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Evidence of recursive mechanisms in the structure of intentional action

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Abstract

In their 2002 seminal paper Hauser, Chomsky and Fitch hypothesize that recursion is the only human-specific and language-specific mechanism of the faculty of language. While debate focused primarily on the meaning of recursion in the hypothesis and on the human-specific and syntax-specific character of recursion, the present work focuses on the claim that recursion is language-specific. We argue that there are recursive structures in the domain of motor intentionality by way of extending John R. Searle's analysis of intentional action. We then discuss evidence from cognitive science and neuroscience supporting the claim that motor-intentional recursion is language-independent and suggest some explanatory hypotheses: 1) linguistic recursion is embodied in sensory-motor processing; 2) linguistic and motor-intentional recursions are distinct and mutually independent mechanisms. Finally, we propose some reflections about the epistemic status of HCF as presenting an empirically falsifiable hypothesis , and on the possibility of testing recursion in different cognitive domains.

Keywords: Action grammar; Basal ganglia; Causal self-referentiality; Communicative intention; Infinite generativity; Intentional action; Linguistic recursion; Motor-intentional recursion; Self-embedding.

Introduction

In their seminal work Hauser, Chomsky, and Fitch (2002, HCF hereafter) argued that linguistic, syntactic recursion can be considered as the only constitutive feature of the faculty of language in the narrow sense. In other words, even though the faculty of language "broad sense" (FLB) also includes a phonological system based on the operations of the sensory-motor apparatus, and a conceptual-intentional system conferring meaning to syntactically structured representations, syntactic recursion is the only component of the faculty of language "narrow sense" (FLN).

More specifically, HCF's hypothesis is that FLB – the set of syntactic, conceptual and phonological mechanisms constituting the faculty of language as a whole – includes mechanisms shared by language with other cognitive skills and shared by humans with other species. FLN, on the contrary, is composed only by "the core mechanisms of recursion as they appear in narrow syntax and the mappings to the interfaces", which are "recently evolved", "unique to our species" and "quite specific to FLN" (HCF, 2002, p. 1573). Recursion and the interfaces allowing interaction with the conceptual-intentional system (responsible for semantics and pragmatics, cf. Fitch, Hauser & Chomsky, 2005, p. 182) and with the sensory-motor, phonological system might be the features differentiating human cognition from non-human animals and the faculty of language from the rest of our cognitive skills. Language essentially is, according to HCF, a system of sound-meaning connections endowed with a core syntactic component enabling the construction of an infinite number of discrete expressions starting from a finite number of primitive elements by means of computational recursive mechanism

The authors regard this hypothesis as providing a multidisciplinary conceptual framework, or research program (Brattico, 2010), able to analyze not only language but also, more generally, human creativity. The idea is that a recursive syntactic engine emerged in a cognitive economy that already included a phonological system and a conceptual system. The phonological and conceptual systems causally bond the syntactic system by way of imposing "legibility conditions": syntactic structures, for example, must be able to express a conceptually valid meaning in a phonologically structurable format (Chomsky, 2000). But recursion allows the previously existing conceptual thought to go beyond the narrow scope of the sensory-motor horizon of the here and now through discrete infinity (Fitch, 2010, cf. Brattico, 2010).

HCF's hypothesis has been criticized in different ways: there is evidence of the ability to discriminate recursive strings in non-human animals (Abe & Watanabe, 2011; Corballis, 2007; Gentner, Fenn, Margoliash & Nusbaum, 2006; cf. Bloomfield, Gentner & Margoliash, 2011; van Heijningen, de Visser, Zuidema & ten Cate, 2009) and there are non-syntactic (i.e., phonological, cf. Schreuder, Gilbers & Quené, 2009) recursive structures in language. Relatively little work has been done, on the contrary, to test the claim that recursion is "quite specific to FLN" – that is, that recursion is language-specific.

In this work we will focus on this latter claim. We will argue that there are sensory-motor recursive structures in the domain of intentional action – that is, at the sensory-motor level that mediates our fundamental interactions with the environment. To this aim, we will first sketch the core concepts of HCF and current objections against it in order to clarify the target of the investigation: what is "recursion"? What are its central properties? What does it mean that they are "quite specific to FLN"? We will then introduce John R. Searle's (1983) analysis of the intentionality of action, which characterizes intentions as logically and biologically primitive mental representations with a causally self-referential (and, therefore, self-embedding) logical structure which cannot be reduced to the logical structure of beliefs and desires (Searle, 1983, p. 36). On the grounds of this analysis, we will then argue that the specific features of recursion (self-embedding, long-distance dependence, identity preservation, discrete infinity) might be already present in the structure of the sensory-motor system. We will then review evidence from cognitive science and neuroscience to support the claim that motor-intentional recursion is language-independent. We will distinguish two explanatory hypotheses. According to the first hypothesis, linguistic recursion is embodied in sensory-motor processing: the available evidence allows us to hypothesize that HCF's causal-evolutionary route might be taken the other way round, identifying in sensory-motor processing the roots of linguistic recursion. According to the second hypothesis, linguistic and motor-intentional recursions might be independent mechanisms, realized in distinct neural circuits, that can be (and in some cases are) double dissociated.

Finally, we will propose some reflections about the epistemic status of HCF as presenting an empirically falsifiable hypothesis, and on the possibility of testing recursion in different cognitive domains.

1. Recursion as the core of the faculty of language

Despite the pivotal role of recursion in HCF in explaining the evolution and uniqueness of language, both the original paper and the answer to the objections raised by Pinker and Jackendoff (2005, cf. Fitch, Hauser & Chomsky, 2005) have very little to say about what the authors mean by "recursion" or about the reasons for regarding this mechanism as language-specific.

In HCF recursion is characterized just as "a core property of FLN" attributed to "narrow syntax", that is "a computational mechanism […] that generates internal representations and maps them into the sensory-motor interface by the phonological system, and into the conceptual-intentional interface by the (formal) semantic system" (HCF, 2002, p. 1571). The system so characterized "takes a finite set of elements and yields a potentially infinite array of discrete expressions" (ibid.).

Tomalin (2007) and Fitch (2010) described the mechanism invoked in HCF respectively in terms of "inductive definition" and "linguistic recursion", while van der Hulst (2011) traces it back to Chomsky's "merge" recursive mechanism (Chomsky, 1995; cf. 2010).

Chomsky writes:

"Any generative system, natural or invented, incorporates in some manner an operation that takes structures X and Y already formed and combines them into a new structure Z. Maximally efficient computation will leave X and Y unchanged […], so we can take Z to be simply {X; Y}.

Call this operation *Merge*. Applying without bounds to a *lexicon* of conceptual/lexical 'atoms,' Merge yields a discrete infinity of structured expressions. In the simplest case, then, unbounded Merge is the sole recursive operation within [Universal Grammar] – part of the genetic component of the language faculty" (Chomsky, 2010, p. 52).

Beyond the terminological differences, the crucial point is the following: given a finite set of primitive elements, the syntactic device governing language creates a hierarchically ordered system of syntactic objects with no upper bound. Chomsky's proposal, then, seems a generalization of the concept of "linguistic recursion" to every syntactic object. Fitch defines "linguistic recursion" as a case in which *"a recursive rule is one which has the property of self-embedding, that is, in which the same phrase type appears on both sides of a phrase structure rewrite rule*" (Fitch, 2010, p. 79, italics in the original paper).

In a notation where S stands for sentence, A stands for noun phrase and B stands for verb phrase, examples of rewrite rules might be S→AB, that is "a sentence can consist of a noun phrase and a verb phrase", and S→ASB ("a sentence can consist of a sentence embedded between a noun phrase and a verb phrase"). Together, these rules give rise to hierarchically ordered strings such as A^nB^n: in fact, embedding a sentence S between an A element and a B element means nesting a sentence within another sentence.

Under this interpretation recursion in HCF would be analogous to the computer science use of the term, whereby a recursive function is "one which calls itself" (ibid., p. 76). However, according to Fitch the linguistic use of this concept has stronger implications than the computer science one, because linguistic recursion involves the ability of the system to generate not only (potentially) self-embedding *strings*, but also, necessarily, self-embedding *structures* (ibid., p. 79). As he writes, in fact, "A key difference […] is that the linguistic definition entails a self-embedded *structure* being specified (*strong* generation), in addition to the computed output string itself (*weak* generation)" (Fitch, 2010, p. 79). He then argues that the linguistic and computer science notions are not really incompatible, because it is not difficult to design a computer program capable of generating recursive structures. However, he also argues that the linguistic interpretation of recursion "extends it in an important way from the computer science interpretation, 'upgrading' recursion from a question of weak (string-oriented) to strong (structure-oriented) generative power" (Fitch, 2010, p. 82).

Recursion is a cognitively demanding mechanism that requires keeping track of potentially infinite degrees of self-embedding in a structure or procedure in order to preserve the overall information of the output. An iterative process, for example, simply keeps track of the last computational step to control the next step of the process instead of keeping track of the various degrees of embedding without loss of complexity. A thermostat, for example, can give rise to open-ended cycles of temperature checking, lowering and raising. But in order to do this, the system needs only a feedback control loop comparing the current temperature with the desired value and acting accordingly (Corballis, 2011, pp. 11-12). Likewise repetition – another device able to give rise to open-ended sets in output – differs from recursion because it does not give rise to hierarchically ordered structures. As Corballis (2011, pp. 9-11) notes, if we say that "it rains, and rains, and rains", we could go on forever but every addition of "and" is not driven by the previous one (it is not required by the structure of the sentence) and it does not convey new information (every addition just conveys the information that it rains a lot).

If this is the meaning of recursion as the term is used in HCF, then it provides a specification of the mechanism itself that goes beyond a mere functional connection between finite input and potentially infinite output that, by itself, could be achieved iteratively (Luuk & Luuk, 2011). Also, this interpretation of HCF has the interesting effect of neutralizing some apparent potential counterexamples. In fact, some criticisms of HCF start with the assumption that linguistic recursion must be, in a sense, considered as both the *explanans* and the *explanandum* of the theory, so that the presence or absence of recursive strings in a given language is considered as index of the presence or absence of an underlying recursive syntactic mechanism.

So, for example, Karlsson (2011) reports that there are no written sentences with three or more levels of self-embedding in known language *corpora* investigated for recursion, while self-embedding of level two is extremely rare in speech. Laury and Ono (2011) conclude, on the grounds of these and other data, that recursion is irrelevant with respect to the activity of real speakers: recursion is, rather, a modeling choice made by language theorists.

This is a difficult issue, since the interpretation proposed by Laury and Ono raises complex epistemological issues that we cannot explore here (cf. Van der Hulst, 2011 for a survey). However, if our reconstruction is correct then the data about recursive strings are compatible with HCF's hypothesis, which describes the structure of linguistic *competence* as distinct from linguistic *performance*. The concept of competence refers, as discussed by Chomsky (1957), to the set of cognitive abilities enabling a system to produce a certain kind of output behavior or performance. As Massimo Piattelli-Palmarini writes, "witnessing the sharpness of the native speaker's grammaticality judgments for a potentially infinite set of sentences never encountered before, it became inevitable that the central object of inquiry shifted from finite corpora and from the speaker's linguistic "behavior" (performance) to the speaker's tacit knowledge of language" (2010, p. 149). This means, as he clarifies some lines before, that the very notion of language as "a corpus of utterances existing 'out there', produced by a certain community of speakers, analyzable in terms of rule-governed combinatorics of morphemes, words, and idioms" and as the primary explanatory target of linguistics and psychology, has been replaced by the notion of "grammar" at first, and then by the notion of "I-language", the internal, computational machinery enabling linguistic performances (Piattelli-Palmarini, 2010, pp. 149-150; cf. HCF, p. 1570). Beyond the terminological differences, the central point here is that the explanatory target of HCF is not "language" as pretheoretically understood (linguistic behavior), but linguistic competence, the set of computational subpersonal mechanisms enabling a speaker to produce and understand a potentially infinite number of sentences.[1]

HCF's target of investigation, then, is not the recursive output *per se*. The point is not that linguistic performance is uninteresting, but rather that whether a system is governed by recursive mechanisms or not is an issue that cannot be decided on the grounds of input-output behavior alone.

This argument has been recently used by Fitch (2010). Some studies in animal cognition have tested species such as cotton-top tamarins and European starlings using the Artificial Grammar Learning test: the animal is trained to discriminate A^nB^n recursive strings as grammatical versus different types of ungrammatical, non recursive strings such as $(AB)^n$. And while cotton-top tamarins fail in performing the task (Fitch & Hauser, 2004), European starlings and other birds succeed, thereby providing a counterexample to the hypothesis that recursion is specific to the human cognitive profile (Abe & Watanabe, 2011; Corballis, 2007; Gentner et al., 2006; cf. Bloomfield et al., 2011; van Heijningen et al., 2009)[2].

As Fitch argues, however, these data show just that some animals can discriminate some strings of a phrase-structure grammar. But these strings could be produced equally well by recursive rules (such as S→AB, that is "a sentence can consist of an element of type A and an element of type B", and S→ASB, which embeds a sentence in the middle of a carrier sentence) or by non-recursive ones (i.e. counting strategies such as "write down n A elements, then write down n B elements"). Furthermore, an $(AB)^n$ string can be generated by recursive rules such as S→AB and S→AB+S

[1] In classical cognitive science and, more generally, in computational functionalism, competence can be characterized as a system of computational rules for information processing and transformation, where information is represented in discrete symbolic, formal structures, and the processing is performed in linear architectures. According to alternative accounts (Noë, 2004; Searle, 1983) competence should be characterized in terms of a procedural know how rather than in terms of internalization of abstract, syntactic rules: cognitive systems are governed, according to this account, by an implicit knowledge of how things are in the world and of how the bodily structure of the organism allows certain kinds of actions (cf. Merleau-Ponty, 1945/1962; Adenzato & Garbarini, 2006; Gallese & Sinigaglia, 2010). Connectionist models, on the contrary, work out massively parallel modular architectures and eliminate the concept of representation. Despite the fact that these different models provide different interpretations of the concepts of competence and performance, the distinction between manifest behavior and subpersonal mechanisms or abilities enabling that behavior remains central.

2 Note that the paper introducing the A^nB^n grammar in animal studies (Fitch & Hauser, 2004) made no mention of "recursion" but squarely focused on the issue of regular (finite state) vs. supra-regular (context-free or above) grammar. With regard to this issue, see also Fitch and Friederici (2012).

(Fitch, 2010, pp. 86-89).[3] Again, then, according to Fitch the issue whether a system works based on a recursive mechanism cannot be decided only on the grounds of the input-output behavior of the system in the forms of grammaticality judgments or of presence of recursion in the output strings[4].

Each one of the abovementioned objections to HCF is complex, controversial and opens important side-issues and research perspectives, so we do not want to make it seem that they are not worthy of further investigations. Rather the basic point is that, formally speaking, they are irrelevant as counterexamples to HCF. This point has important epistemic implications for the status of HCF's hypothesis that we will discuss later: given such a sharp distinction between competence and performance, what are exactly the conditions under which the hypothesis could be falsified (cf. Traxler, Boudewyn & Loudermilk, 2012)?

Meanwhile we can summarize the central features of recursion as resulting from our previous analysis of HCF and related works.

First, under this interpretation the recursive system is extremely powerful and flexible. It can produce:

[3] Note, however, that S→AB+S is not center-embedding recursion. It is, rather, an example of "tail recursion", whereby a procedure invokes itself as its own final step. Unlike center-embedding, tail recursion can be mimicked by a system based on iterative processes (cf. Pinker and Jackendoff, 2005, p. 203). Interestingly, recently Martins and Fitch (2011; see also Martins, 2012) have developed a new task (called the visual recursion task, VRT) with the aim to address these questions and to empirically analyzing recursion in the domain of vision.

[4] Similar considerations apply, according to Fitch, to Dan Everett's argument that Pirahã, a language spoken in the Brazilian amazon, provides a counterexample to HCF because it has no recursive devices or strings. Fitch argues that provided that these speakers can form and communicate recursive conceptual structures (a point on which both parties seem to agree), then the specific way of mapping these structures into phonology is irrelevant as far as underlying cognitive or neural abilities are concerned (Fitch, 2010, p. 89). One might think that this reply is not coherent with HCF: are we saying that "real recursion" characterizes concepts and not language? What about the hypothesis that even though the conceptual/intentional system is a part of the language faculty, it is not the essential part of it because the conceptual/intentional system is shared with non-human animals (HCF, p. 1573)? HCF refers to many studies attesting that "nonhuman mammals and birds have rich conceptual representations", and that "animals acquire and use a wide range of abstract concepts, including tool, color, geometric relationships, food, and number" (HCF, p. 1575) and regard as "more controversial" the hypothesis that animals might have theory of mind (HCF, p. 1576). But, they argue, even though concepts and syntax might constrain each other in various ways (Fitch, Hauser, Chomsky, 2005, p. 203), and even though some aspects of human thought (such as theory of mind) might be uniquely human, it remains an open question whether these aspects are also language-specific (Fitch, Hauser, Chomsky, 2005, p. 205). Fitch's argument, however, does not claim that recursive conceptual structures are language-independent, even though the conceptual system is not a part of FLN: as we will see later (cf. our section 2), it is possible, according to HCF's logic, that a pre-linguistic conceptual system develops recursive structures after the evolution of linguistic narrow-syntax. This is also coherent with the fact that HCF's research target is not language as pre-theoretically understood (that is, as a system for communication shared by a community), but rather language as "I-language", an internal computational, derivational device. Of course, while this interpretation of Fitch's proposal is coherent with the general spirit of HCF's hypothesis we are left with yet another problem concerning the issue of its falsifiability: how can we decide whether the conceptual system is recursive or not? And if it is recursive, how can we decide whether conceptual recursion is language-dependent or not?
A different hypothesis on the relationships between linguistic syntax and thought is put forward by Michael Corballis, who argues that linguistic recursion evolves to express the recursive structure of concepts and thought (see, for example, 2011). And yet, for Corballis and for HCF, the default hypothesis is that concepts and thought are not "linguistic" – they exist before language and, for Corballis, they already have a recursive structure.

1. Simple strings like "John loves Mary", that can be extended by inserting clauses inside or outside the carrier sentence ("Adam thinks that John loves Mary", "John, who never thought it would have been possible, loves Mary", and so on).
2. Strings of a phrase-structure grammar like A^nB^n ("The fact that the book that John was reading was difficult was unusual").
3. Strings of a finite-state grammar, like $(AB)^n$ ("John saw that the book fell down")

Second, the central properties of recursion can be described as follows:

1) Self-embedding: a recursive structure embeds a constituent inside a constituent of the same kind, a recursive process is one that calls itself while the procedure is running.
2) Long-distance dependence: unlike iteration, recursion keeps track of the potentially infinite degrees of embedding in a structure or process.
3) Identity preservation: the elements constituting the finite set of inputs of the system are discrete. They do not change in relevant aspects once entered in the system and embedded in discrete expressions.
4) Discrete infinity: in virtue of self-embedding, given a finite set of discrete elements the system can generate a potentially infinite array of discrete expressions[5].

2. Recursion outside language: some potential counterexamples to HCF

Debate after HCF focused mainly on the issue of what is "recursion" and on whether recursion is human-specific and FLN-specific. By comparison, relatively little work has been done on the claim

[5] Our analysis of HCF and related work suggests that these features are interpreted as individually necessary and collectively sufficient conditions. There are self-embedding structures and procedures which are not recursive: one can put a box within a box, but this is not a recursive structure or procedure (for example, because this operation is not potentially infinite, cf. Luuk and Luuk, 2010). There are systems with infinite generative power which are not recursive (iterative devices, repetition, recurrent networks are examples of this point). Long-distance dependence relationships in space and time do not necessarily exemplify recursion (my TV screen turns on and this depends on the remote control acting at a certain distance, but no recursive mechanism is invoked here). Finally, identity preservation does not necessarily exemplify recursion (repetition preserves the identity of repeated elements, but repetition is not recursion).

that recursion is language-specific[6]. HCF's claim on this issue is that the language-specific mapping of syntactic structures onto conceptual-intentional and sensory-motor structures might derive from a single non-linguistic and domain-specific module in animal cognition (i.e., spatial navigation or number quantification). However, only with the evolution of FLN in humans – that is, with the specialization of the mechanism for language – does the system achieve discrete infinity and the ability to influence other cognitive domains: once adapted for language, the use of recursive devices undergoes a transformation from domain-specific to domain-general (HCF, 2002, p. 1578).

The payoff of this evolutionary movement consists, then, in humans' capacity to express conceptual constellations unbounded in their potential degrees of complexity and abstraction (Fitch, 2010) and in the capacity to use the same device for other computational needs (i.e., arithmetic, problem solving, spatial navigation, social cognition, cf. HCF, 2002, p. 1578; Fitch et al., 2005, pp. 186-187).

However, even though recursion in humans is an open source device the mechanism itself is, according to HCF, still language-specific and, therefore, the recursive structures of non-linguistic cognition are language-dependent. In this sense, then, "there are no unambiguous demonstrations of recursion in other human cognitive domains, with the only clear exceptions (mathematical formulas, computer programming) being clearly dependent upon language" (Fitch et al. 2005, p. 203; cf. Chomsky, 2010; Fitch, 2010).

Jackendoff and Pinker (2005) proposed visual cognition as an example of a non-linguistic recursive process on the grounds that we can see recursive visual patterns (i.e., squares made out of x which are in turn composed of squares made out of x, and so on). Marr (1982) also argued that a recursive device might be used to decompose objects into parts. However, these arguments for the existence of language-independent recursive processes are controversial. Regarding Jackendoff and

[6] Of course the issue of whether recursion is shared with non-human animals is equally important and we do not mean to deny the importance of research in comparative cognitive psychology or in animal cognition. Here we are just identifying our research target with respect to the current state of art of the debate after HCF. It is possible that the fundamental mechanisms of intentional action in human beings are shared with non-human animals, or that these mechanisms are also human-specific. Our analysis, however, is independent of this issue.

Pinker, we should note that seeing a recursive pattern does not necessarily require that the mechanism underlying vision must be recursive: we should distinguish between the structure of the perceived object and the structure of the processes underlying vision. Chomsky (2010, pp. 52-54), on the other side, claims that recursive decomposition of objects into parts might depend on arithmetical skills, which in turn are language-dependent[7].

Gerald Edelman (1989), however, has hypothesized that a recursive process might be responsible for visual consciousness and perceptual categorization without relying on the recursive structure of the stimulus. Here is a brief sketch of Edelman's view: perceptual categorization, allowing an organism to structure an integrated perceptual scene (i.e. seeing a cat "as" a cat and, more generally, categorizing certain perceptual features as "shapes", certain others as "colors", and so on), depends on the existence of a recursive neural device constituted by distributed "neural maps" integrated by "re-entrant signals". According to this model, the perceptual input is analyzed by memory maps (determining the correspondence of the input with an existing category) and "value maps" (including brain mechanisms for self-monitoring of the organism activity) determining the valence of the input for the organism. Re-entrant signals among the maps create an integrated perceptual scene where the perceived object becomes meaningful for the organism. Simultaneously, however, the ongoing perceptual categorization allows a reconstruction, or re-categorization, of the existing categories, which are updated in light of the new information.

According to Edelman, perceptual consciousness arises when new cognitive skills, brain devices and re-entrant connectivity are added to this basic system. In order to be perceptually conscious an organism should be able to draw a basic self/non-self distinction and to construct basic, non-linguistic concepts. Crucially, the organism should develop a "recursively comparative" memory supporting self/non-self categorizations in their relationships with ongoing perceptual categorizations:

[7] For some empirical studies addressing the issue of recursion in language after HCF see Bahlmann et al (2009) and Martins and Fitch (2011).

"[…] consciousness is an outcome of a recursively comparative memory in which previous self/non-self categorizations are *continually* related to ongoing present perceptual categorizations and their short-term succession, before these categorizations have become part of that memory" (Edelman, 1989, p. 155).

This view of perceptual consciousness as based on a recursively comparative memory is based on one of the mechanisms of RCI (Re-entrant Cortical Integration), namely "recursive synthesis", which occurs when re-entrant signals "allow the outputs of a higher area to influence the *inputs* that it (or other higher areas) receive from lower areas […] Recursive synthesis allows constructs derived in higher areas to be recycled to lower areas for use in the generation of additional constructs" (ibid., p. 88).

Some empirical evidence for the existence of non-linguistic recursion comes from dissociation between linguistic recursion and other cognitive skills. A recent experimental report on a patient suffering from agrammatic aphasia (Zimmerer & Varley, 2010) seems to prove that lacking linguistic recursive competence does not significantly affect recursive processes in other domains, such as mathematics and Theory of Mind (ibid., pp. 394-395). However, we should consider that: 1) the Artificial Grammar Learning (AGL) test, used to evaluate syntactic competence in this patient, does not seem to measure competence alone, and the inference from recursive strings to a recursive mechanism, as we have already noted, is not warranted; 2) dissociation of use of a property relates to performance, not to competence (Chomsky, 2010). It is possible that the language module cannot access its own recursive device because of the brain damage causing aphasia, while other cognitive modules could still access that device. In other words, perhaps aphasia impairs language performance, but not language competence. We will return later to discuss this last question.

A further possible example of a recursive structure outside language has been proposed within the theoretical framework of cognitive pragmatics (Airenti, Bara & Colombetti, 1993; Bara, 2010). According to this theory, which develops the philosophical tradition of speech acts theory, (Austin, 1962; Searle, 1969, 1979; Bach & Harnisch, 1979, Grice, 1989), recursion is a specific property of a mental state – i.e., communicative intention – the production and processing of which in a social context constitutes the cooperative activity of meaning-construction that we call "communication" (Adenzato & Bucciarelli, 2008; Bara, Ciaramidaro, Walter & Adenzato, 2011; Enrici, Adenzato, Cappa, Bara & Tettamanti, 2011). The recursive structure of communicative intentions is due to the fact that communication, unlike simple information extraction, requires that the hearer recognizes the information received as intentionally conveyed to him by the speaker (Airenti et al., 1993; cf. Bara, 2010). In other words, a communicative intention requires that the hearer recognizes it as such. Therefore, its structure must be at least:

"$CINT_{xy}p \equiv INT_x\ SH_{yx}\ (p \wedge CINT_{xy}\ p)$" (Bara, 2010, p. 83)

that is, "X has the communicative intention that p toward Y […] when X intends […] that the following two facts be shared by Y and herself: that p, and that she intended to communicate to Y that p" (ibid.).[8]

Overall, then, the counterexamples discussed in the present paragraph open a question: to what extent might non-linguistic cognitive domains (which might also be more primitive than

[8] In our view this structure satisfies the crucial properties of recursion. The communicative intention is self-embedding, since its symbol $CINT_{xy}p$ occurs on both sides of the identity symbol. It has a potentially infinite generative power, limited only by the specific cognitive resources available to the agents involved in communicative interaction. In fact, when I intend to share with you that p and that I intend to communicate to you that p, it is possible to generate a potentially infinite series of inferences deriving from nesting "intending to share" within "intending to share". So, when x intends to communicate to y that p, this involves that x intends to share with y that x intends to share with y that p, and possibly even that x intends to share with y that x intends to share with y that x intends to share with y that p (in symbols, $CINT_{xy}p \supset INT_x\ SH_{yx}\ INT_x\ SH_{yx}\ INT_x\ SH_{yx}\ p$). Put into a better form, "given the fact that A intends to communicate a certain thing to B, we may infer that A also intends that her original intention to communicate that particular thing be recognized. If need be, this includes the further inference that A wishes B to recognize her intention of letting B know that she really did intend him to become aware of her intention to communicate to him that particular message" (Bara, 2010, p. 84).
Moreover, understanding such a communicative intention requires keeping track of the various degrees of embedding of $INT_x\ SH_{yx}$, where each embedding leaves the elements unchanged (identity preservation, no simplification). Finally, one should keep track of the mutual relationship of every embedding with the other and understand the relationship between one of the embeddings and the final "that p" (the communicated fact).

language), like sensory-motor processes, make use of recursive structures or processes to organize and control behavior? Suppose that it is correct to say that there are recursive processes and structures in non-linguistic cognitive domains (i.e., hierarchical sequence processing in mindreading, perception and action), and that there are recursive mechanisms underlying non-syntactic linguistic abilities, such as pragmatics. Supporters of HCF, as we have said, might always argue that recursion in these non-linguistic or non-syntactic domains are language or syntax-dependent, or that the supposed counterexamples to HCF concern performance and not competence. In the next paragraph we will present our hypothesis of recursive processes in the domain of intentional action, and then we will try to understand whether this form of recursion is language-independent.

3. Recursion and the logical structure of intentional action

Our hypothesis is that John R. Searle's (1983) philosophical analysis of the intentionality of acting and perceiving can be extended to capture the presence of the crucial features of recursion (self-embedding, long-distance dependence, identity preservation, discrete infinity) in sensory-motor processing. Intentionality is, in philosophical jargon, a property of mental states in virtue of which some of them (such as beliefs, desires, hopes, fears, intentions, and so on) are directed to, refer to, or are about (phrases that we take as synonymous for the sake of the argument) objects or states of affairs which are independent of these states.

According to Searle an intentional state is a representation of its conditions of satisfaction: the intentional content of an intentional state represents the conditions that satisfy that state according to the direction of fit determined by the psychological mode (Searle, 1983, pp. 11-13). Every intentional state so defined is composed by a content (such as "the glass is full") specifying the state of affairs to which the state is directed, and by a psychological mode (such as belief, desire, etc.) specifying the kind of state we are dealing with. Different psychological modes may take the same proposition as content (I can believe or desire or hope or fear that the glass is full), but they may nonetheless specify different conditions of satisfaction according to different directions of fit. The notion of "conditions of satisfaction" is a generalization of the notion of "truth conditions" (applied to statements) to every intentional state: in the same way that we are able to recognize when a statement is satisfied (that is, what are the conditions under which the statement is true) we are also able to recognize when a belief is satisfied (that is, what are the facts in the world that make it true) and when a desire, an intention, a visual experience are satisfied (that is, what are the states of affairs that make them fulfilled, carried out or veridical).

Beliefs and desires, therefore, have different logical structures: so a belief with the content "the glass is full" is satisfied if and only if the content fits the fact in the world that the glass is full. Here the burden of fit is on the content: if it turns out that the world is not the way the content represents it, then the content must change to fit the world. On the contrary, the desire that the glass is full places the burden of fitness on the world: the world has to change so as to fit the content. Beliefs and visual experiences, on the one hand, have a mind-to-world direction of fit (they try to represent the world as it is), desires and intentions on the other hand have a world-to-mind direction of fit (they represent the world as it should be or try to change the world so that it fits the way it is represented in the content) (Searle, 1983, pp. 18-36).[9]According to Searle's (1983) view the primitive states articulating the holistic network of intentionality are not beliefs and desires, but perception and action: these states are, on this view, the more fundamental ways through which mind mediates and structures the organism-environment relationship, as we will see, both intentionally and causally (ibid., p. 36).

[9] Intentionality, then, as a property of some mental states, differs from intentions (a specific kind of intentional mental states). We should also specify that intentional states might be conscious or not and that their being conscious does not affect their intentional properties: perceptions and actions, for example, are typically realized as conscious experiences of perceiving and acting. But unconscious forms of perceiving and acting are also possible. Searle argues for this point, concerning perception, by way of referring to Weiskrantz's work on blindsight (Searle, 1983, pp. 46-47; cf. Weiskrantz, 1980; 2002). Likewise, Searle argues, there can be cases where one performs intentional actions without conscious awareness of doing so. We might, for example, drive a car while having a conversation. In that context the focus of attention might be on the conversation and we might have no awareness of the fact that, meanwhile, we are shifting gears. Nonetheless shifting gears is an intentional action with an underlying unconscious intention: shifting gears is not a mechanical stimulus-response association (unlike sneezing), rather it is something that the agent might still be held responsible for (Searle, 1983, pp. 91-92).
Saying that perceptions and actions are realized as conscious experiences is, then, an empirical fact in addition to the logical properties of intentionality: whether conscious or not, an intentional state can be characterized as a representation of its conditions of satisfaction under a psychological mode determining its direction of fit.

The argument for this point is that the satisfaction of beliefs and desires does not require that the satisfaction itself be achieved in a specific way: beliefs and desires that the glass is full are satisfied if contents match the facts in the world according to the specified direction of fit. Perception and intention, on the contrary, require that the satisfaction results from a specific causal relationship between the state and the facts in the world. These states, in other words, are satisfied if the required facts are in a certain causal relationship with the state at issue. And since this causal relationship is part of what makes the state satisfied, then it must be specified in the content of the state (ibid., pp. 46-50, pp. 84-87; cf. Vicari, 2008a; 2008b; Di Lorenzo Ajello, 2001).

Consider first the intentionality of a basic motor act, like raising one's arm. This act is constituted, according to Searle's analysis, by an intentional component (the "intention-in-action" to raise the arm) and a bodily movement (the arm goes up). Now, an intentional action does not require just that the movement happens, but that it is produced as an effect of the intention itself. The causal relation, however, is not sufficient to satisfy the intention if the relation itself is not represented by the content as one of the conditions of satisfaction of the intentional state. The argument for this point is that an external causal relation between intentions and actions can give rise to deviant causal chains. In a famous example (Searle, 1983, p. 82-83; cf. Chisholm, 1966; Davidson, 1980) if X intends to kill Y in a car accident, and the intention causes such an anxiety in X that s/he kills a pedestrian who turns out to be Y, then "killing Y" cannot be a case of satisfaction of the intention. We would say, in ordinary speech, that the event was just a car accident and not an intentional homicide, even though X might bear some responsibility for it. What is wrong with this case is that the event indeed occurs as an effect of the intention, but it does not occur as an effect of the intention in the specific way represented in the intentional content.

The point of this discussion is that the content of an intention-in-action has a causally self-referential structure specifying the causal relationship between the state itself and its conditions of satisfaction. The content cannot be just

Intention (that the arm goes up)

rather it must be at least

Intention (that the arm goes up because of this intention).

The content of the intention is, then, causally self-referential, and causal self-referentiality is a self-embedding structure: the content of the state refers to the state itself as causing its own conditions of satisfaction. Intentions are mental states endowed with a content representing the intention itself as the cause of a bodily movement, which means that the intention is satisfied if the movement actually occurs and if it occurs as an effect of the intention. Moreover, it is not sufficient that the causal relationship just happens: it is necessary that the causal chain is represented by the content, that is, the causal relationship satisfying the intention must be the specific causal relationship represented by the content.[10]

This is not to say that experiences of acting and, more generally, intentions, are self-validating claims concerning causation. We are just saying that an intention is satisfied if and only if there is a causal relationship between the intention itself and the bodily movement satisfying the intention, and that the existence of this causal relationship is a specific requirement of intentions

[10] A crucial difference between desires and intentions is that desires do not imply any commitment to action on the part of the agent in order to achieve a goal. On the contrary, intentions are exactly commitments to act in order to achieve a goal. If I simply desire that my arm goes up and the arm goes up because of the action of another person, then the desire is fulfilled. But if I intend to raise my arm, then there is a commitment that the arm goes up as a result of my effort: the arm should go up as an effect of the causal action of the intention.
This is the reason why I can seriously and literally desire to fly like Superman, but it would not make sense – indeed, it would put my life in serious danger – if I seriously and literally intended to fly like Superman: flying is not something that I can actually do.
If we want to make explicit this point in a more specific way, we could say something like this: intentions are related to those states of affairs in the world that determine their success or failure in a much more specific way than desires, because intentions include a commitment on the part of the agent to achieve a goal as a result of the relevant causal action of the intention. Moreover, it is not necessary that every intention presents a hyper-detailed action plan. An agent might simply intend to start his/her car (in a way or another), making a series of random movements in order to start the car and, finally, succeeding. Given the way we describe this case the intention is satisfied, provided that the agent acts on the basis of that intention and makes it effective with his/her behavior. Moreover every random movement, if made intentionally (even if made without effort or specific focus of attention), will be governed by a causally self-referential intention generated to subserve the global intention to achieve the global goal. It is not essential for our argument that every intention to act represents a detailed course of action. The essential points are 1) that every intention to act is satisfied if the intention is causally relevant to produce its own conditions of satisfaction, and 2) that action plans *might* represent a very detailed course of action (this is the point about infinite generativity that we will develop below).

represented in the intentional content of this kind of mental state. The intention to raise one's arm is satisfied if and only if the arm goes up and it does so *because* of the intention to raise one's arm. Whether there really is a causal chain beginning with the intention as a cause and ending up with the arm going up as an effect is a separate issue that should be decided case by case. The statement that "The glass is full", for example, is satisfied (true) if and only if the glass is full. Whether the glass is actually full cannot be established a priori simply by looking at the structure of the statement (one has to look at the relevant fact in the world). Likewise, the content of the intention simply represents the facts that would make the intention satisfied if those facts occurred (Searle, 1983, pp. 130-131). That is: we are not trying to decide by fiat the long-standing and still open debate in neuroscience and cognitive science on the structure of voluntary action and on the causal role of intentions. We are just reconstructing the logical structure of our motor-intentional competence, which is articulated, if this analysis is correct, in self-embedding structures with the specific form of causal self-referentiality. If our approach is correct we could say that agentive illusions are possible in the same way that visual illusions are possible: one might think that s/he has performed an action (that is, that his/her intention has caused a certain bodily movement) even though in fact the bodily movement is the effect of some other cause or there is no bodily movement at all. However, while the possibility of error concerning our cognitive, perceptual and agentive judgments involves the logical possibility that we are radically mistaken (that is, that all our experiences are false), it seems to us that the hypothesis that the experience of agency is systematically distorted is far from being conclusively demonstrated by the available empirical evidence on the structure of voluntary action.[11]

[11] The ongoing debate on the causal structure of voluntary action started with Benjamin Libet's studies on the role of the readiness potential as an unconscious cause in determining voluntary action (Libet, Gleason, Wright & Pearl, 1983; Libet, 1985), and it concerns the possibility that intentions play no causal role for the production of behavior. Libet asked the experimental subjects to make a simple hand movement and to report the onset of their intention to make the movement by way of locating the exact position of a revolving dot on a digital clock. Libet saw that a specific electric activity (the so-called readiness potential) systematically precedes the onset of the intention (about 350 ms), and that the intention comes before the onset of the bodily movement (about 200 ms): therefore, according to Libet, the real cause of the movement is the unconscious readiness potential and not the intention. Soon and colleagues (Soon, Brass, Heinze & Haynes, 2008) replicated Libet's study by using *f*MRI and trying to solve some methodological problems of Libet's paradigm (concerning the reliability of subjective reports as measures of the onset of the intention) and concluded that the brain has "decided" what to do and when the movement should be performed seven seconds before the onset of intention. Finally, according to Daniel Wegner (2002; cf. Wegner & Wheatley, 1999) an intention is just an "indicator"

Now, according to Searle the self-embedding structure of intentions does not yet have the kind of internal complexity allowing free manipulation of elements with semantic content, which brings discrete infinity in language (Searle, 2006). The reason for this point is probably that recursive linguistic structures are characterized by self-embedding of tokens of the same type, while self-embedding of intentions is limited only to self-reference, whereas a token embeds itself within itself. A sentence, for example, can embed another sentence, while an intention simply embed itself within itself. So, since recursion is different from mere repetition because recursion allows the construction of increasingly complex contents conveying different information, then recursion seems also to be fundamentally different from the causal self-referentiality of intentions. But this difference, in our view, is simply apparent: even the conditions of long-distance dependence and discrete infinity can be met, in our opinion, if we look at how basic actions are embedded in complex actions.

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of what an organism is going to do, and not the real cause of the action. Actions are wholly determined by subpersonal, automatic mechanisms which are independent of the cognitive mechanisms generating intentions and thoughts. Wegner argues for this hypothesis through the so-called "I-Spy experiment": an experimental subject and a confederate together control a cursor through a computer mouse, aiming at reaching some target showed on a computer screen. After the task the experimental subject has to answer the question about who actually was in control of the mouse when performing the action, and in some cases the subjects issue wrong judgments of authorship (i.e., they attribute to themselves the "capture" of a target that was actually reached by the confederate). According to Wegner, the experiment demonstrates that intentions are not "real causes": they are just reliable indicators of what is going to happen, indicators that can be altered through the manipulation of some crucial factors (i.e., contiguity in time between thought and movement and coherence between the content of the intention and the movement performed). Further evidence for this hypothesis has been given by Lau, Rogers and Passingham (2007), who showed that applying transcranial magnetic stimulation over the pre-SMA at different times after movement execution during the Libet task shifts the judgment of the onset of the intention backwards in time, thereby corroborating the hypothesis that intentions can also be generated "post hoc" – that is, they can take into account elements that take place after movement execution.

Here we cannot make a complete examination of the debate opened by these and other studies. However, even though epiphenomenalism could be compatible with our hypothesis (since causal self-referentiality is a requirement for the satisfaction of an intention, while the actual satisfaction must be verified case by case), we would like to point out some factors that make epiphenomenalism extremely controversial. First, Libet's experimental paradigm requires that the subject reports the onset of a "urge, desire, decision and will" (Libet, 1985, p. 530) to do the movement, but if our analysis is correct then making up one's mind (deciding, forming an intention) is very different from having a urge or a desire: intentions, unlike desires and urges, are causally self-referential, which means that intentions contain a strong commitment to perform an action in a very specific way, which is absent in the content of a desire (cf. Mele, 2009). It is not clear, in other words (beyond other notorious difficulties regarding the methodological reliability of subjective reports, cf. Tempia, 2010), whether Libet's task actually targets intentions or other mental states that, like desire, have a looser logical relationship with actions.

Second, in Libet-style studies it is difficult to isolate a baseline – a situation in which the subject has no prior intention concerning the experimental task that he is going to perform. It seems reasonable to think that the subject, as a voluntary participant to an experiment, has some prior intention to perform the required movement at some time. If this is correct, how can we rule out the possibility that the readiness potential correlates with the prior intention? The readiness potential could also be a consequence of the prior intention to perform the task: I decide to take part to the experiment, and then I "get ready" to perform the task at a certain time (Searle, 2009, pp. 171-172). Third, even though Wegner, Lau and colleagues are right that an agent can be wrong about the authorship of an action or about the onset of an intention, this does not necessarily mean that mentalistic explanations of behavior are systematically false, in the same way that the existence of optical illusions does not necessarily imply that the content of visual perception is never veridical. Realizing agentive illusions, however, is not that simple. Wegner himself noted that, sometimes, it was extremely hard for the confederate of the I-Spy experiment to force the stop on the desired target without being noticed by the participant, so that some of the data were excluded from the final statistical analysis. Like the conjurer that creates visual illusions, the confederate has to be extremely skillful and careful in doing his magic (Wegner & Wheatley, 1999, p. 489; cf. Bayne & Levy, 2006).

The analysis of a complex action (i.e., taking a glass of water to drink) requires us to distinguish, according to Searle's theory, between prior intentions (the plan governing the complex action as a whole) and the intentions-in-action as intentional components of the subsidiary actions (take the glass, walk, stop to the fridge, open it, and so on). Now, clearly even prior intentions are causally self-referential since the subsidiary actions must be performed because of the prior intentions that embeds them (Searle, 1983, pp. 85-86, 92-96). The content of a prior intention can therefore be represented as follows:

Prior intention (that I take a glass of water to drink because of this prior intention).

Taking into account the further decomposition of prior intentions into subsidiary actions with their own causally self-referential component (intentions-in-action), and oversimplifying the description of the action by limiting it to only two subsidiary actions, we might get a result like this:

prior intention {[that this prior intention causes [intention in $action_1$ (that I take a glass of water because of this intention in $action_1$)] and [intention in $action_2$ (that I drink the water because of this intention in $action_2$)]}.

At this point, we should note the crucial difference between the content of an intention-in-action and the content of a prior intention. An intention-in-action is simply the intentional component of an intentional action, and therefore it refers to itself as causing a bodily movement, which is the second component of the intentional action. But the action plan – that is, prior intention – necessarily refers to itself as causing the entire intentional action, and therefore as causing the intention-in-action which, in turn, causes the bodily movement. In other words, a prior intention embeds a different token (another intention) within a token of the same type. [12]

If this analysis is correct, then it not only makes explicit the multiple levels of self-embedding made possible by the causal self-referentiality of intentions and the logical features of complex actions. It also makes explicit the existence of a specific constraint of long-distance dependence between the prior intention and its embedded intentions-in-action.

In fact, since the same motor act can be embedded in different complex actions, it is necessary that the prior intention governs the performance of its subsidiary actions for these to be cases of satisfaction of the complex intention. Everyday life provides many examples of this point: one can start taking a glass and walking to the fridge. Then, in the middle of the room, one might forget the prior intention and ask him/herself "why did I take the glass?" At this point, a sudden sensation of thirst might drive the agent to take the water, but this would just be a deviant causal chain, and not an example of complex intentional action. Otherwise the action might simply cease, and one would leave the glass somewhere.

Another way of making the same point goes as follows. Suppose that I form the prior intention to pay a debt to the owner of a music store by means of going out for a walk, going to my favorite music store, meeting the owner of the store and paying him the debt. I go out for the walk, but I immediately forget the place where I should go and why I should go there, so I decide to walk

[12] Prior intentions may precede even a single bodily movement (or basic action): I can decide now, for example, that I will raise my arm in five minutes. Therefore, talking about subsidiary actions might seem misleading. However, the mere fact that a prior intention can concern one single bodily movement does not make the action less complex. I can decide now to raise my arm in five minutes to vote, or to take a glass, or to say hello to a friend of mine, or to indicate someone to someone else: one single bodily movement can achieve many different goals, depending on the prior intention embedding it. Or, as we will see later, with the so-called "accordion effect" an agent might perform a lot of different sub-actions (as part of a single prior intention) with a single finger movement: by pulling the trigger one can, for example, fire the gun, killing someone, causing a war. In general, as we have seen, a prior intention necessarily embeds an intention-in-action in its content: in fact the prior intention causes the whole intentional action as consisting of intention-in-action plus bodily movement. Moreover, a prior intention which does not cause a corresponding intention-in-action can give rise to deviant causal chains, like in our example at p. 18. In this sense, then, prior intentions always have the kind of complexity needed to give rise to self-embedding properly understood, as distinct from mere self-reference.
Furthermore, not every intentional action has an underlying prior intention, but every intentional action has an underlying intention-in-action. For example, I can simply stand up from my chair and walk around the room without planning to do so and without any other purpose than doing so. Also, there can be intentional actions that are instrumental to achieve the goal of a complex action without being themselves represented in a prior intention. For example, I can drive towards my office and shift the gears, but I never thought about this when I planned to go to the office (Searle, 1983, pp. 83-84). However, this is not a counterexample to our account: what matters, for us, is whether our motor-intentional system has the *competence* to embed indefinitely many intentions-in-action in one single prior intention without *necessarily* doing so. In the same way, language can generate complex self-embedded structures or express the same conceptual constellation via parataxis.

around downtown. It happens that, during my walk, I find myself before the music store: I enter and begin to give a look at the musical instruments. While I am doing so I meet the owner and start a conversation with him concerning the musical instruments. Suddenly I remember that I owe him some money: luckily enough I have money with me, so I pay my debt and go away.

Now, the events so described fit the content of my prior intention: I went out for a walk, I entered into the music store, met the owner and paid my debt. We would not say, however, that I carried out my plan to pay my debt: we would say, rather, that a series of coincidences led me to pay my debt. The point is not that there is no causal relationship among the events: after all I paid my debt because I entered into the music store, I was there because I went out for a walk and I decided to go out because of my prior intention to go out and pay my debt. What is wrong, then? The point is that even though the right events occurred, they occurred in the right order and the sequence goes back to the prior intention as its causal origin, these are necessary but not sufficient conditions for the satisfaction of a prior intention. We still need that the events represented in the intention are linked to the global goal of the intention in a regular, non deviant, planned way. In our example, the global goal (paying the debt) and the preceding steps of the complex action are linked in a contingent way that leads to the correct outcome only by chance. An intention, instead, is satisfied when the global goal is achieved in the specific way represented by the prior intention through its causally self-referential component, which specifies that the events must occur because of the intention and in the specific way represented in the intention (Searle, 1983, pp. 138-140). In other words, the intention-in-action must be causally effective until the completion of the entire action (Searle, 1991, pp. 298-299; cf. Searle, 2001, pp. 49-51)[13].

A complex action, then, requires long-distance dependence among the prior intention and the subsidiary actions, and this point can be accounted by causal self-referentiality. Also, there seem

[13] See Miller, Galanter and Pribram (1960, pp. 61 ss.) for a similar point, leading to the view that intentions are "*uncompleted parts of a Plan whose execution has already begun*" (italics in the original text). According to these authors the main explanatory work for the presence of recursion in intentional action is played by plans, as they allow for potentially infinite self-embedding of other action plans and subsidiary action within themselves. However, this way of defining an intention seems to presuppose that the Plan itself is not an intention. On the contrary, on our view a planned action is an intentional action having a prior intention governing it.

to be no limit, at least at the competence level, to the expansion of actions through external and internal levels of self-embedding in complex intentions. One can think about extremely complex and long-term action plans, possibly requiring different sub-plans with their own subsidiary actions (e.g., dating a girl to marry her and building a family and so on, as part of one's life plan).

Searle introduces similar cases with reference to the so-called "accordion effect" (Searle, 1983, pp. 98-100), whereby a single bodily movement (i.e., pulling the trigger of a gun) is represented in and caused by a complex intention with multiple conditions of satisfaction (in Searle's example: firing the gun, killing the Archduke Ferdinand, striking a blow against Austria, and avenging Serbia).

What is the point of this discussion? Remember that the crucial properties of recursion as we have reconstructed them are self-embedding, long-distance dependence, identity preservation and discrete infinity. Here we are suggesting that at the level of intentional action we might have structures exemplifying even the last two features of this list.

Regarding discrete infinity, according to Searle the expansion of a complex action via the accordion effect and/or the further embedment of intentions into intentions cannot go on indefinitely: if we expand the description of a complex intention like the one in the example we could meet true descriptions like "moving air molecules" or "started the First World War". Searle's point is that the boundaries of a complex action are the boundaries of the agent's intentionality: perhaps Gavrilo Princip did not know, or took it for granted, that firing the gun would have caused the movement of air molecules, and perhaps he ignored that killing the Archduke would have caused the First World War. We are not entitled to ascribe to an agent the intention to make actions that are, at best, unintentional consequences of his intentional actions (ibid., pp. 99-100).

However, while this argument is valid for Searle's purposes (that is, stating the differences between intentional actions and their unintentional consequences) it does not seem to affect our argument. Searle's argument refers to the empirical limitations and specific peculiarities of the cognitive and agentive systems of a single agent: an agent might not know that his intentional actions will have unintentional consequences caused by that action. However, nothing in this argument precludes that a politically more sophisticated Gavrilo Princip could kill the Archduke precisely for the purpose of causing the First World War, or that a scientifically-minded agent could fire a gun to move air molecules. Searle is right in claiming that the boundaries of an action are the boundaries of the intentionality of the agent, but this does not involve that the intentionality of action cannot be expanded indefinitely.

But even though the accordion effect could expand complex intentions indefinitely, this would not make us more omniscient or omnipotent than discrete infinity in language. HCF's claim that recursion allows us to express in language any conceptual constellation we like, regardless of its level of complexity and abstraction, does not take into account possible empirical limitations concerning, for example, the conceptual apparatus of a specific person because it specifically concerns the computational or logical structure of linguistic competence. Likewise, our argument does not take into account the possible, empirical limitations of the intentionality of a specific agent because it concerns the logical structure of our agentive competencies.

Another objection to our argument might go as follows: part of the computational power of linguistic recursion is that, unlike recurrent networks (cf. Fitch, 2010, pp. 85-86), it allows the production and understanding of increasingly complex structures without combination of the elements and, therefore, without loss of content. On the contrary the motor system does not preserve, apparently, the identity of the motor act under embedding in different prior intentions. So, for example, the elements of "John loves Mary" don't change when we rewrite the sentence as "John, who is married with Susan, loves Mary". But the same motor act (like grasping) changes its kinematics as a function of the different intentions embedding it (a private, individual intention, or a communicative intention, cf. Sartori, Becchio, Bara & Castiello, 2009).

Note, however, that a change in kinematics does not, by itself, affect the identity of the basic motor act: grasping to lift or grasping to offer the object to a partner are still instances of the same motor act (grasping) in the same way that different pronunciations of phoneme /k/ in "Cape Cod" are still different instances of the same phoneme. In the same way, different inflections of the same word depending on its syntactic role (such as in Latin – *rosa*, *rosae*, and so on - or in German) preserve the identity of the basic element under transformation.

The fact that the mental or social context embedding a specific motor act affects the kinematics of movements does not change the identity of the basic motor act at issue – provided that we establish the identity of the act at a reasonably abstract level, not including the fine-grained details of kinematics, in the same way that we do not demand phonological of morphological fine-grained identity to establish the identity of items in our lexicon.[14]

The basic idea here is that as biological organisms we have a finite set of elements in our motor repertoires, and that the same basic motor act might occur in different complex actions (i.e., grasping to eat, grasping to clean, and so on) while preserving its identity.

Pastra and Aloimonos (2012) report current research on "motor primitives" from behavioral and computational perspectives. Based on this research, at a behavioral level complex actions hierarchically organize simpler elements either serially or in parallel. Reaching movements, for example, "appear to be coded in terms of direction and extent, and appear to be composed of discrete submovements, all with a similar stereotypical, serially concatenated shape and overlapping in time", while "Human and monkey grasping and object manipulation has been studied extensively and has been described as consisting of sub-actions executed as a unified coordinated complex act" (ibid., p. 104).

A current hypothesis about the organization of the mirror system (especially of the parieto-frontal cortex) is that it contains a "vocabulary of acts" – specific neuronal groups firing only during

[14] As Chomsky explicitly says (see our quotation from Chomsky, 2010 at p. 6) recursive syntactic transformations of elements merge the elements, but leave them unchanged: if you have X and Y and merge them you will have a new, structured element "XY" for reasons of "optimal computation". As we see this point, at this level of the analysis the invariance is at syntax and lexical levels: the elements may undergo many morphological and inflectional transformations depending on their syntactic role in different sentences, but they are still instances of the same type or category. So when you transform "John loves Mary" in "Mary is loved by John" you keep meaning constant while the verb undergoes a transformation. Yet, "loves" and "is loved" are still instances of the same lexical entry (the verb "loving") and of the same syntactic category (verb phrase). The same holds when a syntactic transformation yields a change in meaning (i.e., when you transform "John loves Mary" in "John is loved by Mary").

Pragmatics introduces yet another dimension of change and invariance: you can use the same proposition (i.e., "that you smoke") to make different speech acts with different conditions of satisfaction (I can state, order, regret, ecc., that you smoke) (cf. Searle, 1969). The same holds for intentional mental states (I can believe, desire, see, hope that you smoke) (cf. Searle, 1983).

execution/observation of specific acts such as grasping, reaching, etc (Rizzolatti & Sinigaglia, 2008), where these neuronal activations are independent of the specific kinematics of the motor act (Umiltà et al., 2001).

Other behavioral approaches interpret the notion of "motor primitive" in terms of motor or perceptuomotor schemas, while computational perspectives use statistical techniques to extract "kinematic, dynamic or kinematodynamic" primitives (Pastra & Aloimonos, 2012, p. 104). According to Pastra and Aloimonos, in other words, the notion of "motor primitives" is well established in current research, whereas the identity can be established at different levels (behavioral, neural, computational, ecc.). What is missing, according to them, is a Chomskyan generative "grammar" of action deriving a potentially infinite set of motor expressions from a finite set of basic motor acts – a research project that we will discuss in the next section.

What we want to point out, for the moment, is that a scientifically informed conceptual analysis like the one suggested by our development of Searle's theory of intentionality seems to be able to capture the crucial features of recursion (self-embedding, long-distance dependence, identity preservation, discrete infinity) in the structure of intentional action in virtue of the causal self-referentiality of intention and of the distinction between prior intention and intention in action.[15]

[15] The definition of recursion that we gave at p. 11 is formulated in a terminology apparently involving an acceptance of strong computationalism, according to which mental states are symbolic, discrete expressions. However, the definition is provided in that terminology because it results from our analysis of HCF and related work. But in order to show that the crucial features of recursion can be found in the domain of intentional action it is not necessary, according to us, to endorse strong computationalism – a position that we do not regard as plausible. We do not regard mental states as "discrete" in the same sense in which linguistic elements are discrete: mental states are not, in our view, discrete symbolic expressions in "mentalese". Searle too (2006) holds that mental states are not "segmented": they are not made out of discrete elements, rather they manifest themselves as a continuous stream. One could observe, however, that Searle's point holds for the phenomenology of mental states, and not necessarily for their logical structure. Though mental states are not discrete in the same sense as linguistic structures, we can nonetheless identify them. We can distinguish the belief that the glass is full from the desire that the glass is full, and the belief that the glass is full from the belief that the glass is empty simply because these states differ in their psychological mode (belief, desire, ecc.) or in their propositional content. We are also able to attribute mental states to other agents in given contexts: if I see someone running towards a bus I can explain his/her behavior by saying that the agent has a desire to go somewhere, a belief that the bus goes to that place, a belief that s/he can take the bus if s/he runs, a desire to take a bus. One might think that mental states are too "elusive" or "fuzzy", so that we cannot really identify them and attribute them to other agents in real life situations. But the same could be said about language: sentences uttered by real speakers in real life situations are very far from usual idealized models such as "John loves Mary". Listening at a recorded conversation, one could question the validity of the principle that there is not something like half a sentence (cf. Pinker, 1994). Nonetheless we can understand what speakers are saying and we can study the syntactic, semantic and pragmatic properties of sentences. So, summing up: we do not think that mental states are symbolic structures in mentalese, nonetheless, as we have seen, they have a logical structure allowing us to identify them and to attribute them to other agents. Moreover, according to our analysis, as we have seen, the logical structure of intentions is recursive.

4. How many recursions? Disentangling the relationship between action and language

In the last paragraph we have discussed our hypothesis of recursive processes and structures in the domain of intentional action. Even assuming that this hypothesis is correct, a question remains: what are the relationships between linguistic recursion and recursion in the structure of intentional action? Adopting a Chomskyan perspective the answer seems reasonably predictable: since recursion is language-specific, then recursion in non-linguistic domains must be language-dependent. Therefore recursion in the domain of intentional action is language-dependent too. But recent evidence coming from cognitive sciences and neurosciences leads to at least other two possibilities. The first one, that we call "the embodied roots of linguistic recursion", inverts the logic of HCF's hypothesis and proposes the primacy of motor-intentional recursion. The second one points to the double dissociation between language and motor domains and proposes two independent recursive processes. We discuss these perspectives in turn.

4.1 The embodied roots of linguistic recursion

The "syntactocentric" (as Jackendoff, 2003, calls it) hypothesis on the evolution and functioning of the faculty of language worked out in HCF is clearly formulated in the spirit of classical computational cognitive science: the faculty of language "narrow sense" is conceived as an "abstract linguistic computational system" (HCF, p. 1571) that can be usefully studied and understood independently of the other peripheral components of the faculty of language (the sensory-motor and conceptual systems) even though these peripheral systems causally constrain the computational mechanism. The basic idea conveyed by HCF seems to be that language is a computational system that takes a finite set of primitive elements as input and produces a potentially infinite set of discrete expressions as output: the more ancient conceptual and sensory-motor systems are important as sources of input and externalization tools of the core computational mechanism, but they play, in fact, no active role in the functioning of the faculty of language. They are just, so to speak, causally enabling mechanisms that allow language to work, but we could understand the faculty of language without looking at the functioning of the peripheral systems .

However today this picture, unlike early days of good-old-fashioned computational cognitive science, is far from being the only game in town, and it has been effectively challenged by many different views looking at sensory-motor processes and non-linguistic cognitive processes as directly involved in the emergence and functioning of language, rather than as passive sources of inputs and effectors (Varela, Thompson & Rosch, 1991; Clark, 1997; Hurley, 1998; cf. Garbarini & Adenzato, 2004; Vicari, 2011).

The existence of a close link between motor system, language, and other cognitive processes has emerged from a series of classical studies in developmental psychology (Piaget, 1950/1972; 1967/1971) and has recently re-surfaced in different fields of cognitive science and neuroscience to the point that Susan Goldin Meadow, drawing the conclusions from her studies on the cognitive role of gestures, claims that hand gestures, language and thought should be considered as a single distributed and self-organized cognitive system (Goldin-Meadow, 1999; 2003; Goldin-Meadow & Singer, 2003; Goldin-Meadow & Wagner, 2005).

Similarly, studies of the role of mirror neurons for action understanding lead to the hypothesis of a sensory-motor root for the faculty of language (Arbib, 2005), while Michael Tomasello embeds a different version of the sensory-motor hypothesis within a complex conceptual framework including a detailed analysis of the role of gestures, mindreading and cooperation for the emergence of human linguistic communication (Tomasello, 2008).[16]

As we have seen, the basic picture of the faculty of language depicted in HCF is that of a computational system taking a finite set of inputs and producing a potentially infinite set of complex output expressions: from this point of view language is essentially a sound-meaning

[16] Of course, the studies on mirror neurons, on the cognitive role of gestures and on human communication exemplify different theoretical perspectives and are, in some cases, in competition. Moreover, the theories and results are not uncontroversial (cf. Hickok, 2009 for some criticisms of mirror neurons, and Piattelli-Palmarini, 2010 for a criticism of "Piagetian" approaches compared with "Chomskyan" ones). However, these studies are all a part of the same paradigm in cognitive science, a paradigm opposing classical computational cognitive science with the tools provided by the investigations on the active role of the body and of sensory-motor processes for the development and functioning of cognitive processes, from the more basic ones to the more complex and abstract cognitive mechanisms.

pairing system characterized by infinite generative power. One consequence of this view is that every discrete element of the set of input ("lexicon") can be embedded in infinitely many complex expressions, that can be very different in their meaning and structure.

However, the fundamental structure of the motor system does not seem to be different: as biological organisms we have a basic set of motor primitives (the basic movements that our body can perform), and these motor primitives can be arranged in a potentially infinite set of complex motor outputs, which can be different with regard to their structure and global goal.

The study of mirror neurons, for example, has gone from investigation of mirror activation in response to simple motor acts to the problem of understanding how the brain deals with complex motor sequences – that is, with the prior intentions providing the global goal of a simple motor act. Iacoboni et al. (2005), for example, studied how the brain reacts when the same basic motor act (grasping a cup) is embedded in different contexts suggesting different prior intentions (grasping to drink, grasping to clean the table). More specifically, when the bodily movement is performed in the absence of context the posterior part of the inferior frontal gyrus is less active than in the condition of contextualized action. Moreover, within contextualized action "grasping to drink" elicits less activation than "grasping to clean", thereby suggesting the activation of distinct neural chains in response to different intentions embedding the same movement.

Katerina Pastra and Yiannis Anoimolos (2012, p. 107) use these and other data to corroborate the idea that prior intention is the coordinating factor of an action sequence and that prior intention is already observable in the onset of its first sub-action. The global goal of an action is conceived, then, as an "inflectional" or "morphological" feature that modulates its constituents. Now, the very existence of the issue of how the brain deals with the problem of embedding the same motor act in different prior intentions seems to presuppose a model of the functioning of the motor system according to which the system takes a finite set of inputs (the basic motor acts of our motor repertoire) and yields a potentially infinite array of complex motor outputs (complex actions). Pastra and Aloimonos (2012) take this model of the motor system and the evidence of shared neural and computational mechanisms for action and language as starting points for the development of a generative grammar for action based on the principles of Chomsky's "Minimalist Programme" for language. So, for example, according to Chomsky the morphosyntactic features of the verb "grasping" require that the "merge" function start a search routine to find an element that can play the syntactic role "object complement" (i.e., a graspable object, such as a knife), thereby creating the output string "grasp the knife", which can be further embedded in more complex sentences through recursive applications of the merge operation.

Likewise, Pastra and Aloimonos's basic idea is that motor primitives are endowed with morphosyntactic features driving a merge operation among simple motor elements, thereby creating hierarchically ordered complex actions. On this view human actions are characterized by three morphosyntactic features: tool complement, object complement, global goal (Pastra & Aloimonos, 2012, pp. 106-107). So, for example, the complex action "grasping the knife to cut the apple" requires:

1. Using the hand to grasp the knife: in this sub-action the hand is the "tool complement" or effector of the action, while "knife" is its "object complement", the object affected by the action.
2. Using the knife in order to cut the apple. The knife is now the effector of the action which affects the apple.

A case like this, according to the authors (ibid., p. 110), results from a recursive application of the merge operator on two constituents sharing an element (the knife) as object complement and effector respectively and can be indefinitely expanded simply by adding a further constituent with a shared element (e. g. grasp the knife, cut the apple with the knife, push the plate with the apple). Or we could create discontinuous action structures with center-embedding recursion, such as "grasp with $hand_1$ knife—grasp with $hand_2$ cutting board, press with cutting board cloth—cut with knife bread" (ibid., p. 112). The main factor driving merge, in this hypothesis, is played by the "tool complement” feature, or better, by the ability to act on something and to use something to act (ibid., p. 115).

Going beyond a purely functionalistic, computational characterization of the motor system, towards a description of the functioning of the relevant brain areas, the authors take as evidence for this argument experiments (Fazio et al., 2009) showing that aphasics have problems in naming tools and tool use, as well as in sequencing biological actions versus non-biological events (e.g., to serve a cup of tea versus a bicycle falling). This is compatible with studies identifying Broca’s area as subserving goal representation and organization of hierarchical motor chains. For example, Clerget, Andres and Olivier (2013) have recently used on-line repetitive transcranial magnetic stimulation (rTMS) to disrupt neuronal processing of the anterior part of Broca’s area (Brodmann area 45) in healthy volunteers and demonstrated the critical role of this area in planning the higher-order hierarchical levels of motor sequences. Furthermore, the same research team demonstrated by means of a set of virtual lesion studies that the more posterior part of Broca’s area (Brodmann area 44) plays a crucial role in encoding complex human movements (Clerget, Winderickx, Fadiga & Olivier, 2009), in organizing the individual components of a motor sequence before its execution (Clerget, Badets, Duqué & Olivier, 2011), and in motor sequence learning (Clerget, Poncin, Fadiga & Olivier, 2012). These results are convergent with the main findings of the fMRI study performed by Koechlin and Jubault (2006) who found that Broca’s area is involved in processing hierarchically structured behaviours[17]. On this view, then, Broca’s area would be the locus of multimodal hierarchical organization, as previously suggested by Greenfield (1991), and Tettamanti and Weniger (2006) on the basis of ontogenetic, phylogenetic, and computational considerations.

Now, the empirical evidence of disruption of linguistic and motor hierarchical organization in aphasia could lead to a Chomskyan conclusion: a language impairment causes a motor impairment. Therefore, motor-intentional recursion is language-dependent. Fazio and colleagues

[17] Note that a shared hierarchical structure in music, language and action was originally proposed by Lashley (1951) who suggested that a modality-independent mechanism contributes to a variety of complex behaviors that are organized hierarchically.

(2009), however, take the causal/evolutionary route to go the other way round. They hypothesize that “Broca’s area might have specialized in encoding complex hierarchical structures of goal-directed actions, and to eventually apply these pragmatic rules to more abstract domains”. More explicitly, they “speculate that an ancient motor syntax might have evolved into a ‘supramodal syntax’, at the basis of the ‘modern’ linguistic one.” (Fazio et al., 2009, p. 1987).

Philip Lieberman (2006; 2010) corroborates these “speculations” with experimental data identifying the crucial factors of Broca’s aphasia at subcortical level. More specifically, Lieberman claims that “Impairment of neural circuits involving the basal ganglia appears to be the root cause of Broca’s aphasia” (2010, p. 166). He reports converging CT and MRI studies confirming that aphasia does not occur unless subcortical damage is present (ibid.; cf. D’Esposito & Alexander, 1995; Dronkers, Shapiro, Redfern & Knight, 1992; Stuss & Benson, 1986), that a purely cortical lesion does not result in permanent aphasia (ibid., cf. D’Esposito & Alexander, 1995) and that in patients with no cortical damage the most severe language deficits correlate with the most extensive subcortical lesions to “basal ganglia [and] peri-ventricular pathways from the basal ganglia to cortical targets […]” (ibid., cf. Alexander, Naeser & Palumbo, 1987).

Based on these data, Lieberman regards recursion as defined in HCF as a specific example of “a general property of human creative capabilities deriving ultimately from motor and cognitive flexibility […]” (Lieberman, 2010, p. 165), that he calls “reiteration” and that in language works as the neural capacity to “produce a potentially limitless number of words from a finite set of motor gestures” (p. 163). Lieberman also reviews convergent evidence from electrophysiological, neuropsychological and neuroimaging studies on the role of basal ganglia and cortical-striatal-cortical circuits for motor, cognitive and linguistic tasks involving flexibility. Electrophysiological studies of rats with lesions in basal ganglia show that these rats can still perform single motor acts but not complex sequences of the same motor acts (Lieberman, 2010, p. 169; cf. Aldridge, Berridge, Herman & Zimmer, 1993; Berridge & Whitshaw, 1992) thereby confirming that dealing with complex, long sequences of motor acts is a very ancient function involving deep subcortical mechanisms.

Neuroimaging studies of healthy human subjects tested with the Wisconsin Card Sorting Test show activation of the basal ganglia and cortical-striatal circuits both during routine application of established cognitive criteria and during formation and application of new criteria (with increased activation of the putamen in this latter case). Also, basal ganglia circuits to dorsolateral prefrontal cortex are active when subjects change the interpretation of an ambiguous sentence (Lieberman, 2010, p. 170; cf. Monchi, Petrides, Petre, Worsley & Dagher, 2001; Stowe, Paans, Wijers & Zwarts, 2004). Finally, lesions and degenerations of basal ganglia and of their connections to the cortex are associated with impaired cognitive, motor and linguistic flexibility in Broca's aphasia and Parkinson's disease (Lieberman, 2010, pp. 168-169).

While being primarily involved in sensorimotor processing, then, the basal ganglia, via their projections to the cortex, would also be involved in complex circuits responsible for various motor, cognitive and linguistic operations.

One might be skeptical about the specific details of Lieberman's theory, such as the association between flexibility, reiteration (as he defines it) and recursion, though it is an association made also by the supporters of HCF (Fitch, 2010; Brattico, 2010). The crucial point, however, seems to be that ancient subcortical structures designed for performing routine tasks and schemas and for flexibility in motor control play a key role even in a higher-level cognitive process such as language, thereby suggesting a possible embodied root for linguistic recursion.

Liebermann's data, however, might also suggest a slightly different interpretation of the hypothesis that linguistic recursion is embodied in motor-intentional recursion. Perhaps recursion is a general property of the human mind considered as a complex system (Lieberman, 2006; 2010) but realized in distinct and mutually independent neural mechanisms at the cortical level (Pinker & Jackendoff, 2005, p. 230), whereas these mechanisms could have a common evolutionary/causal root in more primitive subcortical circuits involved in motor control.

Perhaps, then, selective impairment of a single recursive device might be due to purely cortical damage or to subcortical damage to the basal ganglia and the projections to a specific cortical area, while more extensive damage to basal ganglia and their cortical projections might lead to a more general damage to higher-level, cortically realized cognitive competencies. If this is the case, then perhaps the hypothesis that higher-level, linguistic recursion is embodied in sensory-motor processes is not necessarily incompatible with evidence showing double dissociation between complex linguistic and motor skills.

4.2 Language and action: two recursions for two distinct domains

Whereas our first hypothesis suggests that linguistic recursion might have evolved from a more primitive motor recursive syntax, a second hypothesis might be that distinct functional domains exploit different and mutually independent recursive mechanisms. This perspective is based on neuropsychological evidence showing that the linguistic and the gestural-motor domains are largely anatomically and functionally distinct. For example, Papagno, Della Sala and Basso (1993) have shown a clear aphasia/apraxia double dissociation. A double dissociation occurs when a well-grounded experimental procedure leads us to infer that there are separable subsystems used by two functions (Shallice, 1988). In a study involving a consecutive series of 699 right-handed patients with vascular lesions in the left-hemisphere, Papagno et al. (1993) found 149 patients to be aphasic (i.e., with an acquired language disorder) but not apraxic and 10 patients to be apraxic (i.e., with an acquired disorder affecting the purposeful execution of deliberate movements) but not aphasic. Interestingly, these authors found evidence of the role of at least partially distinct brain networks at the basis of their results (with apraxic non-aphasic patients having mainly subcortical damage to the white matter and aphasic non-apraxic patients having mainly cortical and basal ganglia damage), a criterion proposed to be crucial to add weight to the inference of separable mechanisms from behavioral double dissociations (Plunkett & Bandelow, 2006). In line with these results, Mengotti et al. (2013) recently carried out a voxel-based lesion-symptom mapping in a group of 57 patients with left brain damage who performed tasks exploring their linguistic and praxic abilities. This technique allows the analysis of the relationship between lesion data and continuous behavioural measures. The data confirm that aphasia, ideational apraxia (a failure to generate the mental image of an intended gesture) and ideomotor apraxia (a failure to implement a mental image into the appropriate motor output) can be observed in isolation. In particular, voxel-based lesion-symptom mapping analysis revealed a dissociation between the left angular gyrus, whose damage specifically affected imitation of meaningless gestures (but not linguistic abilities), and the left superior temporal sulcus and the insula, whose damage specifically affected linguistic (but not praxic) proficiency. Mengotti et al. (2013) hypothesize that praxic performance and linguistic performance tend to associate when the gesture to be imitated has a meaning for the imitator, and to dissociate when the gesture to be imitated carries no meaning. Taken together, these results are relevant as they suggest that although it is clear that language interacts with motor experience (e.g., Bedny & Caramazza, 2011), the often observed clinical association between aphasia and apraxia (e.g., up to 90% of patients with apraxia also have aphasia, see Geschwind, 1975) is at least partially due to the encroachment of the lesion upon contiguous brain structures and not necessarily to a common functional organization of language and praxis.

These neuropsychological data suggest that a damage to the linguistic domain may have few or no implications for the domain of intentional action, and vice versa, and thus they support the hypothesis of non-syntactic recursion outside language. Although in a Chomskyan view this kind of evidence pertains to the performance level and not to the competence one, it is appropriate to recall here a question raised by Zimmerer and Varley (2010) according to which if competence cannot be disrupted by brain injury, then it is not a property of the brain.

As we have seen, in fact, HCF's competence-based approach rejects string or output-oriented counterexamples on the grounds that the existence of a recursive competence cannot, computationally speaking, be decided based only on the absence or presence of recursive strings or output behavior such as grammaticality judgments. On this view, evidence of a double dissociation between linguistic recursion and recursion in other cognitive domains would be simply irrelevant as a counterexample to HCF, as double dissociation would give us information concerning just the use of a property, which would be irrelevant for the issue of the existence and realization of the property itself.

But it seems to us that, in a case like this, a great part of the issue consists in solving the epistemological problem of who has to bear the burden of proof. That is: one can accept the logical constraints of a competence-based approach like HCF, provided that it clearly states the conditions under which the hypothesis at issue can be empirically falsified.

4.3: Recursion in language and action: some methodological concerns and reflections

We have argued thus far that recursion can be found in the logical structure of intentional action, and that some evidence from cognitive science and neuroscience could corroborate the hypothesis that motor-intentional recursion is language-independent, allowing us to work out some explanatory hypotheses concerning the relationships between motor and linguistic recursion. We asked, both with respect to AGL tests and with respect to double dissociation between language and intentional action, what the conditions are under which HCF's hypothesis could be false. We could ask, more generally: what counts as a test for recursion?

Both HCF and related works insist, indeed, that the hypothesis that recursion is the only component of FLN is empirically falsifiable (cf. for example, Fitch, Hauser & Chomsky, 2005, pp. 183, 188, 193), even though input-output behavior (in the form of grammaticality judgments and presence or absence of recursive output strings) does not allow us to decide whether a system is based on recursive mechanisms (Fitch, Hauser, Chomsky, 2005, pp. 203-204 on Pirahã; cf. Fitch, 2010).

Now, if we go through HCF we find that a great part of the paper aims to show that the conceptual/intentional system is substantially shared with non-human animals, and that the same holds for the sensory-motor system. But these points simply preclude (if true) that these systems can be a part of FLN as defined in HCF. HCF actually provides very little (if any) empirical evidence that there are recursive mechanisms underlying the faculty of language. HCF simply states that "All approaches agree that a core property of FLN is recursion", or that "At a minimum, then, FLN includes the capacity of recursion" (HCF, p. 1571), where the "then" derives from the premise that the faculty of language is capable of discrete infinity (a result that could be achieved equally well through iterative mechanisms). True, HCF also claims that recursion is a neurally implemented device and not just a notational convenience (p. 1574), and cites "Studies of serial order learning and finite-state grammars in tamarins and macaques" together with "Studies exploring symbol sequencing and open-ended combinatorial manipulation" (p. 1573) among the empirical evidence concerning FLN – that is, exactly the kind of evidence that Fitch (2010) disqualifies from being tests for recursion.

When it comes to the issue of what counts as a test for recursion Fitch (2010, pp. 81-83) holds that meaning can be considered as an "empirical indicator" of structure: that is, if we interpret him correctly, we could empirically investigate whether a system is able to distinguish the change of meaning in sentences such as "John is approaching the dog" when transformed in "The dog is approaching John", or to understand the identity of meaning in sentences such as "Mary loves John" and "John is loved by Mary". We could then conclude that recursive structures underlie this cognitive ability, because the change of meaning in these sentences depends on syntactic transformations. However, we might doubt whether such an experimental setting would test the recursive syntax of FLN alone (which, by hypothesis, contains only narrow syntax and the mappings to the interfaces). What if semantics itself were genuinely (that is, independently of syntax) recursive? Some theorists believe that syntactic recursion might derive from the need to express inherently recursive conceptual structures, including those of the theory of mind (Anderson, 1997; Corballis, 2011, cf. *infra*, note 4). Still others believe that syntactic recursion derive from learning – a "usage-based" theory of recursion recently developed by Christiansen and MacDonald (2009) on the grounds of the Simple recurrent network models (Elman, 1990).

Of course each one of these alternative views is controversial, but the issue is whether Fitch's meaning-based model can help us in deciding for or against them. Actually, Fitch's proposal seems able to tell us whether language is recursive, but it cannot say what system makes it recursive (semantics? syntax?)[18].

Corballis (2007) and Traxler and colleagues (2012) review some work in animal cognition based on the AGL test and arrive at the same conclusion as Fitch, because the experimental paradigm used in studies such as Gentner (2006) induces the structural hierarchical relationships among A and B elements by means of cues which are external to the elements themselves. In a typical experiment (Fitch & Hauser, 2004) pitch information marks the difference between A and B elements, but this has the effect of allowing experimental subjects to issue correct judgments which are not based on the correct parsing of a recursive structure, but rather on a more simple counting mechanism: given a sequence such as AAABBB one can interpret it as {A[A(AB)B]B} or counting the number of A elements and check if it fits the number of B elements. As Traxler and colleagues report, this strategy is also used by human beings in experimental settings: they pass the test when stimuli are presented with pitch information, but not without it (Traxler et al., 2012, pp. 614-615; cf. Perruchet & Rey 2005; see also Hochmann et al., 2008).

According to Corballis and Traxler and colleagues a way for testing recursion could consist in improving the AGL paradigm so that it can exclude the use of counting strategies. The stimuli should have the form $\{A_1[A_2(A_3B_3)B_2]B_1\}$, where each element is unambiguously paired with the corresponding one on this other side. Bahlmann and colleagues (2009), for example, apply this experimental paradigm to visual perception: the visual stimuli are abstract, meaningless shapes divided into A and B categories based on different texture and orientation. A_1 and B_1, in this setting,

[18] We could also note that this setting could not be used in animal studies. Indeed, Fitch himself admits that "In animals the more direct neuroscientific route, mapping out the neurophysiology and connectional anatomy, probably remains our best bet at present" (Fitch, 2010, 83). But in order to apply neuroscientific techniques in animal studies, we would need first to know how to identify the behavioral traits which are specific to recursion – in other words, we would need to develop a behavioral test for animals different from the traditional AGL paradigm and from Fitch's meaning-based paradigm. Therefore, Fitch's paradigm has nothing to say about whether recursion is human-specific. Also, Fitch says nothing about the possibility of extending his method to nonlinguistic cognitive domains. Indeed, the study of visual recursion made by Martins and Fitch (2011), cited in Martins (2012), does not make use of meaningful visual stimuli – rather, it uses meaningless geometric shapes.

present the same meaningless shape with different texture and orientation. A_2 and B_2 present another shape with different texture and orientation, and so on. Note that a counting strategy could not identify a sequence such as $\{A_1[A_3(A_2B_3)B_2]B_1\}$ as incorrect, and that this method still permits the testing of syntactic competencies without making any use of meaning. This paradigm has also been used to test natural language (Makuuchi et al., 2009), and artificial grammars (Bahlmann et al., 2008), allowing Friederici, Bahlmann, Friedrich and Makuuchi (2011) to hypothesize that Broca's area, consistently activated by hierarchical sequence processing in these studies, receives its domain-specificity as a part of a particular network which differs from domain to domain. On this view, Broca's area in a network together with the posterior superior temporal cortex subserves the processing of hierarchically complex natural language sentences, whereas Broca's area as part of a larger network involving the pre-motor cortex, the pre-SMA and parietal regions, subserves the processing of non-linguistic visual-spatial event sequences.

Now, if this is a valid experimental paradigm for recursion, it should not be difficult to extend it to test hierarchical sequence processing in the domain of action and to test whether motor-intentional recursion is language-independent (i.e., by using the paradigm in lesion studies or with TMS techniques to test double dissociation). Of course, adopting such an approach requires us to soften the strong decoupling between competence and performance which is typical of HCF and related works (cf. Lobina, 2011), and that puts HCF's hypothesis in danger of being untestable (Traxler et al., 2012, pp. 617, 619).

True, behavioral evidence of double dissociation might relate to performance rather than competence, and AGL tests deal with input-output behavior alone, without observing directly the "source code", the implementation of the cognitive mechanisms involved. But when these data are compared with data concerning the structure and function of relevant neural circuits, then they reveal something more than a mere behavioristic, stimulus-response connection. After all, HCF (p. 1574) conceives of linguistic recursion as a neurally implemented device, not just as a useful theoretical tool.

So, if it sounds plausible that competence is in principle not accessible via input-output behavior (such as grammaticality judgments and recursive output strings), that double dissociation could be due to a performance deficit, and that syntactic competence could survive in spite of severe brain damage that makes it inaccessible to its own original cognitive domain, then it should sound at least equally plausible that "the performance deficit claim […] becomes weaker the severer the damage to the brain is", and that "the null hypothesis should be that a patient not showing recursion in syntax does not have it, since there can be no evidence for absence" (Zimmerer & Varley, 2010, p. 402).

5. Conclusion

In this paper we examined the issue of whether recursion is language-specific starting from HCF's hypothesis that recursion is the only constitutive mechanism of the faculty of language.

The analysis of the structure of intentional action has led us to hypothesize the presence of recursive mechanisms at the level of motor intentionality. Intentions (both simple intentions-in-action and complex prior intentions) are satisfied if and only if the corresponding action is realized in a specific way as a causal effect of the intention. Developing Searle's analysis, we have argued that this point requires that the intentional content takes into account this causal relationship by way of representing the intention itself as causing its own conditions of satisfaction. If this is correct, then intentions have a self-embedding structure that, in complex intentions, can produce long-distance relationships between prior intentions and subsidiary actions and, via the accordion effect, infinite generativity. Moreover, current empirical research on motor primitives points out the possibility of specifying some basic elements of action that do not change their relevant aspects under embedding in different complex actions.

If this analysis is correct, in other words, then the central features of linguistic recursion (self-embedding, long-distance dependence, identity preservation, infinite generativity) are already present in motor intentionality. Moreover, since our analysis focuses on motor-intentional competence, it cannot be answered with usual objections to string or output-oriented criticisms to HCF that we examined in this work.

We suggested two hypotheses, which are compatible with currently available evidence from cognitive science and neuroscience, to explain how motor-intentional recursion might be independent of linguistic recursion. On the one hand, in the spirit of situated views of cognition (Varela, Thompson & Rosch, 1991; Clark, 1997; Hurley, 1998; cf. Garbarini & Adenzato, 2004; Vicari, 2011) linguistic recursion might be embodied in sensory-motor processing: studies on the motor roots of human communication, on mirror neurons and on the role of Broca's area in goal representation and action planning, together with data on the role of basal ganglia for language can corroborate this hypothesis. On the other hand, evidence of dissociation between recursion in language and in other cognitive domains (such as mathematics and theory of mind), together with evidence of double dissociation between aphasia and apraxia, corroborates the hypothesis of distinct and independent recursive devices for language and action.

However, the two hypotheses are not necessarily incompatible: it is also possible that higher-level recursive structures and processes are realized in separate mechanisms at the cortical level, but also that these separate mechanisms are all subserved by more ancient, subcortical mechanisms involved in motor control, such as the basal ganglia, that also play a significant role in higher level cognitive functions. Selective damage to the cortex and/or to the basal ganglia and their projections to the cortex might lead to selective damage to one single cognitive domain with few or no effects on other cognitive skills, while degenerative, progressive damage to subcortical mechanisms and their projections to the cortex might lead to impairment in several complex, cortically realized cognitive functions (as in Parkinson's disease).

Even if we are right in claiming that recursion is not language-specific, then, the issue of the relationships between motor and linguistic recursion is clearly complex and needing further investigation to assess various explanatory mechanisms.

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