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The inception of simulation: a hypothesis for the role of dreams in young children

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Abstract

In the present paper, we present an argument and an initial model connecting research into the functional role of dreams with simulation theories. Traditionally, although theories that describe the refinement of simulations exist, the origin of these simulations is not considered in detail. Similarly, research into the functional role of dreams tends to focus on adults, with less regard to the dreams of young children.

Here, we suggest that a functional role of dreams in infants through to early childhood may be the inception of these simulations. We show that the proposed model can present a unified explanation for functions of both the phenomenological experience of dreaming as well as other aspects of brain activity during sleeping, *e.g.* the processing of memories. Additionally, it explicitly provides an account for the development of simulations in early childhood, hypothesising that an initial function of dreams is the inception and development of simulations.

Keywords: Simulation Hypothesis; Dream functions; Cognitive Development

Introduction

Where do simulations come from?

With its roots dating at least as far back as the British empiricists, the simulation hypothesis (Hesslow, 2002) (note that this is somewhat different from simulation theories (ST) in research on other minds, *cf.* Carruthers & Smith, 1996) explains features of cognition associated with having an inner world in terms of reactivations of bodily states (Svensson, 2007). That is, the adult brain has the capacity to - through anticipatory and associative mechanisms - recreate the same neural context as during previous interactions with the environment in sensory-, motor-, and somatosensory areas of the brain. In simpler terms, cognition is explained as coupled chains of simulated actions, (*i.e.* redeployment of motor brain areas; see Anderson, 2007a,b), and simulated perceptions (*i.e.* redeployment of sensory and somatosensory brain areas). Thus, an essential aspect of the simulation hypothesis is the ability to predictively associate a particular action with its consequences in different circumstances and the recreation of previous multimodal states.

Evidence has been provided for simulated actions and perceptions in several different areas, *e.g.* motor imagery (*e.g.* Jeannerod, 1994), visual imagery (Kosslyn & Thompson, 2000), bodily imagery (*e.g.* Gibbs & Berg, 2002), action understanding (Rizzolatti, 2005), and language (*e.g.* Glenberg & Kaschak, 2002). For a recent review see Barsalou (2008). Furthermore, there are a number of theoretical (*e.g.* Barsalou, 1999, 2008; Grush, 2004; Hesslow, 2002) and computational models (for a review see Marques & Holland, 2009, *e.g.* Shanahan 2006; Ziemke et al. 2005) of the functionality of simulations and their neural substrate.

However, current accounts of simulation do no address the question of the phylogenetic origin and how simulations develop in the child. Hesslow (2002) emphasized that simulation theory explains cognitive functions in terms of phylogenetically older brain functions, i.e., functions that evolved to allow mammals to eat, move and reproduce. Thus, it might be possible to claim that part of the explanation can be offloaded to the explanation of the evolution and development of perception and action processes themselves. However, while some of the basic neural substrate for developing simulations, such as the ability of the cerebellum to learn sensorimotor contingencies (*cf.* Svensson et al., 2009), might have an evolutionary origin, it is quite clear that simulations have to be learnt during the life-time of an individual. Not only does the world change at various time scales, our body grows and changes in unexpected ways, which means that inner models (or, in simulation theory terms, simulations) must be quite plastic (*e.g.* Wolpert et al., 2001). There is thus a necessity for an explanation of what guides the initial formation of the predictive associations between motor and sensory areas of the brain, resulting in simulations that are independent of the current environment. Although some accounts of simulation have touched upon on it (*e.g.* Gallese, 2003; Grush, 1995), a coherent account of the origin of simulation is largely missing. In the present paper, we argue that such an account can be given by considering the function of dreams in infants and young children.

It should perhaps be pointed out that the origin of simulations is not the same question as that of the origin of representations, which has been extensively discussed in cognitive science (*e.g.* Bickhard & Terveen, 1995). The account of how simulations develop in humans that we seek to establish does not for example entail explaining intentionality and representational content which an account of the emergence of representation would include. However, this does not preclude that it can contribute to the understanding of how intentional states develop (cf. Brinck & Gärdenfors, 1999).

What is the function of dreams in early life?

There is no certainly lack of theories regarding the functionality of dreams. A popular current example is the theory that dreams are used to simulate threats (Revonsuo, 2000). This Threat Simulation Theory (TST) is interesting especially as it is one of the few that attempts to identify an explicit function of the phenomenology of dreaming including the narrative nature of dreams. This is in contrast to several theories that identify functions of, for instance REM sleep without addressing the phenomenal levels of dreams or even the narrative organisation. A popular idea in this line of reasoning is that dreams are involved in memory processing (*e.g.* Hobson 1994 or Crick & Mitchison 1983, 1995). A related theory proposes that dreams are a series of events (influenced by the dreamer's past) within a model of the world in which the dreamer actively participates (Foulkes, 1985). However, as Revonsuo (2000) points out, there still is no function to the narrative beyond "producing novel and unique mnemonic configurations". A different approach theorises that dreams may allow us to deal with emotional concerns (*e.g.* Hartmann, 1998).

For a more complete discussion of these theories briefly mentioned above, see for instance Revonsuo (2000). In the context of the present paper, however, the critical insight is that most, if not all, of these theories aim to identify a functional role that is relevant for *adult* life. Pre-adulthood dreams are typically only cited to support the theories; Revonsuo (2000) for instance cites evidence that children's dreams feature more dangerous animals than adults in favour of his threat simulation theory while Valli et al. (2005) lists dreams of traumatised children as additional support for the same theory.

Domhoff (2001) summarises several relevant studies (Foulkes, 1982, 1999; Foulkes et al., 1990) to illustrate a few key features of children's dream. Most importantly, dreams of children appear to be different from those of adults in that they exhibit a different frequency and cognitive structure until the child reaches an age of around 9-11 years old. Further, Domhoff (2001) notes that dream reports from children below the age of around 11-13 years differ from adult dream reports in length and content. Specifically, dreams of young children under the age of 5 appear to be "bland", featuring mainly static imagery. Between 5 and 8 years old, dreams do contain interactive characters but the narrative does not appear well developed. Overall, Domhoff (2001) concludes that "visual imagination may develop gradually and may be a necessary cognitive prerequisite for dreaming".

It is therefore clear that one cannot compare dreams of adults with dreams of children since the latter tend to be much less sophisticated. This makes it unlikely that theories such as Revonsuo's TST (Revonsuo, 2000) apply to children's dreams. On the other hand, even though the phenomenological aspects of dreams my appear impoverished in children when compared to adult's dreams, there is no reason to believe that they may not serve a function.

In the remainder of this paper, we outline the hypothesis that dreams in young children may in fact play a crucial role in the inception and refinement of simulations. This is motivated in part by the ontogenetic hypothesis (Blumberg, 2010; Roffwarg et al., 1966) of the function of children's dreams, namely that the large amount of REM sleep at the beginning of life can be explained by a need for endogenous stimulation of the nervous system, especially higher cortical areas, which "may be useful in assisting neuronal differentiation, maturation, and myelinization" (Roffwarg et al., 1966, p. 616) of these areas. Thus, the ontogentic hypothesis focuses on the neurophysiological aspects of brainstem induced cortical and muscle spindle activity, rather than a possible function of the conscious experiential aspect. Of interest to our hypothesis, the motor activity initiated by the brain stem, visible as twitches during REM sleep (Blumberg, 2010), is able to assist in the formation of sensory anticipations (*cf.* Blumberg, 2010). Thus, the spontaneous production of motor activity during REM sleep, might be play a role in triggering the formation of simulations, in particular, simulated sensations and perceptions. It might possibly also explain why simulated actions play a crucial role in simulations (*cf. e.g.* Cotterill, 1996, 2001; Hesslow, 2002).

Specifically, we therefore argue in this paper that dreams and simulations form a bootstrapping process in which dreams help creating and refining simulations which are then used within dreams to generate narrative content. We show that this hypothesis is both consistent with available evidence and compatible with theories related to the functions of dreams in adults as well as the position taken by Domhoff (2001).

The role of dreams in the inception of simulations

There are interesting parallels between the insights from research into dreams and the simulation hypothesis. For instance, actions in dreams are thought to be neurophysiologically similar to real actions except for not being executed (Revonsuo, 2000). In the language of the simulation hypothesis, actions in dreams are therefore simulated actions. Furthermore, Hobson (1999, as described by Revonsuo 2000, p. 889), argued that "the experience of movement in dreams is created with the help of the efferent copying mechanism, which sends copies of all cortical motor commands to the sensory system. The brain thus receives internally generated information about issued motor commands and computes the expected consequences of those commands. The sensory system is not informed that these commands were not in actual fact carried out by the muscles, and therefore the illusion of movement comes about". Again, these insights are highly relevant to the simulation hypothesis as the use of efferent copies or more encompassing input from motor areas to sensory areas has also been proposed as a possible neural substrate for establishing simulations generally (Cotterill, 2001; Hesslow, 2002).

One can thus argue that the simulation hypothesis is relevant for theories about the functions of dreams in general since it provides the necessary mechanisms for creating dream narratives based on internal models of the world. Note that this is actually independent of the specific theory one subscribes to, whether it is TST (Revonsuo, 2000) or for instance Foulkes' view (Foulkes, 1985) since most implicitly assume the presence of such a mechanism. However, as argued earlier, it is not likely that simulations are formed (at least beyond a rudimentary proto-simulation) as a result of an evolutionary process. This implies that simulations must be formed (or significantly refined) during the lifetime of the human. Further, according to simulation theory, these simulations are important to cognition and should therefore form at the earliest opportunity.

Additionally, the phenomenological content of dreams can in general have further useful consequences for simulation processes employed when awake (*e.g.* solve problems). Firstly, dreams are somewhat more unconstrained than other thought processes, *e.g.* dream imagery is often more bizarre than wake thoughts, self-reflection is absent in dreams, and dreams lack orientational stability (Hobson et al., 2000). Thus, dreaming allows the emergence of paths of simulated actions and perceptions that would not, by some mechanism, have been thought of while awake. Secondly, dreams might be useful for creating longer and more stable simulations as they contain several organising aspects. Dreams integrate several different dream elements into a coherent story, intensified emotions are experienced which also seem to guide the narratives during dreams, and instinctual programs such as fight-flight mechanisms are also used to guide the dreams (Hobson et al., 2000). There is thus a reason to believe that simulations can benefit from the phenomenological experience of dreams and thus, that dreams may help in form these simulations. We suggest that this process begins in early childhood.

Even though children's dreams are described as "impoverished" (Domhoff, 2001) compared to those of adults, infants spend around 14 hours per day sleeping, compared to 8-9 hours for 16-year olds (Iglowstein et al., 2003). Further, about half of that is spent in REM sleep, dropping to 30% to 40% (but approaching adult levels in quality) in infants aged between 1 month to 1 year (Finn Davis et al., 2004). Although it is hard to know whether or not any phenomenological experience is associated with these sleeping patterns in infants, we do know, as discussed previously that this is the case in young children (Domhoff, 2001). Here we suggest, as outlined before, that the relationship between dreams and simulations actually go both ways: while in older children and adults, simulations are primarily used to form the narratives of dreams, this dependency is reversed in young children where dreams are used to form and refine the simulations. Figure 1 illustrates our model of this process. The critical notion here is the existence of two separate loops: one which uses dreams to refine simulations and a second loop which uses dreams (and therefore simulations) to support other cognitive abilities. The hypothesis is that the first loop is dominant initially and gradually declines in importance as the second loop begins to dominate, marking a transition from functional roles of dreams in children to roles relevant to adults.

In infants and young children, *sensorimotor experiences* are thus hypothesised to be re-enacted within dreams, leading to a *formation* of simulations. This is the inception phase. Since this takes place in young infants, it is hard to know what the phenomenological experience of this phase is; it is therefore somewhat of an assumption that it exists (rather than the inception of simulations being a subconscious process). However, it seems likely that it is initially composed of a more or less direct repetition of the impressions of recent sensorimotor experiences. Once a simulation has been formed, dreams begin to use it at which stage the phenomenological experience begins to increase in complexity, including the generation of event sequences that were not directly experienced but are rather *predictions* of what is possible. These predictions can then be tested by the child while it is awake, leading to a *validation* mechanism which in turn is used to finetune the existing simulations. Within our model, this loop

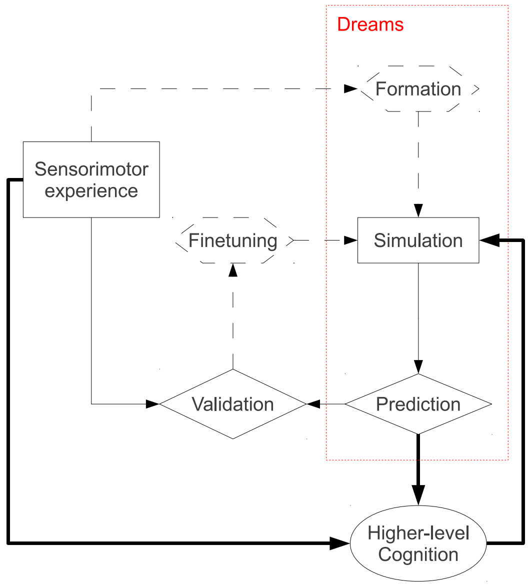

Figure 1: **Schematic of the hypothesised relation between dreams and simulations**. Dashed lines indicate functions that diminish in importance as the child ages whereas thick lines indicate functions that increase. In very young infants, re-enacting of experienced sensorimotor perceptions within dreams shape internal simulations of the world the infant is living in. Based on these simulations, the infant or young child will generate predictions which are then validated while awake, leading to a fine-tuning of the simulation. As the child grows older, the "Formation" mechanism ceases to play an important role (although it may be used if radically new perceptions are encountered) and dreams simply use existing simulations (with their content formed through other cognitive mechanisms). Simultaneously, the accuracy of the simulations increases as the child grows older, leading both to a decrease of required fine-tuning and an increased usage of predictions in other cognitive functions, such as postulated for instance by the Threat Simulation Theory (Revonsuo, 2000). See text for a more thorough description.

is the dominant one during infancy and early childhood. It is clear that simulations that depend on sensorimotor experiences can only be accurate to the extent of the infants abilities, which are themselves continuously developing throughout childhood. The first decade of life is therefore likely to be spent considerably refining the simulations. It is worth pointing out that other models based on simulated actions and perceptions propose similar mechanisms. For instance, Grush (2004), in his emulation theory of representation, proposed a model based on Kalman filters (in control theory) in which the predictions produced by simulations (or emulations in his terms), are also used to update the emulations themselves by comparing them with the corresponding actual input.

At the same time, however, as simulations begin to be accurate, the predictions they generate during dreams can be used in other aspects of *higher-level cognition*. We do not attempt to characterise these other aspects in detail but this would for instance include a function of dreams as postulated by Revonsuo's TST (Revonsuo, 2000). In other words, as the need for fine-tuning is reduced, the function of dreams as support to higher-level cognitive mechanisms increases. This creates a second loop where higher-level cognition defines the narratives of dreams, which increases in complexity as simulations increase in completeness. Within our model, this loop is dominant from late childhood onwards.

The model leads to a number of predictions. First of all, it predicts that the complexity of the dreams and the narration increases over time as the internal simulations become more and more complete. Additionally, dreams will reflect developmental stages of the brain and body. Since the complexity and content of simulations is defined by by what an individual can currently experience, they are intrinsically tied to the overall physiological development of the body. Thus, as brain and body develop and higher-level cognitive functions emerge, more complex simulations are also made possible. These novel aspects of the simulations will need to be fine-tuned as postulated by our model, predicting that during development, the dream contents will reflect newly gained cognitive or bodily abilities. This is at least partly consistent with the development of cognitive abilities in children and to what extent those abilities involve more complex simulations. For example, at the age of 6-12 months infants are able to *e.g.* separate goal from means (Frith & Frith, 2003) and recognize goal-directed actions (Csibra, 2003), in which brief simulations of actions may play a role (Gallese, 2003). It is not until around the age of 5 or 6, however, that more complex simulations have developed. For example, at the age of 5 the child starts to be able to more fully grasp how others behave and think (Frith & Frith, 2003), which would involve longer and more extensive simulated chains of perceptions and actions. Overall, this is in agreement with the description of children's dreams listed by for instance Domhoff (2001).

Second, it predicts that any functionality of dreams related to supporting higher-level cognition, *e.g.* to simulate and prepare for threats Revonsuo (2000) does not appear until the accuracy and complexity of simulations have advanced sufficiently. This is at least indirectly supported by the fact that studies that do show evidence for the threat simulation theories relies on data from children aged on average about 12 years, at which age dreams are already adult-like in their complexity and narrative (Domhoff, 2001).

Third, it predicts that internal simulations are defined heavily by the experiences in early childhood. Although this may be hard to verify, the abundance of bodily metaphors in language (Lakoff & Johonson, 1999) might be a possible consequence thereof.

Discussion

In the present paper, we presented a model that addresses issues in two separate fields. Within the context of simulation theories, it provides a coherent account of simulations might originate and form during early childhood, an aspect that has not been given much attention previously, although it has been touched upon by some (*e.g.* Gallese, 2003; Grush, 1995). Within the context of research into the functional role of dreams, we argued that the traditional focus is on adult dreams and that theories pertaining to the role of dreams in children are still missing. Our model thus provides a hypothesis as to what such a function might be by tying into the development of simulations.

It is worth pointing out that, since the model addresses the role of dreams at an age not normally covered by other theories of the function of dreams, the present hypothesis is not actually at odds with those except with the idea that dreams (as opposed to the activity the brain goes through during a dream) serve no function (*e.g.* Flanagan, 1995); indeed, since our model hypothesises that simulations are fine-tuned based on predictions generated in dreams, the phenomenological experience plays an important role. Threat Simulation Theory (Revonsuo, 2000) for instance, as already argued, specifically requires a form of internal simulation in order to be effective. Additionally, since simulations and the resulting internal models of the world can be seen as a form of memory (of the functioning of the world), the same mechanisms that were used in early life to create these simulations can be used later on to consolidate or process memories during dreams, as hypothesised for instance by Hobson (1994) or Crick & Mitchison (1983, 1995), even if this function of dreaming is not related to the phenomenological experience. Our model thus also offers a way of unifying separate theories by providing mechanisms that allow a natural distinction between (1) functions at a phenomenological level, in which the narrative of the dream has an explicit role in supporting cognition and (2) functions that may be subconscious and relying on mechanisms that were involved in the construction of simulations.

Our hypothesis and the resulting model are developmental in the sense that the function of the model evolves over time by shifting the focus from one loop to the other, which results in a shift from using dreams primarily as a way of refining simulation to using dreams (and the underlying simulations) primarily as a way to generate predictions that can be used in other aspects of cognition (in the same sense that, for instance, TST (Revonsuo, 2000) sees dreams as functional). This approach resulted in the explanation of both phenomenological and other functions of dreams discussed in the previous paragraph, which highlights that taking developmental aspects into consideration is important in general. By restricting themselves to the cognitively developed individual, the phenomenologically focussed TST (Revonsuo, 2000) for instance can not (and does not need to) account for theories pertaining to *e.g.* memory processing within dreams (*e.g.* Crick & Mitchison, 1983, 1995) or vice versa. In other words, the developmental perspective has allowed a unified view of what has previously been considered to be separate processes. The importance of such a perspective in dream research has been realised for instance by Domhoff (2001) when he calls for a new neurocognitive theory of dreams by explicitly noting, amongst others, that dreams evolve throughout childhood and the present model is therefore in the same spirit.

Some aspects of the present model on simulation formation can also be related to research into the development of episodic memory (*e.g.* Atance & O'Neill, 2005; Perner et al., 2007). An important aspect and necessary prerequisite of episodic memory is the ability to recreate previous experiences (*cf.* Perner et al., 2007); in our terms, simulations. However, since episodic memory does not develop fully until around the age of four (Atance & O'Neill, 2005), we would hypothesize that the development of episodic memory is partly determined by the phenomenal quality, stability and validity (*i.e.* correspondence to actual previous experiences) of the simulations. For example, Perner et al. (2007) pointed out that among other things introspection is necessary for episodic memory and this process would certainly be helped by having more stable simulations, which may not be available early in life.

Finally, the present paper illustrates that insights from simulation theories and research into dreams can be mutually beneficial: for research exploring the functions of dreams, simulation theory offers a comprehensive mechanism that may well underlie the generation of the phenomenological experience of dreams. On the other hand, to those interested in the simulation hypothesis, the insights from research into dreams can provide additional validation and examples of mechanisms. The similarity - discussed earlier - between dream mechanisms as described by for instance Hobson (1999) and mechanisms of simulation theories (Cotterill, 2001; Hesslow, 2002) or the explicit reference to simulations (but without considering simulation theories) by Revonsuo (2000) are a prime examples of this potential mutual benefit and therefore potential for a close interdisciplinary cooperation.

Conclusions

We have presented the hypothesis that an initial function of dreams is the inception and fine-tuning of simulations as postulated by simulation theory (Hesslow, 2002). We have outlined an evolving model that describes the changing relations between dreams and simulations and we have illustrated that the hypothesis is compatible with current knowledge of dreams. The hypothesis lead to a number of predictions, which need to be explored more fully in further work.

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