The compatibility within a modular framework of emergent and dynamical processes in mind and brain

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A R T I C L E   I N F O

A B S T R A C T

In the light of the continuing controversy over evidence supporting emergentist and non-emergentist accounts of cognitive and brain development, this commentary compares the proposals for a neuroemergentist framework for studying cognition and the brain (Hernandez et al., in press) and compares it with the Modular Cognition Framework (MCF) also known as Modular Online Growth and Use of Language (Truscott & Sharwood Smith, 2004). Both approaches are intended to optimise the exploration of relationships between mind and brain. The purpose of this comparison is to show that evidence that suggests emergentist and dynamical traits in development and processing can equally be seen as the product of a modular mind with a stable set of independent systems each with its own properties and mode of operation, all basically in place at birth. The fluid dynamical character of performance and the flexible adaptive responses of the mind to a constantly shifting environment can, in other words, also be explained by the way modular systems collaborate and generally interact to solve a continuing flow of tasks. Some key aspects of the MCF are introduced to elaborate on this claim including the way in which structures of different types, created in different modular systems. are associated and used in different combinations to solve tasks during processing as also the effect of shifting resting levels of activation. The discussion concludes with an MCF perspective on bilingual development and behaviour with special reference to how more than one language can coexist in one mind and the cognitive advantages of bilingualism.

1. Introduction

The need to coordinate in some non-haphazard and purely individual way the complex relationships between brain and mind function should be quite clear. For this, a choice of overarching theoretical frameworks is sorely needed and Hernandez et al. have provided one interesting alternative (Hernandez et al., in press; Sharwood Smith, 2014; Truscott & Sharwood Smith, in press).

Neuroemergentism just like any other form of emergentist architecture needs to be compared with various kinds of modularity proposed in the cognitive science literature. If 'modular' means simply possessing specialised functions, the modular nature of both brain and mind is very difficult to deny. Despite exciting work on neuroplasticity and, for instance, how visually impaired people can recruit the resources of their auditory cortex and use echolocation, there is not much mileage in claiming that any part of the brain's anatomy may be recalibrated to perform in an identical manner the function of any other or that the human brain is not bound to develop specialised system from the moment life begins in the womb. The architecture of the mind on the other hand might conceivably be explained in a quite different way as being totally open and non-specialised but is surely best designed to have at least

some indirect relationships with the way the brain is structured and functions as is exemplified in the neuroemergentist account. The devil is of course in the detail: to what degree are specialised systems isolated or encapsulated from each other and how much does their development during life adapt flexibly to the internal and external stimulation provided by experience.

2. Emergentism and the MCF

Emergentist accounts of the mind assume a relatively unconstrained account of development whereby complex systems emerge from simpler ones in response to different experiences and are adapted in distinctly different ways from individual to individual. However, it will be suggested here that complexity and individual variation can also arise through the interaction of stable, specialised systems in response to experience without sacrificing their inherent modularity. For Karmiloff-Smith, for example, much of modularity claimed by others has always been a product of ontogenetic development rather than an account of the initial state (Karmiloff-Smith, 1993). Neuroemergentism seems to follow the same line of thinking. In other words, the (neural or mental) system as a whole begins its life with basic specialisations and then, as a result of continuing interaction with the environment, more complex specialisations 'emerge' as the basic architecture is adapted to cope more effectively with the world. As the examples provided by Hernandez et al. show, some adaptations can be carried out ontogenetically whereas others, like the giraffe's neck require more time and so appear in phylogenetic development. Again, phylogenetic adaptation of the kind described here has not been in question: it is ontogeny that is the area of dispute together with the nature of the architecture at its initial state, that is to say, at birth. For example, take language. Those espousing a generative linguistic perspective based on the idea of an innate 'language module,' – or less misleadingly, a 'grammar module' - propose an encapsulated system whose function is to constrain the shape in which grammars develop in the minds and brains of language acquirers. The process whereby the complex grammatical system of any particular language to which the child is exposed emerges is constrained by this modular facility that only humans possess. This still permits a variety of outcomes albeit reflecting the application of properties and principles that pertain to particular input the child receives. In this way, small cognitively immature, untutored and unreflecting children begin with a relatively simple grammatical system end up regularly and quite quickly with a complex grammatical system many years before they are able to acquire any kind of knowledge of similar complexity. This they typically do intuitively, without instruction or corrective feedback. Speech to babies and foreigners alike is mostly aimed at facilitating comprehension not grammatical development and so it becomes more grammatically complex only in response to evidence from the learner that they have advanced further. Note, however, a crucial feature missed by many critics of this approach. Grammars are not, however, languages. A great deal of what people would generally include as belonging to 'language' is not included in the narrower concept of a grammar. Even some aspects of grammar as used in everyday, traditional usage, do not fall under this definition. In other words, the so-called language module is defined, it directly constrains only some aspects of linguistic growth. This important point will be developed further shortly.

The defining core language ability may be seen phylogenetically as something that has evolved over a relatively short period in evolutionary terms from a less specialised brain (see, for example, Berwick & Chomsky, 2016). However, even ontogenetically, there is much development that could be described, at least in some sense as dynamical and emergentist in character, all of which in fact turns out to be perfectly compatible with the stricter forms of modularity. For one thing both neural and mental modular systems already possess internal flexibility: this is needed to cope with repeated novel examples of the kind of input they are specifically geared to process. Secondly, modular systems can interact in various ways and the outcomes of their interactions can produce the kind of complex behaviour which could be interpreted using dynamical systems or other types of emergentist analyses (Sperber, 1994; Carruthers, 2006; see discussion in; Truscott, 2015, p. 31). I will try briefly to illustrate this later in connection with bilingualism.

Making links between brain and mind is to relate two different levels of description (and explanation), the neural and the cognitive, so it is commonplace for people to assert that there is no one-to one relationship between a function at one level and a function at another. By the same token, emergentism as a way of describing mental architecture does not necessarily entail an emergentist account of neural architecture and vice versa: all options are on the table. Neurocognitivism appears to espouse emergentist explanations at both levels. On the neural side, the brain, stimulated by environmental demands, adapts or fine-tunes its various specialised areas, such as the fusiform gyrus, to effectively make them more specialised, in this case resulting in the emergence of face recognition ability. As discussed by Hernandez et al. concepts used by authors sympathetic to this basic approach such as *re-use, reconfiguration* and *recycling* are employed to describe this process of adaptation. To a greater or lesser extent these terms might all be applicable to a neurocognitivist representation of how mental functions develop. The question really comes down to whether these processes work across the board in a relatively unconstrained manner during the lifetime of an individual, accounting for almost everything that happens, or whether there are specific biological constraints imposed by the functional architecture from start to finish. The debate is naturally complicated by the fact that very few of the areas chosen for the evidence seem to be free of controversy. Take the face recognition example. A critical review of the development of face-recognition in 2013 by McKone et al. strongly suggests to the authors that despite long held beliefs that face recognition develops, slowly driven mainly by experience, almost the reverse is the case: infants are born already equipped with a rich capacity to represent the structure of upright faces. Put another way, what does get fine-tuned through experience is a system which is already specific to faces. This goes against the idea of experience fine-tuning or adapting more basic mechanisms (McKone, Crookes, Jeffery, & Dilks, 2012).

Given the continuing controversial nature of the evidence, it seems more profitable at the moment to consider how neuroemergentism fares when compared with a framework which espouses a greater degree of continuing functional specialisation, from birth onwards, while still allowing for some of the outcomes that any emergentist would expect and regard as important. The one chosen for this discussion is also one that has concerned itself thus far mainly with bilingualism. I refer to the Modular Cognition

Framework (MCF) that is better known within the psycholinguistics and language acquisition literature as the Modular Online Growth and Use of Language (Sharwood Smith & Truscott, 2014; Sharwood Smith, 2017; Truscott & Sharwood Smith, 2004, 2018).

The MCF is primarily concerned with mental rather than neural functioning although it is, at the same time, designed to facilitate the discovery of meaningful relationships between the mind and the brain. A central tenet is that language engages multiple areas at both these levels of description: processing language therefore involves the parallel processing in various combinations of these various systems including those systems that are specific to language alone (Jackendoff, 2011). Language cognition turns out to be a good way to begin an account of cognition in general. Since the representational properties and processing of language have been investigated in great detail for some time and since as just mentioned language behaviour implicates many areas of mind and brain, it provides an attractive window through which to observe the functioning of other less intensively researched kinds of cognitive representation.

As its name indicates MCF is also a modular framework so this requires some elaboration given the many ways in which modularity may be understood. Perhaps the most important distinction in MCF that bears on the present discussion is the difference between those systems that are specific to language and those that are also extremely important for language are nevertheless not exclusive to language and in most cases where processing language is a secondary function. Any of the arguments used to show the value of emergentist or dynamical systems analyses of language focus on areas which MCF designates as falling into the second 'secondary' category. Lexical knowledge is the most obvious example. The way words and phrases are acquired and processed as also the ways in which linguistic structures are used in specific contexts – their pragmatic use – involve some systems that fall outside the domain of what defines human language. This has to do with meaning, specifically the structures that are created as a result of acquiring words and phrases. In other words, as language proficiency develops in an individual, there is a growth of complexity in those parts of the mind that handle meaning, i.e. what is termed the semantic or rather, in MCF, the *conceptual system*. This development continues through the lifetime as new words and phrases are acquired. Where more than one language is involved, there will be further growth in complexity within the conceptual system. This happens wherever new combinations of conceptual properties are required to represent the meaning of the new word, particularly in the case of concepts that do not exist in other languages in the mind of the individual concerned but also where equivalents in the different languages are not semantically identical.

The way conceptual structures (CS) are created, stored and processed in MCF is handled by the conceptual system. This in MCF, should not be understood as a generic, domain-general system and therefore not modular. Psychologists and linguists including some exponents of modularity will often refer to domain-general learning (e.g. Fodor, 1983). Rather, the conceptual system in MCF follows unique principles determining the way CS are processed in the same way as visual structures (VS) representing visual experience are built according to a set of principles that is not shared by other sensory perceptual systems. In this way, the creation of CS and VS in response to experience contributes to a human individual's, respectively conceptual and visual cognition each in its own unique manner. In both cases, the acquisition of each structure (aka representation) will impact on the current network of structures that the individual has already created.

Moving beyond conceptual development alone, the growth of an individual's lexical store should be explained comprehensively as the result of a collaboration between a number of modular systems and their respective processing principles. This still may not necessarily implicate linguistic principles. An auditory structure created in the individual's (generic) auditory system on being exposed to a speech sound like "walk" can, at least in principle, be associated with a given meaning (CS) without the involvement of anything we might call language-specific. The same goes for a visual sign linking a VS to a CS. Such AS-CS or VS-CS pairings result in 'words' in some primitive sense, perhaps a 'pseudo-word' since in this example, it has no syntactic or phonological structure associated with it. Amassing a smallish repertoire of such pseudo-words is clearly within the grasp of other species close to us on the evolutionary scale. This can include more than the primates. Whether or we not we attribute to canine cognition a simple version of the conceptual system, any dog is certainly capable of associating a meaning with the sound of the word 'walk'. In the case of humans with their vastly superior conceptual capacity (which may be associated with the size and complexity of human prefrontal cortex), it is in principle, possible to acquire a much larger number of pseudo-words than even the impressive bonobo, Kanzi could manage (Savage Rumbaugh & Lewin, 1996; see discussion in Sharwood Smith, 2017: 156–158). The kind of collaboration required to make words into linguistic structures, however, requires the further collaboration of the phonological and syntactic modules. Neither dogs or bonobos possess these resources for processing sounds and signs. Together these two species specific components constitute what is otherwise popularly called the language module (Jackendoff, 1987). Only then can they be integrated into larger constructions like sentences and be treated as genuine 'linguistic' words rather than pre-linguistic or pseudo-lexical items. It should be pointed out here that the MCF follows closely the lines laid out in Jackendoff's architecture of the language faculty and not the mainstream Chomskyan account (Jackendoff, 1987, 2002).

In practice, the parallel processing of AS, CS and VS will typically trigger the additional involvement of linguistic processing because, by hypothesis that is the way in which humans will automatically behave even where they do not yet possess existing linguistic structures to match up with the AS or VS, as would happen when listening to a radio broadcast in a totally unfamiliar language. The mind will still make spontaneous attempts to create the full repertoire of associations required for language processing.

It should be clear by now that if linguistic or any other type of cognitive behaviour arises through a continual interaction of various different but all nonetheless modular systems in response to ever changing environmental input, the behaviour of any one unique individual might be viewed as having an emergentist and dynamical character. Whereas, say, conceptual or syntactic or visual performances taken in isolation will not show the emergence of complex structures from simple ones in the way favoured by emergentists, the combined performance may do so. Also, there will also be emergence within modules but it will constrained by the principles pertaining to the module in question, in other words not according to the standard interpretation of emergence. In addition, in MCF, every cognitive structure has a given *resting level of activation*. This renders it more or less accessible for online

processing at any given moment. This means that in an act of processing, there will always be intense competition within each system (conceptual, visual, motor, etc.) before a best-fit match is found for each type of structure (CS, VS, MoS etc) required to form the combined structural chain or network being formed online to solve a given task.

There are in fact two aspects of activation that make typical behaviour flow in a dynamic fashion. Competing structures within, say, the visual system, in order to represent some visual input will have different resting activation levels due to their prior processing history. Newly acquired structures will much of the time be relatively less accessible. During online processing, the more accessible structures, other things being equal, will outcompete the less accessible ones and they will participate in the currently activated structural network. Secondly, resting levels are not really resting: due to constant processing activity and interaction with other structures with different activation levels with which they might be associated their accessibility may be variably boosted or depressed. Despite the fact we are still talking about stable modular systems whose operation always remains the same, this makes for very changeable and not completely predictable behaviour and also much individual variation in development.

Finally, as regards the issue of cognitive advantage, the adoption of a multiple system perspective such as the MCF can cast light on how bilinguals both suffer disadvantages and at the same time display increased ability in areas commonly described as executive function. In MCF, the systems available for developing linguistic ability in one language ability are identical to those used to acquire two or three or more languages. There is no separate facility created in the mind or brain for accommodating more than one language in an individual mind or brain. The ways in which two separate language systems, say, are created, stored and processed online is based on the resulting associations between structures in all the various systems (more specifically their 'stores': Sharwood Smith & Truscott, 2014). The two linguistic (syntactic and phonological) systems in the MCF handle the phonological and the syntactic structures associated with all languages *blindly*. That is, neither syntax nor phonology has any way of 'knowing' what language they happen to be processing. The identity of a given language required for switching between languages or inhibiting one in favour of the other is determined by non-linguistic systems: if there is one place where the language identity is represented, it is in the conceptual system so a given auditory structure (AS) represent the sound of the English word 'house' will get associated with a CS in the conceptual system identifying this as an English sound. The same holds for a written word except it is a VS that is paired with a CS. The AS of 'house' will also be paired with a phonological representation (PS) defining its speech structure and this in turn will be paired with a corresponding syntactic structure (SS). Every time the AS of 'house' is processed it will trigger the language ID in conceptual structure as well as the CS representing the meaning of 'house'. As we know from the pycholinguistics literature, the activation of the 'house' meaning (a CS) will also trigger all other chains of associated structures as well: for example, a Spanish-English bilingual will have every structure pertaining to 'casa' activated as well despite English being the current language in use. This competition ought to create continual confusion but, put briefly, the individual is processing many other aspects of the situation which render English currently more important and consequently boosting the activation levels of the English set of structures and/or inhibiting the Spanish one (for more details see Sharwood Smith, 2017). If, however, in cases where the individual in question is not a balanced bilingual and, say, the Spanish happens to be the stronger, dominant language, the 'casa' network may not get sufficiently inhibited during the use of English and in this situation a disadvantage of bilingualism will become apparent as 'casa' interferes with 'house' This will producing both hidden and observable crosslinguistic effects (Truscott & Sharwood Smith, 2016).

The cognitive advantage of bilingualism, i.e. increased cognitive control in non-linguistic tasks as well is predictable within an MCF perspective. Controlling which language you use is a function located in *non*-linguistic systems, in particular the conceptual system which we see as strongly associated with the PFC, the brain region of the brain most commonly associated with executive functions at the neural level of description. This system gets much extra practice due to the continued co-activation of languages in bilinguals even where only one language is currently relevant. This provides a particularly good example of how language activity, irrespective of the existence of any language-specific modular sub-systems, engages the whole mind.

3. Conclusion

The Hernandez et al. proposal is an interesting and challenging contribution in an area that needs further development, namely, the creation of broad-based theoretical frameworks through which individual, more specialised areas of cognitive science, including neuroscience, can be studied together to reveal common principles in the functioning of both mind and brain. The bottom line in this particular commentary is perhaps as follows: if we emphasise only the contrasts between generally quite distinct alternatives to understanding how the mind works, this can obscure possible ways in which both are open similar ways of analysing the empirical evidence. I have tried in the short space available to give some flavour of how a highly modularised architecture such as the MCF can cope with the kind of evidence that is usually taken to support emergentist points of view, including neuro-emergentism. This it does by exploring the effects of collaboration between modular systems during processing and the consequences of shifting levels of activation. I am not sure whether some integration of the two perspectives might be emerge in the process but in any case, pitting one against the other should be a productive enterprise and help, amongst other things, to promote more understanding of apparently radical alternatives.

Acknowledgements

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jneuroling.2018.04.010.

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