended, and maintained by the same types of environmental variables and principles that* *control non-language behavior* (e.g., antecedent e consequent stimuli of the behavior – Cooper, Heron and Heward, 2020).

Skinner proposed that verbal behavior is “reinforced” (rewarded and therefore learned) through the mediation of another person’s behavior.

In other words, a particular behavior is defined as “reinforced” when his probability to increment its frequency or to being steady in future, grows after the presentation of a specific stimulus. For example, the verbal responses (response is meant as the singular unit of behavior) “Give me the phone” can produce the reinforcer of receiving a phone mediated through the behavior of a listener.

For Skinner language learning is built upon reinforcement contingencies, which associate the auditory stimuli (words) with their meanings.

Considering that Skinner’s main focus on verbal behavior consists in the function of the response, rather than in its form, any response form can become verbal. For example, also the behavior of a 2-month-old infant may be thought as verbal if crying or pointing, or moving his hands allow the infant to get food by his mother. In other words, verbal behavior is not possible without social interaction between a speaker and a listener, except in some cases, as for example for thinking verbally or talking to oneself, condition in which talking and listening are operated by the same individual.

Noam Chomsky criticized harshly Skinner work. For him a child will never acquire the tools needed for develop an unlimited number of utterances if the language acquisition mechanism was dependent only on the environment. In open contrast with the Skinner perspective, he proposed the theory of Universal Grammar: *an idea of innate, biological grammatical categories, such as a noun category and a verb category that facilitate the entire language development in children and overall language processing in adults. Universal Grammar is considered to contain all the grammatical information needed to combine these categories, e.g. nouns and verbs, into phrases. The child's task is just to learn the words of her language* (Ambridge & Lieven).

Following Chomsky consideration and according to the Universal Grammar system, children instinctively know how to combine parts of the sentences, for example a noun (e.g., a cat) and a verb (to scratch) into a full meaning phrase (The cat scratches).

Unit of Analysis (The Verbal Operant)

The unit of analysis for verbal behavior is the functional relation between a response and the environmental variables that "control" it, namely (a) motivating variables, (b) discriminative stimuli (which signal the availability of a certain consequence), and (c) the reinforcement consequences that strengthen it.

Skinner (1957) called these units *verbal operants*, and he defined a verbal repertoire as a specific set of such units for a particular speaker. The verbal operants are antithetical to the units of analysis of language formulated by the formal linguistic theories, that consist of words, phrases, sentences, and the mean length of utterances.

Elementary Verbal Operants

Skinner (1957) identified six elementary verbal operants: mand, tact, echoic, intraverbal, textual, and transcription.

According to Skinner's classification of language, the verbal operant is defined as the elemental unit for the analysis of verbal behavior and therefore each verbal operant is functionally outlined by its sources of stimulus control (environmental variables, considering as environmental for Skinner, not only what happens in the world outside the behaver, but also inside him for instance pain, thirst, hunger, sleepiness etc). Skinner argued that "the understanding of verbal behavior is something more than the use of a consistent vocabulary with which specific instances may be described" (Skinner, 1957), this means that when we meet a specific verbal utterance, we need to take in consideration the "functional analysis" related to its emission, in other words what caused it. Again, is evident as rather than on the form of the response, Skinner's classification is instead based on the functional relationships between stimuli and responses (behaviors), so that a single word can be uttered in different verbal operants, in other words and more specifically, under different antecedent and consequent stimulus conditions.

The experimental work exposed in the next chapters, has been built upon this Skinnerian conceptualization and on the concept of *functional independence* of the verbal operants. As said, the verbal operant is the basic unit of the verbal behavior.

Every verbal operant is functionally independent with respect to the other verbal operants, meaning that we can learn to use a word under the control of specific contingent variables and the use of the same word under other contingent variables is not automatically obtained without a specific training. In adult people the use of the various operants is intertwined at the point that sometime can be difficult to understand the controlling variables of a single operant in an utterance. Skinner discussed largely about this in his “Verbal Behavior” written in 1957.

Each verbal operant, as outlined by Skinner (1957), actually cover a specific function. This consideration is easily visible observing the typical development of the children. In fact, is possible to realize that in the first years of life (3 years) the human being develops language and use the single words or approximations, depending on the function that the words carry out in the environment. This is even more visible in person with language disabilities (for example autism or mental retardation), where the use of a single word can be present under certain environmental circumstances and not under other circumstances.

In the context of this thesis the verbal operants that will be studied, are the following:

- MAND

The mand is a verbal operant in which a speaker asks for what he needs or wants. For example, the behavior of asking for a cookie when hungry, or directions when lost are kinds of mand. Skinner (1957) called this operant mand because the term is conveniently brief and is derived from the plain English words *command*, *demand*, and *countermand*.

The mand is a verbal operant evoked by a particular antecedent motivational condition and that specifies, with its response form (topography) the consequence that strengthens it.

For example, liquid deprivation will (a) make water effective as reinforcement (reward) and (b) evoke behavior such as the mand "water" if this behavior has produced the delivery of water by others, in the past. For this strong correlation between the verbal behavior and the specific result of it, mands are very important for the early development of language. For this reason, mands are likely the first verbal operant acquired by a human child (Bijou & Baer, 1965; Novak, 1996), and are the first verbal operant taught in the early behavioral intervention in ABA, with children presenting language impairments. Early mands can assume form of differential crying according to needs (hunger, tiredness, pain, cold, attention, help, removal of aversive stimuli ecc).

Day by day, typically developing children learn gradually to replace crying with words and signs or other standard forms of communication (P.E.C.S., pointing etc.).

Manding not only lets children control the delivery of reinforcers, but it begins to establish the speaker and listener roles that are essential for further verbal development. (Cooper, Heron and Heward, 2020).

The great value of the mand, as pointed out by Skinner, is that it is the unique type of verbal operant that directly benefits the speaker with edibles, toys, attention, removal of aversive stimuli, information and so on.

- TACT

The tact is the verbal operant referring to the speaker ability to naming, labeling, describing things that come in direct contact with him, through any of the sense modes. For example, a child saying “dad” because he hears his father voice.

The term tact is utilized because it is referred to making *contact* in some way, with the physical environment.

The tact is a verbal operant “controlled” by a nonverbal stimulus, and producing as consequence a generalized conditioned reinforcement (praise, attention, some kind of appreciation). A great variety of nonverbal stimuli can evoke tact responses. For example, a pizza produces visual, tactile, olfactory, and gustatory stimulations, any or all of which can evoke the tact “pizza.” Nonverbal stimuli evoking tacts can be of different nature, for example can regards nouns of objects, animals, persons, relations between objects (prepositions), categories, functions, actions properties of objects (adjectives), private events, like feeling, moods etc.

- ECHOIC

The echoic is a type of verbal operant dealing with the repetition of verbal behavior emitted by another speaker.

The term echoic is deriving by the word “echo”.

We meet this operant for example, when a little child says “milk” after hearing the word spoken by her mother.

Repetition of words, phrases, and vocal behavior of others, corresponds to echoic behavior too.

The echoic operant is defined as “controlled by a verbal stimulus that has point-to-point correspondence and formal similarity with the response” (Michael, 1982).

Point-to-point correspondence means that between the stimulus and the response there’s a perfect parity. In other words, at the beginning, in the middle and at the end, verbal response matches perfectly to the verbal stimulus.

Formal similarity instead occurs when the antecedent stimulus and the response share the same sense mode (e.g., both stimulus auditory) and physically resemble each other (Michael, 1982).
Like for tact, Echoic behavior produces generalized conditioned reinforcement such as praise and attention by other, as consequence.
The ability to echo the vowels, phonemes, words and whole phrases is essential develop other operants, like tact.
For instance, we can say, "That's a dog, can you say dog?" If the child can respond "dog," then we'll say "Right, is just a dog!"
The echoic repertoire in this case works as a bridge from echoic to tact and is very important for teaching language to children, *and it serves a critical role in the process of teaching more complex verbal skills* (e.g., Lovaas, 1977; Sundberg & Partington, 1998).

- INTRAVERBAL

The intraverbal is the verbal operant in which a speaker responds to the verbal behavior of others. For example, saying "Manchester United" as a result of hearing someone else say "Who won the game Saturday?" is an intraverbal behavior. Other kind of intraverbal response is for instance, describing activities when those are not more presents (otherwise is a tact), problem solving, remembering, taking a conversation, singing songs, telling stories, thinking verbally. Intraverbal behavior is very present in daily life. Typically developing adults emit intraverbal behavior at very high rate and thanks to it can develop higher intellectual repertoires, such as saying "Madrid" as a result of hearing "What is the capital of Spain?"; saying "eighty-one" as a result of hearing "nine times nine" and so on.

The intraverbal repertoire of every typical adult speaker is very rich and complex. In the intraverbal relation, we met as antecedent, a verbal stimulus evoking a verbal response that does not have point-to-point correspondence with the verbal stimulus (Skinner, 1957). In the intraverbal, respect to echoic and textual, the verbal stimulus and the verbal response don't match each other. Like all verbal operants except the mand, the intraverbal produces generalized conditioned reinforcement (attention, praise, a point, the chance to going to the next question etc.).

Just as an important and complex tact repertoire facilitates the development of the intraverbal operant, a rich and articulate intraverbal repertoire facilitates the acquisition of other verbal and nonverbal behavior.

Intraverbal behavior plays an important role in the social interactions and specifically in conversation. In other words, we may say that intraverbal is a person's "intellectual repertoire", so it can be considered as the basis and the very core of complex verbal behavior.

- TEXTUAL

Textual behavior (Skinner, 1957) corresponds to reading, meant here as reading without comprehension of what is being read. Understanding a text read involves other verbal and nonverbal operants such as intraverbal behavior and a listening repertoire (receptive language) as following instructions etc.

If I say "table" when I see the written word "table" is textual behavior. Understanding that table is that kind of furniture element upon which I can work, study or eat, goes beyond the simple reading and need a development of a good tact and intraverbal repertoire.

Textual operant has point-to-point correspondence, but not formal similarity, between stimulus and response. For example, the verbal stimulus is visual and the response is auditory, but the auditory response matches the visual stimulus. Textual operant does not have formal similarity with the antecedent stimulus, the stimuli are not in the same sense mode and do not physically resemble each other. The response product of textual can be covert or overt.

- TRANSCRIPTION

Transcription consists in writing spoken words (Skinner, 1957). Taking dictation is another name that Skinner used for this operant. Like for textual operant, there is point-to-point correspondence between the stimulus and the response, but not formal similarity, indeed the stimulus and the response product have point-to-point correspondence, but they are not in the same sense mode, that is physically don't resemble each other. (Cooper, Heron and Heward, 2020).

<u>Additional considerations</u>

Intraverbal and Tact

The operant that constitutes the bricks of the "thought/thinking" and of what we call "complex verbal behavior", is primarily the intraverbal.

Intraverbal represents a verbal behavior macro-category that can assume several forms. Given its complexity, it remains probably the harder operant to learn, especially for the individuals with language disabilities. That can be due to the complexity of its variables of control of this operant.

For the development of a complex intraverbal repertoire and for the constitution of a person's "stream of thoughts", another verbal operant is fundamental: the tact.

In a way, Skinner set aside the study of thinking, because he considered it something not observable, not measurable and not quantifiable, due to the lack of adequate tools to assess in detail this kind of behavior.

Things have now changed. While in 1957 (year of publication of Skinner's *Verbal Behavior*) valid technologies for the observation and understanding of covert behavior were not present, it is now possible to use neuroimaging technologies (functional magnetic resonance imaging for instance) which allow us to analyze brain activity with great precision and richness of details.

Therefore, we are not so far from possessing the instruments that Skinner wished we would possess to further extend his analysis of high order verbal behavior.

The objective of the present work is precisely to describe a developed line of research which moves the analysis of covert behavior up a notch from just being “science fiction”.

Chapter 2

The analysis of *verbal operants* in functional neuroimaging (fMRI)

The present study is aimed at creating the *neural fingerprints* of the Skinnerian Verbal Operants, which would be represented by the observable specific patterns of neural activity when the corresponding public response is emitted, in terms of the amount of neural resources and their spatial distribution in the four brain lobes (frontal, occipital, parietal and temporal). We conducted a functional Magnetic Resonance (fMRI) experiment to display brain activity related to the verbal operants in four neurotypical adult volunteers, reproducing the natural sources of control for each operant. The emission of each verbal operant is associated to a pattern of neural activity that is unique in its global shape, while single pattern components can overlap with other operants. A common neural component in the patterns subserving different verbal operants is likely to be the basis for multiply controlled verbal behavior. On the contrary, the differences among neural patterns are most probably explaining functional independence of verbal operants.

Already in Behavior of Organisms (1938) and later in About Behaviorism (1974), B. F. Skinner acknowledged the need to a comprehensive analysis of behavior given by the convergence between behavior analysis and physiology. This goes in the direction of neurosciences finally providing tools of observation of the neural activity subserving public behaviors at different levels of complexity, thus allowing a thorough understanding of the neural mechanisms underlying the emission of public behavior, linking public to private behavior in a true radical behaviorism perspective.

Skinner argued that "The understanding of verbal behavior is something more than the use of a consistent vocabulary with which specific instances may be described" (Skinner, 1957), this implying that when we think of a specific verbal utterance, we need to take into account the functional analysis related to its emission. It is noteworthy to also say that, in Skinner's classification, there is a common functional ground for echoic, textual, intraverbal and tact operants, for which the responses contact nonspecific consequences, and are all different from the mand for which the "response … comes to *specify* its characteristic consequences" (Verbal Behavior, p. 83). Given this dissimilarity in the consequences between the mand and the other verbal operants, the mand operant appears particularly difficult to study in ‘restricted environments’ like the Magnetic Resonance one.

The experiment we conducted was aimed at singling out the brain area(s) where the neural behavior subserving the emission of verbal operants takes place, investigating the relative amount of neural resources a given verbal operant uses compared to the other operants, and providing *neural fingerprints* intended as specific patterns of neural activity related to each verbal operant. The patterns of neural activity of each operant were expected to include specific brain regions (i.e. not activated by the other operants) and regions overlapping with the other operants. A further analysis of both overlapping and differentiated neural loci for verbal operants was thought to contain fine-grained information about the differential use of neural resources related to the sources of control of each operant, and to be relevant to create a conceptual basis for discussing how phenomena as opposite to each other as multiple control and functional independence of verbal operants are strongly grounded in the organization of verbal behavior at the neural level.

The experiment focused on 4 primary verbal operants: echoic, tact, intraverbal and textual operants. The reason why the other verbal operants were not involved is due to technical limitations posed by the particular environment in which the experiment was carried out. In particular, the functional resonance environment narrows the possible array of reinforcers managed by the experimenter and necessary for the implementation of mand trials, makes it difficult to monitor and experimentally demonstrate motivational variables, and the realistic presentation of the stimuli correlated to the availability of the specific reward. Also the verbal operant of Transcription was not considered in this study because its nature is incompatible with the fMRI environment. The four participants in the study were naturally developing adults, vocally verbally competent and with high (university) cultural backgrounds.

The experiments were conducted in a hospital setting, in the Advanced Magnetic Resonance Unit of the University of Salerno. Imaging data were collected using a 3-Tesla Scanner. The different stimulus conditions of the experiment were presented to the volunteers using a specific hardware system (Magnetic Resonance Technologies) and the software Presentation®, which allows the experimenter to create scenarios with the stimuli to be presented in the experiment and the precise timing of each stimulus presentation.

For each participant the experiment consisted of one fMRI session which lasted 25 minutes. There were 8 different stimulus conditions presented within a conceptually Reversal/Withdrawal experimental design; the conditions were repeated 9 times each in an interspersed and random fashion, with a 20 seconds return to baseline in between each presentation of a condition and the following.

In ABA the Reversal/Withdrawal design is considered the stronger design to demonstrate the functional relation between environmental variables and behavior (independent and dependent variables).

During the echoic condition, the participants were asked to repeat a single word provided by a pre-recorded stimulus from the software scenario. The verbal auditory stimulus that evoked the response of the volunteer was composed by an instruction to repeat immediately followed by the word to repeat. During the textual condition, the volunteer was given an auditory instruction with which they were asked to read aloud a written word provided by the software scenario at the center of a black screen. The stimulus conditions corresponding to the echoic and the textual operants were composed of both “sense” and “nonsense” verbal stimuli (Italian words). The nonsense words were sequences of letters, and their inclusion in the experiment procedure determined a way to study these operants in their pure nature, reducing the possible risk of the emission of private multiply controlled operants (echoic-tacts, echoic-intraverbals, textual-tacts, textual-intraverbals) along with the public verbal response. During the tact condition, the volunteer was given a verbal stimulus (“What is it?”) and was asked to say aloud the name of a pictured object or of a sound in the form of a single word. In the intraverbal condition the volunteer was given the instruction “associate” and was asked to produce a single word association to a verbal stimulus which was provided in visual (textual) or auditory form. The tact and intraverbal conditions were composed of both visual and auditory stimuli (nonverbal stimuli for the tact condition and verbal stimuli for the intraverbal condition). The tact and intraverbal operants conditions were designed to have both visual and auditory antecedents with the aim of enabling the experimenters to study the operant in an independent way from the physical nature of the controlling antecedent stimulus.

A short pre-experiment training was implemented for all of the 4 volunteers with a different set of stimuli than the one used for the experiment, permitting the volunteers to become familiar with the particular setting in which the experiment was carried out, which requires the volunteer to stay still and to reduce to the bare minimum any kind of movements, included the ones (mouth and tongue movements) required to emit the vocal responses, which would otherwise be captured as “noise” in the temporal series of images registered by the scanner.

The single-case experimental design used is conceptually a reversal/withdrawal design, with many (72) applications and withdrawals of the independent variable which consisted in the presentation of the antecedent stimuli that evoked the different verbal operants involved in our study.

The dependent variable (neural response) was a point-by-point (voxelwise) measurement of % signal variation during the emission of the vocal responses (which were also registered and used to validate the neural responses) in the single volunteers. The fMRI data were analyzed in 4 subjects with the Brain Voyager QX 2.8 software package (Brain Innovation, Maastricht, The Netherlands). Functional and anatomical data sets were aligned in a common space (after a structural transformation to a Talairach template). The data pertaining to each subject were analyzed individually, as a single subject study, but were also combined together in a second level analysis to enhance internal validity.

There is a particular reason why so many applications and withdrawals of the independent variable and a second level group analysis of the 4 volunteers was meaningful for our experiment. As Skinner (1974) expected that bridging the gap between physiology and behaviorism would produce "more behavior to explain", studying neural behavior brings the analysis on a more complex level due to the intimate nature of the neural environment where a concept as simple as the "absence" of activity does not probably exist. Every neural region, in fact, takes *continuously* part into dynamically varying neural assemblies acting chorally as functional patterns, which assemble and disassemble themselves changing their shape moment-by-moment following the specific features of the stimulation and the efficiency in generating a neural product.

Activity will still be detected, even if in minor amount, in brain areas not significant to the task being performed and generated by private processes in some way intersecting the neural patterns relevant to the task. To state the idea more loosely, it is not possible to manipulate the brain in an "on-off" fashion and to really isolate "adiabatic" and self-coherent single processes, as it is commonly done in the domain of public behavior. When studying public behavior, it is possible to inhibit accessory responses and detect more easily extraneous variables, as well as conduct baseline sessions with a relatively fair certainty that the relevant independent variables are not in action. In an experiment involving the analysis of neural behavior then, performing several reversals is the best way to protect the data from the inherent presence of extraneous and confounding variables, enhancing the experimental internal validity.

One relevant concept needs to be taken as a premise of the analysis of brain activity. Opposed to what we are used to consider in the world of public behaviors, where one specific behavior can be taken "in isolation" as the appropriate dependent variable to measure, "isolated" behaviors are rare, if ever possible, in the inner world of private behaviors. Seen as dynamic neural activities in the brain, all behaviors take the form of choral or combined activities, instead of isolated ones. From the perspective of neural activation, there is no simplistic one-to-one correspondence between one public behavior and one isolated neural activity, and single public behaviors are always corresponding, instead, to "patterns" of neural activity. So the equivalence with the public behavior must be looked for in the space of “brain activity patterns”, instead of simply in the space of brain activity.

The verbal operants studied in this experiment were clearly distinguishable from each other on the basis of the allocation of neural resources needed to produce them, so that specific protocols reproducing the controlling variables of each Verbal Operant in the Functional Neuroimaging environment produced specific patterns of brain activity that could be recognized with a simple visual analysis and were as unique as the classes of contingencies they reflect (Pappalardo et al., 2019).

The experiment provided a “neural fingerprint” of each verbal operant on the basis of the location and the amount of neural resources used in each cerebral lobe.

The same analysis can be displayed in a more conventional form with a bar graph and the corresponding table (Fig. 1).

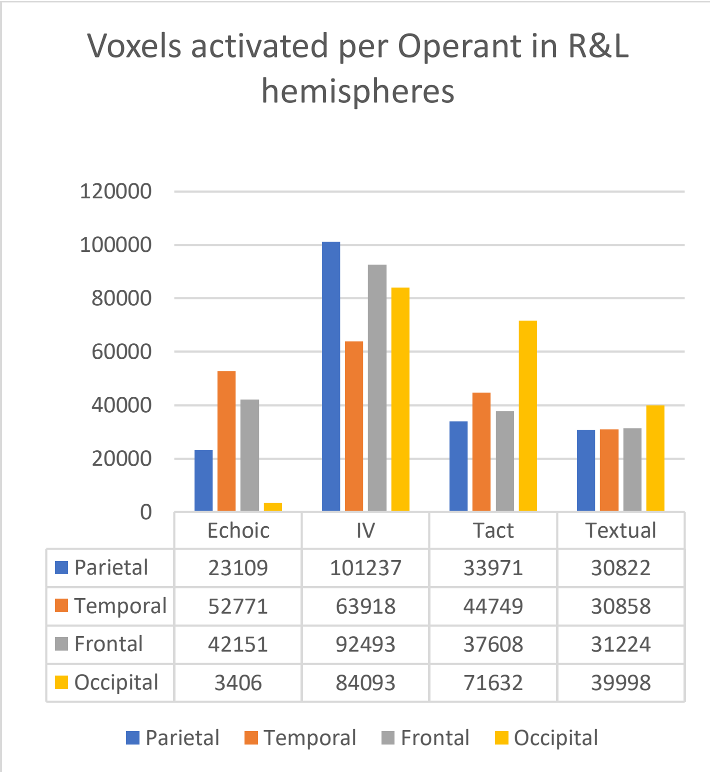


Fig. 1 Number of voxels activated in each verbal operant in right and left hemispheres.

- *Echoic*

A direct analysis of the activity patterns shows, for the echoic operant, a prevailing spatial involvement of the temporal lobes, i.e. the highest amount of neural resources recruited come from the temporal cortex. The superior surface of temporal lobes has been linked to the processing of auditory stimuli by an extensive neuroscientific literature (Formisano 2002, Seifritz 2003) in this aspect being completely in line with the contingency of the echoic operant, which implicates only auditory stimuli and response products of the same nature, as Skinner defined it ("the response generates a sound-pattern similar to that of the stimulus"- Skinner, Verbal Behavior, p.55).

This same pure auditory nature of the stimuli involved in the echoic contingency also explains well the very low amount of neural resources employed in the occipital lobes, where the neuroscientific literature has clearly demonstrated a prevailing processing of visual stimuli (Sereno et al., 1995).

The activity in the frontal lobes is less pronounced than in the temporal lobe, with a huge difference between the word and non-word conditions (12505 vs 29646 voxels – a 58% difference), as shown in Fig. 1.

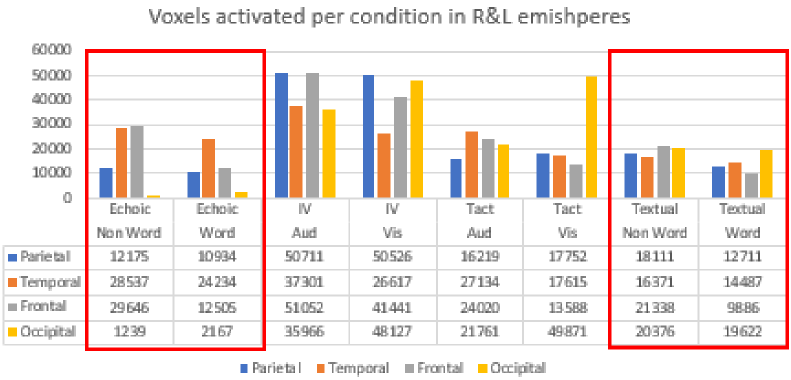
This difference is likely related to the use of "memory" in the emission of echoic responses. In contrast to any task using a visual stimulus, where a substantial part of the stimulation persists during the time needed to emit the response, a task relying only on a pure auditory stimulation needs to *let* the stimulus persist, which is attainable through "memory" processes. The need for active “memory” processes to support the stimulus persistence increases parallel to the complexity of the vocal/verbal stimulation, reflecting an incremental allocation of neural resources depending on the response effort. The topic of memory has been conceptually discussed in behavior analytic literature and widely studied by the neurosciences. In the absence of sensory input, to maintain the information in what neuroscience calls “working memory”, it is crucial to activate some kind of “stationary process” through the circulation of stimuli back and forth in between specific brain regions and the relevant sensory cortex, involving extensively frontal areas (Eriksson et al., 2015 - Mustovic et al., 2003) in the region neuroscience calls the Dorsolateral Prefrontal Cortex (DLPFC). “Keeping the stimulus active” creates, in other words, the neural “configuration” of verbal private mediation strategies that functionally underpin the self-echoic behavior at the neural level. The prevalence of the frontal activity in the non-word condition suggests a greater neural amplitude of the self-echoic behavior in the case of a stimulus (like a non-word) exerting reduced discriminative functions but evoking “purer” echoic responses (less likely to be multiply controlled). A residual evocative power notwithstanding the absence of a learning history for a “non-words” stimulus, is possible given the particular characteristics of the echoic repertoire and its faster generalization with respect to the other verbal operants (Skinner, 1957).

What neurosciences define “memory”, can be identified as the complex of activities/strategies performed at the neural level and aimed at preserving, across time, the stimulus control over a particular response, coping well with the idea that “memory” is linked to stimulus control as in conceptual frameworks already proposed in the behavioral literature (Palmer, 1991). The main point of this conceptualization consists in the need for *that exact stimulus* to persist in order to be able to exert stimulus control. The “neural solution” to the need of stimulus persistence stays in making dynamically active all the neural components that make that single stimulus unique, and this can be realized within patterns of activity exploiting the possibility to “lock together” the single neurons involved in the pattern through mechanisms of functional connectivity and synaptogenesis. The greater involvement of the frontal cortex in tasks where a non-word is present probably reflects a stronger effort of the private mediation links of a hypothetical behavioral chain leading to the public “output” echoic response. In this behavioral chain intermediate links would need to avoid a progressive decline in stimulus control paralleling the latency for the emission of the public target behavior. The creation of neural activities sustaining self-echoic behaviors would also act as supplementary sources of stimulus control which can compete with the possible evocative effects of other public or private environmental events on competitive responses.

The use of sense and nonsense words as antecedents was designed to reduce in the first place the possibility of emission of private multiply controlled responses (echoic-tacts or echoic-intraverbals). Accordingly, the activation in the occipital cortex shows a substantial prevalence in the ‘word’ condition (43% difference compared to ‘non-word’), suggesting some kind of involvement of private visual mediation in the echoic response to “word” stimuli. In a minor way a prevalence for the non-word condition is found, although the difference percentage of parietal activation between the two said conditions is minor (the non-word condition shows 10% more of activation), also the parietal activation would appear to suggest that what is being observed is a phenomenon related to the visual manipulation performed by the parietal cortex, as in the visualization of the stimuli in the form of written words or in the expression of some kind of problem solving strategy consisting in trying to “manipulate” the stimulus and generate, once again, a more “powerful” stimulus, as can be one with already established discriminative functions, like a more evocative version of the stimulus itself (i.e., trying to anagram the “non-words” to find a “word”).

- *Textual*

The pattern of activation related to the textual behavior appears to be the least differentiated, with a similar amount of neural resources employed in the temporal, frontal and parietal cortexes, and, as it happens for the tact, a more pronounced activation of the occipital lobes with respect to the other lobes (Fig. 6, bottom right panel). The occipital activation shows no significant difference between the words and non-words, possibly because the visual stimulus remains present across the whole duration of the task for both of them, and consequently it does not need to be “recreated” at the private level in order to maintain or even enhance its evocative power. Since textual and echoic share the presence of a “word” and a “non-word” condition in the experiment, their activity pattern can be compared it the two conditions:



	Echoic Non Word	Echoic Word	IV Aud	IV Vis	Tact Aud	Tact Vis	Textual Non Word	Textual Word
Parietal	12175	10934	50711	50526	16219	17752	18111	12711
Temporal	28537	24234	37301	26617	27134	17615	16371	14487
Frontal	29646	12505	51052	41441	24020	13588	21338	9886
Occipital	1239	2167	35966	48127	21761	49871	20376	19622

Fig. 2
This picture shows the total number of voxels activated per condition ("word" conditions vs "non-word" condition) in parietal, temporal, frontal and occipital lobes in both brain hemispheres.

revealing a similar prevalence of the non-word condition in temporal, frontal and parietal regions, where similar "memory" and other possible stimulus manipulation strategies can be active. The reduced amount in the textual of the auditory stimulation (only the response product has an auditory nature), can explain a reduced extension of the temporal activity compared to the echoic, with a prevalence for the "non-words" condition. The differential activation in the word and non-word conditions can find different conceptualizations in the frontal compared to the parietal lobe. Given the presence of "memory related activities" in the frontal lobe, the prevalent activity in the "non-word" condition suggests neural "memory" strategies aimed at avoiding the decay of stimulus control. The differential activation in the parietal lobe suggests, instead, a visual manipulation of the information provided by the stimuli, which has been showed by the neuroscientific literature to have its core in the parietal lobes and in particular in the intraparietal sulci. In the textual operant this phenomenon is accentuated compared to the echoic operant because of the visual nature of the stimuli.

The following figure shows the activation produced by the environmental stimuli evoking the textual operant, in both word and non-word conditions:

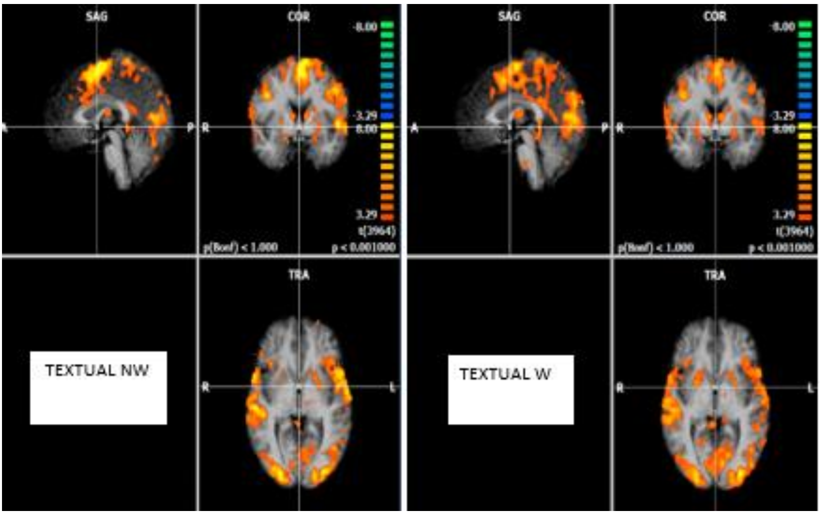
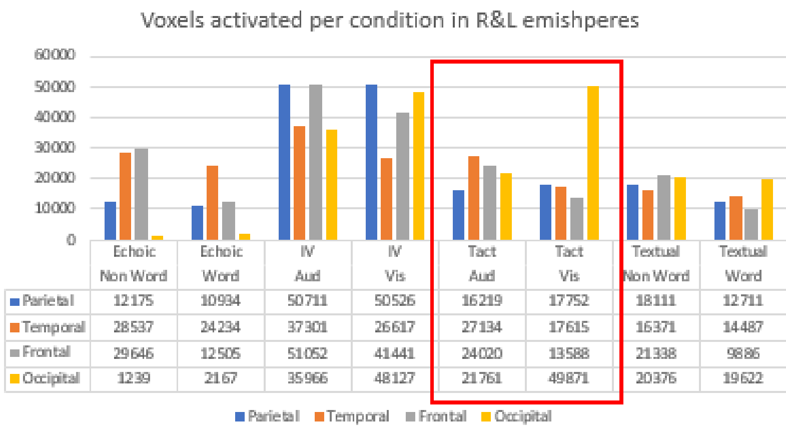


Fig. 3

- *Tact*

The “fingerprint” of the tact operant is marked by a more pronounced activity in the occipital lobe, where neurosciences locate the core of vision-related processing. The occipital activation is present in both the conditions comprised in the experiment (auditory tact and visual tact), even if more prominent in the visual one. The occipital activity in the visual tact can be explained by the perceptual public tact contingency, but the presence of occipital activation also in the auditory condition (Fig. 4) suggests that the emitted public response is



	Echoic Non Word	Echoic Word	IV Aud	IV Vis	Tact Aud	Tact Vis	Textual Non Word	Textual Word
Parietal	12175	10934	50711	50526	16219	17752	18111	12711
Temporal	28537	24234	37301	26617	27134	17615	16371	14487
Frontal	29646	12505	51052	41441	24020	13588	21338	9886
Occipital	1239	2167	35966	48127	21761	49871	20376	19622

Fig. 4

mediated by visual private stimuli also in the absence of public visual stimulation. Conversely, the temporal lobe activity is more pronounced in the auditory condition of the experiment, probably due to the combined nature of the antecedent non-verbal stimulus and the auditory instruction “What is it?”, whereas in the visual condition the less pronounced neural activity in the temporal cortex is probably due to the presence of the auditory instruction alone.

The “fingerprint” of the tact also includes parietal activation. Interestingly, in addition to linking to the parietal cortex the neural processing related to the construction of visual images (Formisano et al, 2002), neurosciences locate in the parietal lobe a specific convergence of the pathways of visual perception and imagination (Trojano, 2000; Sack et al, 2002). The parietal cortex is also involved in execution of tasks in which participants are asked to name the category of seen objects, and thus considered involved in “semantic processing” (Devereux, 2013). B.F. Skinner addresses “semantic theory” in Verbal behavior (“The problem of reference”) in the particular case of the tact. He notes that a linear relation is often supposed to exist between an uttered response and, let’s say, a particular object, but that, in reality, “there is always an element of abstraction” (Verbal Behavior, p. 117). The “semantic process” or, as Skinner writes, the “idea” of something is then possibly operationally defined by a private mediation operated by the parietal cortex checking if a stimulus belongs to a particular class of stimuli. As much as this phenomenon can share its dynamics with stimulus generalization processes, the presence of parietal activity in the tact "neural fingerprint" is intriguing, because it suggests that, in the presence of non-verbal stimulation and even of a particular history of reinforcement, the public tact possibly requires some contribution by a private imaginative mediation, and potentially reflects that perception and imagination are linked to each other. In this scenario, perception and imagination work together in a way that involves possible private category tact responses performed at the level of the parietal cortex in the very moment in which a simple tact is emitted. The parietal activation found in the tact is common to the two conditions it comprised in the experiment (Fig. 5), suggesting a shared phenomenon independent of the antecedent stimulus nature.

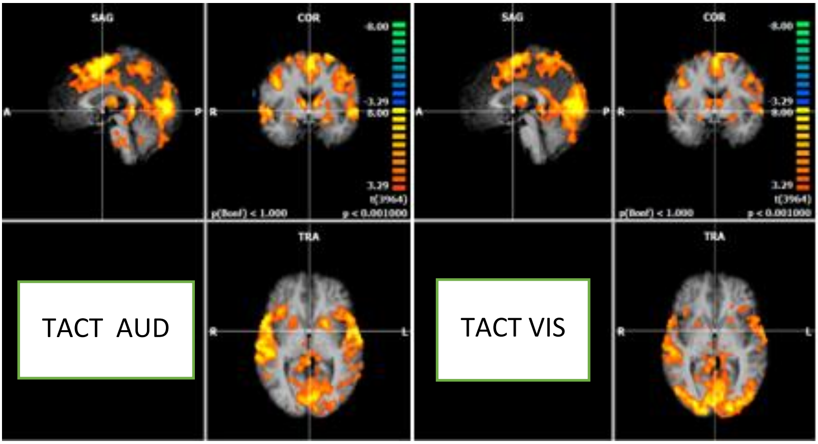


Fig. 5 Parietal activation in the intraparietal sulci in the two conditions of the tact operant.

- *Intraverbal*

The neural activity related to the intraverbal operant is definitely marked by the richest pattern of distribution, which parallels the complex nature of this operant. Sautter & LeBlanc (2006) noted that “this operant includes perhaps the most diverse group of responding and accounts for reading comprehension, conversation, and question answering and events that are traditionally conceptualized as thought or memory” (Sautter & LeBlanc, p. 41) and encouraged to conduct more research on the intraverbal. The attention dedicated to the intraverbal by the behavior-analytic community has in fact increased lately

(Aguirre, 2016), and it has also involved further investigation on its definition (Palmer, 2016).

The intraverbal word association task executed in our experiment comprised auditory or written (visual) stimuli, allowing a comparison between the spatial distribution of neural resources across these two different stimulus conditions. Both the conditions comprised though an auditory instruction to associate that can be responsible for the temporal lobe activation in both of them, together with the auditory product of the response. The wider activation of temporal cortex in the auditory condition suggests the involvement of private self-echoic behavior in the absence of a steady representation of the antecedent stimulus. This is in keeping with Skinner analysis of the "word association" activity.

In Verbal Behavior (1957) Skinner talks about the "word association" experiment, conceptualizing that echoic control is probably involved in the production of even a single word association and acknowledging the possibility of the emission of an echoic behavior beginning from the very first moment, unless the participant is instructed not to do so:

In the standard "word association" experiment, a stimulus word is presented and the subject is asked to report the first word he finds himself saying in response to it. It is necessary to instruct the subject not to repeat the stimulus word; even so, a fragmentary echoic behavior appears in what are called "clang associations" – responses which are alliterative or rhyming or otherwise similar to the stimulus word" (Skinner, 1957, p. 56).

In a broader perspective aimed at comparing both tact and intraverbal tasks which contain visual and auditory stimulation in the experiment, data show that the activity in the temporal and frontal cortices is consistently stronger in the auditory condition, probably aimed at increasing the persistence of the antecedent stimuli. Temporal and frontal cortices are so possibly active in reproducing over time the stimulation, preserving from decay the stimulus control over the response.

The prominent activation in the intraverbal pattern is though parietal. Said activation is prominent in brain regions active in imagination, suggesting a massive involvement of imagination in the intraverbal. The parietal activity is similar in the visual and auditory conditions, suggesting a possible stable involvement of imagination in the intraverbal behavior regardless of the nature of the antecedent verbal stimulus. The results also suggest that the possible imagination activity mediating the emission of the intraverbal public response is accompanied by occipital activation, which is typically related to visual perceptual activity. The visual condition presents a greater occipital activation, possibly because of the nature of the antecedent stimulus, but occipital activity is still present in the auditory condition, suggesting a common involvement of visual perceptual activity in the intraverbal, the distribution of neural resources in the occipital lobes being consistent with the one found in the tact.

To summarize, we can list the findings provided by the experiment.

Every single Verbal Operant is associated to a peculiar pattern of brain activity, which could give us the opportunity to recognize what kind of verbal operant a particular individual would be emitting in a specific moment in time by just observing his brain activity pattern.

The importance of the differences among the patterns observed notwithstanding, their similarities are also significant because they can bring about new language teaching strategies for establishing or strengthening verbal complex repertoires or the prerequisites skills than can lead to them. Indeed, the so-called “stimulus control transfer procedures” (for example tact to intraverbal, echoic to tact, etc.) are already implemented in applied behavior analysis and basically consist in teaching a "weak" operant from a "stronger one". If, as shown by the behavior analytical literature, these procedures work, it can be of interest to further investigate possible commonalities among the private emission of verbal behavior.

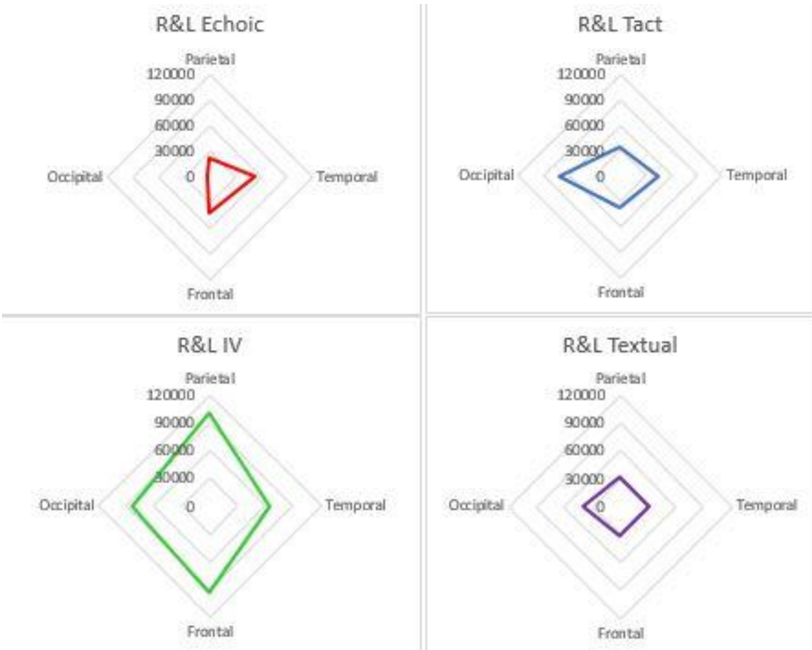


Fig. 6

Synopsis of the neural fingerprints related to verbal operants. While polar graphs are not generally used in Applied Behavior Analysis, they do permit to catch the lobar distribution of activity patterns at-a-glance.

- **Chapter 3**

Complex verbal behavior and the role of the Intraparietal sulcus (IPS)

The following figure shows the commonalities between the patterns of activity related to the tact and intraverbal operants:

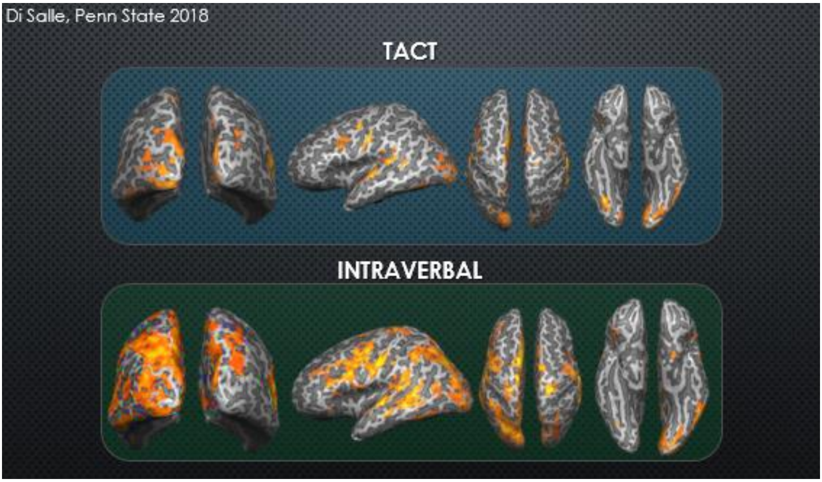


Fig. 7 Brain activation during tact and intraverbal task

These commonalities are better represented in a very common kind of analysis of neuroscientific data called "conjunction analysis". The following figure shows the brain areas in which the activity patterns of tact and intraverbal overlap:

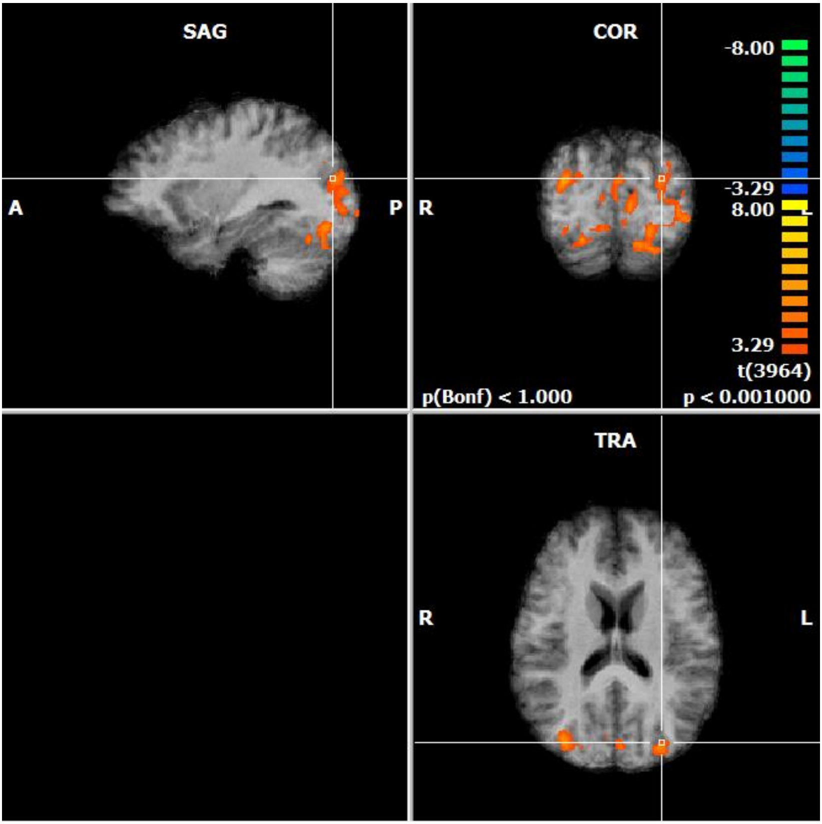


Fig. 8 Overlapping in the activity patterns of tact and intraverbal in the IPS

The overlapping area is the IPS, a brain area that has been shown to be active during imagination tasks.

When he discussed the analysis of the inner world like perception, Skinner *ruled out all the mentalistic explanations to the "imaging or imagining" intended as retrieving or storing* *information in some place in our brain, and argued that, instead, it simply means reproducing what we did when a particular stimulus was present* (Pappalardo et al., 2019). In other words, for Skinner, the imagination is the skill to engage in visual or auditory behavior in the absence of the current stimuli, in practice "seeing does not require a thing seen". (Skinner 1974, p. 95).

In the same chapter of *About Behaviorism,* Skinner considers perception conceptually near to daydreaming or remembering as in "bringing again to mind". (Skinner 1974, p. 91)

Clinical implications

Visual imagination has been linked to the Intraparietal Sulcus (IPS), where neuroscientific literature has located the activation deriving from visual imaginative tasks.

In our experiment, the IPS represented the point of intersection between tact and intraverbal patterns of activity. This implies that visual imagination is critical for the production of both tact and intraverbal operants and that, if intraverbal production is defective, we could probably improve it through a tact training exploiting the common neural ground between the two operants.

Tact training is common in ABA to mainly strengthen the tact repertoire. In fact, a strong tact repertoire is a prerequisite for learning the most of the intraverbal repertoire. This way, the tact is used as a "prompt"[3] in stimulus control transfer procedure.

In the study that will be presented in the next chapter, a *tact training* will be implemented instead.

Considering that the IPS has been shown to be the "point of contact" between tact and intraverbal operants, we tried to "train directly the IPS" by the use of an intensive tacting, which in this case is not used as a prompt, but as a specific teaching strategy for developing performance in a possible weak link of a more complex private and public behavioral chain. The aim was increasing the capability of responding ("excitability" in the terms of neuroscience) of the IPS, thus determining a momentary improvement in the intraverbal performance.

Developing procedures to improve performances in the weak repertoire through the training of the strong one, could make a difference in the clinical work and facilitate learning (Pappalardo et al., 2019)". That's just what Skinner announced when he pointed out that the physiological and in our case neural

---

[3] In ABA a prompt is a supplementary antecedent stimulus which is used to occasion a correct response together with the stimulus that should naturally evoke the behavior (Cooper, Heron and Heward, 2020).

account for the inner world can complete and integrate behavior analysis. These neuroscientific opportunities might allow to us to know more precisely what happens at the level of private events in order to make changes in the nervous behavioral chains.

As Pappalardo et al. (2019) pointed out, “once the chained responses underpinning behavior become known, then a focal neuromodulation of their nodes may be of great advantage to the conventional behavioral training of weak repertoires” (p. 28).

- **Chapter 4**

Clinical implications: *Intensive Tact training* and *neurofeedback* as strategies to train IPS

In the present chapter an experiment aimed at strengthening the intraverbal repertoire will be presented.

In the last decades, behavior analysis produced several research studies on the intraverbal behavior. The experiment exploited the results of the study of the verbal operants in the brain environment, and in part confirms that tact to intraverbal stimulus control transfer procedures are conceptually suitable.

From 2005 to 2015 the role and the importance of the intraverbal operant in typically developing people, as well as in people with language impairment and cognitive disability, were widely studied (Aguirre et al., 2016).

Aguirre et al. (2016), conducted a literature review in which they grouped the existing studies on intraverbal depending on their specific procedures. Many studies involved direct training of intraverbal responses.

Most of them focused on the types of prompts (e.g. Echoic, tact, textual) used to directly teach a vocal response to a vocal stimulus (Ingvarsson & Le, 2011; Kisamore, Karsten, Mann, & Conde, 2013).

Ingvarsson and Le (2011) demonstrated that echoic prompts took fewer trials to meet mastery criterion of target responses during initial training.

Some studies have also shown that tact prompts can be effective in teaching intraverbals. For example, Goldsmith, LeBlanc, and Sautter (2007) taught children with autism to list items in common categories.

In a similar study, Ingvarsson and Hollobaugh (2011) demonstrated that tact and echoic prompts were both effective in teaching intraverbals to children with autism but fewer trials to criterion were required with tact prompts.

There is also some evidence suggesting that textual prompts can be an effective transfer-of stimulus-control procedure to teach intraverbals especially when participants have an existing textual repertoire.

Vedora and Conant (2015) found tact, textual, and echoic prompts to be equally effective in teaching intraverbals to young adults with autism.

There are also a series of studies reporting the “emergence” of the intraverbal, that is when it has not been directly taught yet.

Many studies focused on the emergence of the intraverbal as a result of training other kinds of responses (Grannan & Rehfeldt, 2012; Petursdottir, Carr, Lechago & Almason, 2008a).

There were also studies focusing on the development of more complex intraverbals, as in problem solving.

Skinner characterized problem solving as any behavior that makes a problem's solution more probable (Skinner, 1953). When problem solving, individuals emit behavior that generates supplementary stimuli (e.g., self-prompts).

Self-prompting strategies might take the form of an intraverbal prompt or covert visualizing, among others.

For example, Sautter et al. (2011) evaluated the effects of teaching verbal self-prompts on intraverbal categorizations in four typically developing preschool children. None of the four participants showed significative increases in the number of items listed in an intraverbal categorization task (e.g., tell me some clothes) until they were prompted to use a verbal self-prompt strategy.

Participants engaged in overt self-prompts which gradually decreased as accurate performance increased within one category and as additional categories were targeted (Aguirre 2016, p.148).

In a follow up study, Kisamore, Carr, and LeBlanc (2011) showed that the use of a prompted visual imagining strategy could increase intraverbal categorizations.

The teaching procedure used in our experiment is based on what we've called "Crossword strategy".

The consideration underpinning this strategy is that different behaviors are differentiated in the brain by their pattern of activity. In fact, we know that neural patterns of different behaviors can overlap in certain brain areas, so training the common nodes in one behavior can result in the improvement of other behaviors.

We examined the effect of the tact training as an independent variable, on the dependent variable represented by the number of intraverbal responses produced. With respect to the other strategies commonly used in behavior analysis, we didn't use the same stimuli (words) in the *tact training* phase and in the intraverbal-related phases of the experiment (pretest and posttest).

The following is a sample of the stimuli used in the tact training, i.e. common object to be named by the participants:

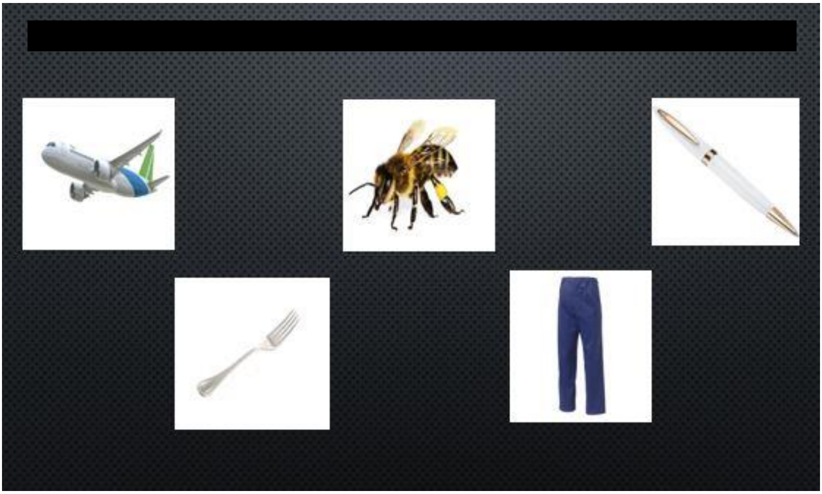


Fig. 9 Sample of images utilized in the *tact training*

<u>Methods</u>

19 volunteers divided in 4 groups were involved in the experiment. They all were typically developing adults and they were required to:

- make free word association in 80 seconds per trial for a total of 10, 15, 20 or 30 trials (PRETEST);
- label 200 images. The picture stimuli lasted 3 seconds each and there was an interval of 2 seconds in between 2 successive tact trials for a total of 5 seconds per trial (TRAINING - independent variable);

- to repeat the task performed in the pretest, but after the tact training and with different stimuli (POSTTEST).

In general, the stimuli involved in the experiment were balanced with respect to their frequency in spoken and written language and to imageability (their power to evoke imaginative behavior). The participants were instructed to listen to the auditory stimuli provided and, before starting to produce the word associations, to generate a private image which could guide the response production.

The dependent variable measured was the total count (number) of intraverbal associations provided by the participants.

The experimental design utilized for this experiment was a nonconcurrent multiple baseline design across subjects.

The multiple baseline design is one of the most widely used experimental design for evaluating treatment effects in applied behavior analysis, above all when it is not possible to annul the independent variable effect.

It is a highly flexible tactic that enables researchers to analyze the effects of an independent variable across multiple behaviors, settings, and/or subjects without having to withdraw the treatment variable to verify that the improvements in behavior are a direct result of the application of the treatment. In multiple baseline designs the independent variable is applied in sequential fashion and experimental control is demonstrated if each behavior shows similar changes when, and only when, the treatment variable is introduced (Cooper, Heron and Heward, 2020).

As a general result, we noticed a consistent increase of the dependent variable (number of word associations) across the four groups of subjects after the introduction of the independent variable.

More precisely, only 2 participants reported a slight decrease in the number of word associations produced (-4% and -5%) after the intervention (tact training).

The average increase of the percentage of words uttered by the other 17 subjects in the posttest was 22% with respect to the pretest.

Considering the total of 19 participants, the average of increase from pretest to posttest was 19%.

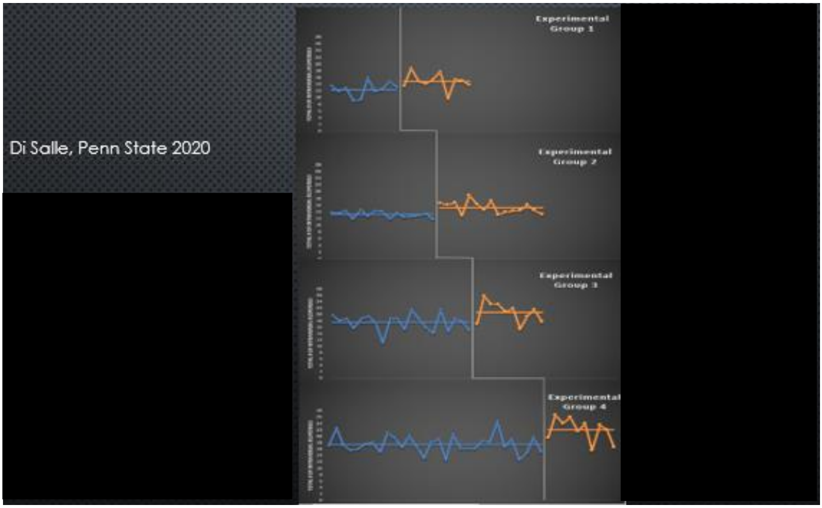


Fig. 11 Number of word associations produced in pretest and posttest by 4 group of participants.

We also developed an fMRI replication of the experiment.

The two figures below (Fig. 12, Fig. 13) show the effect of the tact training on the IPS activation in the two participants involved in this version of the experiment.

The data show an increased activity in the IPS, but there was no increase in the public emission of the behavior (number of word associations produced) probably because of the particular experimental setting (namely postural discomfort, loud noises, total duration of the task, etc).

Different sets of stimuli, as well as follow up probes should be evaluated to assess if longer tact training phases can produce a stronger effect or how much time the effect lasts. Also, other dependent variables could be measured, for example rate of responding or IRT (interresponse time).

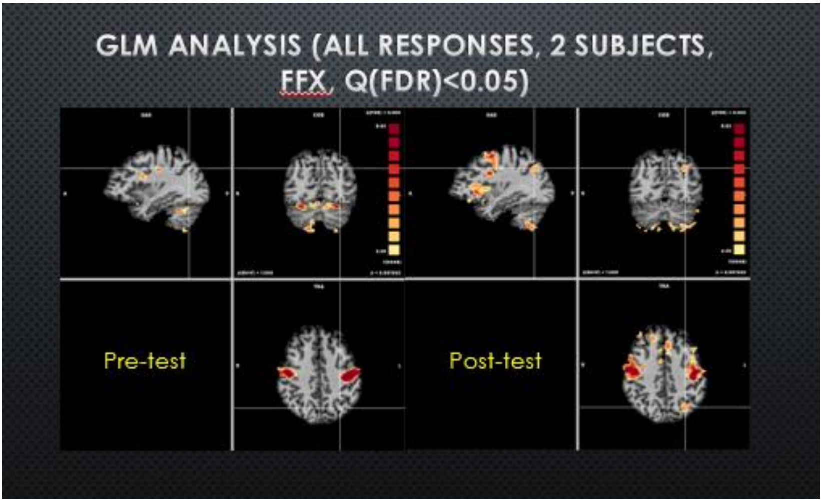


Fig. 12 IPS activation in pretest and posttest in a group of 2 volunteers

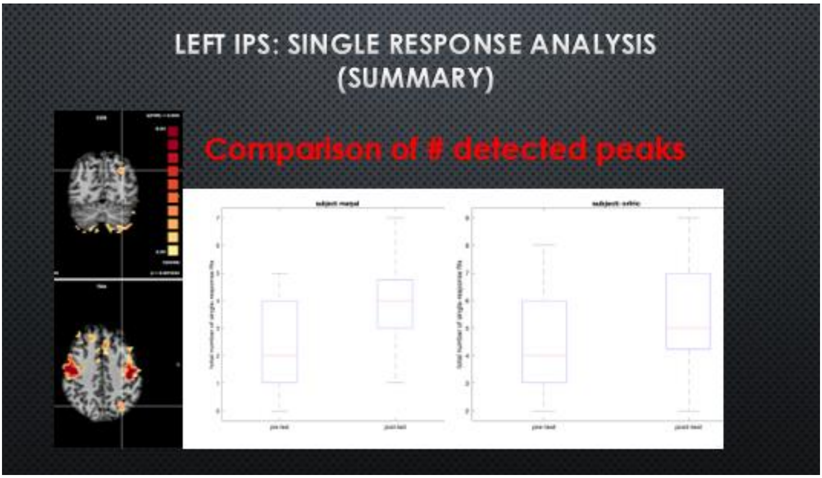


Fig. 13 A sample comparison of detected peaks of activation in pretest and posttest

Neurofeedback

Starting from the 1960s, some researchers discovered the possibility to train different brainwave patterns.

The first works focused on the training to increase alpha brainwave activity to facilitate relaxation, while other works originating at UCLA were used in epilepsy treatment.

This training was called EEG biofeedback or neurofeedback.

Its mechanism of action is based on operant conditioning and is aimed at training the brain.

In years, these techniques have improved and the effect of the training has proved to be more enduring.

Neurofeedback starts as a specific form of biofeedback[4]*, which feeds back information about brain activity to allow for training of voluntary regulation of brain activity* (Weiskopf et al., 2004b).

As Weiskopf delineated in his review about neurofeedback (2011), its first use was primarily based on using electroencephalography (EEG), but this first application showed

[4] Biofeedback is a treatment that allows to learn individuals controlling not voluntary physical functioning like muscular tension, heart frequency and so on.

some limits, as the low reliability localization of active brain areas and the very limited access to deep subcortical regions. These issues notwithstanding, the EEG feedback was successfully used clinically, for different neurological impairment, thus opening a new way of non-invasive interventions for clinical disorders.

Gradually the use of neurofeedback was broadened to investigations about chronic pain (DeCharms et al., 2005), tinnitus (Haller et al., 2010), depression (Habes et al., 2010), schizophrenia (Ruiz et al., 2013), psychopathy and stroke (Sitaram et al., 2012).

DeCharms et al. (2005) studied the effect of real time fMRI neurofeedback in patients with chronic neuropathic pain.

Studies results about fMRI neurofeedback use suggest efficacy and longer lasting effects, like the ones found in auditory cortex regulation (Haller et al., 2010; Yoo et al., 2007).

Moreover, a great number of studies indicate an important transfer of the self-regulation skill from the feedback to its absence. The ability to control brain activity while competing in the so-called Brain Pong game (Goebel et al., 2004) - where the position of the racket is determined by the local BOLD activity-is a further evidence of the generalization of the self-regulation skill (fig.14).

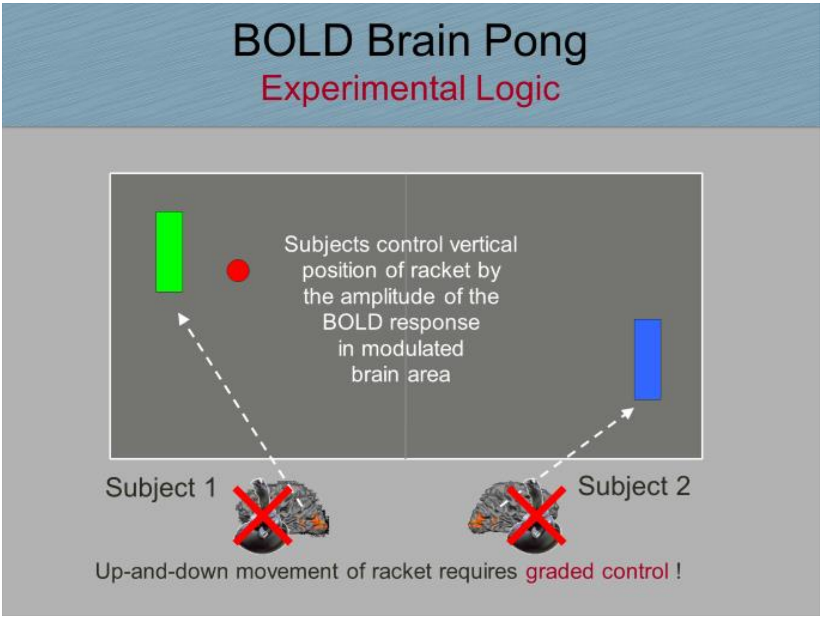


Fig. 14 (Goebel, 2004)

The use of fMRI neurofeedback ensures a better and a more reliable spatial resolution of brain regions activations.

Since subjects can learn to regulate their own brain activity of circumscribed brain regions, it might be an important tool for clinical applications.

Significant evidence of the efficacy of real time fMRI neurofeedback has been produced in the recent years. For example, an important study of Linden (2014) showed that a 12 weeks training reduced depressive symptoms by over 40% (Hamilton Depression Rating Scale HDRS), with improvements lasting until follow-up (week 18).

Moreover, data indicate that the experience itself of successful self-regulation during fMRI-NF carries an important therapeutic component.

The use of neuromodulation technique could represent a further development of the line of research presented in this thesis by directly training possible weak links of hybrid private and public behavioral chains. It would then be an alternative teaching modality to increase complex verbal repertoire in light of the findings related to the study of the neural pattern associated with the verbal operants.

- Conclusions

The present work started from a series of conceptual considerations encompassing different fields of knowledge, and in particular behaviorism, linguistics and neuroscience. In this conceptual framework the specific “functional” use of language, typical of behaviorism and intended as a functional extension of classical linguistics, is analyzed through neuroimaging techniques.

Several and incremental objectives underpinned this work, all of them strongly intertwined and dependent from each other.

Behavior analysis and neuroscience have produced a great amount of research, exploring language as a common field of study, but their efforts were produced without a real dialogue between the two disciplines. The first objective of this study was then to find a bridge connecting conceptually neurosciences and behavioral sciences, two disciplines which had been scarcely in contact before, but that could both benefit from this perspective of convergence.

The second objective was to extend the analysis of behavior to processes and functions which are not observable and measurable from the outside. The availability of new technologies allows us to observe a complex field of "covert responses", underpinned by neural activities, that had never been accessible in such detail before. This scenario, where neural and behavioral responses are intimately connected to each other and are both accessible through neuroimaging techniques, has indeed significantly changed in the last decades, enabling us to observe the neural bases of behavior, or the "neural behavior" as we commonly refer to it, fulfilling the expectations of the fathers of behaviorism.

The third objective was to find new strategies and techniques to improve language skills, specifically for people with developmental disorders, like autism. Behavior-analytic research literature has shown countless teaching strategies to be effective, but the potential of using knowledge about behavior observed at the neural level is certainly relevant to further develop intervention strategies.

The fourth and final objective was to conceptually open to an extension of these new modalities of teaching, and therefore of learning, to nonverbal repertoires. Notwithstanding the fundamental role of language in the social life, even nonverbal abilities can take advantage of the development of new strategies of teaching devised at the neural behavior level. Moreover, the populations benefitting of such extended study of behavior could be also broadened, including for example people with behavioral problems not related to language, or patients with depression and anxiety.

In conclusion, the future improvement of the behavior-analytic teaching technology and strategies could benefit from a neuroscientific perspective, like the one pointed out in my study. Further research could replicate the results of the experiments presented in this work with a greater amount of volunteers, and with a different kind of training including naming of complex scenarios, and possibly using other kinds of verbal training in a "reversal condition" to further prove that the training of naming alone is responsible for the effects observed on the intraverbal responses and to rule out any possible effect derived by multiple control.

The possibility of integrating an analysis of private responses into the study of public behavior, into the complex field of neural behavior, can represent a huge advantage for both behaviorism and neural sciences with the perspective of bringing great improvement in the life of individuals with learning disabilities or behavioral disorders.

- References

Aguirre, A. A., Valentino, A. L., & LeBlanc, L. A. (2016). Empirical investigations of the intraverbal: 2005–2015. The Analysis of Verbal Behavior, 32(2), 139-153.

Ambridge, B., & Lieven, E. V. (2011). Child language acquisition: Contrasting theoretical approaches. Cambridge University Press.

Ayllon, T., & Michael, J. (1959). The psychiatric nurse as a behavioral engineer 1. Journal of the Experimental Analysis of Behavior, 2(4), 323-334.

Baer, D. M. (1960). Escape and avoidance response of preschool children to two schedules of reinforcement withdrawal. Journal of the Experimental Analysis of Behavior, 3(2), 155-159.

Baer, D. M. (1962). Laboratory control of thumbsucking by withdrawal and re-presentation of reinforcement.

Journal of the Experimental Analysis of Behavior, 5(4), 525-528.

Barman, B. (2012). The linguistic philosophy of Noam Chomsky. *Philosophy and Progress*, 103-122.

Barry Anita, K. (2002). English grammar: language as human behaviour.

Bijou, S. W. (1955). A systematic approach to an experimental analysis of young children. Child Development, 161-168.

Bijou, S., & Baer, D. M. (1965). Child development: II. Universal stage of infancy

Bijou, S. W. (1957). Methodology for an experimental analysis of child behavior. Psychological Reports, 3(3), 243-250.

Bijou, S. W. (1957). Patterns of reinforcement and resistance to extinction in young children. Child Development, 47-54.

Bijou, S. W. (1958). A child study laboratory on wheels. Child Development, 425-427.

Bijou, S. W. (1958). Operant extinction after fixed-interval reinforcement with young children. Journal of the Experimental Analysis of Behavior, 1(1), 25.

Bloom, L. M. (1968). Language development: Form and function in emerging grammars.

Chomsky, N. (2014). *Aspects of the Theory of Syntax* (Vol. 11). MIT press.

Cooper, J. O., Heron, T. E., & Heward, W. L. (2007). Applied behavior analysis.

Cooper, J. O., Heron, T. E., & Heward, W. L. (2020). Applied behavior analysis. Hoboken.

DeCharms, R. C., Maeda, F., Glover, G. H., Ludlow, D., Pauly, J. M., Soneji, D., ... & Mackey, S. C. (2005). Control over brain activation and pain learned by using real-time functional MRI. Proceedings of the National Academy of Sciences, 102(51), 18626-18631.

DeMyer, M. K., & Ferster, C. B. (1962). Teaching new social behavior to schizophrenic children. Journal of the American Academy of Child Psychiatry, 1(3), 443-461.

Devereux, B. J., Clarke, A., Marouchos, A., & Tyler, L. K. (2013). Representational similarity analysis reveals commonalities and differences in the semantic processing of words and objects. Journal of Neuroscience, 33(48), 18906-18916.

Donahoe, J. W., Palmer, D. C., & Burgos, J. E. (1997). The S-R issue: Its status in behavior analysis and in Donahoe and Palmer's Learning and Complex Behavior. Journal of the Experimental Analysis of Behavior, 67(2), 193-211.

Eriksson, J., Vogel, E. K., Lansner, A., Bergström, F., & Nyberg, L. (2015). Neurocognitive architecture of working memory. Neuron, 88(1), 33-46.

Faux, S. F. (2002). Cognitive neuroscience from a behavioral perspective: A critique of chasing ghosts with Geiger counters. *The Behavior Analyst*, *25*(2), 161-173.

Ferster, C. B., & De Myer, M. K. (1961). The development of performance in an automatically controlled environment.]. chron. Dis.

Ferster, C. B., & DeMyer, M. K. (1962). A method for the experimental analysis of the behavior of autistic children. American Journal of Orthopsychiatry, 32(1), 89.

Formisano, E., Linden, D. E., Di Salle, F., Trojano, L., Esposito, F., Sack, A. T., ... & Goebel, R. (2002). Tracking the mind's image in the brain I: time-resolved fMRI during visuospatial mental imagery. Neuron, 35(1), 185-194.

Glenn, S. S., Ellis, J., & Greenspoon, J. (1992). On the revolutionary nature of the operant as a unit of behavioral selection. American Psychologist, 47(11), 1329.

Goebel, R., Sorger, B., Kaiser, J., Birbaumer, N., Weiskopf, N., 2004. BOLD brain pong: self-regulation of local brain activity during synchronously scanned, interacting subjects. Abstract viewer/itinerary planner. Society for Neuroscience, Washington, DC (online)

Goldsmith, T. R., LeBlanc, L. A., & Sautter, R. A. (2007). Teaching intraverbal behavior to children with autism. Research in Autism Spectrum Disorders, 1(1), 1-13.

Grannan, L., & Rehfeldt, R. A. (2012). Emergent intraverbal responses via tact and match-to-sample instruction. Journal of Applied Behavior Analysis, 45(3), 601-605.

Habes, I., Johnston, S.J., Tatineni, R., Boehm, S.G., Linden, S.C., Sorger, B., Healy, D., Goebel, R., Linden, D.E.J., 2010. Functional magnetic resonance (fMRI)-based neurofeedback as a potential treatment method for depression. FENS Abstr. 5 (017), 15.

Haller, S., Birbaumer, N., & Veit, R. (2010). Real-time fMRI feedback training may improve chronic tinnitus. European radiology, 20(3), 696-703.

Ingvarsson, E. T., & Hollobaugh, T. (2011). A comparison of prompting tactics to establish intraverbals in children with autism. Journal of applied behavior analysis, 44(3), 659-664.

Ingvarsson, E. T., & Le, D. D. (2011). Further evaluation of prompting tactics for establishing intraverbal responding in children with autism. The Analysis of Verbal Behavior, 27(1), 75-93.

Kimball, J. W. (2002). Behavior-analytic instruction for children with autism: Philosophy matters. Focus on Autism and Other Developmental Disabilities, 17(2), 66-75.

Kisamore, A. N., Carr, J. E., & LeBlanc, L. A. (2011). Training preschool children to use visual imagining as a problem-solving strategy for complex categorization tasks. Journal of Applied Behavior Analysis, 44(2), 255-278.

Kisamore, A. N., Karsten, A. M., Mann, C. C., & Conde, K. A. (2013). Effects of a differential observing response on intraverbal performance of preschool children: a preliminary investigation. The Analysis of Verbal Behavior, 29(1), 101-108.

Linden, D. E., Habes, I., Johnston, S. J., Linden, S., Tatineni, R., Subramanian, L., ... & Goebel, R. (2012). Real-time self-regulation of emotion networks in patients with depression. PloS one, 7(6), e38115.

Linden, D. E. (2014). Neurofeedback and networks of depression. Dialogues in clinical neuroscience, 16(1), 103.

Lindsley, O. R. (1956). Operant conditioning methods applied to research in chronic schizophrenia. Psychiatric research reports.

Lindsley, O. R. (1964). Characteristics of the behavior of chronic psychotics as revealed by free-operant conditioning methods. In Conditioning Techniques in Clinical Practice and Research (pp. 231-254). Springer, Berlin, Heidelberg.

Lovaas, O. I. (1977). The autistic child: Language development through behavior modification. Irvington.

MacCorquodale, K., & Meehl, P. E. (1948). On a distinction between hypothetical constructs and intervening variables. Psychological review, 55(2), 95.

Michael, J. (1982). Distinguishing between discriminative and motivational functions of stimuli. Journal of the experimental analysis of behavior, 37(1), 149-155

Moore, J. (1995). Radical behaviorism and the subjective-objective distinction. *The Behavior Analyst*, *18*(1), 33-49.

Moore, J. (2002). Some thoughts on the relation between behavior analysis and behavioral neuroscience. The Psychological Record, 52(3), 261-279.

Mustovic, H., Scheffler, K., Di Salle, F., Esposito, F., Neuhoff, J. G., Hennig, J., & Seifritz, E. (2003). Temporal integration of sequential auditory events: silent period in sound pattern activates human planum temporale. Neuroimage, 20(1), 429-434.

Novak, G. (1996). Developmental psychology: Dynamical systems and behavior analysis (No. Sirsi) i9781878978257).

Ortu, D., & Vaidya, M. (2017). The challenges of integrating behavioral and neural data: bridging and breaking boundaries across levels of analysis. *The Behavior Analyst*, *40*(1), 209-224.

Owens, R. E. (2016). Language Development: An Introduction 9e.

Palmer, D. C. (1991). A behavioral interpretation of memory. Dialogues on verbal behavior, 261-279.

Palmer, D. C. (1998). On Skinner's rejection of SR psychology. The Behavior Analyst, 21(1), 93.

Palmer, D. C. (1998). The speaker as listener: The interpretation of structural regularities in verbal behavior. *The Analysis of Verbal Behavior*, *15*(1), 3-16.

Palmer, D. C. (2016). On intraverbal control and the definition of the intraverbal. The Analysis of Verbal Behavior, 32(2), 96-106.

Pappalardo, E., Ianniello, M., Di Salle F., Carbone V.J. Looking inside the Black Box: Fulfilling B.F. Skinner's expectations about Neuroscience. Operants, Issue IV, 2019, pag 23-29.

Petursdottir, A. I., Carr, J. E., Lechago, S. A., & Almason, S. M. (2008). An evaluation of intraverbal training and listener training for teaching categorization skills. *Journal of Applied Behavior Analysis*, *41*(1), 53-68.

Piaget, J., & Cook, M. T. (1952). The origins of intelligence in children.

Ruiz, S., Lee, S., Soekadar, S. R., Caria, A., Veit, R., Kircher, T., ... & Sitaram, R. (2013). Acquired self-control of insula cortex modulates emotion recognition and brain network connectivity in schizophrenia. *Human brain mapping*, *34*(1), 200-212.

Sack, A. T., Sperling, J. M., Prvulovic, D., Formisano, E., Goebel, R., Di Salle, F., ... & Linden, D. E. (2002). Tracking the mind's image in the brain II: transcranial magnetic stimulation reveals parietal asymmetry in visuospatial imagery. *Neuron*, *35*(1), 195-204.

Sautter, R. A., & LeBlanc, L. A. (2006). Empirical applications of Skinner's analysis of verbal behavior with humans. The Analysis of Verbal Behavior, 22(1), 35-48.

Sautter, R. A., LeBlanc, L. A., Jay, A. A., Goldsmith, T. R., & Carr, J. E. (2011). The role of problem solving in complex intraverbal repertoires. *Journal of Applied Behavior Analysis*, *44*(2), 227-244.

Seifritz, E., Di Salle, F., Esposito, F., Bilecen, D., Neuhoff, J. G., & Scheffler, K. (2003). Sustained blood oxygenation and volume response to repetition rate-modulated sound in human auditory cortex. NeuroImage, 20(2), 1365-1370.

Sereno, M. I., Dale, A. M., Reppas, J. B., Kwong, K. K., Belliveau, J. W., Brady, T. J., ... & Tootell, R. B. (1995). Borders of multiple visual areas in humans revealed by functional magnetic resonance imaging. *Science*, *268*(5212), 889-893.

Sitaram, R., Veit, R., Stevens, B., Caria, A., Gerloff, C., Birbaumer, N., & Hummel, F. (2012). Acquired control of ventral premotor cortex activity by feedback training: an exploratory real-time FMRI and TMS study. *Neurorehabilitation and neural repair*, *26*(3), 256-265.

Skinner, B. F. (1938). The behavior of organisms: An experimental analysis. New York: Appleton-Century-Crofts.

Skinner, B. F. (1957). Verbal Behavior. Mansfield Centre: Martino Publishing.

Skinner, B. F. (1974). About Behaviorism. Vintage Books Edition.

Sundberg, M. L., & Partington, J. W. (1998). Teaching language to children with autism and other developmental disabilities. Pleasant Hill, CA: Behavior Analysts.

Trojano, L., Grossi, D., Linden, D. E., Formisano, E., Hacker, H., Zanella, F. E., ... & Di Salle, F. (2000). Matching two imagined clocks: the functional anatomy of spatial analysis in the absence of visual stimulation. Cerebral Cortex, 10(5), 473-481.

Vedora, J., & Conant, E. (2015). A comparison of prompting tactics for teaching intraverbals to young adults with autism. The Analysis of Verbal Behavior, 31(2), 267-276.

Watson, J. B. (1913). Psychology as the behaviorist views it. *Psychological review*, *20*(2), 158.

Weiskopf, N., Mathiak, K., Bock, S. W., Scharnowski, F., Veit, R., Grodd, W., ... & Birbaumer, N. (2004).

Principles of a brain-computer interface (BCI) based on real-time functional magnetic resonance imaging (fMRI). *IEEE transactions on biomedical engineering*, *51*(6), 966-970.

Weiskopf, N., Scharnowski, F., Veit, R., Goebel, R., Birbaumer, N., & Mathiak, K. (2004). Self-regulation of local brain activity using real-time functional magnetic resonance imaging (fMRI). *Journal of Physiology-Paris*, *98*(4-6), 357-373.

Weiskopf, N. (2012). Real-time fMRI and its application to neurofeedback. *Neuroimage*, *62*(2), 682-692.

Yoo, S.-S., Lee, J.-H., O'Leary, H., Lee, V., Choo, S.-E., Jolesz, F.A., 2007. Functional magnnetic resonance imaging-mediated learning of increased activity in auditory areas. Neuroreport 18, 1915–1920

Zuriff, G. E. (1985). *Behaviorism: A conceptual reconstruction*. Columbia University Press.