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Alterations of Agency in Hypnosis: A New Predictive Coding Model

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Abstract

Hypnotic suggestions can lead to altered experiences of agency, reality and memory. The present work is primarily concerned with alterations of the sense of agency (SoA) following *motor suggestions*. When people respond to the suggestion that their arm is rising up all by itself, they usually have a feeling of passivity for their action. The mechanisms leading to such alterations of the SoA are still controversial. We propose a theoretical model based on the framework of predictive coding: the view that the brain constantly generates hypotheses that predict sensory input at varying levels of abstraction and minimizes prediction errors either by updating its prior hypotheses — perceptual inference — or by modifying sensory input through action — active inference. We argue that suggested motor behaviour and the experience of passivity accompanying it can be accounted for in terms of active inference. We propose that motor suggestions optimize both proprioceptive predictions and actual proprioceptive evidence through attentional modulation. The comparison between predicted and actual sensory evidence leads to highly precise prediction errors that call for an explanation. The motor suggestion readily supplies such an explanation by providing a prior of non-agency to the subject. We present this model in detail and discuss how it relates to, and differs from, other recent models of hypnosis. We compare its predictions with the predictions derivable from these other models. We also discuss the potential application of our predictive account to reality and memory alterations in hypnosis and offer an explanation of inter-individual differences in hypnotic suggestibility.

Keywords. Hypnosis; Sense of Agency; Predictive Coding; Memory Alterations; Hallucinations; Inter-individual differences

1. Introduction

Hypnosis is a situation producing altered experiences of reality, memory, and agency through the administration of specific (self- or hetero-) verbal suggestions in persons sensitive to them (for similar definitions, see Dienes, (2012); Kihlstrom, (1982; 2008)). Hypnotic suggestions usually consist in directives for imagining that such or such is the case while keeping external conditions constant (Kirsch et al., 2011). In other words, there are no changes in the stimulus conditions (Kirsch et al., 2011, p. 110) accompanying the suggestion (in contrast to a placebo suggestion where the stimulus conditions are usually fitted to the suggestion, e.g., the application of a fake analgesic cream in the context of an analgesia placebo). Three types of hypnotic suggestions are usually distinguished (e.g., Heap, Brown, & Oakley, 2004; Hilgard, 1965; Kallio & Ihamuotila, 1999; Laurence, Beaulieu-Prévost, & Chéné, 2008; Perry, Nadon, & Button, 1992; Shor & Orne, 1963; Weitzenhoffer & Hilgard, 1962; Barber, 1969; Spanos, 1986). In *motor suggestions*, the operator asks the subject to imagine that some movement, such as their raising an arm, will occur all by itself. In challenge suggestions, the operator asks the subject to imagine that some movement, such as their bending their arm, is now impossible. Finally, in *cognitive suggestions*, the operator might ask the subject to imagine the presence of absent perceptual events (hallucination suggestion) or to forget some material learnt during the hypnosis session (amnesia suggestion).

In the present work, we focus on motor suggestions and on the alteration of the sense of agency that is its hallmark: subjects typically report a compelling experience of passivity with regard to their suggested actions. Hypnosis, however, is not the only situation producing alterations of the SoA in the form of passivity experiences associated with self-generated actions. Some neurological conditions, such as the *alien hand syndrome* (Aboitiz et al., 2003), and psychiatric conditions, including schizophrenia (Schneider, 1959; Frith, 1992), produce similar SoA alterations. In recent years, models of SoA alterations in schizophrenia based on the Bayesian predictive view of the brain/mind, or predictive coding for short, have been developed (e.g., Corlett et al., 2010; Fletcher & Frith, 2009; Frith & Friston, 2013). Here we propose a theoretical model of motor suggestions that is also based on this predictive coding approach.

We start with an overview of the main principles and concepts of predictive coding. We then provide a short review of SoA disturbances in schizophrenia, in particular delusions of control, and of recent attempts to account for them within the framework of predictive coding. We then turn to motor suggestions. We present our cognitive coding model of motor suggestion in detail and discuss how it relates to, and differs from, other recent models of hypnosis, including an alternative predictive coding approach to hypnosis recently proposed by Jamieson (2016). We compare the predictions of our model with the predictions derivable from these other models. We also discuss the potential application of our predictive account to reality and memory alterations in hypnosis and offer an explanation of inter-individual differences in hypnotic suggestibility.

2. Main Principles of Predictive Coding

Predictive coding belongs to a family of models that regard the brain as an inference machine. Their origins can be traced back at least to Helmholtz and his insight that perception is a form of unconscious inference (Helmholtz, 1866). According to inferential models, the function of perception is to infer the structure of the world. It does so through an active process of hypothesis formulating and testing. The brain generates predictions about incoming sensory information based on prior beliefs about the structure of the world. If the incoming information is not what was expected (a prediction error), the prior beliefs on which the predictions were based are updated and these updated beliefs drive future predictions.

To determine the source of sensory signals, the brain has to 'build back' (infer) the cause from the effect (Hohwy, 2013). However, this is not an easy task as there are no one-to-one relations between external hidden causes and sensory effects: different causes can give rise to identical or very similar effects (e.g., the perception of a face *versus* the photography of the same face, Hohwy, 2013), and different effects can result from the same cause (a classical laboratory instance is the case of bistable images such as the famous Rubin's vase in which the same image can be interpreted as a vase or as the profiles of two faces looking at each other). A number of contemporary models of perception have therefore proposed that these inferential processes take the form of *Bayesian* inferences (e.g., Kersten, Mamassian, & Yuille, 2004; Maloney & Mamassian, 2009; Rao, Olshausen & Lewicki, 2002).

Bayesian treatments of perception represent subjects' beliefs about the potential causes of sensory information as a probability distribution. In accordance with Bayes' theorem, the hypothesis with the highest posterior probability (i.e., most probable given the input) wins and gets to determine the content of the perceptual belief. The posterior probability depends on how well the hypothesis predicts the input (likelihood) and on how probable the hypothesis was before the input (prior probability).

This Bayesian approach can be used to determine the statistically optimal combination of sensory evidence from different sources as well as the extent to which new evidence requires that we update our beliefs about the world. Thus, different sources of sensory evidence should be weighted according to their precision or reliability (the inverse of their variance), with the more precise evidence being given the greater weight. For instance, Ernst and Banks (2002) have shown that, when combining visual and haptic information, humans estimate object size in a way that is entirely consistent with this principle: when both types of information are available, estimates are strongly influenced by (the more reliable) visual information, and when the quality of visual information is degraded (by adding noise), the influence of haptic information increases. Likewise, when incoming sensory information is not what was expected (prediction error), whether and to what extent we update the beliefs on which our expectations were based depends on the relative precision of the incoming information and of these beliefs (their prior probability).

Predictive coding is at present the most popular implementation of Bayesian inference (e.g., Feldman & Friston, 2010 ; Friston, 2005, 2010 ; Hohwy, 2013; Clark, 2016). Frith and Friston describes its basic tenets as follows:

> [T]he brain uses a hierarchy of predictions, where expectations at any level provide prior beliefs for the level below (these are known as empirical priors in statistics). Each

level integrates new evidence from the level below and (empirical) prior expectations from the level above to generate a prediction error. This prediction error is fed upwards as the evidence for the next level of the hierarchy. Likewise, the prior expectations at the higher levels of the hierarchy (empirical priors) are fed downwards to constrain the possible explanations of the prediction errors coming from the lower levels. Crucially, the weights assigned to bottom-up prediction errors and top-down predictions depend upon the relative precisions (possibly encoded by dopamine) at each level of the hierarchy. (Frith & Friston, 2013: 11)

The processing aim of a predictive coding system is to minimize prediction errors and thus improve predictions at all levels of the hierarchy.[1] There are two ways in which the brain can reduce prediction errors: perceptual inference and active inference. As neatly captured by Clark (2016), perceptual inference works by "altering predictions to fit the world" and active inference works by "altering the world to fit the predictions" (2016: 122).

Perceptual inference involves finding the prediction that best accommodates the current sensory information and adjusting our prior beliefs (i.e. our hypotheses about the world) accordingly. Precision is a key concept of the predictive coding approach since how a prediction error is minimized depends on the relative precision of the belief (or prior) on which the prediction is based and of the incoming information. That is, when the precision of sensory evidence is higher than the precision of the prior, the former will be weighted more than the latter in perceptual inference leading to an updating of the prior belief. Conversely, when the

1 The standard implementation of predictive coding in brain circuitry (Rao and Ballard, 1999; Friston, 2005, 2010) uses a hierarchy of neural populations, alternating between populations of error-detecting neurons and populations of prediction neurons. Each population of prediction neurons sends excitatory connections forward to the subsequent population of error-detecting neurons, and also sends inhibitory connections backwards to the preceding population of error-detecting neurons, while each population of error-detecting neurons sends information via excitatory connection to the following population of prediction neurons and via inhibitory connections to the preceding population of prediction neurons. It should be noted, however, that alternative hypotheses regarding the implementation of predictive coding in brain circuitry have been proposed. For instance, it is possible to group neural populations differently so that feedforward connections between cortical areas carry predictions rather than errors (Spratling, 2008). The theory can also be implemented using different algorithms (Spratling 2018). For a review of predictive coding in the nervous system, see Wang and Rao (2011).

precision of sensory evidence is lower than the precision of prior, the latter will be weighted more than the former in perceptual inference: the prior is maintained, and prediction errors suppressed (e.g., Hohwy, 2013).

The precision of a prior belief is a function of its probability compared to the probability of alternative priors: the broader the probability distribution is, the more uncertain, and thus the less precise, the belief is. The precision of sensory evidence depends on its reliability, understood as the inverse of its variance. It is context-dependent in the sense that some contexts are associated with more uncertainty (more noise) than others. Cocktail parties are usually associated with acoustic noise, thus making auditory signals uncertain, and dust is usually associated with visual noise, thus making visual signals uncertain (Hohwy, 2013). In both cases, sensory signals are expected to be quite imprecise. As a result, prior beliefs will be assigned more weight than those signals. In contrast, libraries, for example, are usually associated with a low level of acoustic noise and auditory signals will be expected to have high precision. Similarly, well-illuminated rooms are associated with a low level of visual noise and visual signals will be expected to have high precision. In these contexts, prediction errors will be more likely to be reduced by updating priors. In a nutshell, what that the system will do is concentrate on – i.e., optimize– the signals that are expected to be precise. Optimizing the precision of signals in such a *selective* manner is exactly what attention is for, according to the predictive framework (Feldman & Friston, 2010; Friston, 2010; Hohwy, 2013, Summerfield & Egner, 2009).

The other way to minimize prediction errors is active inference. It consists in performing actions that generate patterns of sensory input that conform to our predictions. As Friston and Frith (2015) put it:

> In active inference, action is regarded as the fulfilment of descending proprioceptive predictions by classical reflex arcs. In other words, we believe that we will execute a goal-directed movement and this belief is unpacked hierarchically to provide proprioceptive, and exteroceptive predictions generated from our generative or forward model. These predictions are then fulfilled automatically by minimizing proprioceptive

> prediction errors at the level of the spinal cord and cranial nerve nuclei […]. Mechanistically, descending proprioceptive predictions provide a target or set point for peripheral reflex arcs – that respond by minimising (proprioceptive) prediction errors. (2015: 133)

Thus, within the framework of active inference, the traditional notions of intention, plan and action are redescribed in terms of priors, conditional expectations, predictions and error minimization. Intentions are redescribed as beliefs (i.e. priors) that we will execute movements producing a certain desired outcome. Goals or desired outcomes are ultimately represented as patterns of sensory input. Action planning is a matter of using forward models (i.e. sets of conditional expectations about how sensory input would change if the system acted in a certain way) to generate a cascade of predictions about the sensory consequences of the action. These predictions are finally unpacked into proprioceptive predictions that directly elicit motor action by engaging "classical reflex arcs to suppress proprioceptive prediction errors and produce the predicted motor trajectory" (Brown et al., 2013, p. 415). As a simple illustration, imagine that Megan intends to drink from the bottle of water in front of her. In the predictive coding framework, this means that Megan has a belief that she will execute a movement aimed at drinking from the bottle. She (or at least her cognitive system) also has a number of relevant conditional expectations: if she is to drink from a bottle, she will (very probably) reach for it; if she reaches for it, she will (very probably again) reach with her arm; if she reaches with her arm, her arm will probably follow such an and such a trajectory; if her arm follows that trajectory, her proprioceptive input should change in such and such a way. From Megan's intention (i.e. belief) together with these conditional expectations, a cascade of predictions will be derived, bottoming out in proprioceptive predictions that will elicit motor action by engaging reflex arcs that will automatically minimize proprioceptive prediction errors.

In contrast to many previous models of action production (e.g., Sperry, 1950; Wolpert, 1997; Frith et al., 2000), there is thus no need in this framework to postulate efference copies or to draw a distinction between inverse models in charge of computing motor commands and forward models in charge of predicting their sensory consequences. Rather, what the predictive coding approach proposes is that "a subset of predicted sensory consequences (predicted proprioceptive trajectories) are acting as motor commands already" (Clark, 2016).

However, these two error minimization strategies, perceptual inference and active inference, give rise to a conflict between perception and action. On the one hand, self-generated movements require predictions to override the sensory evidence that one is not (yet) actually moving. On the other hand, attending to sensory evidence enables the detection of externally generated events but prevents the generation of actions. This conflict can in principle be resolved through the attentional modulation of precision. Focusing attention away from actual sensory input will decrease the expected precision of sensory evidence and increase the expected precision of predictions, thus enabling action. Focusing attention instead on sensory input will have the reverse effect and bolster the detection of external events. According to Brown et al. (2013), this is what explains the presence of sensory attenuation, i.e., a reduction of the precision of actual sensory evidence, during action. For actions to be triggered by proprioceptive predictions, these predictions must be given more weight than the sensory evidence that the subject is not actually moving. This is made possible by attending away from actual sensory information, resulting in sensory attenuation (Brown et al., 2013). On this approach, sensory attenuation is thus necessary for action.

We now turn to experiences of passivity in schizophrenia and predictive coding accounts of these experiences.

3. Active Inference and Experience of Passivity in Schizophrenia

People with schizophrenia who have *delusions of alien control* experience some of their actions as not being under their control –experience of passivity– but rather under the control of outside forces –experience (or judgement) of alienation (Schneider, 1959). It has been argued that the experience of passivity associated with delusions of alien control could result from a lack of sensory attenuation of the sensory consequences associated with the specific action involved (Blakemore et al., 2000; Feinberg, 1978; Fletcher & Frith, 2009; Frith & Friston, 2013; Frith, 2005; Frith, Blakemore, & Wolpert, 2000). According to optimal control models, such as the comparator model (Frith et al., 2000), the lack of sensory attenuation could be a consequence of malfunctions at the level of efference copies production (Blakemore et al., 2000).

In the 1990s and early 2000s Chris Frith and his colleagues developed the very influential comparator model of the sense of agency. According to the model, when the motor system computes the motor commands needed to achieve a desired state, copies of these commands, termed efference copies, are sent to a forward model. The forward model predicts the sensory consequences of implementing these commands. By comparing the predicted state to the desired state, the motor system can check whether the proposed motor commands are correct before they are actually implemented. Once the motor commands are implemented, incoming sensory information (the estimated actual state) is compared to the desired state and error signals arising from this comparison are used to optimize the computation of motor commands. The estimated actual state is also compared to the predicted state: the sensory consequences that correspond to predicted sensory consequences are attenuated, while error signals are used to optimize the forward model.

Frith and colleagues proposed that in addition to their role in sensorimotor control, these comparisons also underlie the sense of agency: whether one has a sense of agency for an action and how strong this sense of agency is depends on the degree of congruence between desired state, predicted state and estimated actual state. Frith and colleagues also proposed that in schizophrenia patients with delusions of control, predictive processes are impaired. As a result, sensory attenuation mechanisms are disrupted and comparisons between desired and predicted states and between predicted and actual states yield spurious error signals (Blakemore, Smith, Steel, Johnstone, & Frith, 2000; Frith, 2005; Frith, 2000). Thus, (some of) the voluntary movements or actions of people with schizophrenia instantiate sensory qualities similar to the sensory qualities instantiated by genuinely passive movements, leading (or contributing) to the experience of passivity accompanying delusions of alien control.

Strong evidence indeed suggests that in people with schizophrenia, in particular people showing passivity experiences, predictive processes are impaired and sensory attenuation greatly reduced. Blakemore et al., (2000) showed that patients with passivity phenomena rated the intensity of self-produced tactile stimuli as identical to the intensity of externally-produced tactile stimuli. In contrast, control subjects and patients without passivity phenomena rated the former as less intense than the latter. Similarly, when healthy participants have to match the force of a stimulus applied to one of their hands by an external device through self-generated actions, they exaggerate the matching force owing to sensory attenuation processes (Shergill, Samson, Bays et al., 2005). In contrast, patients with schizophrenia are more accurate in the matching task, providing evidence for altered sensory attenuation processes. At a neuronal level, passive movements are usually associated with, *inter alia*, a greater activity in the parietal cortex than voluntary movements (Weiller et al., 1996). Similarly, the activity of the parietal cortex increases with discrepancies between self-generated movements and visual feedback (Fink, 1999). Finally, the activity of the parietal cortex is negatively correlated with the level of felt control (Farrer et al., 2003; for a short overview see Jeannerod, 2009; see also Schnell et al., 2008). Interestingly, when comparing the patterns of brain activation of patients with passivity phenomena with those of control participants during *voluntary* movements (or freely produced movements *versus* automatized movements) patients show, among other things, a hyperactivity of the parietal lobe in comparison to control participants (Spence et al., 1997). In other words, patients' brain activity during active movements resembles control subjects' brain activity during passive movements.

To recap, empirical evidence seems to support the hypothesis that the experience of passivity associated with some actions in people with schizophrenia having delusions of alien control is the result of a lack of attenuation of sensory consequences associated with these actions and that this lack of attenuation is itself a consequence of deficits in predictive mechanisms. Conversely, in the normal case, the sense of self-agency is associated with weak sensory feedback (Frith, 2005).

Our understanding of the cognitive basis of the sense of agency has advanced considerably since the comparator model was first proposed, showing it to be a more complex, multi-level phenomenon than initially envisioned (Chambon, Sidarus & Haggard 2014;

Haggard & Eitam 2015; Haggard 2017; Moore 2016; Synofzik, et al. 2013). This has led a number of researchers, including former proponents of the comparator model, to embrace a hierarchical Bayesian approach to the sense of agency (Corlett, Frith & Fletcher 2009; Fletcher & Frith 2009; Frith 2012; Frith & Friston 2013; Moore & Fletcher 2012; Moore & Haggard 2008).

In particular, an alternative explanation of SoA disturbances in schizophrenia based on the notion of active inference has been proposed within the predictive coding framework (Brown et al., 2013; Friston, Daunizeau, Kilner et al., 2010; Hohwy, 2013 (chap. 4); Clark, 2016 (chap. 4)). This alternative approach rests on the new way predictive coding accounts for sensory attenuation. Remember that this approach proposes that sensory attenuation does no simply accompany voluntary movements, as the classical comparator model suggests, but is a necessary counterpart of active inference and of the production of movement (Brown et al., 2013).[2] In the context of active inference, delusions of control in schizophrenia would result from an abnormally high weighting of the expected precision of current somatosensory evidence associated with some intended movements (Adams et al., 2013; Brown et al., 2013). This abnormal weighting of the expected precision of sensory evidence reduces sensory attenuation[3] and generates highly precise prediction errors when compared to proprioceptive predictions. This means that the movement can only be elicited when the decrease of sensory attenuation is compensated by an increase in the precision of proprioceptive predictions and of

[2] Proponents of the predictive coding approach argue that their account of sensory attenuation has greater generality and explanatory power than optimal control approaches such as the comparator model. Thus, Brown et al. (2013) point out a number of advantages of the predictive coding approach. First, the predictive coding approach takes sensory attenuation, understood as the attenuation of sensory precision, to be necessary for action rather than being simply a 'quirk' of motor control. Second, it can in principle explain results the optimal control approach explains (e.g., the force-matching illusion) but also results the optimal control approach cannot account for, such as evidence that during self-generated movements, sensory attenuation can be found for externally generated stimuli or for stimuli that occur before movement onset (e.g., Voss et al. 2008). Third, it can also account for a body of evidence suggesting that attention towards movement, a process opposite to sensory attenuation in that it increases sensory precision, can be detrimental to performance (e.g., the well-known phenomenon of 'chocking' in sports, where expert athletes sometimes fail to perform over-learned action when under pressure (Beilock and Carr 2001)).

[3] The lack of sensory attenuation here could result from pathological excessive dopaminergic activity which control the precision of prediction errors (Friston et al., 2012; Frith & Friston, 2013).

predictions at higher levels of the hierarchy. However, when both predictions and sensory inputs are given high precision, prediction errors will *persist* and be fed upwards in the predictive hierarchy as neither sensory predictions nor sensory evidence are updated. Ultimately, this leads individuals to infer the existence of an external hidden cause at higher levels, since the only case where sensory evidence of bodily movement can be highly precise is when the movement is passive and some external cause is responsible for its production (e.g., someone else raising your arm). The only way to minimize prediction errors will thus be to adopt, despite its low prior probability, the belief that someone else is controlling their movements (delusion of control).

In the next section, we propose that the type of behaviour and the feeling of passivity accompanying motor suggestions depends on similar mechanisms.

4. Sense of Agency Alterations in Motor Suggestions: A Predictive Coding Approach

In *motor suggestions*, an operator asks the subject to imagine that some movement will occur all by itself. A typical motor suggestion in hypnosis is *arm levitation*, in which the hypnotist suggests to the participant that her arm is raising up all by itself. Another well-known motor suggestion is the *magnetic hands* suggestion (Anlló, Becchio & Sackur, 2017). In the Waterloo-Stanford Group Scale of Hypnotic Susceptibility, Form C (Bowers, 1998), the magnetic hand suggestion is phrased as follows:

> Now, extend your arms ahead of you, with palms facing each other, hands about a foot apart. Hold your hands about a foot apart, palms facing each other. I want you to think about a force acting on your hands to pull them together, as though one hand were attracting the other. You are thinking of your hands being pulled together, and they begin to move together... coming together... coming together... moving together... closer together... more and more toward each other... more and more.

There are at least three features of motor suggestions such as these that need explaining. Firstly, motor suggestions lead to the production of movements in a large majority of cases.

About 80% of people are susceptible to motor suggestions, compared to 50% for challenge suggestions and 10% for cognitive suggestions (see e.g., Hilgard, 1965; Kallio & Ihamuotila, 1999; Perry, Nadon, & Button, 1992). Secondly, the movements produced under motor suggestions are typically slow, hesitant and dysfluent. Thirdly, motor suggestions produce a temporary alteration of the SoA, with a large proportion of participants reporting a compelling experience of passivity with regard to their suggested actions. An account of motor suggestions must therefore explain these three features. Why do subjects respond to the motor suggestions (i.e., move at all)? Why is the production of the movement typically dysfluent? Why are alterations of the SoA readily produced by means of specific motor suggestions?

We hypothesise that these three effects of motor suggestions are best accounted for within the framework of the predictive coding approach. In a nutshell, we argue that hypnotic suggestions create a specific context characterized by (i) an increase in the precision of kinaesthetic and proprioceptive signals, (ii) an increase in the precision of predictions regarding movement, (iii) a corresponding increase in the precision of prediction errors, and (iv) the provision of a highly accessible explanation for these prediction errors in terms of the operation of an external force. We propose that the simultaneous increase in the precision of sensory input and in the precision of proprioceptive predictions accounts for the characteristic features of suggested motor behaviour (i.e., movement is produced but is typically slow and dysfluent). We also propose that the increased precision of prediction errors together with the immediate availability of an explication of these errors in terms of the operation of some external force accounts for the experience of passivity in motor suggestions.

4.1. Motor Behaviour

As we have seen in previous sections, in the context of active inference sensory attenuation amounts to a reduction of the precision of actual sensory evidence (Brown et al., 2013). Crucially, according to Brown et al., (2013), this is equivalent to "*attending away* from the consequence of self-made acts" (p. 411, our emphasis). Conversely, *attending to* sensory consequences would increase the precision of sensory evidence, thus reducing or eliminating sensory attenuation.

Hypnosis creates a specific context in which we can usually note “an increase in absorption, focused attention, disattention to extraneous stimuli and a reduction in spontaneous thought” (Oakley & Halligan, 2009, p. 264). In other words, the context of hypnosis leads participants to pay very close attention to what is going on internally and especially to their body when motor suggestions are administered. The magnetic hands suggestion, for instance, leads subjects to pay very close attention to kinesthetic and proprioceptive signals.

Hypnosis is thus a context usually associated with a particularly low level of noise. Through motor suggestions the hypnotist creates a context wherein the participant expects somesthetic signals to be precise. The gain of the signals will be amplified rather than reduced, thus explaining the absence of sensory attenuation accompanying suggested actions. In sum, during hypnosis subjects pay close attention to signals, such as proprioceptive signals, that are usually (i.e., in normal non-hypnotic conditions) not attended. In other words, hypnosis makes the usually silent acting body quite loud.

The question remains, therefore, how the suggestion generates the movement in the first place, given that sensory signals are attended and their precision increased. Recall that according to the predictive coding approach, active inference, i.e. prediction error minimization through action, is possible only if predictions are given higher precision than sensory input and that this is normally achieved through sensory attenuation. Sensory attenuation cannot be the process enabling action in the context of motor suggestions, however, if this context promotes attention to bodily, and in particular proprioceptive, signals. Rather, as Brown et al. suggest: "In the absence of sensory attenuation, movement can only be elicited when there is a compensatory increase in the precision of proprioceptive predictions" (2013: 422). We propose that this increased precision of predictions is also produced by the operator's suggestion. Hypnosis creates a context where spontaneous thought is reduced and the subject is ready to believe what the hypnotist suggests. When an experimenter administers a motor suggestion, she is implanting in the subject a (momentary) belief that his arm is indeed moving and this belief is continuously reinforced during the suggestion. Consider again the magnetic hand suggestion described in Section 1. The experimenter's suggestion continuously accompanies the movement: "You are thinking of your hands being pulled together, and they begin to move together... coming together... coming together... moving together... closer together... more and more toward each other... more and more". In other words, at the same time that the hypnotic context focuses the subject's attention on their kinaesthetic and proprioceptive input, it counteracts this increase in the precision of sensory input by also inducing and reinforcing beliefs about movement, thus leading to the formation of highly precise proprioceptive predictions, creating an imbalance between sensory precision and prediction precision that is sufficient for the production of movement. At the same time, since the precision of sensory input is high, the imbalance cannot be massive. This in turn can contribute to explaining the typical lack of fluency of the movements produced. Suggested movements are typically very slow and relatively “saccadic” (at least in untrained people and in the laboratory context, see e.g., Barnier et al., 2008; McConkey, 2008; McConkey & Barnier, 2004). For instance, in arm levitation it usually takes many seconds for the subject to move her arm a few centimeters and the initiation of the movement is usually not instantaneous.

To recap, during suggestions and the induction that precedes them, the experimenter asks the subject to pay close attention to their sensations but also to what she says. There is a “back and forth” or oscillation between increasing the precision of sensory evidence and increasing the precision of motor predictions (see virtually every classical hypnotisability scale, e.g., Weitzenhoffer & Hilgard, 1962). The dysfluent character of suggested movement is thus reminiscent of one important form of the phenomenon of "choking" evoked by Brown et al. (2013) where movement is impaired when we focus too much on proprioceptive input.

4.2. Subjective Experience

So far we have shown how the production of movement concordant with the suggestion and the relative dysfluency of the movement produced could be accounted for using the predictive coding approach. How about the third characteristic of motor suggestion, the feeling of passivity or involuntariness for the suggested action? How do passivity experiences under motor suggestion relate to passivity experiences in schizophrenia?

As we saw in the previous section, within the predictive coding framework, the proposed explanation for experiences of passivity and delusions of control in schizophrenia runs as follows. Actual sensory evidence is given abnormally high precision (Brown et al., 2013, see also, Fletcher & Frith, 2009; Adams et al., 2013; Frith & Friston, 2013), inducing strong prediction errors when compared to proprioceptive predictions. In addition, for any movement to occur, this high precision of sensory evidence has to be offset by a high precision of proprioceptive predictions. This allows the movement to occur but leads to a persistence of prediction errors as the high precision of both proprioceptive predictions and sensory evidence prevents the updating of one or the other (Brown et al., 2013; Adams et al., 2013). The presence and persistence of highly precise prediction errors thus leads to the formation of delusions (e.g., to delusions of control) at higher levels in the hierarchy: the agent infers "an additional external force — a 'hidden external cause' for what is, in fact, a purely self-generated pattern of sensory stimulations" (Clark, 2016, p. 219).

We propose that similar mechanisms are responsible for SoA alterations in hypnotic motor suggestions. In the context of a motor suggestion, we have seen that participants are led to pay close attention to their sensations, increasing the precision of sensory evidence (no sensory attenuation). As in schizophrenia, this increase in sensory precision leads to strong predictions errors when proprioceptive input is compared to proprioceptive predictions. To offset the increased precision of sensory evidence, the suggestion must also boost the precision of proprioceptive predictions (see previous section).

As a result of the increased precision of both sensory evidence and proprioceptive predictions, prediction errors persist. The high precision and persistence of the latter cry out for an explanation, as it does in schizophrenia. However, whereas schizophrenia patients are left to their own devices to infer a hidden external cause of their movements, hypnosis subjects have their explanatory work done for them by the hypnotist. The very point of motor suggestions is to make the subject believe that her movements are executed *passively*. For instance, in the magnetic hand suggestion, the experimenter tells the subject: ‘I want you to think about a force acting on your hands to pull them together’. Similarly, in arm levitation, she can suggest to the subject that a helium balloon is attached to her wrist. The suggestion that some external force is responsible for the movement may be said to induce a non-agency prior that in turn provides an explanation for the presence of highly precise prediction errors.

In addition, this non-agency prior might also contribute to the decrease of sensory attenuation in the hypnotic context. Typically, in experiments using sensory attenuation protocols, the sensory effect is produced by the participant's voluntary action and the participant is told or is led to believe that their action causes the sensory effect. In other words, a participant in such a task has an agency prior. Desantis et al. (2012), however, have shown that manipulating beliefs about authorship has an effect on sensory attenuation. In some cases, participants thought they were the source of the sensory event (tones), in other cases they thought it was someone else, while actually the sensory event was always triggered by the participant. Participants perceived the sound as less intense when they believed they were the source of the event in comparison as when they believed it was another person. This suggests that the lack of sensory attenuation for movements resulting from a motor suggestion might have two complementary (and mutually reinforcing) sources, namely the self-focused attention induced by the hypnotic context and the non-agency prior contained in the suggestion.

In sum, we propose that during motor suggestions there is a back and force between a gain of proprioceptive predictions and a gain of proprioceptive evidence. As a consequence, the relative precision and then weighting of proprioceptive predictions and proprioceptive evidence are changing and alternating over time, explaining the production of a movement in the first place but also its slowness and dysfluency. Finally, this also induces strong prediction errors that are minimized by inferring an external cause.

4.3. Brain mechanisms in motor suggestions

So far, the arguments we have developed in favour of our approach find support essentially from the behavioural research on hypnosis. In the next subsections, we ask whether the relevant neuroimaging literature may tell us something about the mechanisms underlying motor suggestions and the related experience of passivity accompanying them. We start with some general remarks on the current state of the neuroscientific research on brain mechanisms associated with hypnosis.

Preliminary general remarks about brain mechanisms in hypnosis

The neuroimaging literature on brain processes or neural correlates associated with hypnosis in general or specific suggestions in particular, is far from offering a clear picture (Landry, Lifshitz and Raz 2017; Landry and Raz, 2015, 2016). The current body of research is marked by heterogeneity and, more disturbingly, by inconsistency. For instance, some studies find an increased activity of the Anterior Cingulate Cortex (ACC) (e.g., Egner et al., 2005) associated with hypnosis or specific suggestions, while others show a decreased activity of this region (e.g., Raz et al., 2005). As pointed out by Landry et al., (2017), such inconsistent results have many potential sources: the absence of standardized procedures for the induction of hypnosis, methodological differences in experimental designs and interindividual differences in the strategies used by subjects to respond to hypnotic suggestions (Cardeña, 2014).

Based on a systematic review of neuroimaging findings and theoretical propositions on hypnotic phenomena — namely, hypnotic susceptibility, hypnotic induction and hypnotic suggestions— Landry et al. (2017) identify three key networks potentially mediating these phenomena: the Central Executive Network (CEN), the Salience Network (SN) and the Default Network (DN).

The first of these networks is associated with cognitive control (Spreng et al., 2010; Vincent et al., 2008), the anticipation of events and response preparation (Landry et al., 2017; Alahyane et al., 2014; Niendam et al., 2012). Accordingly, Landry et al., (2017) hypothesise that the activation of the CEN, in the context of hypnosis, might reflect the maintenance of attentional focus on specific mental representations or images in accordance with the instructions of the operator during e.g., the induction phase. In support of this hypothesis, Landry et al., (2017) refers to two studies showing that the subjective level of “trance depth” or “mental absorption” during a hypnosis session correlate with the activation of specific regions of the CEN, namely the dorsolateral (Deeley et al., 2012) and frontopolar (Rainville et al., 2002) areas, respectively. Furthermore, the role of the CEN in the anticipation of events is congruent with a specific socio-cognitive approach of hypnosis (Landry et al., 2017) — The Response-Set Theory (Kirsch and Lynn, 1998) — that holds that the expectation of specific subjective and behavioural events, implemented by the directives of the operator, produces the hypnotic phenomena (see Section 4 for a more detailed discussion of this theory).

Landry et al., (2017) propose that the modulation of the SN in hypnosis (e.g., Rainville et al., 2002; Jiang et al., 2016) might “index the monitoring of attentional focus to prioritize relevant signals and keep others outside the scope of awareness” (p. 8). The SN, comprising the anterior cingulate cortices and the anterior insula (Landry et al., 2017), indeed plays a key role in the integration and the monitoring of information from different sources, including both external sensory information and internal cognitive events (e.g., Cai et al., 2014; Seeley et al., 2007; Menon, 2015).

Finally, the DN includes a set of interacting brain regions such as the Posterior Cingulate Cortex, the Medial Prefrontal Cortex and the Angular Gyrus (e.g., Andrews-Anna, Smallwood and Spreng, 2014). Basically, the DN is active when the subject is involved in internally-oriented and task-unrelated activities, such as mind wandering, and deactivated when engaged in externally-orientated task/goal-related activities (e.g., Anticevic, Cole, Murray et al., 2012). Deactivation of the DN during hypnosis (Deeley, Oakley, Toone et al., 2012; Demertzi, Soddu, Faymonville et al., 2011; McGeown, Mazzoni, Venneri et al., 2009) is consistent with the idea that hypnosis may reduce the occurrence of spontaneous thoughts (i.e., may reduce mind wandering; Lynn et al., 2015) “following from the engagement of top-down regulatory processes” (Landry et al., 2017, p. 9).

To recap, in reviewing the neuroimaging literature on hypnosis, Landry et al., (2017) hypothesised that three potential networks — the CEN, SN and DN — would mediate hypnotic phenomena. To further assess this hypothesis, the authors conducted a quantitative meta-analysis and calculated overlapping trends across neuroimaging studies of hypnosis using activation likelihood estimation meta-analysis in order to identify potential common patterns of brain activation across these studies. Only the lingual gyrus (a higher-order visual area) emerged from this meta-analysis as a common brain pattern across the selected neuroimaging studies (Landry et al., 2017). The lingual gyrus is notably involved in mental imagery (e.g., Ganis, Thompson, Kosslyn et al., 2004) and, according to Landry et al., (2017), the presence of such a brain pattern might reinforce the idea that mental imagery is an essential component of hypnosis (e.g., Hilgard, 1970; Sapnos, 1991; Bowers, 1992). At the same time, the results of this meta-analysis do not corroborate the original hypothesis derived by Landry et al., (2017) from their review of the neuroimaging literature on hypnotic phenomena. Nonetheless, a number of potential limitations prevent strong generalisation from this meta-analysis (Landry et al., 2017), such as the limited number of studies included in the meta-analysis and the lack of robust standardised experimental procedures in hypnosis research.

In sum, the current body of research on brain processes associated with hypnosis (induction and/or suggestions) leaves us with inconsistent results and an absence of scientific consensus. The results are also potentially compatible with a number of theoretical propositions on hypnosis (see Section 4) and, consequently, cannot adjudicate between these theories. It is worth noting, however, that the review and quantitative analysis led by Landry et al., (2017) open new perspectives for grounding future neuroimaging research on the neural correlates of hypnosis. In what follows, we focus more specifically on brain processes that have been studied in relation to specific motor suggestions and the related disturbances of the sense of agency.

Brain mechanisms associated with motor suggestions

Blakemore, Oakley, & Frith (2003) showed that the activity of specific cerebellar and parietal regions was higher during an arm levitation suggestion than during the same movement correctly identified by subjects as self-generated. In the context of the comparator model, evidence suggests that the cerebellar cortex might be the region housing the forward model as well as the site where predicted and actual sensory feedback are compared (Blakemore et al., 2000). The role of the parietal cortex has already been pointed out in Section 2. Based on

Blakemore et al., (2003)'s results, Jamieson (2016) argues that during a motor suggestion the movement is generated in the absence of effective corollary discharges [i.e., efference copies] (see Section 4). The absence of effective corollary discharges would prevent the forward model from accurately predicting the next pattern of sensory reafferences. As a consequence, reafferent sensory signals would be unexpected, leading to an absence of sensory attenuation and explaining the higher activation in the specific cerebellar and parietal regions identified by Blakemore et al. (2003).

However, we think that a simpler interpretation of these data in terms of attentional modulation is available. First, the cerebellum is known to be involved in attentional modulation (e.g., Gottwald, Mihajlovic, Wilde, & Mehdorn, 2003) and its over-activation in the suggestion condition can be interpreted as the result of an increase of attention during hypnosis. As for the higher activation of the parietal cortex and the related reduction of sensory attenuation, Blakemore et al. (2003) themselves propose a clear alternative to the 'corollary discharge' account in terms of attentional modulation: "here, we suggest that subjects' attention is more highly focused on the sensations associated with passive movement in the Deluded Passive Movement condition [i.e., suggestion condition] than in the Active Movement condition [i.e., control condition]. This increased attention produces activation in brain regions that process such sensations (the parietal cortex). It is the activation in these regions, we suggest, that causes the movement to feel external" (p. 1065).

Walsh, Oakley, Halligan et al., (2015), found results consistent with the study of Blakemore et al., (2003) for a hypnotic suggestion of automatic hand writing, namely an increase of activity of parietal-cerebellar regions compared to the non-suggested, "voluntary", condition. The authors concluded that "alien control of movement may result from attenuation of feedforward inhibition of somatosensory processing that occurs during voluntary movements" (p. 388). We maintain that the attentional story we just offered for the overactivation of parietal-cerebellar regions in Blakemore et al. (2003) study may also account for the overactivation of such regions in the study of Walsh et al. (2015).

Finally, Deeley, Walsh, Oakley et al. (2013) investigated brain mechanisms associated with suggested actions for moving a joystick. They found no significant differences in brain activity between voluntary actions and suggested involuntary actions but found significant differences between suggested involuntary actions and suggested involuntary actions additionally accompanied by a suggestion of reduced awareness for the arm executing the action (and the body in general). When contrasting these latter two conditions, authors found a reduced activity in different areas, notably in the parietal cortex (left inferior and parietal lobules) as well as in areas in the left temporal region and visual region. The simplest explanation for these results is that suggestions for reduced awareness lead participants to redirect their attention away from motor sensory feedback, explaining the reduced activity in the indicated regions (see also Walsh et al., 2017). For instance, in the context of post-hypnotic suggestions for temporary amnesia (i.e., suggestions for reduced awareness of learnt material) participants use different attentional strategies in order to fit the content of the suggestion (Hilgard, 1986). Finally, when comparing functional connectivity patterns between voluntary actions and suggested involuntary actions, the authors found a reduced connectivity between the supplementary motor area (SMA) and some motor regions such as M1 (primary motor cortex). According to Jamieson (2016), such functional "disconnectivity" provides evidence in favour of the idea that suggested actions are executed through pathways that do not engage action intentions, implemented in the premotor cortex (see Section 4). However, as acknowledged by Deeley et al., (2013) themselves, their results cannot be taken at face value given the weak sample size for the connectivity analysis (N = 7). (See also Deeley, Oakley, Walsh et al., (2014) who investigated brain processes associated with different types of experiences of functional agency disruptions for hand movements following specific suggestions).

In the next section we compare the PCM with recent models of hypnosis.

5. Comparison of the PCM with current models of hypnosis

Important and influential theories of hypnosis have been developed during the 20th century. Some of them revolved around the concept of *dissociation* (Hilgard, 1896; Woody & Bowers, 1994), others developed a social-cognitive account of hypnosis (Barber, 1969; Sarbin, 1950; Spanos 1986). In order to put the PCM into perspective we compare it with contemporary versions of the latter theories and with recent cognitive approaches of hypnosis. In particular, we compare our proposal with Jamieson's predictive approach (2016), the social-cognitive Response Set Theory (Kirsch & Lynn, 1998, 1999), Second-Order Dissociated Control Theory (Jamieson & Woody 2007), the Cold Control Theory (Dienes and Perner, 2007; Dienes, 2012), and the Discrepancy-Attribution Theory (Barnier and Mitchell, 2005; Barnier, Dienes, & Mitchell, 2008), respectively. To be clear, the aim of this section is not to assess the strengths and weaknesses of these different theories (this is outside the scope of the present work). It is rather to identify differences between the theories from which empirical predictions can be derived and used to falsify or corroborate one or another of them.

Jamieson's predictive approach

Jamieson proposes an account of motor suggestions that also relies on the notion of active inference. However, his account is importantly different from our own and generates different empirical predictions (see Section 5). While our account rests on the notion of sensory attenuation as reframed within the framework of active inference by Brown et al., (2013), Jamieson argues that the suggested movement is "generated without triggering proprioceptive representations and their associated feedback predictions". It is this absence of proprioceptive predictions that leads the system to hypothesise the suggested movement as non-volitional and then to the experience of passivity.

Jamieson holds that in hypnosis pathways different from the pathways producing non-suggested actions generate suggested actions. Otherwise, we could not account for the absence of predictions of the relevant sensory signals. Jamieson (2016) proposes that hypnotic suggestions, such as arm levitation, modify the self-physical model of the individual in such a way that the model is updated and replaced by the suggested model. For instance, in arm levitation the suggestion that the arm is raised by means of an helium balloon becomes the new model and is able to trigger the suggested action “directly” i.e., using “pathways [that] are distinct from action intentions” (p 322). As stated by Jamieson (2016): “high level representations of the meaning of hypnotic suggestions are able to effect changes in experience and behavior” (p 315). Therefore, in Jamieson’s view it seems that the suggested action is non-intentional; the participant had no intention to produce it.

The PCM and Jamieson’s approach are radically different with respect to the postulated mechanisms leading to the lack or diminution of sensory attenuation during suggested actions. The PCM posits that suggested actions are generated in a ‘normal’ way (i.e., via proprioceptive predictions). However, owing to attentional modulation, sensory evidence and proprioceptive predictions are weighted in a way that produces highly precise prediction errors, which form the basis for the experience of passivity.

In a nutshell, on Jamieson’s approach the lack of sensory attenuation is a consequence of the absence of sensory predictions, while according to the PCM it is a consequence of attentional modulation.

Response-Set Theory

The social-cognitive Response-Set Theory (RST, Kirsch & Lynn, 1998, 1999; Lynn, Laurence, & Kirsch, 2015) postulates that the initiation of any action (intentional or non-intentional) is automatic (i.e., does not result from a conscious act of will). Actions are triggered by preparatory sets. In this respect, intentions and response expectancies constitute such preparatory sets that prepare actions for automatic activation (Kirsch & Lynn, 1998, p. 73). Therefore, the fact that a suggested movement is intentional and/or expected does not mean that it is not automatic. Hypnotic responses are part of a larger behavioural plan, which is the desire by the subject to experience hypnotic phenomena. This planned behaviour constitutes the preparatory set for the automatic activation of the suggested movement. In this context, the suggestion acts as a triggering cue but is nonetheless not sufficient to activate it. The movement must be preceded by an altered subjective experience (which constitutes a condition (a situational cue) for the suggestion to be able to trigger the movement). For instance, the suggested movement of raising one's arm following an arm levitation suggestion requires the altered experience of feeling the arm as light. As for the altered subjective experience of lightness, it is directly generated by the expectancy of its occurrence (Kirsch, 1985). In this view, the "feeling" of will in everyday actions is an illusion and amounts to a *post hoc* judgement (determined by situational cues) rather than to a subjective introspectible experience (i.e., there is no actually *feeling* of will). The judgment of involuntariness about the suggested movement is therefore accurate.

The PCM differs from the RST in many respects. First, the theoretical background underlying the issue of agency attribution is different between the theories. The PCM argues that attribution of agency mostly relies on the prediction of internal sensorimotor cues (e.g., predictions of proprioceptive consequences). In line with *cue integration approaches* (Moore & Fletcher, 2012), it allows that situational cues (e.g., the specific context in which the action is performed) can also participate in agency attribution, particularly in the context of ambiguous contexts. Kirsch & Lynn (1998), by contrast, take the view that attribution of agency relies mainly on external, situational cues (Wegner, 2004). They also agree that internal cues such as goals and intentions strongly participate to agency attribution, but these cues are not sensorimotor. Second, we propose that the experience of passivity accompanying suggested movements results from an attempt to interpret abnormally high predictions errors resulting from abnormally weighted proprioceptive predictions and sensory evidence. The RST, in contrast, argues that the experience of passivity (of lightness to be precise) results from the expectancy of its occurrence alone. Third, in our view, contrary to the RST, the experience of passivity does not precede the suggested action but is concomitant with it.

Second-Order Dissociated Control Theory

Different versions of dissociation theory have been proposed (Hilgard, 1977; Woody & Bowers, 1994), but here we will focus on the most recent version of this theory, namely the Second-Order Dissociated Control Theory or 2DCT for short (Jamieson & Woody, 2007).

According to this view actions are driven by an executive system, composed of a control and monitoring module, and lower subsystems of control. Lower subsystems "directly handle the selection and tracking of behavior; the executive system offers a second level of control, associated with conscious volition, which functions by modulating and monitoring the subsystems of control" (Woody & Sadler, 2008, p. 90). Different feedback loops between these three elements (executive control, executive monitoring, lower subsystems of control) insure good control of, and flexibility in, actions. Of particular importance for the 2DCT is the feedback from the monitoring module, which receives information from lower subsystems of control, to the executive module. The monitoring module monitors the course of the action driven by lower subsystems of control (i.e., monitor the activity of these systems). The information thus given to the executive control allows it to adjust lower levels in case of errors signals, thus making action control a flexible mechanism. Therefore, the dissociation between executive control and executive monitoring prevents flexibility. In addition, because error signals are not transmitted to executive control it cannot readjust and mismatches ensue between this executive control system and lower systems of control. The feeling of passivity associated with behavioral responses to motor suggestions would result from these mismatches. In other words, self-attribution of agency would result from a matching process between what is predicted by executive control and what is done by lower systems. Conversely, a mismatch between executive control and lower systems would participate to agency misattribution.

The mechanisms postulated by the 2DCT to underlie agency misattribution and the experience of passivity with respect to motor suggestions are radically different from the mechanisms proposed by the PCM. The 2DCT argues that motor suggestions temporally disrupt the processes involved in action control (by dissociating the monitoring module from the executive module). The PCM hypothesises no such disruption. Rather, it holds that motor suggestions modulate the strength of sensory evidence, proprioceptive predictions and prediction errors *via* attentional processes and provide the subject with a non-agency prior that can explain the presence of such prediction errors.

Cold Control Theory and Discrepancy-Attribution Theory

The Cold Control Theory (CCT; Dienes and Perner, 2007; Dienes, 2012) argues that hypnosis specifically affects *meta*cognition, not cognition itself. Metacognition can roughly be defined as cognition about cognition. Explicit metacognition involves forming *meta*representations, that is representations about representations. As an illustration, in the statement, "I know (or I believe) that I am seeing a red tomato on the table", the knowledge assertion is a (meta)representation about the perceptual representation, "I am seeing a red tomato on the table". Metarepresentations are specifically about mental states themselves (here the mental state of seeing) while first-order representations are specifically about the world (here the tomato). According to the CCT, hypnotic suggestions would temporarily inhibit or affect the accuracy of metarepresentations, generating what is usually referred to as a *metacognitive error*. In other words, the participant entertains erroneous representations about their own cognitive states – which are not affected at all according to the CCT. For instance, hypnotic hallucinations would be the result of an imagining event erroneously considered as being a case of perception. Here participants are making a specific kind of metacognitive error, namely they are misattributing the mental/cognitive source of a sensory event.[4]

With respect to SoA alterations accompanying motor actions, the CCT states that hypnosis affects the metarepresentation of the intention to act (Barnier et al., 2008; Dienes and Perner, 2007; Dienes, 2012). The intention to act is left untouched (i.e., executive control works properly) but the metarepresentation of this intention is inhibited or affected, leading to the inaccurate metarepresentation that the suggested action is passive (alternatively, hypnosis could directly lead to the inaccurate metarepresentation that the suggested action is not willed by the

[4] There are different possible factors leading to these metacognitive errors. One of them might be *expectation* (Dienes and Perner, 2007). It has been shown that the level of expectation subjects hold about their hypnotic "abilities" is highly correlated with their actual responding (Braffman & Kirsch, 1999). Dienes and Perner (2007) suggest that expectations specifically affect metarepresentations rather than first-order states. In other words, the expectation that I will be able to perceive the suggested mosquito flying around my head will affect my metarepresentation (e.g., my belief) about the source of the sensory event. In particular, the expectation will make me wrongly believe that I am perceiving the fly while in fact I am only imagining it. The expectation does not create a simulated perceptual sensory event; it simply affects my beliefs or judgments about my current mental state.

participant). In the case of the arm levitation suggestion, for instance, subjects have the intention to raise their arm but entertain the inaccurate metarepresentation (e.g., the inaccurate belief) that their arm is rising without their willing it. The participant attributes the source of the action to hypnosis rather than to themselves (metacognitive error). Importantly, it is the metacognitive error itself that generates the hypnotic experience i.e., the experience of passivity associated with the suggested action. There are no first-order alterations of action mechanisms or first-order experience leading to the metacognitive error.

Turn now to the Discrepancy-Attribution Theory (DAT, Barnier and Mitchell, 2005; Barnier et al., 2008). This theory can also be conceptualized as metacognitive, since it characterizes hypnotic responses as arising from a misattribution process. Hypnotic hallucinations, for instance, would also result from a misattribution of the cognitive source of the sensory event (Johnson, Hashtroudi, & Lindsay, 1993). In particular, the hypnotic hallucination of a cat is nothing more than a mental image of a cat the subject attributes to the external word – mistakes for a perception of a cat. Mental imagery is confused with perception.

However, contrary to the CCT, this misattribution has an experiential basis. Barnier and Mitchell (2005) propose that the misattributed event (e.g., the imagining of a cat) is generated with a degree of fluency higher than it would have been expected by the subject and it is this felt ease of production that leads the subject to misattribute the event at stake. In the case of hypnotic hallucinations, for instance, the mental image is generated with a degree of fluency higher than the subject would have normally expected if she had generated the same image outside the hypnotic setting. According to Barnier and Mitchell (2005) this higher degree of fluency is due to the hypnotic context, which is an impoverished and highly motivating context (Barnier et al., 2008, p. 162). However, the subject (unconsciously) misattributes the source of this fluency to the world rather than to the hypnosis setting itself. The world is the focus of the attribution because it would be "the most obvious or natural source" (Barnier et al., 2008, p. 159). With regard to sense of agency disruptions in the context of motor actions the proposed explanation is similar. The rising of the arm would be achieved with a degree of fluency higher than expected by the participant who misattributes this higher fluency to the fact that her arm is not under her control or will. To be clear, Barnier et al., (2008) do not deny that suggested actions are laborious and dysfluent in the absolute, they argue that it is the discrepancy between expected and actual fluency that would constitute the basis of the hypnotic experience[5].

The PCM and the two metacognitive accounts just presented conceptualise the hypnotic response quite differently, independently of the differences in theoretical background concerning, for instance, the way the SoA is conceptualised. According to the CCT, the experience of passivity is generated completely top-down (wrong metarepresentation) while the PCM postulates fairly substantial modulations of sensory evidence and proprioceptive predictions. As for the DAT, the postulated mechanisms are obviously quite different from the PCM. In addition, the PCM does not agree that fluency is what best characterises the hypnotic response. The phenomenological experience postulated by the PCM, beyond simply the experience of passivity, is characterised by a higher consciousness of somesthetic sensory signals linked to the relevant body part and movement involved, owing to attentional modulations of such sensory signals. In addition, given the potential large prediction errors resulting from abnormally weighted proprioceptive predictions and sensory evidence, the experience of the movement itself, of its production, would be better characterised by an experience of dysfluency. In sum, as indicated in Section 3, attention to movements reduces fluency (Brown et al., 2013; Clark 2016). Yet, we do not deny that the experience of passivity

[5] As pointed out by a reviewer, Chambon & Haggard, (2012) found that increased action selection fluency can enhance the sense of agency, rather than reducing it. This finding does not directly contradict Barnier and Mitchell's claim, however. First, the study by Chambon and Haggard investigated the effects of the fluency of action selection, not of action production, on the sense of agency, whereas Barnier and Mitchell's claim pertains to action production. Second, whereas Barnier and Mitchell are concerned with the sense of agency for suggested movements, that is purely non-operant movements, Chambon and Haggard are concerned with operant actions, that is actions that have effects on the world ("participants were explicitly given the instruction to judge the extent to which they thought they had controlled the appearance of the coloured patch through their action" Chambon & Haggard, 2012). The process of deciding whether I am in control (or the agent) of a non-operant movement or of the external effect(s) following an operant action might rely on very different cues (Frith, 2005). Producing a non-operant movement requires some effort, even if minimal, while a passive movement requires no effort (such as when someone is raising your arm). Therefore, if hypnosis marginally increases the ease of motor production, as argued by Mitchell and Barnier (2005), this can be a cue for passivity. A crucial question is whether improving the ease (fluency) of motor production of non-operant actions outside hypnosis would lead one to feel more or less in control of one's movements. In other words, independent empirical evidence from hypnosis is needed.

generates, or is accompanied by, sensations of lightness, for instance (Kirsch and Lynn, 1998, 1999).

6. Some predictions of the Predictive Coding Model

In what follows we describe some empirical predictions that can be derived from the PCM. We will also examine whether the different theories described above share or not these predictions.

A first empirical prediction is that the experience of passivity should be modulated by the amount of attention allocated to the suggested action. In this respect, distracting tasks (even simple ones) during the suggested action should decrease the experience of passivity associated with it. Reduced attention to somesthetic sensory signals would increase sensory attenuation and therefore the precision of prediction errors resulting from the comparison between proprioceptive predictions and actual sensory evidence. Therefore, we predict that distracting tasks should reduce the experience of passivity. Kirsch, Burgess, & Braffman (1999), in a design comprising only highs and simulators (no mediums), have shown that cognitive load during the execution of suggestions indeed reduces the subjective experience associated with certain suggestions, including motor suggestions.

This prediction accords with the claim made by the RST that attention is necessary to "generate and monitor" (Kirsch & Lynn, 1998, p. 76) the experience of lightness or involuntariness (Kirsch, Burgess, et al., 1999). This prediction is not something a pure version of the CCT would agree with. According to the CCT the experience of passivity is purely top-down: it results from the wrong metarepresentation about the first-order mental state at stake, that is from the metacognitive error *itself*. Therefore, once the wrong non-agency metarepresentation has been formed, modulating the amount of attention allocated to the suggested action should not affect it. Similarly, Jamieson's predictive account would not predict that attention should affect the experience of passivity. According to his view hypnosis leads to an absence of prediction; therefore, the saliency of sensory feedback in this view is not something that is dependent on attention. The DAT would also disagree with such a prediction. It holds that suggested actions are misattributed to some external cause to the extent that their fluency is higher than expected by the participants. Reduced attention to somesthetic signal in the context of a distracting task should further increase the fluency of the action and thus also increase the experience of passivity associated with it. Finally, the 2DCT would probably make the opposite prediction, as cognitive load should disrupt even more the communication between the monitoring module and the executive control module.

A second prediction is that a pre-test phase in which subjects would be trained to pay close attention to some movements, e.g., a slow raising of their arm, should reduce the experience of passivity associated with the same movements executed following an arm levitation suggestion, for instance, in the experimental phase. The reason is that in the pre-test phase the increase in sensory evidence will be associated with a self-agency prior. Therefore, the non-agency prior produced by a motor suggestions should not be a better fit to the current pattern of sensory evidence than the non-agency prior. To our knowledge there are no available empirical data directly testing this prediction, which fits the DAT but not the CCT, Jamieason's approach, the RST, or the 2DCT.

A third prediction is that the experience of passivity should increase in the course of the suggestion: attention increases the saliency of sensory consequences and the higher saliency resulting from this increase attracts attention even more which in turn further increases the saliency of sensory evidence and so on. In this respect, the experience of passivity should be weak at the beginning of the suggestion while gradually increasing in the course of it. This prediction is already partly corroborated by McConkey et al., (1999). In this study participants rated their subjective experience for three suggestions, including an arm levitation suggestion. The subjective rating was carried out by means of a semi-rotatable dial during the suggestion (rather than retrospectively after the suggestion). Experimenters distinguished three phases during the suggestion, namely the suggestion phase (when the experimenter is delivering the suggestion), the test phase (when the experimenter is evaluating whether the subject is passing or failing the suggestion)[6] and the cancellation phase (when the experimenter is cancelling the

[6] For the arm levitation suggestion, for instance, the test phase consisted in "the hypnotist remaining quiet while the subject experienced the suggested effect" (McConkey et al., 1999, p. 28) and during this

suggestion). Data clearly indicate that for arm levitation and for those who passed the suggestion, ratings increased in the course of the suggestion from the suggestion phase to the test phase before starting to decrease during the cancellation phase (note that ratings during the cancellation phase were usually higher than ratings at the beginning and the middle part of the suggestion phase). This prediction fits the DAT too as fluency could probably be hypothesised to increase in the course of the motor action. It could also fit the CCT as the later could argue that the formation of an incorrect metarepresentation is not immediate.[7] The 2DCT could probably argue that the dissociation between the monitor and the executive increases in the course of the suggested action. However, Jamieson's approach would not generate such a prediction as, in this view, the suggested action is 'directly' triggered by the suggestion. Similarly, the RST would not agree with this prediction, as the subjective experience must *precede* the suggested movement.

A fourth prediction is that the weight given to the prior of non-agency provided by the suggestion should also modulate the experience of passivity. This prediction could be tested by influencing the beliefs/expectancies of (naïve) subjects about their general hypnotic abilities or about their abilities to respond to specific suggestions so as to modulate the weight given to the non-agency prior. This prediction is already corroborated, at least partially, by some empirical evidence. In one condition of their study, Wickless & Kirsch (1989) gave six additional suggestions to participants after the induction phase of the Stanford Hypnotic Susceptibility Scale, Form C (SHSS:C) (Weitzenhoffer & Hilgard, 1962) but before the traditional test suggestions included in this scale. As an illustration, they administered suggestions for seeing the colour red, the colour green, hearing unusual music, etc. However, these suggestions were

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time evaluated whether the subject passed or failed the suggestion (here, for the subject passing the suggestion she had to lift her hand at least 15 cm).

[7] However, the CCT argues that it is the incorrect metarepresentation itself that leads to the hypnotic experience. So if the subject at the beginning of an arm levitation suggestion (for instance) has a correct metarepresentation ("I have the intention to move my arm"), the CCT has to explain why and how it gets transformed into an incorrect metarepresentation ("my arm is moving by itself") after a while. The variables turning the correct metarepresentation into an incorrect metarepresentation must not be first-order processes and/or experiential variables because if it were so the incorrect metarepresentation would be the end product of some other more fundamental variables and not, as CCT claims, the factor directly producing the hypnotic experience (e.g., the experience of passivity).

surreptitiously accompanied by corresponding veridical stimulations, e.g., a faint green colour was illuminating the room in the case of the suggestion for seeing the colour green. Subjects were unaware of this experimental manipulation so that they thought they were 'internally' generating the green colour (Kirsch, Wickless, & Moffitt, 1999). This experimental manipulation increases quite drastically the hypnotisability scores: 7.80 (out of 12) for the group in this experimental manipulation against 5.47 (out of 12) for the control group (in another condition hypnotisability scores raised up to 8.60) (but see Benham, Bowers, Nash, & Muenchen, 1998). Within the PCM these results can be interpreted as the fact that the six additional suggestions increased the weight participants put on their priors during test suggestions. In the case of the hallucination suggestion of the SHSS:C, the perceptual prior produced by the suggestion (i.e., the subject forms the hypothesis that she will have a perceptual experience) is given strong weight as a result of the six additional suggestions so that the presence of weak sensory evidence (the mental image of the suggested event) is potentially overcome by this strongly weighted prior (Hohwy 2013 and see next section). With regard to ideomotor suggestions, the non-agency prior is given strong weight too, reinforcing the experience of passivity. This suggests that in some cases prior expectations might be sufficient to generate the experience of passivity, provided that they are given sufficient weight.

This last prediction fits the CCT, the RST and Jamieson's approach but not necessarily the DAT or the 2DCT. Indeed, according to the DAT, the metacognitive error is due to increasing fluency of production (e.g., the production of mental imagery) and influencing prior expectations does not vary the level of fluency. Of course, the DAT is probably not saying that fluency is the only factor behind hypnotic experience. However, it probably takes it to be a necessary factor. The fourth prediction says that, in some conditions, strongly weighted priors could be sufficient to generate a hypnotic response i.e., even in a context of very poor fluency. Finally, according to the 2DCT the experience of passivity has probably nothing to do with the modulation of prior expectations.

In sum, according to the PCM, by systematically varying the level of sensory evidence and the weight put on priors we should be able to modulate the specific experience associated with specific suggestions. In addition, the different empirical predictions described above – taken together – should help adjudicate between the different models of sense of agency alteration in hypnosis (Table 1 recaps the predictions made by the PCM discussed in this section. More predictions are given in the following sections).

Table 1.

Predictions \ Theories	Predictive Coding Model (PCM)	Jamieson Theory	Response-Set Theory (RST)	Second-Order Dissociated Theory (2SDT)	Cold-Control Theory (CCT)	Discrepancy-Attribution Theory (DAT)
Attention modulates the experience of passivity	Y	N	Y	N	N	N
A pre-training phase should reduce the experience of passivity during suggestion phase	Y	N	N	N	N	Y
The experience of passivity increases in the course of the suggestion	Y	N	N	Y	Y	Y
Prior weighting modulates the experience of passivity	Y	Y	Y	N	Y	N

Summing up predictions. The table shows instances of predictions made by the PCM and whether these predictions are shared or not by other theories of hypnosis. *Y* stands for YES and *N* stands for NO.

7. Some perspectives on the PCM: hypnotic hallucinations and hypnotic memory alterations

We proposed that alterations of the SoA in hypnosis result from an attempt by the cognitive system to explain the highly precise predictions errors resulting from abnormally weighted proprioceptive predictions and sensory evidence. In addition, the suggestion provides to the subject a prior of non-agency, which fits the abnormal experience the subject is facing. Is the PCM well suited to account for the other kinds of hypnotic experiences, especially to account for hypnotic reality distortions (i.e., hypnotic hallucinations) and hypnotic memory effects? In what follows, we briefly outline how our model could be extended to account for these phenomena.

Within the PCM framework, an explanation of hypnotic hallucinations would run along similar lines as the explanation given for SoA hypnotic alterations. However, in the context of hypnotic hallucinations, we shift back from the notion of active inference to the notion of perceptual inference (see Section 1) in which predictions are issued from a perceptual prior about external hidden causes. In particular, a hypnotic hallucination would be a mental image given high precision –through attentional mechanisms– coupled with a perceptual prior – brought about by the suggestion. The prior would correspond to the following hypothesis, "there is an *x*" (e.g., a fly). This prior hypothesis generates specific predictions, notably that the sensory evidence should be highly precise (as in the case of actual sensory data). Because the sensory quality of the mental image, through attention, is gaining in precision there is a potential match between these predictions and the current sensory evidence.

At first sight this explanation is similar to the explanation given of hallucinatory phenomena (in particular, to Auditory Verbal Hallucinations or AVHs) in the context of schizophrenia. It has been argued that AVHs would result from patients misattributing mental images to the world (Blakemore et al., 2000; Ditman & Kuperberg, 2005; Chloe Farrer & Franck, 2007; Fletcher & Frith, 2009; Ford & Mathalon, 2004; Ford, Roach, Faustman, & Mathalon, 2007; Johnson et al., 1993). In schizophrenia, pathological efference copy mechanisms, for instance, have been postulated to be responsible for this misattribution (e.g., Ford & Mathalon 2004). However, in contrast to this explanation, our explanation does not postulate any alterations of mechanisms underlying the production of imagery

Let us turn now to memory effects in hypnosis. Memory, and particularly reconstructive memory (i.e., the recall of past events), has been analysed in Bayesian terms (Hemmer & Steyvers, 2009). On the Bayesian approach, the recall of past events is an inferential process based on noisy memory evidence and prior knowledge. For instance, when trying to remember the numbers you played for the last lotto, your recall can be driven by (suboptimal) memory evidence and general knowledge such as, for instance, the numbers you usually play. The recall will be biased towards memory evidence or priors according to their relative precision. If memory evidence is vague (i.e., imprecise) recall will be biased towards prior knowledge and, conversely, if your prior knowledge is vague, recall will be biased towards memory evidence.

There are two major memory effects in hypnosis according to the experimental manipulation in force i.e., whether one is trying to enhance memory –hypnotic hypermnesia– or whether one is trying to induce forgetting –posthypnotic amnesia (for reviews, see e.g., Erdelyi, 1994; Mazzoni, Laurence, & Heap, 2014).

With respect to hypnotic hypermnesia (HH) it is well established (within experimental research) that hypnosis actually does not improve memory performances. As stated by Mazzoni et al., 2014, “increases in correct responses are generally offset by increases in incorrect responding, leaving accuracy unchanged or, at times, decreased” (p. 157). In addition, and importantly, hypnosis induces an increase in confidence for both correctly and incorrectly recalled items, especially in highly hypnotisable participants (e.g., Nogrady, McConkey, & Perry, 1985).

Turn now to posthypnotic amnesia (PHA). Within a PHA protocol participants are given suggestions for forgetting some materials after hypnosis (e.g., lists of words, autobiographical memories and so on) until a cue to cancel the suggestion is given. In highly hypnotisable subjects PHA will usually affect explicit memory (“the conscious recall of [the relevant] information”, David, Brown, Pojoga, & David, 2000, p. 268) but not implicit memory (see e.g., David et al., 2000; Kihlstrom, 1980; but see Spanos, Radtke, & Dubreuil, 1982). This suggests that PHA mainly alters specific retrieval processes but that “the memories as stored are not disrupted” (Hilgard, 1986 p. 78). That is to say, words having received a PHA suggestion cannot be recollected but still can influence the behaviour of subjects on subsequent tasks such as word-association tasks (Williamsen, Johnson, & Eriksen, 1965) or stem-completion tasks (e.g., David et al., 2000; see, Mazzoni et al., 2014 for a review). As an illustration, Kihlstrom (1980) showed that words that had been previously learned and which received a PHA could not be recalled by highly hypnotisable subjects but were more likely to be given as associates in a word-association test than non-previously learned words that had the same original probability to be elicited by their respective cues as previously learned words (but see Spanos et al., 1982 and Smith, Oakley & Morton, 2013). Might a predictive/Bayesian perspective account for HH and PHA?

With regard to HH, specifically in the case of retrieving or recalling autobiographical memories, it has been shown that hypnosis can create false memories with high confidence. For instance, Laurence & Perry (1983) suggested to 27 highly hypnotisable participants that they had heard some loud noise during a night they selected from the week preceding the experimental session and that this noise had awakened them (prior to the suggestion, experimenters made sure that participants had had no “specific memories of awakening or of dreams occurring during the specified night” p. 523). Seventeen (63%) participants stated that they had heard a loud noise that awakened them. Thirteen (76%) out of these 17 participants maintained after hypnosis (7 days after the experimental session took place) that they had heard some loud noise during the specified night. When experimenters confessed to these participants that the noise had actually been suggested to them none gave up the belief that it had happened.

At first the memory evidence for a false suggested memory is low (as the event never actually occurred). It has been shown that imagination *per se* is known to influence autobiographical memories (e.g., Mazzoni & Memon, 2003). In this regard, we can speculate that during hypnosis participants form a mental image of the suggested memory and that in paying close attention to this mental image the sensory evidence associated with this image is increased so that it gains “specific perceptual-like qualities” (Mazzoni et al., 2014) usually associated with true memories. Increasing the sensory evidence associated with the mental image increases the memory evidence as well. As a consequence of this increase of memory evidence, the mental image is mistaken for an actual memory (Dywan, 1995; Mazzoni et al., 2014). As in the case of SoA alterations and hypnotic hallucinations, the suggestion creates a false prior –here the prior that the sound came from a perceptual event– thus generating specific predictions, namely that the mental image of the sound should have specific sensory qualities (as in the case of actual memories). For instance, the prior could generate predictions that the image should be generated with high fluency as it is the case for actual memory images, Dywan, 1995). Once more, a match between predicted and actual sensory evidence corroborates the prior hypothesis.

In the context of non-autobiographical memory tasks such as in recall or recognition tasks of images (e.g., Nogrady et al., 1985) or words, we can give a very similar explanation. Participants in the hypnotic condition form a mental image of the event selected in their mind to which they pay close attention, eventually leading to an increase of memory evidence by the same process as described above (Dywan, 1995).

In the context of PHA we can hypothesize that a decrease in memory evidence is happening. For instance, in tasks where participants are presented with lists of words to recall in the test phase (e.g., David et al., 2000), we can conjecture that participants turn their attention away from the material learned during the test phase for which they had received a PHA suggestion (see e.g., Spanos et al., 1982; Spanos, 1986). Participants can use different strategies to implement this process of selective inattention (Hilgard, 1986). While some subjects apparently are simply "clearing their mind" others use mental imagery (Hilgard, 1987, p. 77-78). As a result, the to-be-forgotten material is not available to consciousness and memory evidence is weak until selective inattention is removed (when the cue to cancel the PHA suggestion is delivered).

Smith et al., (2013) have shown that hypnotic amnesia is not limited to the "alteration" of explicit or episodic memory but includes effects on implicit memory (as shown by the reduction of the priming effect). Smith et al., (2013) argue (as we do) that the learned material is retrievable even after the suggestion of amnesia has been administered. In addition, however, they postulate that the fact that some information is retrievable does not mean that the information is available to consciousness (Morton, Hammersley & Bekerian, 1985). In this framework, retrievable information is available to consciousness only if it is transferred into a monitor. Whether information is transferred or not depends on higher goals and is under the control of an Executive: "if there is a current, conscious goal, such as remembering the address of a particular friend, then relevant information in the buffer store would be transferred into the monitor while other information that had been fortuitously retrieved (such as the name of the friend's wife) would be ignored" (Smith et al., p. 1306). Within this framework, Smith et al., (2013) propose that the suggestion of amnesia suggestion provides a higher goal to the Executive which "blocks" the learned material — targeted by the amnesia suggestion — from entering the monitor and being available to consciousness. The operations of the Executive would be involuntary here, hence the feeling of forgetting brought about by the amnesia suggestion.

The PCM and Smith et al 2013's view lead to different empirical predictions. First, the PCM predicts that a competing attentionally demanding task executed during an amnesia suggestion should *increase* the effect of the suggestion. In contrast, Smith et al., would predict that such a task should *decrease* the effect of the suggestion, preventing the executive of the memory system from efficiently screening and blocking the material targeted by the suggestion. Previous evidence from Kirsch et al., (1999) suggests the effect of an amnesia suggestion is increased rather than decreased in a dual-task paradigm. They had subjects count backward (load condition) or not (no-load condition) during different suggestions. While the competing task *decreased* the effect of motor suggestions (as also predicted by the PCM) it *increased* the effect of the amnesia suggestion (i.e., more subjects passed the amnesia suggestion in the load condition and their subjective experience of forgetting was increased compared to the no-load condition). Second, the PCM predicts that increasing the weight on the prior of forgetting should increase the effect of the suggestion of amnesia as shown by Wickless & Kirsch (1989) (see also Kirsch, Wickless, & Moffitt, 1999, but see Benham, Bowers, Nash, & Muenchen, 1998). It is not clear how Smith et al., account for these results.

We now turn to inter-individual differences in hypnotic suggestibility and propose an explanation of these inter-individual differences based on our predictive coding approach of hypnosis.

8. Explaining inter-individual differences in hypnotic suggestibility

In the preceding section, we have shown that the PCM has the potential to apply to different hypnotic phenomena. However, the literature on hypnosis shows that there are strong inter-individual differences in the level of hypnotic suggestibility. As described in Section 1, suggestions are usually divided into three categories: motor suggestions (e.g., hand lowering, arm levitation, magnetic hands), challenge suggestions (e.g., arm rigidity; the participant is suggested that her arm is unbendable but asked to test this fact by trying to bend it) and cognitive suggestions (e.g., positive and negative hallucinations, amnesia). Now, about 80% of people can pass motor suggestions, about 50% challenge suggestions and 10% cognitive suggestions (see e.g., Hilgard, 1965; Kallio & Ihamuotila, 1999; Perry, Nadon, & Button, 1992).

The existence of these inter-individual differences in hypnotic performances is one of the most intriguing issues in the field of hypnosis and is still in need of a convincing explanation. Many researchers argue that differences in hypnotisability may reflect other trait differences among individuals (But see e.g., Barber, 1969; Sapnos, 1986). Nonetheless, no firm cognitive profiles differentiating highs from lows surface from the literature when tested in non-hypnotic contexts (Council, Kirsch, & Hafner 1986; Heap, Brown, & Oakley 2004; Laurence, Beaulieu-Prévost, & Du Chéné 2008). In addition, no marker, whether genetic, physiological, behavioural or phenomenological, allowing us to categorize an individual as high, medium or low, has been found so far. In other words, the question of inter-individual differences in hypnotic suggestibility is still unsettled (Martin, Sackur & Dienes, 2017).

An important proposal in the field has been that inter-individual differences in hypnotic suggestibility would result from highs exhibiting more efficient executive functions, such as better sustained and/or selective attention, than lows or mediums (Crawford, 1991, 1994 ; Crawford, Brown & Moon, 1993). The relevant literature shows strong inconsistency, however. A number of studies found no significant behavioural differences related to subjects' level of hypnotic suggestibility in baseline performances for various executive and attentional tasks (Cojan, Piguet, & Vuilleumier 2015; Dienes et al. 2009; Egner, Jamieson, & Gruzelier 2005; Iani, Ricci, Gherri, & Rubichi 2006; Iani, Ricci, Baroni, & Rubichi 2009; Raz, Fan, & Posner 2005; Varga, Németh, & Szekely 2011). Other studies found demonstrate significant differences, but going in either direction (Crawford et al. 1993; Dixon, Brunet, & Laurence 1990; Dixon & Laurence 1992; Farvolden & Woody 2004; Miller, Hen- nessy, & Leibowitz 1973; Martin et al., 2017; Miller 1975; Rubichi, Ricci, Padovani, & Scaglietti 2005; Wallace 1986; Wallace & Garrett 1973; Wallace, Garrett, & Anstadt 1974; Wallace, Knight, & Garrett 1976)

Within the current predictive account of hypnosis, we propose that the difficulty of a suggestion would depend on the level of sensory evidence provided by the suggested event and inter-individual differences would result from inter-individual differences in the "ability" to assign more or less weight to ones' prior expectations.

The main focus of the present article was one sense of agency alterations with respect to motor suggestions in which inter-individual differences are weak. With motor suggestions, there is a huge amount of sensory evidence as the participant is moving one or another limb so that somesthetic cues (e.g., proprioceptive signals) are changing over time giving a lot of sensory information. Therefore, the available sensory evidence – whose phenomenological saliency is increased by attention – easily fits the prior of non-agency provided by the motor suggestion.

At the opposite end we find cognitive suggestions, such as positive hallucinations, in which there is no distal sensory evidence available. We hypothesise that inter-individual differences might result from inter-individual differences in the "ability" to assign more or less weight to the perceptual prior. In the preceding section, we proposed that hypnotic hallucinations result from a match between predictions generated by a perceptual prior provided by the suggestion and a mental image with high sensory qualities. However, the level of sensory evidence provided by the mental image might not be sufficient in itself for the image to be mistaken for a perceptual event. We propose that highly hypnotisable subjects are able to put unusual strong weight on their prior expectations allowing them to counter the weakness of sensory evidence.

Indeed, Hohwy (2013, p. 70) suggests that inter-individual differences in perceptual inference could be explained by how people "set their gain" (p. 70) on their prior expectations *versus* sensory evidence. For people able to give strong weight to their prior the weakness of the sensory evidence could simply be overcome. In other words, the perceptual decision that there is a mosquito in the room or not, for instance, is essentially determined by the perceptual prior. In contrast, for people not able to give strong weight to their priors perceptual decision is essentially determined by the available sensory evidence (no actual mosquito, no mosquito at all). On this view, the presence of a mental image is necessary but not sufficient to give rise to a hallucinatory-like state. The perceptual prior has to be given a strong weight in order to ignore prediction errors signals arising from the comparison between predicted highly precise sensory evidence and actual weak sensory evidence (Fig 3.).

Lloyd, Lewis, Payne, & Wilson (2011) showed that the number of hallucinatory events participants experienced during perceptual deprivation conditions correlated with their predisposition to hallucinate ($r = 0.61$) in an everyday context (such as measured by the Revised Hallucination Scale (RHS), Morrison, Wells, & Nothard, 2002). This can be interpreted as inter-individual differences in perceptual inference style: people prone to hallucinate would be people who have a tendency to set the gain on their prior expectations rather on sensory evidence (Hohwy, 2013). Similarly, highly hypnotizable subjects could be people who have a propensity to set the gain on their prior expectations rather than on sensory evidence.[8] If we are right, the hypnotisability score (at least the hallucination item) should correlate with the RHS. In addition, highly hypnotisable participants should manifest a higher propensity to hallucinate during sensory and perceptual deprivation conditions than medium and low hypnotizable participants. Importantly, we assumed here that the prior produced by the suggestion was a perceptual prior (e.g., *there is a fly*) but the exact nature of this prior would have to be empirically determined. The prior could equally be conceptualised as an "hyper-prior", in the sense that it could be more about the nature of mental state (perception vs. imagination) the subject is in than about the world: *I am perceiving that there is a fly* or *I am not imagining that there is a is a fly* (what the CCT would call a HOT). In this respect, the propensity to hallucinate might not be higher in highs than in lows or mediums but the level of felt reality attached to their hallucinations or the level of confidence that hallucinations are like perceptions (rather than mere hallucinations) would be higher in highs than in mediums and lows. In addition, if hypnotisability is a function of the gain set on priors, hypnotisability might be (maybe temporarily only) increased after a sensory or perceptual deprivation procedure, to the extent that sensory deprivation conditions 'force' the system to rely on priors in order to achieve perceptual inference. Some empirical evidence already supports this latter prediction. Sanders & Reyher (1969) showed that hypnotisability score was increased (by an average of 4.80 points) after participants had received a sensory deprivation procedure. Finally, if the ability of highs to put strong weight on their prior amounts to a trait ability, we should find differences between highs, mediums and lows outside the hypnotic context in tasks where the level of sensory evidence is varied systematically while the prior is held constant and *vice versa*. The influence of priors should be higher in highs than in mediums and lows. Thus, highs would need more (and more precise) sensory evidence to update their priors than mediums or lows.

[8] For a similar explanation of hallucinations in the context of schizophrenia, see Wilkinson (2014) and Powers, Kelley & Corlett (2016). These authors propose that people with schizophrenia have a bias toward priors.

Halfway between motor suggestions and cognitive suggestions we find challenge suggestions. In challenge suggestions, such as in arm rigidity, there are no movements produced by the participant and the available sensory evidence is low relatively to motor suggestions but there is still some available sensory evidence such as muscular activity signals. During an arm rigidity suggestion we can distinguish different profiles of participants according to the way they conform to the suggestion (Winkel, Younger, Tomcik, Borckardt, & Nash, 2006). Among the participants passing the suggestion, some of them show main activation (as measured by electromyogram or EMG) of both the biceps and triceps thus producing antagonist activity while other participants show main activation of the triceps only. Participants failing the suggestion, bending their arm, show little activation of their triceps (Winkel et al., 2006). We can hypothesise that the arm rigidity suggestion creates the prior that the arm in unbendable (henceforth, unbendable-prior) and that inter-individual differences can still be explained by inter-individual differences in setting the gain on priors. Challenge suggestions are easier than cognitive suggestions, such as hallucination suggestions, because the predictions generated by the prior can be validated by available actual sensory evidence but are more difficult than motor suggestions, such as magnetic hands, because the available sensory is more ambiguous (weak) than in the motor suggestions. The unbendable-prior can generate different sensory predictions, for instance that the triceps and biceps should both activate, as it is the case when we try to bend our arm blocked in something. It can also predict that the triceps only should activate, as it would be the case if our arm were really like an unbendable bar. So, the different strategies employed by the different profiles of participants passing the suggestion (i.e., trying to bend the arm or not trying at all) fit the unbendable-prior well.

9. Conclusion: what about psychosocial factors?

According to the predictive model we proposed, sense of agency distortions in hypnosis result from the specific implication of four factors: attention, sensory evidence, proprioceptive predictions and a prior of non-agency. Attention amplifies movements-related sensory signals reducing sensory attenuation and proprioceptive predictions are given strong weight too by means of the operator's words. The combination of abnormally weighted sensory evidence and proprioceptive predictions give rise to the suggested movement, usually dysfluent. In addition, this combination gives rise to highly precise prediction errors that are minimized by the prior of non-agency provided by the suggestion.

We extended our predictive account to hypnotic hallucinations and hypnotic memory alterations. According to the specific way attention is manipulated –towards or away from sensory evidence– and the specific content of priors, our model seems to have the potential to explain many hypnotic phenomena. Finally, we have shown that the current model can also give a plausible account of the level of difficulty of the different types of suggestions and of inter-individual differences. The difficulty would depend on the level of sensory evidence provided by the suggested event and inter-individual differences in the "ability" to give more or less weight to priors.

Of course, the factors put forward in the present account are not the only factors involved in hypnotic responses, but they constitute in our view the determining factors in explaining the subjective experiences accompanying the behavioural responses to suggestions. Barber (1969) and colleagues uncovered many independent variables (definition of the procedure as "hypnosis", motivational instructions included in the induction, relaxation suggestions, subjects attitude, expectancies and so on) influencing the different dependent variables involved in the experimental setting of hypnosis (e.g., behavioural and subjective scores to suggestions, the statement that subjects enter hypnosis or not, report of abnormal subjective experiences during the induction phase, hypnotic appearance). Barber (1969) subsumed these different independent variables under three broader psychosocial categories (only as a working hypothesis for future empirical research): task-attitudes, task-expectancies, and task-motivations.

In our view, psychosocial factors constitute necessary but not sufficient factors when subjective experience is the main dependent variable to be explained. In other words, we agree that it is necessary that subjects have a positive attitude towards hypnosis, be motivated and have the "right" expectations regarding the task in order to respond to the suggestions in the first place. Nonetheless, these psychosocial factors alone do not suffice to explain, for instance, the experience of passivity accompanying behavioural responses to motor suggestions. For that, intermediary variables –attention, sensory evidence, priors– between psychosocial factors and subjective experience are necessary. To a certain extent, our account tries to systematize Spanos's view (1986) according to which subjects implement cognitive strategies to fulfil their hypnotic role. We tried to give a precise explanation of what these (largely unconscious) cognitive strategies could be and of how they give rise to the specific subjective experiences accompanying behavioural responses to suggestions.

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